

International Nano-Optoelectronics Workshop 2026

August 6-16, 2026

Tsinghua University

Co-Chairs



Dieter Bimberg

CIOMP of CAS, Changchun & TU Berlin

Connie Chang-Hasnain

Berxel Photonics & The Chinese University of Hong Kong, Shenzhen

Yidong Huang

Tsinghua University





iNOW 2026

August 6-16, Beijing and Tianjin, China

Organizer

Tsinghua University

Co-Chairs

Dieter Bimberg, Changchun Institute of Optics, Fine Mechanics and Physics, CAS/
TU Berlin

Connie Chang-Hasnain, Bercel Photonics and Chinese University of Hong Kong
(Shenzhen)

Yidong Huang, Tsinghua University

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TU Berlin

Connie Chang-Hasnain, Bercel Photonics and Chinese University of Hong Kong
(Shenzhen)

Gadi Eisenstein, Technion - Israel Institute of Technology

Alfred Forchel, nanoplus Nanosystems and Technologie/Sensalight Technologies/
University of Würzburg

James Harris, Stanford University

Yidong Huang, Tsinghua University

Guillaume Huyet, Université Côte d'Azur

Fumio Koyama, Tokyo Institute of Technology

Grzegorz Sęk, Wrocław University of Science and Technology

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Preface

Chairs' Welcome Message

Launched in 2006, exploring cutting-edge developments in semiconductor optoelectronics and nanophotonics, the international Nano-Optoelectronics Workshop (iNOW) has flourished for 20 years in its unique form. Unlike conventional conferences, iNOW features a distinctive immersive interactive mode, featuring tutorial-style talks given by optoelectronic science and technology leaders from academia and industry, poster sessions for student presentations, and ample time for discussions and informal interactions among all participants. A hallmark of iNOW is its dedication to young talent cultivation, offering graduate students and early-career researchers valuable face-to-face interactions with top photonics experts to access frontier research and broaden academic horizons.

iNOW-2026 will be hosted by Tsinghua University in the campus of the University of Chinese Academy of Sciences (UCAS) located by the beautiful Yanxi Lake in the suburb of Beijing and Tianjin Sino-Canton Ecological City, the base for the industrial transformation of optoelectronic technology of Tsinghua University. iNOW-2026 inherits the mature, well-structured agenda of past events. It includes twenty-three sessions for invited lecture, two poster sessions, and an industrial forum. A special tour of H-Chip Tech, which is a large-scale wafer fabrication platform for nano-optoelectronic chips in China, as well as variety of events, such as excursions to the APEC venue at Beijing Yanqi Lake and Mutianyu Great Wall, Haihe River cruise, and a concert of "A date with light" are also organized.

We would like to express our gratitude to all invited speakers, sponsors, and organizers who have made iNOW-2026 possible, and extend our warmest welcome to all the participants. We hope you will enjoy the lectures and the social events, and take advantage of the unique workshop format to establish collaboration and exchange ideas with colleagues from all over the world. Have a great time at iNOW-2026!

iNOW 2026 Co-Chairs



Dieter Bimberg

Changchun Institute of Optics,
Fine Mechanics and
Physics, CAS/TU Berlin



Connie Chang-Hasnain

Berxel Photonics and Chinese
University of Hong Kong (Shenzhen)



Yidong Huang

Tsinghua University

Program at a Glance

	Thu, 8/6	Fri, 8/7	Sat, 8/8	Sun, 8/9	Mon, 8/10
08:00-08:30		Registration	Registration	Registration	Registration
08:30-09:00		Opening Session	Session II-1 Chair: Yasuhiko Arakawa Gadi Eisenstein (08:45-09:30) Kei May Lau (09:30-10:15)	Session III-1 Chair: Kei May Lau Hong-Bo Sun (08:45-09:30) Siyuan Yu (09:30-10:15)	Session IV-1 Chair: Frédéric Grillot Grzegorz Sęk (08:45-09:30) David Gershoni (09:30-10:15)
09:00-09:30		Session I-1 Chair: Connie Chang-Hasnain Dieter Bimberg (09:00-09:45) Yasuhiko Arakawa (09:45-10:30)			
09:30-10:00					
10:00-10:30					
10:30-11:00					
11:00-11:30		Session I-2 Chair: Dieter Bimberg Connie Chang-Hasnain (11:00-11:45) Fumio Koyama (11:45-12:30)	Session II-2 Chair: Grzegorz Sęk Fabrice Raineri (10:45-11:30) Qijie Wang (11:30-12:15)	Session III-2 Chair: Hong-Bo Sun Frédéric Grillot (10:45-11:30) Xiaowei Sun (11:30-12:15)	Session IV-2 Chair: Fabrice Raineri Nobuhiko Nishiyama (10:45-11:30) Wei Shi (11:30-12:15)
11:30-12:00					
12:00-12:30					
12:30-13:00		Lunch	Lunch	Lunch	Lunch
13:00-13:30					
13:30-14:00		Session I-3 Chair: Fumio Koyama Kenichi Iga (13:30-14:15) Huiyun Liu (14:15-15:00)	Session II-3 Chair: Siyuan Yu Yoshiaki Nakano (13:30-14:15) Xiulai Xu (14:15-15:00)	Industry Forum Chair: Yidong Huang	
14:00-14:30					
14:30-15:00					
15:00-15:30	Registration	Session I-4 Chair: Gadi Eisenstein Alfred Forchel (15:15-16:00) Fei Ding (16:00-16:45)		Event 1	Event 2
15:30-16:00					
16:00-16:30			Poster Session I Chair: Dieter Bimberg		
16:30-17:00					
17:00-17:30		Visit UCAS			
17:30-18:00					
After 18:00	Welcome Reception	Special Dinner for Invited Speakers Buffet Dinner for Students	Casual Buffet Dinner	Award Banquet	Casual Buffet Dinner



	Tue, 8/11	Wed, 8/12	Thu, 8/13	Fri, 8/14	Sat, 8/15			
08:00-08:30	Registration	Bus to Tsinghua University	Registration	Registration	Registration			
08:30-09:00	Session V-1 Chair: Bala Pesala Xingde Li (08:45-09:30) Weijian Yang (09:30-10:15)		Session VI-1 Chair: Limin Tong Vladimir G. Dubrovskii (08:45-09:30) Hongsheng Chen (09:30-10:15)	Session VII-1 Chair: Lars Samuelson Ady Arie (08:45-09:30) Fang Liu (09:30-10:15)	Session VIII-1 Chair: Cunzhu Tong Baile Zhang (08:45-09:30) Min Qiu (09:30-10:15)			
09:00-09:30								
09:30-10:00								
10:00-10:30								
10:30-11:00	Session V-2 Chair: David Gershoni Bala Pesala (10:45-11:30) Ming Li (11:30-12:15)	Tsinghua Campus Tour	Session VI-2 Chair: Guillaume Huyet Limin Tong (10:45-11:30) Tao Li (11:30-12:15)	Session VII-2 Chair: Baile Zhang Lars Samuelson (10:45-11:30) Zhangyuan Chen (11:30-12:15)	Session VIII-2 Chair: Ady Arie Cunzhu Tong (10:45-11:30) Jin Liu (11:30-12:15)			
11:00-11:30								
11:30-12:00								
12:00-12:30								
12:30-13:00	Lunch	Lunch	Lunch	Lunch	Lunch			
13:00-13:30								
13:30-14:00	Session V-3 Chair: Xingde Li Sven Höfling (13:30-14:15) Takuo Tanemura (14:15-15:00) Qing Dai (15:00-15:45)	Concert	Session VI-3 Chair: Hongsheng Chen Si-Cong Tian (13:30-14:15)	Session VII-3 Chair: Hongyan Fu Guillaume Huyet (13:30-14:15)	Session VIII-3 Chair: Vladimir G. Dubrovskii Hongyan Fu (13:30-14:15) Xinghui Li (14:15-15:00)			
14:00-14:30			Poster Session II Chair: Yidong Huang	Visit H-Chip	Free			
14:30-15:00						Bus to Tianjin		
15:00-15:30								
15:30-16:00		Free						
16:00-16:30			Event 3	Award Banquet				
16:30-17:00								
17:00-17:30								
17:30-18:00								
After 18:00	Casual Buffet Dinner	Casual Buffet Dinner	Casual Buffet Dinner					

Detailed Program

iNOW 2026 Program Summary

Venue 1: Conference Center of UCAS

Venue 2: Hilton Tianjin Eco-City

Thursday, August 6, 2026 (Venue 1)

15:00-18:00	Registration
18:15-21:00	Welcome Reception Dinner

Friday, August 7, 2026 (Venue 1)

8:00-8:30	Registration
8:30-9:00	Opening Session <i>Opening Remarks by Dieter Bimberg</i> Connie Chang-Hasnain
Session I-1 Chair: Connie Chang-Hasnain	
9:00-9:45	Dieter Bimberg , Changchun Institute of Optics, Fine Mechanics and Physics, CAS/TU Berlin <i>Quantum Dot Lasers and Amplifiers for Energy-Efficient Multi Terabit Data Communication</i>
9:45-10:30	Yasuhiko Arakawa , The University of Tokyo <i>Quantum Dots: A Key Nanostructure for Photonic-Electronic Convergence for Future AI</i>
10:30-11:00	Group Photo Tea & Coffee Break
Session I-2 Chair: Dieter Bimberg	
11:00-11:45	Connie Chang-Hasnain , Berxel Photonics and Chinese University of Hong Kong (Shenzhen) <i>High-Speed Back Emitting 1060 nm VCSEL for AI Scale-up Optical Interconnects</i>
11:45-12:30	Fumio Koyama , Institute of Science Tokyo <i>Forty Years of VCSEL Innovation: From Fundamental Principles to Terabit-Scale Optical Interconnects</i>
12:30-13:30	Lunch



Session I-3 Chair: Fumio Koyama	
13:30-14:15	Kenichi Iga , Institute of Science Tokyo (Online: ZOOM)
	<i>Vertical-Cavity Surface-Emitting Laser (VCSEL): Principle, Physics, and Industries</i>
14:15-15:00	Huiyun Liu , University College London
	<i>Si-based III-V Quantum Dot Lasers for Si Photonics</i>
15:00-15:15	Tea & Coffee Break
Session I-4 Chair: Gadi Eisenstein	
15:15-16:00	Alfred Forchel , nanoplus Nanosystems and Technologie/Sensalight Technologies/University of Würzburg
	<i>Progress in Longitudinal Single Mode Lasers for Sensing</i>
16:00-16:45	Fei Ding , Leibniz University Hannover
	<i>Towards Long Distance Quantum Communication with Deterministic Single Photon Sources</i>
16:45-18:30	UCAS Campus Tour for Invited Speakers Free Time for Students
18:30-20:30	Special Dinner for Invited Speakers Buffet Dinner for Students

Saturday, August 8, 2026 (Venue 1)

8:15-8:45	Registration
Session II-1 Chair: Yasuhiko Arakawa	
8:45-9:30	Gadi Eisenstein , Technion - Israel Institute of Technology
	<i>Quantum Optics and Noise Squeezing in Quantum Dot Gain Media</i>
9:30-10:15	Kei May Lau , Hong Kong University of Science and Technology
	<i>TE and TM InP/GaAsP Dot-in-Well (DWELL) Lasers and Lateral DBR Lasers Selectively Grown on SOI</i>
10:15-10:45	Tea & Coffee Break
Session II-2 Chair: Grzegorz Sęk	
10:45-11:30	Fabrice Raineri , Université Côte d'Azur
	<i>InP on Silicon Nanolaser Diodes</i>
11:30-12:15	Qijie Wang , Nanyang Technological University
	<i>Electrically-pumped Topological Photonic Crystal Lasers</i>

12:15-13:30	Lunch
Session II-3 Chair: Siyuan Yu	
13:30-14:15	Yoshiaki Nakano , Toyota Technological Institute
	<i>Optical Neural Network Chip Based on Multiple-Plane Lightwave Conversion</i>
14:15-15:00	Xiulai Xu , Peking University
	<i>Controlling Excitons and Their Interactions with Cavities</i>
15:00-15:30	Tea & Coffee Break
Poster Session I Chair: Dieter Bimberg	
15:30-16:30	Poster Summary Talk (2 minutes each)
16:30-18:00	Poster Viewing
18:00-20:30	Casual Buffet Dinner

Sunday, August 9, 2026 (Venue 1)

8:15-8:45	Registration
Session III-1 Chair: Kei May Lau	
8:45-9:30	Hong-Bo Sun , Tsinghua University
	<i>Optical Close-to-atom-scale Manufacturing for Quantum Chips</i>
9:30-10:15	Siyuan Yu , Sun Yat-sen University
	<i>Heterogeneous Integration of Photonic and Optoelectronic Materials and Components</i>
10:15-10:45	Tea & Coffee Break
Session III-2 Chair: Hong-Bo Sun	
10:45-11:30	Frédéric Grillot , Université Laval
	<i>Quantum Photonics Enabled by Semiconductor Quantum Dots</i>
11:30-12:15	Xiaowei Sun , Southern University of Science and Technology
	<i>A Metasurface Waveguide for Full-color AR Displays</i>
12:15-13:30	Lunch



Industry Forum Chair: Yidong Huang	
13:30-14:00	Alexey Gubenko
	<i>Quantum Dot Lasers and SOAs for Modern Datacom and Optical Ranging</i>
14:00-14:30	Yi (Frank) Rao , Goeroptics
	<i>Scaling Augmented Reality Waveguide by Nanofabrication</i>
14:30-15:00	Pan Cao , Huawei Technologies Co., Ltd.
	<i>Optical Interconnect Evolution for AI Data Center</i>
15:00-15:30	Jun Wang , Sichuan University & Suzhou Everbright Photonics Co., Ltd
	<i>High Performance Semiconductor Lasers</i>
15:30-16:00	Kaiyu Cui , Tsinghua University
	<i>Lab to Fab: On-chip Spectral Imaging and Sensing</i>
16:00-18:00	Event 1
18:00-21:00	Banquet

Monday, August 10, 2026 (Venue 1)

8:15-8:45	Registration
Session IV-1 Chair: Frédéric Grillot	
8:45-9:30	Grzegorz Sęk , Wrocław University of Science and Technology
	<i>Exploring the Unique Properties and Application Potential of InAsP/InP Quantum Dots in Nanowires</i>
9:30-10:15	David Gershoni , Technion - Israel Institute of Technology
	<i>Deterministic Generation of a Large-scale Multi-photon GHZ state</i>
10:15-10:45	Tea & Coffee Break
Session IV-2 Chair: Fabrice Raineri	
10:45-11:30	Nobuhiko Nishiyama , Institute of Science Tokyo
	<i>Photonic Integrated Circuits with Heterogeneous Materials Integration and Photonic-Electronic Co-design Technologies</i>
11:30-12:15	Wei Shi , Université Laval
	<i>Ultra-High Bandwidth-Density Integrated Coherent Optics</i>
12:15-14:00	Lunch
14:00-16:00	Event 2
18:00-19:20	Casual Buffet Dinner

Tuesday, August 11, 2026 (Venue 1)

8:15-8:45	Registration
Session V-1 Chair: Bala Pesala	
8:45-9:30	Xingde Li , Johns Hopkins University
	<i>Low-Coherence Biophotonic Imaging for Seeing the Unseen</i>
9:30-10:15	Weijian Yang , University of California, Davis
	<i>High-speed Miniaturized Two-photon Microscope</i>
10:15-10:45	Tea & Coffee Break
Session V-2 Chair: David Gershoni	
10:45-11:30	Bala Pesala , Ayur.AI & Adiuvo Diagnostics
	<i>Photonics for Clinical Diagnostics: Cancer Margins, Bacterial Detection, and Pulse Diagnostics</i>
11:30-12:15	Ming Li , Institute of Semiconductors, CAS
	<i>Photonics-Electronics Convergence: Oscillation, Computation and Integration</i>
12:15-13:30	Lunch
Session V-3 Chair: Xingde Li	
13:30-14:15	Sven Höfling , University of Würzburg
	<i>Deterministic Telecom-wavelength Quantum-dot Devices for Scalable Quantum Photonics</i>
14:15-15:00	Takuo Tanemura , The University of Tokyo
	<i>Metasurface Devices for Optical Communication and Interconnects</i>
15:00-15:45	Qing Dai , Shanghai Jiao Tong University
	<i>Engineering Polariton Dispersion: Reversed Cherenkov Radiation and Flatland Wakes</i>
15:45-16:15	Tea & Coffee Break
16:15-18:00	Free
18:00-20:45	Casual Buffet Dinner



Wednesday, August 12, 2026

Tsinghua Campus Tour

8:00	Check out from Venue 1
8:00-9:30	Bus to Tsinghua University
9:30-12:00	Tsinghua Campus Tour
12:00-13:20	Lunch
14:00-15:00	Concert
15:00-17:00	Bus to Venue 2 (Tianjin)
18:00-20:00	Casual Buffet Dinner

Thursday, August 13, 2026 (Venue 2)

8:15-8:45	Registration
Session VI-1 Chair: Limin Tong	
8:45-9:30	Vladimir G. Dubrovskii , St. Petersburg State University <i>III-V Ternary Nanowires: Building Blocks for Quantum Information Technologies</i>
9:30-10:15	Hongsheng Chen , Zhejiang University <i>Frontiers of Intelligent Metamaterials and Metamaterials Intelligence</i>
10:15-10:45	Tea & Coffee Break
Session VI-2 Chair: Guillaume Huyet	
10:45-11:30	Limin Tong , Zhejiang University <i>Optical Nanofibers for Extreme Photonics</i>
11:30-12:15	Tao Li , Nanjing University <i>Meta-optics 3.0: On-chip Metasurface for Revolutionary Applications</i>
12:15-13:30	Lunch
Session VI-3 Chair: Hongsheng Chen	
13:30-14:15	Si-Cong Tian , Changchun Institute of Optics, Fine Mechanics and Physics, CAS <i>Energy-Efficient High-Speed Vertical-Cavity Surface-Emitting Lasers for Data Communication</i>
14:15-14:45	Tea & Coffee Break

Poster Session II Chair: Yidong Huang	
14:45-15:45	Poster Summary Talk (2 minutes each)
15:45-17:00	Poster Viewing
18:00-20:00	Casual Buffet Dinner

Friday, August 14, 2026 (Venue 2)

8:15-8:45	Registration
Session VII-1 Chair: Lars Samuelson	
8:45-9:30	Ady Arie , Tel Aviv University
	<i>Generation of High Dimensional Quantum Light and Its Application in Communication, Sensing and Computing</i>
9:30-10:15	Fang Liu , Tsinghua University
	<i>Free-Electron Radiation with Micro/Nanostructures</i>
10:15-10:45	Tea & Coffee Break
Session VII-2 Chair: Baile Zhang	
10:45-11:30	Lars Samuelson , Southern University of Science and Technology / Lund University
	<i>Nanoscale Electrooptical Studies of Nanowires and NanoLEDs</i>
11:30-12:15	Zhangyuan Chen , Peking University
	<i>Transmission over Anti-resonant Hollow-core Fibers</i>
12:15-13:30	Lunch
Session VII-3 Chair: Hongyan Fu	
13:30-14:15	Guillaume Huyet , Univ. Provence-Alpes-Côte d'Azur
	<i>Coherent Coupling of Semiconductor Lasers for Energy-Efficient Frequency Combs and High-Bandwidth Sources</i>
14:15-14:45	Tea & Coffee Break
14:45-17:00	Visit H-Chip
17:00-21:00	Event 3



Saturday, August 15, 2026 (Venue 2)

8:15-8:45	Registration
Session VIII-1 Chair: Cunzhu Tong	
8:45-9:30	Baile Zhang , Nanyang Technological University
	<i>Topological Photonic and Phononic Crystals: A Synthetic Universe of Waves</i>
9:30-10:15	Min Qiu , Westlake University
	<i>Metasurface Nanophotonic Devices Based on Superhard Materials</i>
10:15-10:45	Tea & Coffee Break
Session VIII-2 Chair: Ady Arie	
10:45-11:30	Cunzhu Tong , Changchun Institute of Optics, Fine Mechanics and Physics, CAS
	<i>Triple-lattice Photonic Crystal Surface Emitting Lasers</i>
11:30-12:15	Jin Liu , Sun Yat-Sen University
	<i>Semiconductor Cavity Quantum Electrodynamics</i>
12:15-13:30	Lunch
Session VIII-3 Chair: Vladimir G. Dubrovskii	
13:30-14:15	Hongyan Fu , Tsinghua University
	<i>Integrated Photonics for LiDAR</i>
14:15-15:00	Xinghui Li , Tsinghua University
	<i>Holographic Lithography for Grating Fabrication and Atomic-scale Characterization of Gratings</i>
15:00-15:30	Tea & Coffee Break
15:30-17:30	Free
18:00-20:30	Award Banquet

Sunday, August 16, 2026 Departure

Invited Speakers List

Invited Speakers List		Paper
Yasuhiko Arakawa	The University of Tokyo	20
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Dieter Bimberg	Changchun Institute of Optics, Fine Mechanics and Physics, CAS/TU Berlin	19
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Zhangyuan Chen	Peking University	190
Kaiyu Cui	Tsinghua University	103
Qing Dai	Shanghai Jiao Tong University	123
Fei Ding	Leibniz University Hannover	30
Vladimir G. Dubrovskii	St. Petersburg State University	125
Gadi Eisenstein	Technion - Israel Institute of Technology	32
Alfred Forchel	nanoplus Nanosystems and Technologie/Sensalight Technologies/University of Würzburg	28
Hongyan Fu	Tsinghua University	198
David Gershoni	Technion - Israel Institute of Technology	107
Frédéric Grillot	Université Laval	95
Alexey Gubenko	VP of RnD at Innolume	98
Sven Höfling	University of Würzburg	120
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Kenichi Iga	Institute of Science Tokyo	25
Fumio Koyama	Institute of Science Tokyo	23
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Tao Li	Nanjing University	129
Xingde Li	Johns Hopkins University, Baltimore	112



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Xinghui Li	Tsinghua University	200
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Jin Liu	Sun Yat-Sen University	197
Yoshiaki Nakano	Toyota Technological Institute	36
Nobuhiko Nishiyama	Institute of Science Tokyo	108
Bala Pesala	Ayur.AI & Adiuvo Diagnostics	116
Min Qiu	Westlake University	194
Fabrice Raineri	Université Côte d'Azur	34
Yi (Frank) Rao	Goeroptics	100
Lars Samuelson	Southern University of Science and Technology / Lund University	188
Grzegorz Sęk	Wrocław University of Science and Technology	105
Wei Shi	Université Laval	110
Hong-Bo Sun	Tsinghua University	92
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Takuo Tanemura	The University of Tokyo	122
Si-Cong Tian	Changchun Institute of Optics, Fine Mechanics and Physics, CAS	131
Cunzhu Tong	Changchun Institute of Optics, Fine Mechanics and Physics, CAS	195
Limin Tong	Zhejiang University	128
Jun Wang	Sichuan University/Suzhou Everbright Photonics	102
Qijie Wang	Nanyang Technological University	35
Xiulai Xu	Peking University	37
Weijian Yang	University of California, Davis	114
Siyuan Yu	Sun Yat-sen University	93
Baile Zhang	Nanyang Technological University	193



Papers

Quantum Dot Lasers and Amplifiers for Energy-Efficient Multi Terabit Data Communication

Dieter Bimberg

Bimberg Chinese-German Center for Green Photonics of the Chinese Academy of Sciences at CIOMP and
Center of Nanophotonics TU Berlin

Abstract QD-based lasers and amplifiers present a backbone of novel energy-efficient multi-Tb/s optical networks at 1.3 and 1.55 μm . Fundamentals are explained and latest progress is reported.

The rapidly growing demand for higher data rates in metropolitan area networks, local area networks, and optical access networks, requires novel ultra-high bit rate sources, which are more energy efficient than any semiconductor laser sources presently existing [1,3,4]. Quantum Dot Lasers based on GaAs/InP emit at 1.3/1.55 μm , respectively. They show record low threshold current density, and complete temperature stability beyond 80°C [2]. Emission from the saturated ground state shows a hat-like structure with intensity differences of the longitudinal modes below 0.5 db. Passive mode-locking generates pulses down to the sub- ps range at repetition rates up to 90 GHz. Optical self-feed-back reduces the jitter to 200 fs, reaching an electrical linewidth of 2 kHz. PML QD-lasers are also excellent microwave sources showing the same extremely small phase noise as the optical pulses. Multiplexed 80 Gbit/s RZ OOK based on PML-QDLs and Mach-Zehnder modulators show a S/N of 12, rms timing jitter of 452 fs and BER below $10\text{exp-}9$. Data transmission across 45 km using RZ Differential Quadrature Phase-Shift Keying (DQPSK) with BER below $10\text{exp-}11$ is demonstrated. The hat spectrum of one single laser of several tens of closely spaced narrow is a pulse source for bit rates ~ 6 TBit/s. SOAs based on QDs show superior properties at 1.3 μm as compared to QW-based ones. These devices and more have been commercialized by Innolume GmbH, Dortmund.

References

1. G.Eisenstein and D.Bimberg, eds.: "Green Photonics and Electronics", Springer 2017
2. N. Kirstaedter-et al., Low threshold, large To injection-laser emission from (InGa)As Quantum dots, El. Lett. 30, 1416, 1984
3. D. Bimberg Quantum dots for lasers, amplifiers and computing, J. Physics D (Applied Phys) 38, 2055, 2005
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Dieter Bimberg is the CEO of the "Bimberg Chinese-German Center for Green Photonics" of the CAS at CIOMP and is the Founding Director of the Center of Nanophotonics at TU Berlin. He was chairman of the Department of Solid-State Physics at TUB from 1991 to 2012. He served as Distinguished Adjunct Professor at KAU, Jeddah 2012-2018. He was holding guest professorships at the Technion, Haifa, U.C. Santa Barbara, CA, USA, and at Hewlett-Packard Labs in Palo Alto, CA. He has authored more than 1600 papers, 71 patents, and 8 books resulting in more than 72,000 citations and a Hirsch factor of 118. His honours include the Russian State Prize in Science and Technology 2001, his

election to the German Academy of Sciences Leopoldina in 2004, to the Russian Academy of Sciences in 2011, to the American Academy of Engineering in 2014, to the American Academy of Inventors 2016, to the Chinese Optical Society in 2022. He was elected as Fellow of the American Physical Society and IEEE in 2004 and 2010, respectively. He received the Max-Born-Award and Medal 2006, awarded jointly by IoP and DPG, the William Streifer Award of the Photonics Society of IEEE in 2010, the UNESCO Nanoscience Award and Medal 2012, Heinrich-Welker-Award 2015 and Nick Holonyak jr. Award of OSA in 2018, the IEEE Nishizawa Award and Medal in 2019 the Stern-Gerlach Award of DPG in 2022 (the highest German physics award) Since 2023 he is Vice-President of the International Artificial Intelligence Association He received honorary doctorates of the University of Lancaster, UK, and the St. Petersburg Alferov University of the Russian Academy of Sciences. His research interests include the growth and physics of nanostructures and nanophotonic devices, ultrahigh speed and energy efficient photonic devices, like quantum dot-based mode-locked lasers and VCSELs, and ultimate nano flash memories based on quantum dots.

Quantum Dots: A Key Nanostructure for Photonic–Electronic Convergence for Future AI

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Abstract This lecture reviews the evolution of quantum dots from semiconductor quantum structures to key enabling technologies for photonic–electronic convergence, silicon photonics, quantum photonics, and Physical AI, highlighting their transformative impact on future information infrastructures.

Recent advances in XPU computing, represented by graphics processing units (GPUs), have driven a dramatic leap in the computational capability of artificial intelligence (AI). AI is now evolving from the era of Generative AI toward Physical AI, which directly interacts with the physical world, while computing architectures are shifting from centralized cloud computing to distributed edge computing capable of real-time processing. At the same time, this AI revolution has led to an explosive increase in both data traffic and power consumption in data centers, exposing the fundamental challenge of ensuring the energy sustainability of future information infrastructures.

Against this backdrop, data-center architectures are rapidly transitioning from conventional electrical interconnects based on metallic wiring to optical interconnects. This technological trend is accelerating the realization of a new design paradigm—Photonic–Electronic Convergence (PEC)—in which photonic and electronic technologies are co-designed and seamlessly integrated. Since the late 2000s, as the continued scaling of electronic circuits has encountered fundamental physical and power-consumption limits, replacing electrical interconnects within and between LSIs with optical links has emerged as a practical approach to simultaneously improving system performance and energy efficiency. Today, PEC has expanded beyond data-center communications to encompass AI computing infrastructures and edge computing, with silicon photonics and co-packaged optics (CPO) serving as its key enabling technologies.

One of the most critical components of silicon photonics is the optical light source. However, because silicon is an indirect-bandgap semiconductor, it is intrinsically incapable of efficient light emission. Consequently, hybrid integration of III–V compound semiconductors with silicon is expected to remain the most practical solution for the foreseeable future. In this context, quantum dot (QD) lasers have attracted considerable attention as ideal light sources for CPO, owing to their unique combination of low threshold current, excellent temperature stability, and exceptional tolerance to optical feedback, enabling ultra-compact optical engines to be integrated in close proximity to heat-generating LSIs.

The concept of quantum dots can be traced back to the superlattice and quantum-well structures proposed by Leo Esaki in 1970 [1]. Quantum wells subsequently led to the development of quantum-well lasers and high-electron-mobility transistors (HEMTs), which have become indispensable technologies supporting today's information society. Nevertheless, carriers in quantum wells retain at least one degree of freedom. In contrast, the quantum dots proposed by Arakawa and Sakaki in 1981–1982 [2] introduced complete three-dimensional carrier confinement, resulting in fully discrete energy states and establishing a new paradigm in semiconductor quantum nanostructures. Subsequent advances in self-assembled growth technology enabled the practical realization of QD lasers, whose outstanding device characteristics have since been extensively demonstrated [3–5].

Quantum dots have subsequently evolved beyond laser gain media to become versatile quantum light sources that exhibit excellent compatibility with photonic nanostructures and can be electrically driven [6–9]. They are now regarded as key building blocks for quantum integrated photonics, with promising applications ranging from quantum key distribution and quantum networks to optical quantum computing.

Viewed from this broader perspective, the progression from Esaki's quantum structures to the three-dimensional quantum confinement of quantum dots, and further to photonic–electronic convergence and Physical AI, represents a continuous evolution of semiconductor quantum science. One hundred years after the birth of quantum mechanics, semiconductor quantum science is entering a new era in which it is no longer

merely an enabling technology for electronic and photonic devices, but a fundamental scientific platform that will shape the information infrastructure of future society.

In this presentation, we first review the early development of quantum dot lasers, including the original theoretical proposal, the experimental demonstration of temperature-insensitive threshold current operation, and their subsequent commercialization. We then discuss the evolution of photonic–electronic convergence based on silicon photonics and quantum dot lasers, highlighting hybrid III–V/silicon integration technologies and integrated photonic chips for future information systems [5]. We also present recent progress in quantum photonics based on quantum dots, including silicon-integrated quantum dot lasers and single-photon sources enabled by transfer printing and other heterogeneous integration technologies [6–9]. Finally, recent advances toward further improving quantum dot laser performance, including Co-doping techniques [10], will be discussed together with future prospects for quantum-dot-based photonic and quantum information technologies.

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He received various awards, including IBM Science Award (1991), Leo Esaki Award (2004), IEEE/LEOS William Streifer Award (2004), Fujiwara Award, Prime Minister Award (2007), IEEE David Sarnoff Award, the Medal with Purple Ribbon (2009), C&C Prize (2010), Heinrich Welker Award, OSA Nick Holonyak Jr. Award (2011), the Japan Academy Prize (2017), IEEE Junichi Nishizawa Medal (2019), URSI Balthasar Van der Pol Gold Medal (2023), and Ichimura Prize in Science for Outstanding Achievement (2024). He received Honor of a Person of Cultural Merit (2023).

High-Speed Back Emitting 1060 nm VCSEL for AI Scale-up Optical Interconnects

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Abstract The VCSELs have been the proven choice for short distance optical interconnects for datacenters with low power consumption and high data-rates for data communications. In this talk, we discuss novel VCSEL arrays for potential near-packaged optics (NPO) and co-package optics (CPO) for scale-up interconnects in datacenters. We report recent development of high-speed 1060-nm back-emitting VCSEL for near-package optics (NPO) and co-packaged optics (CPO) applications. We will show 212-Gbps PAM4 eye openings are further observed over 30~100 m multimode-fiber links. We will show flip-chip bonding configuration with low power consumption, rendering 1060-nm back-emitting VCSELs excellent choice for high bandwidth-density optical engines.



Connie Chang-Hasnain is Chairperson of Bixel Photonics Co. Ltd., X.Q. Deng Presidential Chair Professor at the Chinese University of Hong Kong (Shenzhen) and Whinnery Chair Professor Emerita at the University of California (UC) Berkeley. She is member of the US National Academy of Engineering and an international member of the Chinese Academy of Engineering.

Chang-Hasnain received her Ph.D. in Electrical Engineering and Computer Science (EECS) from UC Berkeley in 1987. She was a Member of the Technical Staff at Bell Communications Research (1987–1992) and Assistant Professor at Stanford University (1992–1995). She joined UC Berkeley as Professor of EECS in 1996. She was Whinnery Distinguished Chair Professor 2006-2020; Chair of the

Nanoscale Science and Engineering Graduate Group 2006-2017; and Associate Dean for Strategic Alliances of College of Engineering 2014-2019.

Prof. Chang-Hasnain's research interests range from semiconductor optoelectronic devices to materials and applications. Over the past 40 years, she worked on many aspects of VCSELs including planar VCSEL structure, MEMS-VCSEL for wavelength tuning, and VCSEL arrays for 3D imaging. She has been honoured with the 2024 IEEE Nick Holonyak Jr. Medal, 2018 Okawa Prize, 2015 UNESCO Medal For the Development of Nanoscience and Nanotechnologies, and 2011 IEEE David Sarnoff Award. She was the Editor-in-Chief of Journal of Lightwave Technology 2007-2012, a member of IEEE LEOS Board of Governors, OSA Board of Directors, and the 2021 President of Optica.

Forty Years of VCSEL Innovation: From Fundamental Principles to Terabit- Scale Optical Interconnects

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Abstract Reviewing forty years of VCSEL research innovation, this tutorial talk highlights critical achievements enabling energy-efficient, ultrahigh-speed modulation and multi-terabit optical interconnects designed specifically to satisfy the rigorous demands of future AI datacenter networks.

Introduction

Vertical-cavity surface-emitting lasers (VCSELs) have become one of the most influential innovations in semiconductor laser technology. Invented in 1977 by Kenichi Iga, the VCSEL introduced a fundamentally new laser geometry in which light is emitted perpendicular to the wafer surface. This concept enabled wafer-scale testing, dense two-dimensional laser arrays, and highly scalable photonic integration.

VCSEL Photonics Innovation

The first VCSEL oscillation was demonstrated in 1979, followed by room-temperature continuous-wave operation in 1988, establishing VCSELs as practical semiconductor light sources. Around the same period, the demonstration of sub-milliwatt-threshold microcavity VCSELs highlighted their potential for low-power operation. Over the subsequent decades, advances in materials, epitaxial growth, and microfabrication transformed VCSELs from laboratory devices into highly manufacturable products. Owing to their unique vertical-emission architecture, VCSELs have become the dominant light source for short-reach optical interconnects and numerous sensing applications. In recognition of their technological and societal impact, VCSEL technology was honored as an IEEE Milestone in 2025.

Today, the rapid growth of artificial intelligence (AI) and large-scale data processing is creating unprecedented demands on data-center interconnects. As data movement increasingly dominates system power consumption, energy-efficient optical links have become essential. VCSELs are particularly well suited to address this challenge because of their small active volumes, low threshold currents, and capability for high-speed direct modulation, enabling compact and low-power optical transmitters without external modulators.

Recent advances have pushed VCSEL performance far beyond traditional limits. By exploiting photon–photon resonance and coupled-cavity effects, modulation bandwidths exceeding 60 GHz have been achieved, supporting per-lane data rates beyond 200 Gb/s. Furthermore, VCSELs are intrinsically compatible with dense two-dimensional arrays. Large-scale VCSEL arrays integrating dozens of emitters have demonstrated aggregate capacities approaching 10 Tb/s, providing the bandwidth density required for next-generation AI computing systems.

Another key advantage is energy efficiency. Directly modulated VCSEL chips have demonstrated energy consumption approaching 50 fJ/bit, making them attractive candidates for sustainable photonic infrastructures.

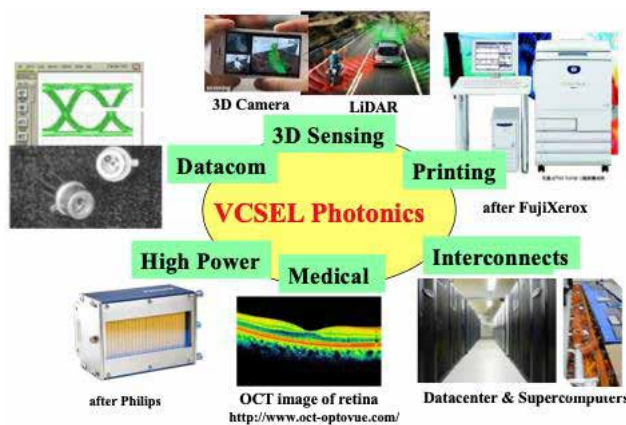


Fig. 1 Various applications of VCSELs

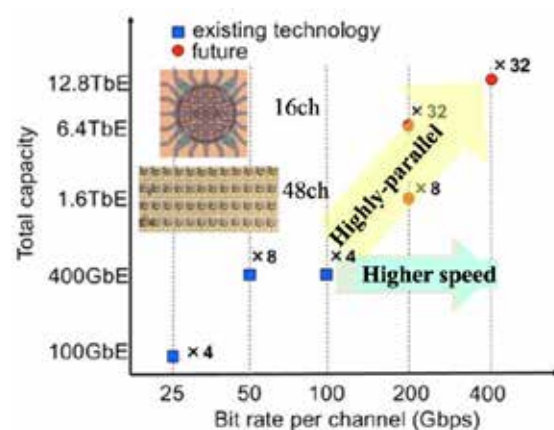


Fig. 2 Toward a multi-Tbps optical engine based on a high-speed 2D VCSEL array.

Conclusions

This presentation reviews the major breakthroughs that have driven the evolution of VCSEL technology and highlights recent progress in ultrahigh-speed operation, large-scale VCSEL arrays, and energy-efficient optical interconnects. The

outlook for future applications in AI datacenters, co-packaged optics, and advanced photonic integration will also be discussed.

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His research interests include high-speed VCSEL photonics, photonic integrated devices, 3D optical sensing, and LiDAR. He has authored or co-authored more than 1,000 journal and conference papers, including over 100 invited presentations. For more than four decades, he has been a leading researcher in VCSEL photonics and single-mode semiconductor lasers for broadband optical communications. Prof. Koyama has received numerous awards, including the IEEE/LEOS William Streifer Scientific Achievement Award (2008), the Izu Hayashi Award (2012), the Okawa Award (2018), the Optica Nick Holonyak, Jr. Award (2019), the IEEE Nick Holonyak, Jr. Medal (2024, co-recipient), and the IEICE Distinguished Achievement and Contributions Award (2024). He is a Life Fellow of IEEE and Optica, an Honorary Member of IEICE, and a Fellow of the Japan Society of Applied Physics. He was elected an International Member of the U.S. National Academy of Engineering (NAE) in 2025.

Vertical-Cavity Surface-Emitting Laser (VCSEL) : Principle, Physics, and Industries

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Abstract: We will review a tiniest semiconductor laser VCSEL (Vertical-Cavity Surface-Emitting Laser). On October 28, 2025, the VCSEL received IEEE Milestone. We will introduce how the milestone was reviewed to be finalized to dedicate. We survey the VCSEL photonics systems and industries beyond the millstone.

The VCSEL (pronounced as [vic-cell]) was born in 1977. It was just an inspiration after a considerable struggle to discover a laser, which should realize; (i) single mode, (ii) monolithic manufacturability, and (iii) frequency reproducibility.

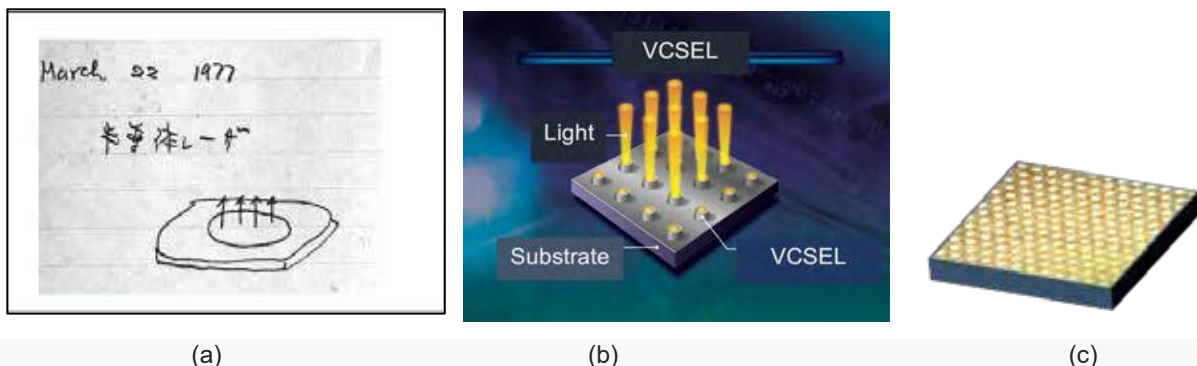


Fig. 1. The initial idea (a) of surface-emitting laser sketched by K. Iga in a page of research note dated on March 22, 1977 [1]. The light output comes from the surface as (b). Fig.1(c) is a photo of a currently used VCSEL device.

Toward this ideal semiconductor laser, the author considered three requirements as stated above [1][4]. In 1977, the author of formerly Tokyo Institute of Technology conceived a unique semiconductor laser of which simple drawing is shown in Fig. 1 [1] and named "surface Emitting Laser". Contrary to the conventional Fabry-Perot edge-emitting semiconductor lasers, this idea comprises a laser cavity which is short and vertical to a wafer surface. It was later named VCSEL (Vertical-Cavity Surface-Emitting Laser) that should be the tiniest current injection laser.

In 1979, H. Soda (Iga's graduate student) successfully demonstrated lasing operation of a GaInAsP/InP VCSEL under pulsed injection current condition at 77 K [2]. This is the first demonstration of the current-injected VCSEL lasing oscillation at 77K, which clearly showed the possibility of a VCSEL as a practical vertical-cavity laser. Iga and his team concentrated on paving the way for this new and attractive semiconductor laser. Iga, Y. Motegi and H. Soda (graduate students) made a breakthrough by fabricating a short cavity of about 10-micron long [3]. They developed a fine chemical etching technology to realize such a short cavity length. In 1986, Iga's graduate student, S. Kinoshita succeeded in reducing the threshold current of VCSELs to less than 10 mA for the first time in the world [4]. The threshold current was 4.5 mA at 77 K under CW current and 6 mA at room temperature under pulsed injection, with a buried hetero-structure AlGaAs/GaAs VCSEL. This low-threshold current achievement was paid attention from the community of semiconductor lasers. Since then, Iga and his team have been continuously conducting elaborate research and development on VCSELs and achieved many results, which have contributed to the growth of VCSEL devices and related applications.

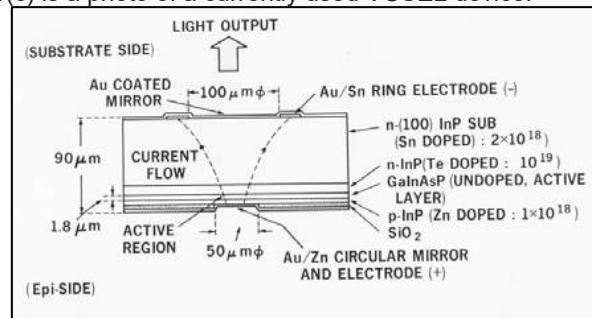


Fig.2 A first current injection surface-emitting laser operating at 77 K.

Theoretical and experimental studies for VCSELs done by Iga's team were summarized as a paper in IEEE Journal of Quantum Electronics in 1988 [5]. Based on the research results, dynamic single frequency operation, extremely low threshold current of <1 mA, and a possibility of room temperature CW operation of VCSELs were predicted in the paper. Fundamental results on a 5x5 two-dimensional array were also described.

Continuous-wave (CW) operation at room temperature was achieved by Fumio Koyama of Iga's team in 1988 [6]. We used an AlGaAs/GaAs VCSEL structure with a micro-cavity made of dielectric multilayer mirrors at the wavelength of 0.8 microns.

Owing to the short cavity length, a VCSEL emits single-frequency light defined by the cavity length as shown in Fig. 3. Continuous-frequency tuning was demonstrated by N. Yokouchi, graduate student of Iga's team with an InGaAsP/InP VCSEL. One of the mirrors of was replaced by a mechanically movable external mirror in 1992 [7].

The VCSEL photonics systems as shown in Fig.4 has been expanded beyond the millstone such as in high-speed transceivers in Data centers, 3D face recognition in mobile phones, LiDAR in automotive, mobility networks, OCT in various body inspection, atomic clocks, industrial heating, and so [8][9].

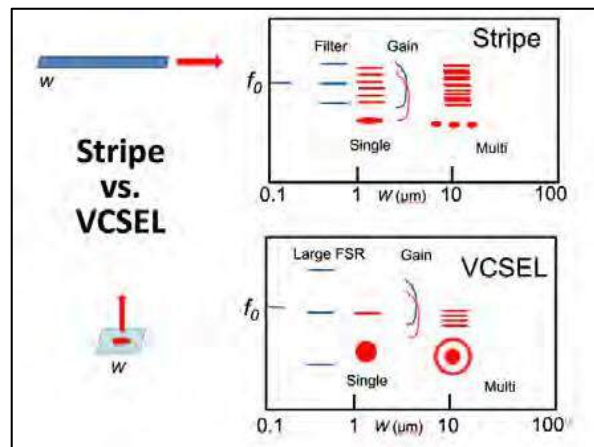


Fig.3 Resonance of edge-emitting laser and surface-emitting laser

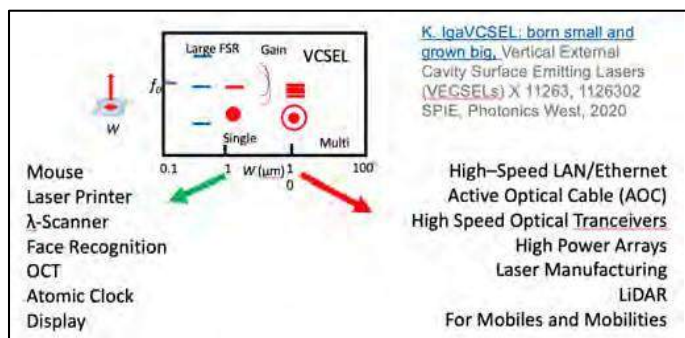


Fig. 4 Applications of Vertical-Cavity Surface-Emitting Laser

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Biography



Dr. Kenichi Iga is Honorary Professor, Institute of Science Tokyo and the 18th President of former Tokyo Institute of Technology.

Born in 1940, Hiroshima, Japan. 1963 BE, 1965 ME, and 1968 Dr. Eng. all from Tokyo Institute of Technology.

Assistant Professor at Tokyo Institute of Technology (1968-1973), Associate Professor (1973-1984), and Professor (1984-2001). Professor Emeritus at Tokyo Institute of Technology (2001), Executive Director of the Japan Society for the Promotion of Science (2001-2007), President of Tokyo Institute of Technology (2007-2012). Honorary Professor at Tokyo Institute of Technology (2022), Honorary Professor at Institute of Science Tokyo (2024). Chair of Micro-Optics Research Group, Japan Society of Applied Physics (2003-present). He is an IEEE Life Fellow, an OPTICA Life Fellow, a Fellow of IEICE, JSAP, and Laser Society, a Foreign Member of the U.S. National Academy of Engineering.

Dr. Iga's numerous awards include the 1987

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Foundation. the 1998 IEEE John Tyndall Award, the 1998 Asahi Award, the 2002 Rank Prize in Optoelectronics, the 2003 Fujiwara Prize, the 2003 IEEE Daniel E. Noble Award, the 2013 Franklin Institute Bower Award and Prize, the 2021 IEEE Edison Medal, and 2024 Optica's Frederic Ives Medal/ Jarus W. Quinn Prize.

He received the Medal with Purple Ribbon from the Emperor of Japan in 2001 and is designated the Person of Cultural Merit by the Japanese government in 2022. He had an honor of receiving the Japan Academy Prize in 2026.

He is a hobby contrabassist and has been playing in orchestra and chamber ensemble for 67 years.

Si-based III-V Quantum Dot Lasers for Si Photonics

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Abstract This presentation summarizes the development milestones of III-V quantum dot (QD) lasers monolithically grown on Si in the past decade. It also presents recent development on III-V QD lasers grown on Si and III-V substrates.

Silicon (Si) has been the foundation of modern electronics, but its extensive utilization in light-emitting sources is hindered by the inefficiency of bulk Si as an emitter. Direct epitaxial growth of III-V compound nanostructures on Si substrates presents a promising avenue for realizing photonic devices on a silicon platform. The primary challenge in monolithic integration of III-V on a group IV platform lies in the formation of high-density threading dislocations (TDs). As a zero-dimensional material, quantum dots (QDs) exhibit three-dimensional quantum confinements, leading to a delta-function-like density of states. Consequently, III-V QD lasers possess low threshold currents, temperature insensitivity, and reduced sensitivity to threading dislocations, making them an ideal candidate for forming the active region in III-V lasers grown on Si substrates. High-performance 1300-nm InAs/GaAs QD lasers have been successfully developed at UCL since 2011 [1-4]. Furthermore, 1550-nm InAs/InP QD lasers with an operating temperature exceeding 100 °C have been recently demonstrated on Si substrates at UCL [5]. This presentation will summarize the development milestones of III-V QD lasers monolithically grown on a Si platform over the past 15 years. Additionally, recent results on the development of high-performance InAs/GaAs QD lasers grown on III-V and patterned Si substrates will be presented with high gain, high operational temperature, and emission from 1300 nm to >2000 nm [6-9], and the potential trend in the next decade will also be predicted.

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Huiyun Liu received his PhD from form Institute of Semiconductor, Chinese Academy of Sciences. After receiving his PhD, he joined the EPSRC National Centre for III-V Technologies at Sheffield University. In 2007, he started his academic career in the Department of Electronic and Electrical Engineering at UCL with commissioning the first new Molecular Beam Epitaxy reactor. In 2012, he was promoted as Chair Professor of Semiconductor Photonics at UCL. His current research interest concentrates on the nanometre-scale engineering of low-dimensional semiconductor structures by using Molecular Beam Epitaxy and the development of novel optoelectronic devices including lasers, detectors, solar cells, and modulators.

Progress in longitudinal single mode lasers for sensing

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Abstract Novel semiconductor laser designs provide longitudinal single mode lasers at any wavelengths from the visible to the IR. These permit trace component sensing for virtually unlimited applications.

Introduction

Laser based gas, liquid and solid trace component sensing constitutes a field that currently is still small. In comparison to the main stream application areas of semiconductor lasers like data communications and storage, however, it is growing dynamically, driven by the need for sensitive, selective, fast and long term maintenance free sensors for e.g. inline production optimization and control or the supervision of green house gas emissions. Compared to other optical sensing approaches like FTIR, based on thermal light sources, or LED based sensing, laser based sensing provides several orders of magnitude higher output intensity per 0,1 nm and extremely compact systems, however, at the expense of a limited spectral range.

Sensing Laser Concepts

Laser based sensing uses a narrow (longitudinal single mode) laser line which is scanned over a spectroscopic feature by temperature or laser current variation. The scan includes sections with the trace component signal as well as sections without contribution of the trace component. Using the optical pathlength and the specific absorption the amount of the trace component can be obtained. The sensitivity of laser based detection can reach into the ppb-range.

As the characteristic features are located at substance specific wavelengths between below about 1 μm and more than 10 μm , different material systems and heterostructure concepts are required for sensing. Whereas the GaAs- and InP-based material systems are used for data and telecom lasers, the GaSb material system is of particular importance for trace component sensing. It permits to cover the wavelength range from about 1,7 μm to above 6,5 μm including particularly strong absorption features of many substances. To cover this wide wavelength range direct gap quantum wells as well as spatially indirect recombination in interband cascade lasers¹ as well as interband recombination in quantum cascade lasers is used. In order to realize longitudinal single mode lasers, we have developed distributed feedback laser concepts specially adapted to the use of a wide variety of material systems and heterostructures as well as e.g. coupled cavity designs, which allow to extend the tuning range of the lasers at the expense of using discontinuous tuning.

Examples of Applications

The talk will highlight advances in sensing laser design and performance as well as laser based analyzers for solids, liquids and gases. Lasers developed and fabricated at nanoplus and Sensalight Technologies are used for a wide variety of topics including green house gas detection (CO_2 , CH_4 , N_2O), for corrosion prevention in natural gas pipelines, for surveillance of proper functioning of spacecrafts, supervision of lung development in preterm babies, etc. Using these lasers we have developed laser analysers for inline applications in building material and paper fabrication.

Conclusions

Laser based sensing permits highly selective, quantitative detection of a wide variety of substances. Due to its capability to detect compositional changes quantitatively in real time an important application area is inline detection of material composition and quality, which can be used to optimize production processes. Other important application areas include monitoring of green house gas emissions, medical applications, automotive etc. As modern societies are increasingly demanding on evaluations of potential hazards, semiconductor laser based sensing of trace components, which was proposed about 30 years ago, will expand to a wide variety of novel applications in the future.

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Robert Weih, was born in Schwerin, Germany in 1985. He received his Diploma degree in nanotechnology engineering and PhD degree in Physics from the University of Würzburg in 2011 and 2018, respectively. His main research interests covered molecular beam epitaxy for mid infrared emitting and detecting devices in the GaSb material system. In 2015, he joined the epitaxy division at nanoplus Advanced Photonics Gerbrunn GmbH. He is responsible for the epitaxy and chip development for innovative devices based on III-V semiconductors such as GaAs, InP and GaSb.



Peter Gold studied physics from 2005-2010 (Diploma) and received his PhD degree from University of Würzburg in 2015. Peter's research interest has been in the area of semiconductor nanostructures. Since 2017, he is head of department frontend production at nanoplus Nanosystems and Technologies GmbH in Gerbrunn.



Nicolas Koslowski received his Dipl.-Ing. (FH) degree in Engineering from the University of Applied Sciences Würzburg–Schweinfurt in 2002. After joining nanoplus in 2002, he specialized in semiconductor laser development and laser spectroscopy and became Director of Engineering in 2010. Since 2022, he has been Director of Engineering at Sensalight Technologies, focusing on advanced laser technologies and sensor systems.



Steffen Falkenstein received his B.S. degree in Technical Physics and his M.S. degree in Photonics from the Munich University of Applied Sciences, Germany, in 2020 and 2022, respectively. Since joining the semiconductor laser industry in 2022, he has been involved in the development of longitudinal single-mode laser sources and their integration into industrial sensing systems. His research interests include semiconductor lasers, laser spectroscopy, optical sensing, infrared spectroscopy, and applied photonics for industrial process monitoring.



Johannes Koeth received his Diploma in Physics (equivalent to an MS degree) from the Julius Maximilians University of Würzburg in 1997, and his PhD (Dr. rer. nat.) in Physics from the same university, where he specialized in molecular beam epitaxy (MBE), semiconductor lasers, and VCSELs. He is the co-founder and has served as Managing Director/CEO of nanoplus Nanosystems and Technologies GmbH (Germany) since its founding in 1998. In 2020, he co-founded Sensalight Technologies GmbH to advance volume production of semiconductor laser components, with a current focus on the automotive sector. He has authored or co-authored over 200 papers (including journal articles and conference proceedings) in leading technical journals and conferences such as Optics Express, IEEE Photonics Technology Letters .



Alfred Forchel received his Diploma Degree as well as his PhD at University of Stuttgart in 1978 and 1983, respectively, for studies of semiconductors under high optical excitation. As the head of the Microfabrication Facility of the Physics Institute at Stuttgart University he carried out investigations on nanofabrication processes for electronic and photonic devices. In 1990 he was appointed full professor of Applied Physics at Wuerzburg University, where he built up a nanofabrication laboratory for III-V semiconductor nanodevices including single mode lasers in the near and mid-IR. He started together with Johannes Koeth in 1998 nanoplus and in 2019 Sensalight Technologies and in 2024 Photonics Sensing Systems. Alfred Forchel has been awarded honoris causa doctorates from Technion, Haifa, and University of Science and Technology, Wroclaw as well as e.g. the Welker Award.

Towards long distance quantum communication with deterministic single photon sources

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Abstract This talk presents deterministic semiconductor quantum-dot single-photon sources for scalable quantum photonic devices, long-distance quantum key distribution, and future quantum internet applications.

Introduction

This talk will present our recent progress in semiconductor quantum-dot-based deterministic single-photon sources for scalable quantum information technologies and long-distance quantum communication. Single photons are central carriers of quantum information in quantum key distribution, quantum networks, and the future quantum internet. Compared with conventional weak coherent sources, deterministic single-photon sources can generate genuine single-photon states on demand, thereby suppressing multi-photon emission at the source level and improving security, transmission efficiency, and loss tolerance. Developing high-performance, tunable, integrable, and network-compatible deterministic single-photon sources is therefore a key step towards practical quantum communication.

Main text

The talk will first introduce the material and device foundations of semiconductor quantum-dot light sources. Starting from the controlled growth of quantum dots, we have developed deterministic single-photon and entangled-photon sources with high brightness, high purity, and high indistinguishability. By combining strain engineering, nanomembrane technologies, and semiconductor nanophotonic structures, key parameters such as emission wavelength and exciton fine-structure splitting can be precisely controlled. At the same time, photon extraction efficiency and light-matter interaction strength can be significantly enhanced. These advances enable quantum-dot light sources not only to achieve excellent single-device performance, but also to become compatible with on-chip photonic integration, providing essential building blocks for future large-scale quantum photonic circuits.

At the device level, we further develop scalable quantum photonic devices, including on-demand entangled-photon sources, multi-quantum-dot waveguide-integrated architectures, and efficient semiconductor light-matter interfaces. These devices provide key functions for the generation, manipulation, transmission, interference, and measurement of quantum states. In particular, multi-quantum-dot integration is important for future multi-node quantum networks, where stable connections, synchronized emission, and entanglement distribution between independent nodes are required. Owing to its advantages in material growth, nanofabrication, photonic integration, and electrical control, the semiconductor platform offers a promising route to bridge fundamental quantum physics and deployable quantum technologies.

The main focus of the talk will be recent experimental progress in long-distance quantum communication using deterministic single-photon sources. First, we will present a field demonstration of intercity quantum key distribution using a semiconductor quantum-dot deterministic single-photon source. Secure key distribution was achieved over a deployed 79 km optical fiber link with low quantum bit error rates and high key efficiency, showing that deterministic single-photon sources can operate reliably not only in laboratory environments but also in real urban fiber networks. We will then discuss time-bin encoded quantum communication for even longer transmission distances. By integrating telecom C-

band quantum dots with self-stabilized time-bin encoders, quantum key distribution over 120 km of standard optical fiber was achieved, while maintaining a quantum bit error rate below 11% for more than six hours. This demonstrates the long-term stability and practical network compatibility of true single-photon-source-based systems.

Finally, the talk will introduce an ultra-stable, low-error dynamic polarization encoding scheme. This approach enables high-fidelity manipulation of single-photon polarization states and maintains stable operation under environmental fluctuations, offering a new technical route for deploying deterministic single-photon sources in complex network conditions.

Conclusion

Overall, these results show that semiconductor quantum-dot deterministic single-photon sources are evolving from laboratory prototypes into key enabling components for deployable quantum networks. With further improvements in brightness, coherence, tunability, integration density, and system stability, this platform is expected to play an important role in quantum key distribution, quantum repeaters, multi-node entanglement distribution, and the future quantum internet.

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Fei Ding is a W3 full professor at Leibniz University Hannover, where he also takes the role of the Board member at the Institute for Solid State Physics and the Laboratory of Nano and Quantum Engineering. Prof. Ding received BSc degree in 2003 from Hefei University of Technology. In 2009 he obtained PhD degree from the joint doctoral promotion program between Max Planck Society Germany and Chinese Academy of Sciences. From 2010 to 2012 he was a Marie Curie Fellow at IBM Zurich Research Laboratory. In 2012 he became a group leader in IFW Dresden and then in 2016 moved to Hannover as a full professor. His group is funded by a number of national and EU projects, including the highly prestigious ERC grants for 3 times (Starting, Consolidator, and Proof-of-concepts).

Quantum Optics and Noise Squeezing in Quantum Dot Gain Media

Gadi Eisenstein

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Session II-1

Abstract Short optical pulses propagating in quantum dot gain media induce a variety of quantum coherent phenomena which impact on the noise properties accompanying the pulses that can be squeezed below the shot noise.

Introduction

Optical pulses with durations shorter than the coherence time in quantum dot gain media induce coherent interactions. For a single excitation pulse, effects such as Rabi oscillations and coherent revival have been demonstrated while two pulses enable observation of Ramsey fringes and photon echoes. These have been observed often using X-FROG characterization accompanied by a semi-classical numerical model.

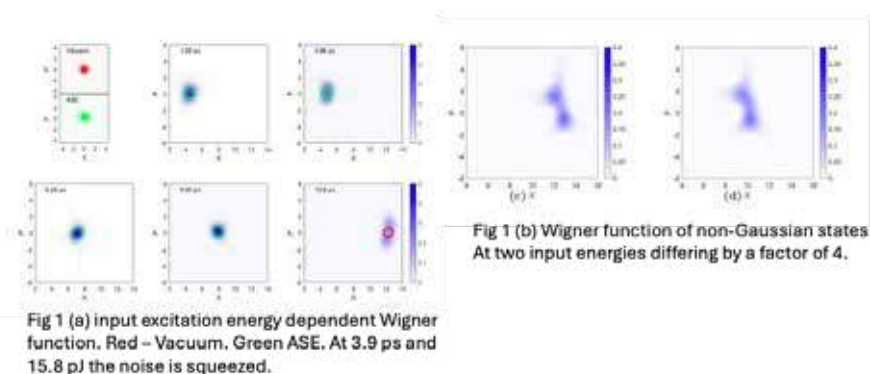
Noise properties

The many initial experiments neglected the noise properties of the pulses emerging from the quantum dot gain medium. Addressing these noise properties requires employment of homodyne measurements in which the pulses to be analyzed serve as the signal and a replica of the excitation pulse serves as the local oscillator. However, the pulses interacting with the gain medium, not only induce coherent interactions but also broaden from 100 fs to roughly 1 ps. This means that the homodyne measurements depend on the temporal overlap between the two pulses feeding the two detectors of the homodyne system. It turns out that the balance detection system can also serve for cross correlation what enables to replicate the X-FROG pattern under Rabi oscillations, and this enables to choose an optimum sampling point for homodyne characterization.

Results

Homodyne characterization together with the inverse Radon transform yield Wigner functions that depend on this sampling position and more important on the excitation pulse energy. The measurements yield sequences of Wigner functions that exhibit simple thermal states, quadrature squeezed states and for very high input pulse energies, non-Gaussian squeezed states. The most intriguing property is the fact that the various Wigner function types are cyclical with input pulse energy so that they repeat for increases in energy by a factor of four which amounts to 2 changes in the pulse area. Hence, we observe quantum squeezing that is governed by Rabi oscillations.

The cyclical nature of the squeezing is shown in Fig. 1 (a) while the non-Gaussian states are presented in Fig. 1 (b)



Gadi Eisenstein received his PhD degrees in 1980, in Electrical Engineering and Applied Physics. He worked for 10 years at Bell Labs before joining Technion in 1989. His research concentrates on semiconductor nano structured laser and amplifiers, ultrafast optics, quantum optics, atomic clocks, and optical communication. He has authored well over 350 papers in leading technical journals and received many international awards.

TE and TM InP/GaAsP Dot-in-Well (DWELL) lasers and lateral DBR lasers selectively grown on SOI

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Abstract – Compared with well-established TE-polarized QD lasers, TM-polarized QD lasers are less common, primarily due to the low aspect ratio and the inherent compressive strain present in QDs. We investigated the polarization in InP/GaAsP Dot-in-Well (DWELL) lasers by modifying the phosphorus (P) composition of the GaAs_{1-x}P_x capping layer. Stable TE and TM polarized emissions were observed with different phosphorous composition. The controllable TE/TM polarization in lasers demonstrates potential for applications in Si photonics. In addition, Distributed Bragg reflector (DBR) lasers selectively grown on (001) silicon-on-insulator (SOI) wafers by lateral metal-organic chemical vapor deposition (MOCVD) will also be reported. The optically pumped DBR lasers with five periods of Bragg reflectors demonstrate low lasing thresholds with an average value of 12.8 $\mu\text{J}/\text{cm}^2$ at 1.5 μm band.



Kei May Lau is a Research Professor at the Hong Kong University of Science & Technology (HKUST). She received her degrees from the University of Minnesota and Rice University, and served as a faculty member at the University of Massachusetts/Amherst before joining HKUST in year 2000. Lau is an elected member of the US National Academy of Engineering, a Fellow of IEEE, Optica (formerly OSA), and the Hong Kong Academy of Engineering Sciences. She was also a recipient of the Welker Award, IPRM award, IET J J Thomson medal for Electronics, Optica Nick Holonyak Jr. Award, IEEE Photonics Society Aron Kressel Award, and Hong Kong Croucher Senior Research Fellowship. She was an Editor of the IEEE Transactions on Electron Devices and Electron Device Letters, an Associate Editor for the Journal of Crystal Growth and Applied Physics Letters.

InP on Silicon nanolaser diodes

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Abstract. In this talk, I will describe our latest work on nanolaser diodes on silicon and related devices.

Nanophotonics has demonstrated over the years to be the solution to provide extremely large light matter interactions which are at the center of numerous applications in data communications and processing as well as quantum optics. Photonic crystals are certainly amongst the most emblematic nanophotonic structures. They enable the conception of the best photonic cavities with the highest measured Q factor over modal volume ratios which scale with intracavity electromagnetic field intensity. Our research activity is focused on the exploration of these interactions in III-V semiconductor/Silicon hybrid photonic crystal (PhC) structures and their exploitation for the achievement of smaller, smarter, faster energy-efficient optoelectronic components which will revolutionize our world, governed by information and communication technology.

Indeed, these hybrid structures combine the best of Silicon and III-V semiconductor photonics, merging the fantastic capacity of Silicon and especially Silicon on insulator (SOI) to provide an excellent way to achieve highly compact low loss passive optical circuitries, with the optical gain and nonlinearity of III-V semiconductor compounds. This is the key technology for achieving the convergence of microelectronics and photonics.

Amongst all the devices to be developed, sources are of utmost importance as they provide the necessary electro-optical conversion functionality. In this talk, I will describe our latest work on nanolaser diodes [1] and related devices [2-4].

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Fabrice, Raineri received his PhD degrees from Université Paris Sud (France) in 2004, 19__ and all in Physics. His research interest has been in the area of Nanophotonics. He has authored more than 100 papers in leading technical journals and conferences. He was awarded with ERC consolidator grants and nominated as a senior member of Institute Universitaire. He is one of the co-founders NcodiN and acts as its Chief Technology Officer.

Electrically-pumped topological photonic crystals lasers

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Abstract Electrically-pumped semiconductor lasers using photonic crystals and topological design achieve compact, robust performance. Band topology enables lasing states, while Dirac vortex cavities and flatband BICs support frequency stability, beam control, and miniaturization without sacrificing efficiency.

Introduction

In electrically-pumped semiconductor lasers, microfabricated structures like photonic crystals have been employed to reduce device footprints. Recently, topological concepts have been integrated into the design of photonic crystal lasers, enabling unprecedented robustness to perturbations and unique laser performance. In this talk, I will present how band topology, which is invariant under small deformations, generates robust topological lasing states in semiconductor laser platforms. In addition, I will introduce how photonic crystals lasers are designed using other promising topological concepts, such as Dirac vortex (or Majorana zero) cavities [1], Dirac-Scaled Valley Edge Modes lasers [2], and topologically nontrivial flatband bound states in the continuum (BICs) [3], for achieving robustness of lasing frequencies, structural beam engineering, and miniaturization while maintaining good laser performance.

Acknowledgement

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Prof. WANG Qijie is a President Chair Professor in Optoelectronics at the School of Electrical and Electronic Engineering (EEE) and the School of Physical and Mathematical Sciences (SPMS), and the Associate Dean (Graduate Students) of College of Engineering, Nanyang Technological University, Singapore. He is an IEEE and OPTICA Fellow. He is a co-recipient of the Institution of Engineers Singapore, Prestigious Engineering Achievement Team Award of Singapore twice in 2005 and 2017, respectively, the prestigious Singapore Young Scientist Award 2014, Nanyang Research Award 2015 (Young Investigator), ARC Sciences Nanotechnology Medal and Prize, 2021, and NTU College of Engineering Research Excellence Award, 2022.

Optical Neural Network Chip Based on Multiple-Plane Lightwave Conversion

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Abstract

Optical neural networks (ONNs) based on programmable photonic integrated circuits (PICs) offer a promising route toward low-latency and energy-efficient deep learning. However, conventional photonic implementations of matrix–vector multiplication (MVM) rely on locally connected architectures, such as Mach–Zehnder interferometer (MZI) meshes, whose number of active components scales quadratically with matrix size, severely limiting scalability. Here presented is a scalable ONN that overcomes this limitation by exploiting the intrinsically diffractive and nonlocal nature of coherent light inside a silicon photonic chip. Our approach employs cascaded stages of multiport directional couplers (MDCs) interleaved with compact phase-shifter arrays, enabling strong non-local coupling among multiple optical modes. We experimentally implemented a 32-input silicon photonic MVM chip with a tenfold reduction in active components and validate its performance on various classification tasks.



Yoshiaki Nakano is the President and Professor with Toyota Technological Institute (TTI). He formerly was with the Department of Electrical Engineering and Information Systems (EEIS), Graduate School of Engineering, the University of Tokyo until 2025, where this research was conducted. He received the B. E., M. S., and Ph. D. degrees in electronic engineering, all from the University of Tokyo, Japan, in 1982, 1984, and 1987, respectively. In 1984, he spent a year at the University of California, Berkeley, as an exchange student.

In 1987, he joined the Department of Electronic Engineering, the University of Tokyo, became an associate professor in 1992, a full professor in 2000, and the department head in 2001. He moved to RCAST, the University of Tokyo, in 2002 as a professor, and served as the Director General of the center from 2010 till 2013. Then he moved back to the Engineering School to fill up the professorship position with the Dept. of EEIS. Since 2010, he has also been serving as the co-director of Presidential Endowed Chair on Global Solar Plus Initiative attached direct to the University of Tokyo president office. In April 2025, he moved to TTI, and became its President in September. His research interests have been physics and fabrication technologies of semiconductor distributed feedback lasers, semiconductor optical modulators/switches, monolithically-integrated photonic circuits, and high-efficiency heterostructure solar cells, as well as metal-organic vapor phase epitaxy of III-V compound semiconductors. In 1992, he was a visiting associate professor at the University of California, Santa Barbara.

Dr. Nakano is currently the Research Supervisor of JST CREST program on “Frontier exploration via the synergy of photonics/optics with information, communication, sensing, and material technologies”, and the Council Member of the Optoelectronics Industry and Technology Development Association (OITDA). He used to serve as a member of the Science Council of Japan (SCJ), the President of the Japan Institute of Electronics Packaging (JIEP), the Vice President of the Institute of Electronics, Communication, and Information Engineers (IEICE), the President of Electronics Society, IEICE, Chair of the IEEE Tokyo Section, an elected member of the Board of Governors of IEEE LEOS, a member of the Board of Directors of the Japan Society of Applied Physics (JSAP), Editor-in-Chief of Applied Physics Express (APEX) and Japanese Journal of Applied Physics (JJAP), and a member of the Board of Directors of the JIEP. He is the Life Fellow of IEEE, the Fellow of Optica (former OSA), IEICE, and JSAP.

He is the recipient of the 1987 Shinohara Memorial Prize from the IEICE, the 1991 Optics Paper Award from the JSAP, the 1997 Marubun Science Prize, the 2007 Ichimura Prize, the 2007 IEICE Electronics Society Award, the 2007 Sakurai Medal from the OITDA, the 2019 IPRM Award, the 2022 Distinguished Achievement and Contributions Award from the IEICE and the 2024 Distinguished Achievement Award from the JIEP. He was presented the Prime Minister Award in Collaborative Research between Academia and Industry in 2007. He authored and coauthored over 500 refereed journal publications and over 1000 international conference papers, and holds 23 patents.

Controlling Excitons and Their Interactions with Cavities

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Abstract Semiconductor quantum dots can be tuned by acoustic, electric and magnetic fields and coupled to engineered nanostructures for on-chip quantum photonics. We realize selective exciton control, chiral cavity-waveguide interfaces and moiré nanocavity Purcell enhancement.

Introduction

Semiconductor quantum dots (QDs) based on III-V materials are atom-like solid-state emitters, playing a central role in the development of single-photon sources, spin-photon interfaces and on-chip quantum networks. Their optical performance critically depends on the ability to control exciton energies, charge states, spin selection rules and radiative decay rates. Here, we report our recent progress in controlling excitons and their photonic interactions, including dynamic control of individual excitons by surface acoustic waves, single-photon emission from excitons coupled to moiré photonic crystal nanocavities, and chiral waveguide interfaces for directional photon transport.

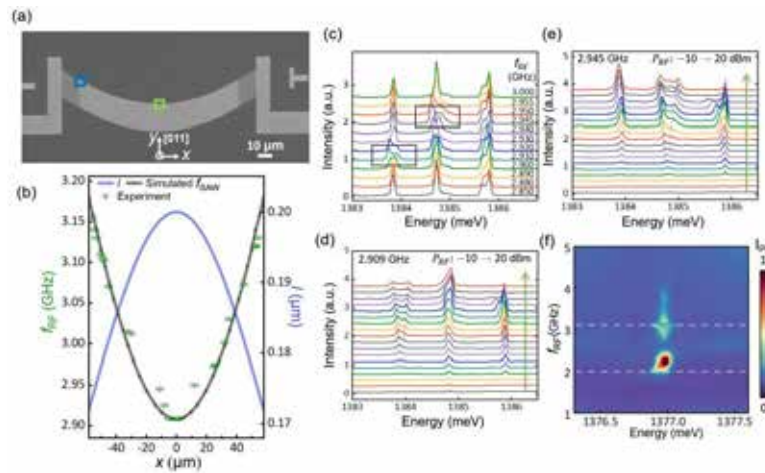


Fig 1. Selective control of single quantum dots with surface acoustic waves in frequency-gradient interdigital transducer devices.

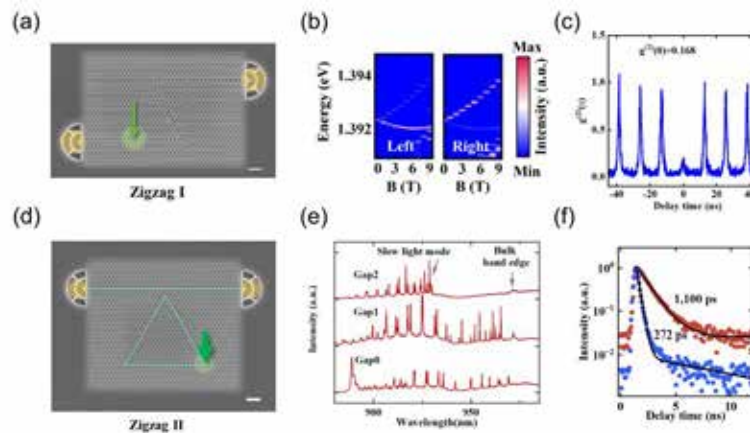


Fig 2. Chiral single photon transport and Purcell effect in a triangular-lattice topological valley photonic crystal waveguide platform.

Selective control of excitons

In frequency-gradient interdigital-transducer devices, surface acoustic waves and local radio-frequency (RF) electric fields provide complementary control channels for single InGaAs QDs. Position-dependent acoustic eigenfrequencies allow different QDs to be addressed by different RF frequencies, while the dynamic quantum-confined Stark effect leads to electric-field-driven shifts and splittings. Combining strain, electric-field and magnetic-field control makes it possible to switch between deformation-potential modulation and Stark modulation within individual emitters, providing an efficient

route to exciton tuning in multi-node quantum photonic systems [1].

QD-cavity coupling and chiral interactions

To exploit light-matter interactions for controlling exciton emission, we further integrate QDs with engineered photonic nanostructures. In moiré photonic crystal nanocavities formed by twisted photonic lattices, flatband localization enables high-Q, low-mode-volume cavity modes. Experimentally, fundamental modes with Q factors of around 2000 were obtained. With improved spatial overlap with embedded QDs, an approximately 8.4-fold photoluminescence enhancement and a Purcell factor of about 3 were observed when a single QD was tuned into resonance with the moiré cavity mode [2].

For on-chip quantum photonic circuits, optical waveguides are fundamental building blocks. Triangular-lattice topological valley photonic crystal waveguides support high-bend-transmittance propagation, enlarged chiral coupling regions and accessible slow-light modes. By integrating QDs into these structures, we experimentally demonstrate chiral photon routing in Z-shaped waveguides, confirming robust directional photon transport. A whispering-gallery-mode cavity-waveguide structure is incorporated to achieve Purcell-enhanced QD emission with a Purcell factor of 4, as well as spin-dependent single-photon transport with a directional contrast of 82%. These results show that triangular-lattice topological photonic crystal waveguides provide a promising and scalable platform for low-loss, high-chirality quantum photonic devices [3].

Conclusions

We present recent advances in controllable semiconductor QDs and their coupling to photonic cavities and waveguides. Together, these results form a toolbox for controlling excitons: acoustic and electrical actuation enables fast spectral and charge-state control, scalable moiré nanocavities enhance the local optical density of states, and chiral cavity-waveguide structures convert spin or polarization into directional on-chip routing. These functions are important for tunable quantum nodes, efficient single-photon sources and spin-photon interfaces based on actively controlled, cavity-enhanced excitonic building blocks.

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Xiulai Xu is a Boya distinguished professor in School of Physics, Peking University. He received his PhD from Cavendish Laboratory, University of Cambridge. After that he worked as a senior research scientist in Hitachi Cambridge Laboratory and a professor in Institute of Physics, Chinese Academy of Sciences before moving to Peking University. His research has been mainly focused on the quantum optoelectronic properties of low dimensional semiconductor systems for optical quantum information processing.



Poster Session I

ID	Content
PI-01	Intrinsic GaAs-engineered p-i-n GaAs/GaAs/AlGaAs nanowires for improved-performance solar water splitting Fahad Alghamdi, University College London
PI-02	Pulsed Phase-Sensitive Amplification in a Semiconductor Optical Amplifier Technion - Israel-Institute of Technology
PI-03	Astigmatic metalens-based wide field-of-view and high spatiotemporal resolution LiDAR Shujian Gong, Institute of Optics and Electronics, Chinese Academy of Sciences
PI-04	Photon-Counting Compressed Spatial-Spectral Imaging for 4D Information Retrieval Mingzhong Hu, Tsinghua University
PI-05	Broadband Modulator with Periodically Slotted Traveling-Wave Electrodes Shurui Huang, Tsinghua University
PI-06	Optimize wet etch method for high yield AlAsSb/ InGaAs avalanche photodiode fabrication Haifeng Kan, University College London
PI-07	Hybrid Confinement Techniques for Polariton Simulators David Laibacher, University of Würzburg
PI-08	Compact Optical Convolution Processor via Multi-Layer Phase-Only Metasurfaces Chiyun Li, The University of Tokyo
PI-09	Low threshold InAs/InP quantum dot lasers on InP and Si Jun Li, University College London
PI-10	All-Solid-State Anti-Resonant Fiber: A New Paradigm for Large-Mode-Area Ultrafast Laser Gain Media Pengpeng Li, XI'AN INSTITUTE OF OPTICS AND PRECISION MECHANICS OF CAS
PI-11	Fabrication of a III-V-SiO/SiN Hybrid Cavity Incorporating a Single Stark-Tunable InGaAs Quantum Dot for High-Rate Single-Photon Generation on Silicon I. Limame, Technical University of Berlin
PI-12	Preferential Lasing through Mode-selective Gain sharing Runze Liu, Institute of Optics and Electronics, Chinese Academy of Sciences
PI-13	Spiking Nanolasers for All-Optical Neural Network Daniel Lizotte, Universite Cote D'Azur
PI-14	Spatiotemporal Longitudinal Multi-Foci Femtosecond Laser for Manufacturing Large-Aperture, High-Damage-Threshold Metasurfaces Yu Meng, Institute of Optics and Electronics, Chinese Academy of Sciences
PI-15	Energy efficient MBE-grown wafer fused 1310 nm VCSELs Iqra Naeem, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences
PI-16	Fabrication of High-Quality YIG Magneto-Optic Ceramics for Integrated Nonreciprocal Devices Shiji Shen, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences
PI-17	Monolithic Multilayer Diffractive Neural Networks for Deep and High-Capacity Spectral Parallel Computing Huajun Shu, Institute of Optics and Electronics, Chinese Academy of Sciences
PI-18	Ultra-Narrow Linewidth Phonon Laser Based on Dissipation Dilution Chenxuan Wang, Tsinghua University
PI-19	Single-frame Motion Vector Imaging with Phonon-Engineered Perovskite Optoelectronic Synapses for Neuromorphic Visual Perception Hao Wang, University of Chinese Academy of Sciences
PI-20	Halogen substitution in Lead-Free Double Perovskites toward Ultralow-Dose X-ray Detection and Signal Decoding Lixia Wang, University of Chinese Academy of Sciences
PI-21	Momentum-Space Observation of Chiral Bloch Resonances in Supercell Photonic Crystals Jie Wu, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences
PI-22	Surface-Plasmon-Polaritons-Assisted Cherenkov Radiation Xiaotong Xiong, Tsinghua University
PI-23	Large Scale Universal Optoelectronic Hybrid Computing Ziyue Yang, Tsinghua University
PI-24	Improvement of SiON Edge Coupler by Hybrid Inverse Design with Trident Geometry Kaibin Yao, Institute of Science Tokyo
PI-25	Compact Heterogeneously Integrated Thin-Film Lithium Niobate Coherent Modulator on Silicon Photonic Platform Jianmin Zhang, Shanghai Institute of Microsystem and Information Technology
PI-26	A Wireless Optoelectronic System for Deep Brain Neural Activity Monitoring Wanghan Zhang, Tsinghua University
PI-27	Eliminating the confined dark-exciton qubit precession using an externally applied magnetic field Zu-En Su, The Quantum Science Center of Guangdong-Hong Kong-Macao Greater Bay Area

PI-01

Intrinsic GaAs-engineered p-i-n GaAs/GaAs/AlGaAs nanowires for improved-performance solar water splitting

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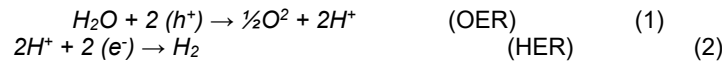
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Abstract We demonstrate the formation of p-i-n NW photocathode with 135 nm-thick of i-GaAs that plays a key role in enhancing device performance and establishes III-V NWs as viable strategy to overcome carrier recombination for solar water splitting.

Introduction

Photoelectrochemical (PEC) water splitting is a promising approach that enables the direct conversion of sunlight into chemical fuel, providing a cost-effective method for solar energy storage and sustainable hydrogen production [1]. To drive this process with light requires the absorption of photons with energies greater than 1.23 eV to trigger the two half-reactions governing water splitting. These are: the oxygen evolution reaction (OER) and the hydrogen evolution reaction (HER), at the semiconductor/electrolyte interface inside the PEC cell:



We showed that the addition of an intrinsic GaAs shell to form p-i-n junction with GaAs/GaAs/AlGaAs core/shells nanowire enhances the photocurrent density by fivefold compared to p-n junction GaAs/AlGaAs nanowire.

Experiments

Self-catalysed GaAs/GaAs/AlGaAs core/shell and GaAs/AlGaAs core/shell NW samples were grown by solid-source molecular beam epitaxy (MBE) on p-type Si (111) substrates using Al and Ga solid sources and As₄ cracker cells. A ~15nm-thick TiO₂ layer was deposited directly onto NW using ALD, then an 8 nm thick Ni co-catalyst coating was deposited using Physical Vapor Deposition (Fig. 1 (a)). Simulations of the conduction and valence band profiles were performed using nextnano++ as shown in Fig. 1 (b) and (c)

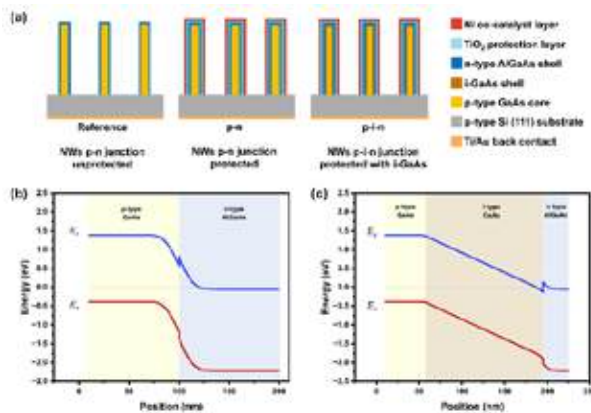


Fig. 1 (a). A schematic showing the fabricated devices. (b) and (c) obtained from nextnano++ simulations show the energy band diagrams.

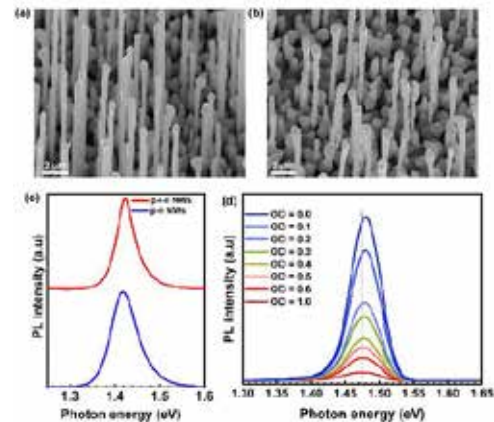


Fig. 2. (a) SEM image of the p-n NWs. (b) SEM image of the p-i-n NWs. (c) PL of p-n and p-i-n NWs. (d) Excitation power dependent PL at 10 K of p-i-n NWs.

Results and discussion

SEM images show good shape of NWs in Fig. 2 (a) and (b). The optical properties of the NW samples were studied using photoluminescence spectroscopy (PL) at room temperature, as shown in Fig. 2 (c). The PL emission peaks at energies of 1.42 and 1.41 eV for the p-i-n and p-n NWs, respectively. The full width at half maximum (FWHM) of the p-i-n sample (20 meV) is narrower, showing higher uniformity, compared to the FWHM of the p-n sample (33 meV) [2]. Further investigation of the optical properties in the intrinsic shell was carried out using excitation power dependent PL at a low temperature of

10 K, the intensity of the emission increases and the emission shifts to higher energy (Fig. 2 (d)), because of band filling effect [3].

The crystal quality and composition of the NWs and p-i-n photocathodes were investigated by the transmission electron microscopy (STEM) and annular dark field (ADF-STEM) imaging is shown in the upper left of Fig 4 (a). The i-GaAs shell, with a thickness of 135 nm, between the p-type core and the n-type AlGaAs shell is indicated by the white arrow. Energy dispersive x-ray (EDX) mapping was performed as shown in Fig. 4 (a) as well.

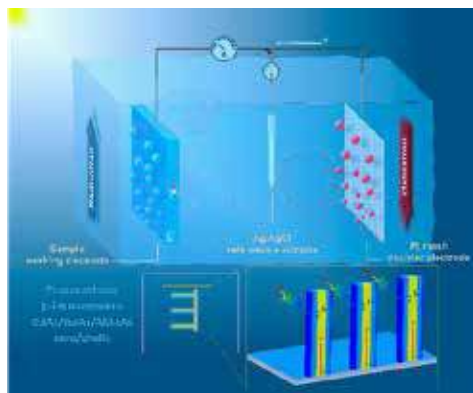


Fig. 3. A schematic diagram showing the three-electrode PEC cell. The lower figure illustrates the electron-hole pairs generated after the NWs photocathode absorbed photons.

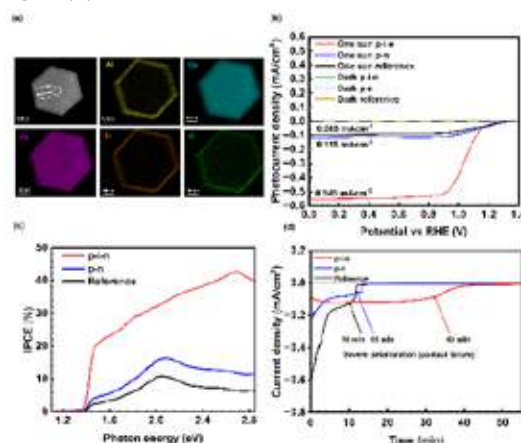


Fig. 4. (a) ADF-TEM image of the ultramicrotome sectioned of p-i-n NW photocathode and EDX mapping. (b) J-V curves for the three structures. (c) IPCE as a function of photon energy. (d) Stability measurements

Fig. 3 shows a three-electrode PEC cell used to evaluate the performance of the samples, J-V measurements were conducted for the three structures as shown in Fig. 4 (b). In a p-i-n NW, the intrinsic shell plays a vital role in the separation of photo-generated carriers. In the present case the thickness of the i-GaAs is 135 nm, which is much smaller than the diffusion lengths of the charge carriers: electron diffusion lengths $\sim 20 \mu\text{m}$ to $2 \mu\text{m}$ and hole diffusion lengths $< 1.0 \mu\text{m}$ [4]. In the present study, the beneficial effect of the i-GaAs shell is evident in its ability to enhance the photocurrent density by reducing carrier recombination and providing a shorter carrier transfer distance [5].

The incident photon-to-current efficiency (IPCE) quantifies how efficiently the NW photocathode converts incident light into photocurrent (e-h pairs) as a function of photon energy. For the p-i-n photocathode as shown in Fig. 4 (c) maximum IPCE value of 44% at 2.69 eV is achieved, indicating efficient charge carrier transfer at the semiconductor/electrolyte interface [6-8].

To assess the corrosion resistance and durability of the NWs photocathodes in electrolyte, a stability test was conducted under one-sun illumination in 1.0 M KOH (pH = 14) for the three structures, as shown in Fig. 4 (d). The p-i-n NW photocathode shows the best stability. This result can be attributed to the greater diameter of the p-i-n NWs [9-10].

Conclusions

Our work demonstrates the suitability of GaAs/GaAs/AlGaAs core/shells NWs for an enhanced performance PEC solar water splitting device and highlights promising potential of this platform for green hydrogen production. we have demonstrated the synthesis of a p-i-n NW photocathode structure based on GaAs/GaAs/AlGaAs core/shell NWs with an i-GaAs shell exhibiting improved photocurrent density. In terms of the IPCE, a significant improvement was found for the p-i-n NW photocathode which indicates efficient charge carrier transfer.

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PI-02

Pulsed Phase-Sensitive Amplification in a Semiconductor Optical Amplifier

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Abstract

Phase-dependent parametric amplification in a semiconductor optical amplifier is investigated using pulsed excitation near 1553 nm. A 4.3 dB phase dependent gain variation is observed, which is confirmed by a split step Fourier transform model.

Introduction

A unique property of optical wave mixing is the ability to enact phase sensitive amplification (PSA) [1] which enables, in principle, gain accompanied by a noise figure (NF) below 3dB. PSA requires a preparatory stage in which the signal and two pumps are set with a well defined mutual phase relation. PSA can be implemented in any $\chi^{(3)}$ nonlinear medium and is most commonly demonstrated in nonlinear fibers. PSA can also be obtained in a semiconductor optical amplifier (SOA). In this case, the nonlinear wave mixing process must also overcome the added amplifier noise due to amplified spontaneous emission. PSA in an SOA was reported in a few papers. Most noticeably, [2] describes a fully integrated PSA. However, that work used strictly CW signals what enables operation with very small detunings between the pumps and the signal thereby increasing significantly the wave mixing efficiency.

We report here PSA in a quantum well SOA where the signal and pumps are pulses of 20 ps duration. The signal and pumps originate from a fiber laser that emits ~ 100 fs pulses. Two pumps and the signal are carved out from the pulse spectrum using a wave shaper. The wave shaper is also used to scan the signal phase before the three pulses feed the SOA. A tunable filter is used to select the amplified output signal which is detected by a fast detector and sampled 3500 times by a sampling oscilloscope. The phase dependent gain is confirmed by a split step Fourier transform (SSFT) simulation.

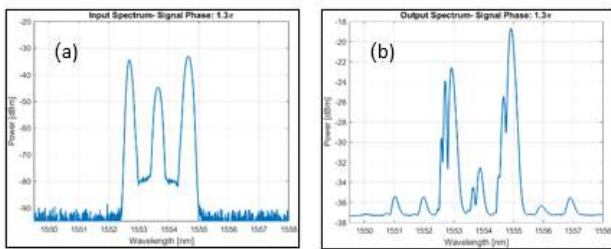


Figure 1 – Spectra. (a) input, (b) output for a signal phase of 1.3π

somewhat modified by additional spectral features. The entire signal is filtered and detected for the gain analysis.

Results

Fig. 1 (a) shows the measured input spectrum for a signal – pump detuning of 1 nm where the three spectral components have absolutely no overlap, what ensures that the PSA gain is not masked by conventional linear interference. The output spectrum is shown in Fig. 1 (b). Each spectral component is shifted towards longer wavelengths due to a degree of saturation and is also

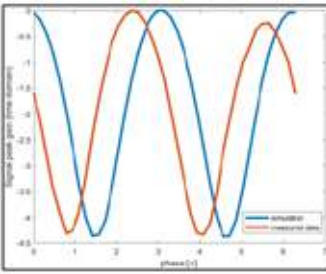


Figure 2- Normalized PSA gain

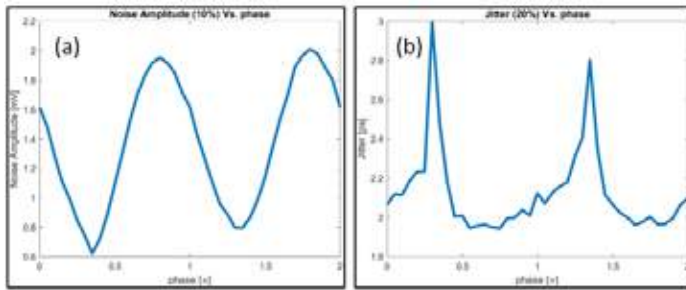


Figure 3- Noise. (a) Amplitude noise (b) Jitter

Fig. 2 shows normalized measured PSA gain together with the simulation results. The maximum change due to the phase scanning is 4.3 dB. The change is moderate due to the relatively large detuning that is dictated by the spectral width of the input pulses that are not allowed to overlap. While sampling the filtered output signal, it is easy to obtain the amplitude noise accompanying the phase dependent signal as well as the corresponding jitter. Phased dependent amplitude noise and jitter are described in Fig. 3. The amplitude noise follows the gain function while the jitter is maximum where the amplitude noise is minimum and is minimum for the largest amplitude noise.

Simulation

Pulsed PSA was modeled using an SSFT simulation. The envelope evolution is governed by linear effects and nonlinear effects:

$$(1) \quad \frac{\partial A}{\partial z} = \mathbf{L}_{\left[\frac{\partial}{\partial t}\right]} \{A\} + \mathbf{N}_{[A]} \{A\}$$

$$(2) \quad \mathbf{L}_{\left[\frac{\partial}{\partial t}\right]} \{A\} = -\frac{\alpha_{loss}}{2} A + j \sum_{n=2}^N \frac{\beta_{(\omega_0)}^{(n)}}{n!} j^n \frac{\partial^n A}{\partial t^n}$$

$$(3) \quad \mathbf{N}_{[A]} = \left(j\gamma_{Kerr} - \frac{\gamma_{TPA}}{2} \right) |A|^2 + \frac{g_0}{2} \exp \left\{ -\frac{1}{E_{sat}} \int_{-\infty}^t |A(\tau)|^2 d\tau \right\} \cdot (1 - j\alpha_{lw})$$

Using various parameters of the SOA and inserting measured values for the input signals and the amplifier small signal gain, we calculate the PSA gain, shown in Fig. 2, which fits the experiment except for a constant shift in the phase which can be easily compensated for in the wave shaper.

Conclusion

These results demonstrate phase-sensitive amplification in a pulsed SOA-based system. A moderate gain variation of 4.3 dB is obtained limited by the required input signal detuning. An SSFT simulation confirms the results. Amplitude noise and jitter dependencies on the input signal phase have also been presented.

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PI-03

Astigmatic metalens-based wide field-of-view and high spatiotemporal resolution LiDAR

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Abstract: We propose an inertia-free wide-FOV LiDAR architecture with astigmatic metalens coordinated spectral-acousto-optic scanning, addressing inter-axis rate mismatch and beam astigmatism, achieving 36.6 MHz FPAR and 0.37° resolution within 102° FOV, enabling high spatiotemporal 3D imaging.

Introduction

High spatiotemporal resolution light detection and ranging (LiDAR) is critical for autonomous systems and robotics^[1]. Traditional mechanical-scanning LiDAR offers a wide field-of-view (FOV) but suffers from low speed. Existing inertia-free scanning schemes also face inherent trade-offs among point acquisition rate (PAR), FOV and spatial resolution: spectral scanning^[2] delivers MHz-level pixel-wise PAR (PPAR) but suffers from slow-axis rate bottlenecks and narrow FOV, while beam astigmatism from diffractive optics further degrades spatial resolution. Here, we present a wide-FOV LiDAR architecture with astigmatic metalens (AML)-coordinated spectral-acousto-optic (spectral-AO) scanning. By inter-axis rate matching and astigmatism correction via a tailored AML, we simultaneously achieve ultra-high frame-wise PAR (FPAR), wide FOV and high spatial resolution, outperforming state-of-the-art solid-state LiDARs^[3].

Implementation of astigmatic metalens-based LiDAR architecture

We constructed an AML-based LiDAR architecture as shown in **Fig. 1a**. Broadband pulsed light is converted into a discrete sequence of chirped pulses via spectro-temporal encoding, which time-stretches the spectral scanning period to the microsecond scale compatible with the acousto-optic response. The beam then passes through the acousto-optic deflector (AOD) and a blazed grating (BG) to implement inter-axis rate-matched spectral-AO scanning, as depicted by **Fig. 1b**. At the back end, an AML-based wide-FOV optical module is integrated to expand the FOV while suppressing beam divergence. Target echoes are detected by a photomultiplier tube (PMT), and the 3D scene is reconstructed based on pulse time-of-flight (TOF) information. Ultimately, 30 spectral channels are generated from a 1.22 MHz pulsed laser, delivering a PPAR of 36.6 MHz. By inter-axis rate matching, redundant fast-axis spectral scanning is eliminated and the achievable effective FPAR is aligned with the maximum PPAR.

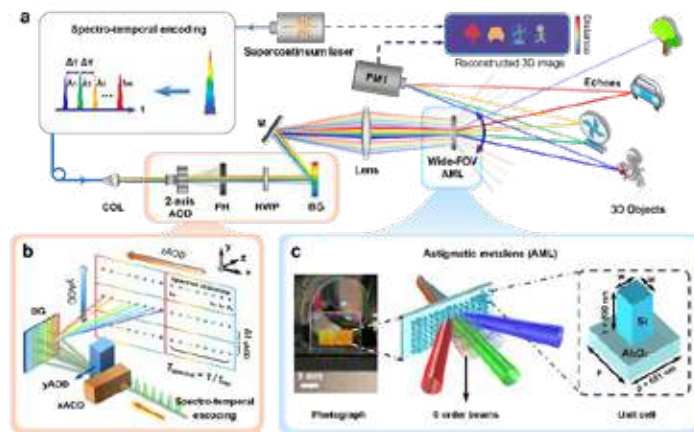


Fig. 1. (a) Experimental setup; (b) Architecture of spectral-AO cascaded scanning for inter-axis rate-matching; (c) The astigmatic metalens (AML) achieves simultaneous FOV expansion and spatial resolution improvement (left: photograph of the fabricated AML; right: meta-atom unit cell structure).

As the core component of the system, the custom-designed AML significantly enhances the spatial detection capability of LiDAR, as illustrated in **Fig. 1c**. Compared with unmodulated 0th-order beams, the AML achieves both FOV expansion and spatial resolution improvement. This improvement stems from the beam astigmatism caused by the BG's intrinsic anisotropy. A normal quadratic-phase metalens^[4] can extend the FOV but cannot mitigate astigmatism, thereby degrading the spatial resolution. By contrast, the proposed AML introduces additional high-order astigmatic phase terms, enabling

simultaneous astigmatism correction and FOV expansion. Characterization yields a total scanning FOV of $102^\circ \times 26^\circ$, with beam divergence angles of $\theta_x = 11.8$ mrad and $\theta_y = 10.2$ mrad in the two directions, which are largely consistent compared with the original astigmatic beams.

High spatiotemporal resolution 3D imaging

We first conducted dynamic 3D imaging experiments as shown in **Fig. 2a**. Leveraging an FPAR of 36.6 MHz, the system delivers an imaging frame rate of 734 fps with 600×83 points per frame, with the time-sliced results illustrated in **Fig. 2b**. Furthermore, we performed experiments with resolution targets, as shown in **Fig. 2c**. Benefiting from the reduced beam divergence achieved by AML-based astigmatism correction, the system ultimately attains a spatial resolution of 6.46 mrad via further subpixel reconstruction, as shown in **Fig. 2d**.

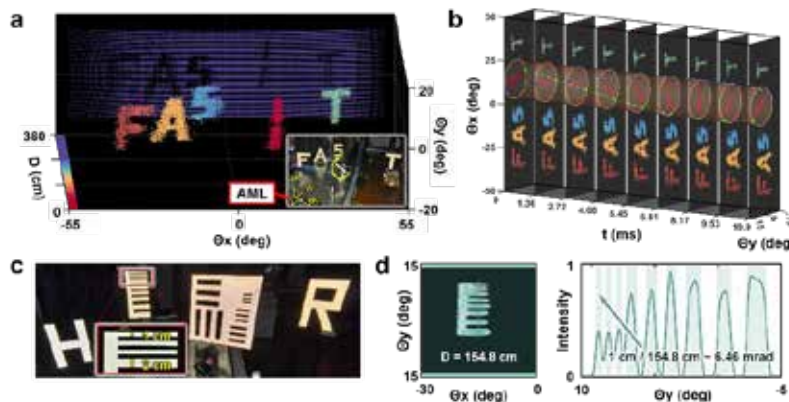


Fig. 2. (a) Dynamic 3D imaging scene and corresponding results; (b) Time-sliced evolution of fan rotation; (c) Static imaging scene; (d) Depth-slice image and the intensity profile along the marked line at $D = 154.8$ cm.

Conclusions

We demonstrate a high spatiotemporal resolution LiDAR based on AML-coordinated spectral-acousto-optic scanning, achieving 36.6 MHz FPAR, 102° FOV and 0.37° spatial resolution simultaneously. This work provides a compact metasurface-based^[5] solid-state solution for ultra-high-speed 3D perception, with promising applications in autonomous driving and high-speed target tracking. Future work will explore integrated photonic sources^[6] and parallel detection^[7] schemes to further improve performance.

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PI-04

Photon-Counting Compressed Spatial-Spectral Imaging for 4D Information Retrieval

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Abstract We proposed Photon-Counting Compressed Spatial-Spectral Imaging for sensitive 3D-spatial and spectral imaging in photon-sparse scenarios. With a homemade SNSPD photon-counting spectrometer, we carried out proof-of-principle experiments, showing potential for spectral remote sensing and fluorescence imaging.

Introduction

The sensitivity of spectrometers is of great concern, especially in spectral light detection and ranging (LIDAR) at far distances, astronomical spectroscopy and fluorescence spectroscopy. Motivated by these applications, researchers have employed single-photon detectors, especially ultra-sensitive superconducting nanowire single-photon detectors (SNSPDs), to enhance the sensitivity. Early work [1] based on monochromators was limited by the slow wavelength-scanning process, making spectral imaging impractical due to excessive acquisition time.

Here we proposed an imaging scheme using single-photon detectors to carry out high-dimensional imaging with compressed sensing on both spectral and spatial dimensions. We called the scheme Photon-Counting Compressed Spatial-Spectral Imaging (PCCSSI). Compressed sensing method enable signal reconstruction with good quality even when highly under-sampled. In this way, PCCSSI can accelerate the imaging process with fewer numbers of measurements. Besides, narrowband spectral filtering in traditional monochromators can be replaced with spectral modulation for higher broadband transmission, which elevates photon utilization and thus is favorable under photon-sparse scenarios. To demonstrate the principle of this scheme, we set up a PCCSSI imaging system using a photon-counting spectrometer based on SNSPDs and metasurfaces, which is an improved device based on our previous work [2]. The function of high-dimensional imaging, including 3D spatial and spectral information, is demonstrated, showing the potential of on fast, high-dimensional imaging tasks in photon-sparse scenarios.

PCCSSI system

PCCSSI, as shown in Fig.1, is an imaging scheme with active illumination. A pulsed laser is expanded to illuminate the scene with targets. The reflected light is spatially modulated by a digital micromirror device (DMD), which encodes the 2D scene into a series of compressed measurements under different patterns. After that, the modulated light is collected and spectrally encoded via detector-dependent spectral responses before detection. Finally, time-correlated single-photon counting (TCSPC) is carried out to measure the time of flight (ToF) of each photon for depth information. By employing algorithms from compressed sensing, we can reconstruct the 3D-spatial and spectral information of the targets by TCSPC results of different detectors under different DMD patterns.

Imaging results

As illustrated in Fig.2, we used four bandpass filters backed with paperboards as imaging targets. Inset of Fig.2(a) is their photo captured by a visible light camera. In Fig.2(b), the four peaks in the TCSPC results of 12 SNSPDs used in the experiment directly reveal the depth position of the four targets. In the experiments, the total photon counting rate is about 123 kHz under a pulse repetition frequency of 5 MHz, indicating a highly photon-sparse scenario.

Picking the rightmost peak as an example, which corresponds to the result at the depth of 2.83 m, we successfully reconstructed the spectral image and showed it in Fig.2(c). The target at this depth can be seen clearly at the wavelength around 950 nm. At other wavelengths, only a hollow circle can be observed, which is the metal mount of the filter and reflects photons at all wavelengths. This is consistent with the fact that the filter in the target has a center wavelength of 950 nm. PCCSSI has a good quality of spectrum reconstruction under compression. To confirm this, the spectra of all the pixels surrounded by the red circle in Fig. 2(c) are plotted in Fig. 2(d). The solid lines were the reconstructed results of 12 pixels, and the blue dashed line was obtained by measuring the reflection spectrum of the specific target at a close distance with bright illumination and a commercial spectrometer. It can be seen that the reconstructed results agreed well with the main spectral components of the measured reference spectrum.

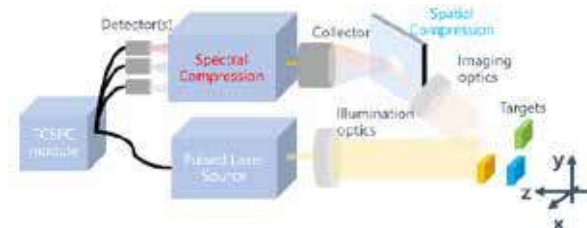


Fig. 1 Schematic of the PCCSSI system.

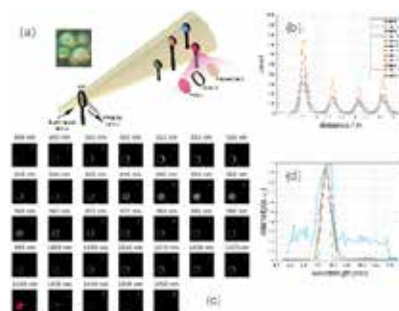


Fig. 2. 4D imaging results.

Conclusions

The experimental results show that PCCSSI can reconstruct 3D spatial information and 1D spectral information under photon-sparse scenarios. Therefore, PCCSSI has great potential for imaging applications under photon-sparse scenarios, such as spectral remote sensing and fluorescence imaging.

Acknowledgements

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PI-05

Broadband Modulator with Periodically Slotted Traveling-Wave Electrodes

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Abstract We demonstrate an electro-optic modulator on a thin-film lithium niobate platform, which achieves a measured 3-dB bandwidth exceeding 110 GHz and supports 224 Gbit/s PAM4 transmission. The half-wave voltage-length product is 1.7 V·cm.

Introduction

Driven by the rapid growth of artificial intelligence technology, cloud computing, and big-data services, next-generation optical interconnects toward 1.6 Tb/s and beyond demand ever higher per-channel capacity¹. Although coherent modulation can improve spectral efficiency and increase the data rate, it usually increases transceiver complexity, power consumption, and latency². Therefore, increasing the symbol rate remains a direct and effective route toward higher single-channel capacity, requiring electro-optic (EO) modulators with large bandwidth, high modulation efficiency, and low optical loss. Thin-film lithium niobate (TFLN) is a particularly promising platform for such ultrahigh-speed EO modulators, owing to its large EO coefficient of approximately 30.8 pm/V and intrinsic potential for terahertz-scale modulation bandwidth³. The practical bandwidth is primarily governed by three factors: microwave loss, velocity matching, and impedance matching⁴, all of which are strongly governed by the traveling-wave electrodes (TWEs). Conventional coplanar waveguide (CPW) TWEs have long been subject to an inherent trade-off between bandwidth and modulation efficiency. To address this trade-off, capacitively-loaded traveling-wave electrodes (CL-TWEs) have been widely adopted. However, CL-TWEs often rely on non-CMOS-compatible quartz substrates, undercut silicon substrates, or additional low- k cladding layers to optimize the velocity matching. Here, we propose a broadband TFLN modulator with periodically slotted TWEs (PS-TWEs). By introducing periodic slots into TWEs, the proposed electrodes generate an equivalent inductive loading effect, thereby tailoring the microwave refractive index and RF loss. The fabricated TFLN modulator exhibits a 3-dB bandwidth exceeding 110 GHz and supports 224 Gbit/s PAM4 data transmission. Meanwhile, the device preserves high modulation efficiency, with a half-wave voltage-length product of only 1.7 V·cm. Furthermore, the proposed PS-TWEs feature a minimum linewidth of 5 μm , providing a more fabrication-compatible route toward broadband modulators.

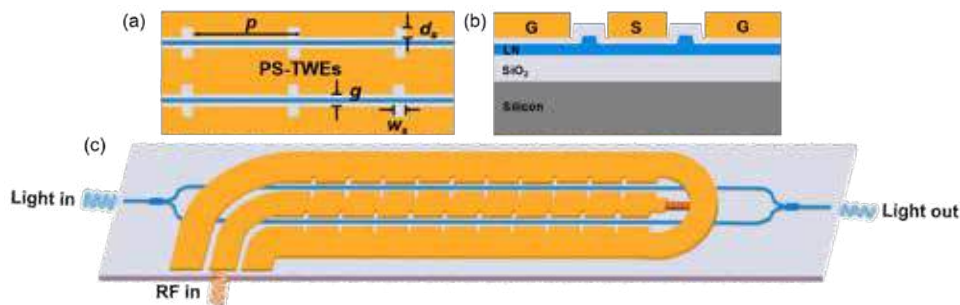


Fig. 1 (a) Details of the PS-TWEs. (b) The cross-sectional view of the modulation region. (c) Schematic diagram of the proposed TFLN modulator.

Device Design

Fig. 1 shows the schematic diagram of the proposed TFLN modulator employing PS-TWEs. The modulator is fabricated on a lithium-niobate-on-insulator (LNOI) wafer consisting of a 400-nm-thick X-cut TFLN layer, a 2- μm -thick buried SiO_2 layer, and a 525- μm -thick high-resistivity silicon substrate. The TFLN layer is patterned into single-mode

ridge waveguides. The waveguide width is set to 1 μm , the etch depth to 200 nm, and the sidewall angle to 70°. Gold (Au) is selected as the electrode material owing to its extremely low surface resistance and correspondingly low microwave loss, together with excellent thermal and chemical stability. PS-TWEs offer additional structural degrees of freedom, including the electrode gap g , slot period p , slot width w_s , and slot depth d_s . Therefore, they provide greater flexibility and broader tunability for optimizing the microwave characteristics of the transmission line. Frequency-domain finite-element method (FEM) simulations are performed to model the TFLN modulator and optimize the electrode parameters.

Device Characteristics

The EO performance of the device is systematically characterized. Fig. 2(a) shows the measured modulation curve under an 800-kHz driving signal. For the 5-mm-long modulator, the measured half-wave voltage V_π is 3.4 V, corresponding to a voltage-length product of 1.7 V·cm. An appropriate DC bias voltage is applied together with the input microwave small signal to bias the modulator at its linear operating point. The EO response was characterized by a 110 GHz lightwave component analyzer (Keysight N4372E), as shown in Fig. 2(b). The 3-dB EO bandwidth of the device extends beyond 110 GHz. To further evaluate the high-speed data transmission capability of the proposed ultrabroadband modulator, eye diagram measurements were performed using both non-return-to-zero (NRZ) and pulse-amplitude modulation (PAM) formats. Fig. 2(c) shows the measured eye diagrams at 1550 nm for NRZ and PAM4 signals at symbol rates of 100 and 112 Gbaud. Clear eye openings are observed at all tested symbol rates, and high-speed transmission up to 112 Gbaud PAM4, corresponding to 224 Gbit/s, is successfully demonstrated. The achieved data rate is mainly limited by the 55 GHz analog-bandwidth electrical amplifier in the measurement setup, rather than by the intrinsic bandwidth of the device.

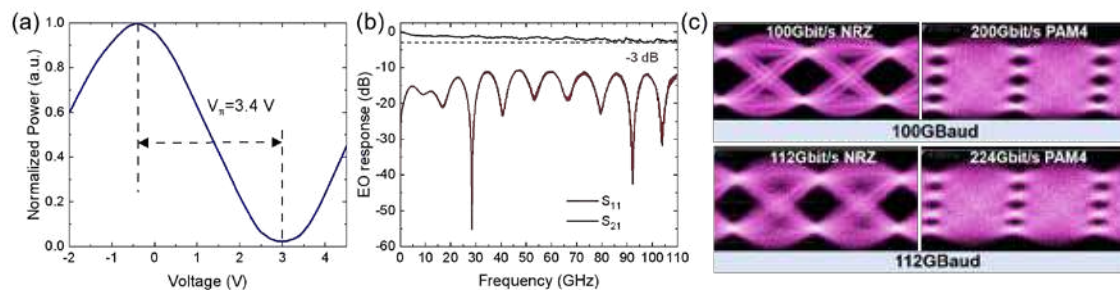


Fig. 2 (a) Measured modulation curve. (b) Measured EO response and electrical reflection. (c) Measured eye diagrams.

Conclusions

We have demonstrated a broadband TFLN EO modulator with a measured 3-dB bandwidth exceeding 110 GHz, supporting 224-Gbit/s PAM4 transmission while maintaining a low half-wave voltage-length product of 1.7 V·cm. With relaxed electrode dimensions compatible with ultraviolet photolithography, this approach provides a scalable route toward high-efficiency ultrabroadband TFLN modulators for future high-capacity optical interconnects.

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PI-06

Optimize wet etch method for high yield AlAsSb/ InGaAs avalanche photodiode fabrication

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Abstract We report an optimized two-step wet-etching method for AlAsSb/InGaAs avalanche photodiodes, using colour change as an endpoint indicator to remove oxidized residues, yielding cleaner sidewalls, lower leakage current, enhanced avalanche gain and reliable high-yield fabrication.

Keywords: avalanche photodiode, AlAsSb, InGaAs, wet etching, oxidation residues

Introduction

Low-noise avalanche photodiodes (APDs) at 1550 nm are important for fibre-optic communication, eye-safe LiDAR and infrared imaging. Compared with conventional InAlAs/InP APDs, AlAs_{0.56}Sb_{0.44} lattice matched to InP provides a very low hole-to-electron ionisation coefficient ratio, enabling low excess noise at practical gain. However, AlAsSb oxidizes rapidly during mesa etching. The resulting dark, cracked residues on sidewalls or contact regions increase surface leakage, destabilize breakdown and reduce device yield. This work develops a simple wet-etching route for AlAsSb/InGaAs separate-absorption-and-multiplication APDs, in which the visible colour change of oxidized AlAsSb is used as a practical endpoint signal for switching etchants [1-4].

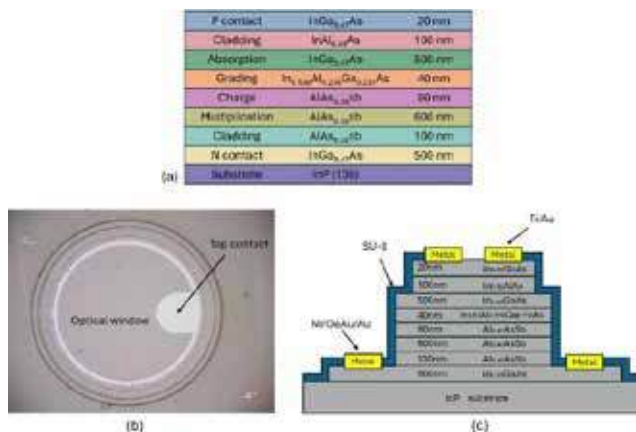


Fig. 1 . Overview of the designed AlAsSb/InGaAs/InP APD showing the layer structure, top view, and cross-sectional schematic.

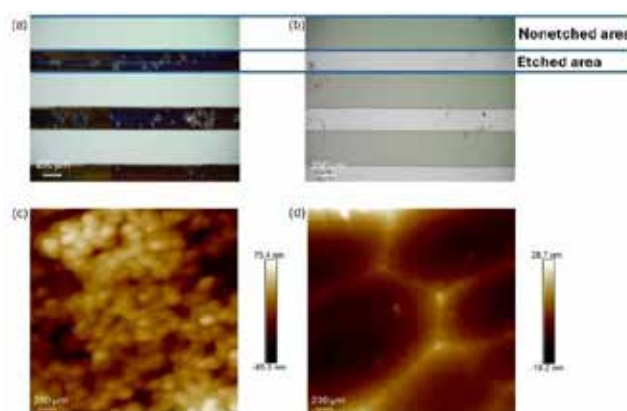


Fig. 2 Microscope and AFM images of AlAsSb/InGaAs samples after selective etching using H₂SO₄:H₂O₂:H₂O and HCL:H₂O₂:H₂O solutions.

Device structure and etching method

The wafer was grown by molecular-beam epitaxy on a semi-insulating InP substrate. It includes n- and p-type InGaAs contact layers, a 500 nm InGaAs absorption layer, a 600 nm undoped AlAsSb multiplication layer, AlAsSb cladding layers and an 80 nm charge layer. A two-step wet etch was optimized. H₂SO₄:H₂O₂:H₂O was first used to remove non-Sb-containing InGaAs/InAlAs layers. When the surface turned dark, indicating AlAsSb oxidation, the sample was transferred to HCL:H₂O₂:H₂O to remove the oxidized Sb-containing layer. Microscopy, AFM, SEM and EDX verified surface morphology and residue composition. HCL:H₂O₂:H₂O ratios from 1:1:3 to 1:1:6 were tested; the AlAsSb etch rate decreased from 129 nm/s to 20 nm/s as water increased. Because oxidation and air exposure affect the apparent rate, the colour transition provides a more reliable process indicator than thickness measurement alone.

Results and discussion

After the first sulphuric-acid-based etch, the AlAsSb surface became black and cracked. SEM revealed local delamination, while EDX confirmed oxygen within the dark residue region. AFM showed that surfaces treated only by H₂SO₄:H₂O₂:H₂O were much rougher than those cleaned by HCL:H₂O₂:H₂O, confirming efficient removal of oxidized AlAsSb. For circular

150 μm APDs, devices with clean surfaces showed one to two orders of magnitude lower dark current and higher multiplication factor under reverse bias, demonstrating the electrical benefit of residue removal.

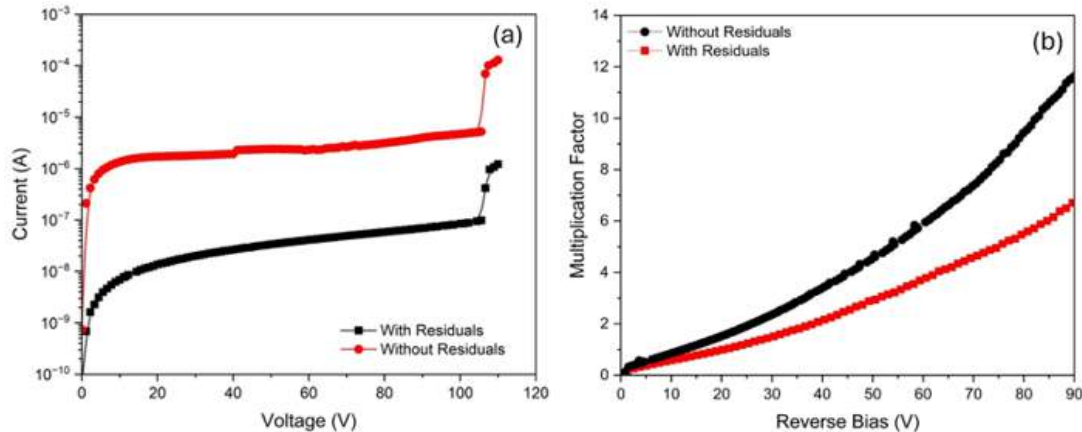


Fig. 3 Dark-current and multiplication comparison of APDs fabricated with and without oxidized AlAsSb residues.

Conclusions

A colour-indicated two-step wet etch was demonstrated for AlAsSb/InGaAs SAM APD fabrication. The combination of $\text{H}_2\text{SO}_4:\text{H}_2\text{O}_2:\text{H}_2\text{O}$ for non-Sb layers and $\text{HCL}:\text{H}_2\text{O}_2:\text{H}_2\text{O}$ for Sb-containing AlAsSb removes oxidation-induced residues effectively. The visible blackening of AlAsSb offers a simple endpoint for etchant exchange, overcoming the difficulty of depth measurement caused by oxidation, cracking and delamination. The method reduces dark current by up to two orders of magnitude and improves gain, making it suitable for high-yield low-noise infrared APD processing.

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PI-07

Hybrid Confinement Techniques for Polariton Simulators

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Abstract

We introduce two novel fabrication techniques that enable the creation of polaritonic potential landscapes inside the cavity layer and complete the cavity using sputtered amorphous mirrors, improving on challenges faced by established fabrication techniques.

Introduction

Exciton-polaritons (polaritons) are hybrid light-matter quasiparticles formed by microcavity photons and quantum well excitons that facilitate Bose-Einstein condensation at elevated temperatures [1]. In a planar semiconductor microcavity, polaritons behave as free particles with finite mass in two dimensions. Introducing an in-plane potential enables the creation of polaritonic lattices [2], which have proven to be a powerful platform for quantum simulators [3] and the emulation of complex Hamiltonians [4]. An established method of creating lateral photonic and excitonic confinement is the etching of micropillars. In this process, selected regions of the upper DBR, cavity, and active material layer are removed to depths of approximately 5 μm using plasma etching. This approach faces challenges when trying to realize densely packed periodic structures such as trigonal or square lattices. Narrow structures with high etch-depth-to-feature-size ratio are typically etched more shallowly than intended, reducing structural homogeneity. Additionally, inter-site coupling is limited because neighboring micropillars must be in direct contact to allow polariton interaction.

The etch-and-overgrowth (EnO) technique has proven to be a powerful tool for overcoming this challenge [5]. In this approach, the grown half-cavity is patterned by etching before the upper DBR is deposited by MBE, thereby creating photonic confinement. Typical confinement potentials of $E_{\text{pot}} \approx -10$ meV can be achieved with an etch depth of ~ 10 nm, offering significantly improved homogeneity compared to micropillar etching.

In this work, we explore two alternative approaches for generating in-plane photonic confinement with adjustable coupling between the lattice sites [6]. An MBE-grown half cavity is modified either by chemical wet-etching (EnS) or by sputter deposition of TiO_2 (DnS). Both approaches elongate the cavity locally, thereby redshifting the photonic mode and creating a photonic in-plane potential. Unlike EnO, the upper DBR is replaced with a sputtered dielectric mirror, removing the need to reintroduce the etched sample into an MBE chamber for crystalline overgrowth.

Structural comparison of the EnS and DnS processes

Atomic force microscopy performed on the patterned cavity layer demonstrates that the root mean-square surface roughness σ of DnS is about one order of magnitude smaller than for EnS and comparable to an unprocessed half-cavity. Furthermore, DnS yields uniform mesa heights throughout the lattice, whereas EnS exhibits an increased mesa height of up to 11% toward the lattice edge because of the etching process.

Photoluminescence spectroscopy of coupled resonators and Kagome lattices

Three samples from the same epitaxial material with varying mesa height are processed using EnS or DnS, respectively. Photoluminescence measurements on coupled resonators with varying overlap are fitted to a numerical solution of the 2D Schr dinger equation to extract the local photonic potential depth, revealing photonic confinement

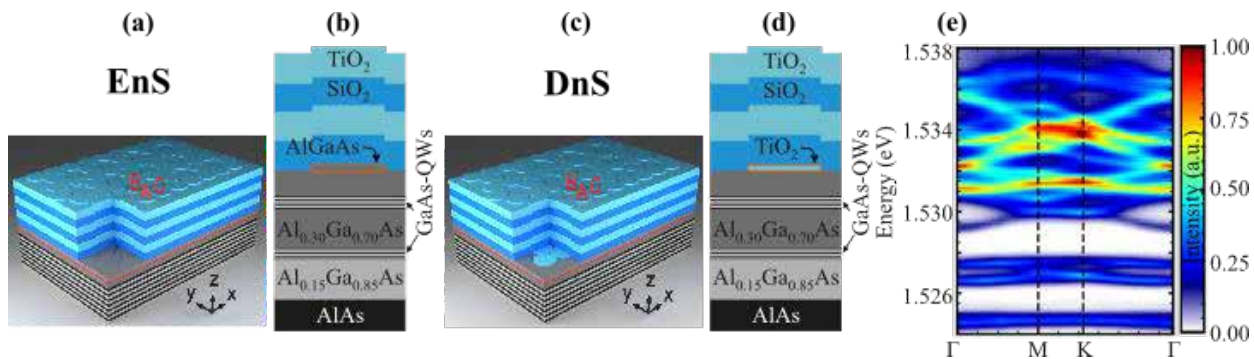


Fig. 1 Schematic of the EnS and DnS methods. (a,c) Artistic impressions of the Kagome lattice for the EnS and DnS technique. Characters A, B and C denote sites on different sublattices. The corresponding epitaxial layouts are shown in (b) and (d). (e) Bulk band structure of a DnS Kagome lattice along its Γ -M-K- Γ direction.

per nanometer of cavity length difference of (2.232 ± 0.019) meV/nm for EnS and (0.613 ± 0.020) meV/nm for DnS.

The different fabrication methods EnS and DnS are compared to the established method EnO by measuring the polaritonic band structure of Kagome lattices using momentum- and real-space spectroscopy. For the ground state, the photonic linewidth is found to be $\delta E_{\text{DnS}} = 680 \mu\text{eV}$, while $\delta E_{\text{EnS}} = 500 \mu\text{eV}$ is comparable to $\delta E_{\text{EnO}} \approx 400 \mu\text{eV}$. Differences are attributed to batch-to-batch variations of the sputtered DBR, a mismatch between emission wavelength and DBR center wavelength, as well as detuning.

Furthermore, we demonstrate polariton lasing from a 0D edge state and observe 1D edge states in a breathing Kagome lattice, a modified Kagome lattice with different inter- and intra-cell coupling strengths.

Conclusions

Our results show that the EnS and DnS techniques can readily compete with established methods for the realization of complex potential landscapes. In addition, their shorter iteration cycles provide significant potential for further optimization and future applications. While EnS is better suited for creating deep potentials, DnS excels at fabricating homogeneous potential landscapes without etching the cavity material. These methods establish a versatile platform for emulating complex Hamiltonians in a highly controlled environment.

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PI-08

Compact Optical Convolution Processor via Multi-Layer Phase-Only Metasurfaces

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Abstract We demonstrate convolution-level classification using a compact three-layer phase-only metasurface optical processor. As all the layers are trainable, the hybrid optical–electronic system achieves accuracy higher than 4f convolution architecture while significantly reducing propagation distance.

Introduction

Convolutional neural networks (CNNs) are widely adopted as a fundamental architecture in modern machine learning due to their strong feature extraction capability [1,2]. However, digital electronic implementations suffer from large energy consumption and latency, motivating the exploration of optoelectronic hybrid CNNs that combines intrinsic parallel computation and low-power consumption of optical neural networks (ONNs) with flexible digital layers [3-7]. Many previous studies have employed discrete single [3-6] or two [7] metasurfaces (MS) to realize optical convolutional layer by modulating phase or jointly modulating amplitude and phase. However, single phase-only MS suffers from limited representation capacity and amplitude modulation introduces inevitable optical power attenuation.

To this end, we have recently revealed that multi-layer phase-only MSs can significantly enhance the optical mode manipulating capability without inducing intrinsic optical loss [8]. Due to the high numerical-aperture (NA) phase masks that can be implemented by dense array of subwavelength meta-atoms, such multi-layer MSs can be realized on a compact module. Here, we study the applicability of such multi-layer MS optical frontend to perform convolution operations in optoelectronic hybrid CNN. Due to the enhanced representational capacity, we reveal that three-layer phase-only MSs can achieve high accuracies comparable to the digital baseline with 38.4% reduction in the total floating-point operations (FLOPS).

Method

Figure 1 shows the hybrid ONN architecture using 3-layer MSs considered in this work. By placing 3 MS layers at a constant distance of l and designing the first (MS1) and the last (MS3) layer to provide the basic functionalities of meta-lenses (MLs), they can implement the classical ONN architecture based on 4f optical system [3]. By using high-NA MLs, we can reduce l below 1 mm to realize a compact single-block device attached onto an image sensor as shown in Fig. 1.

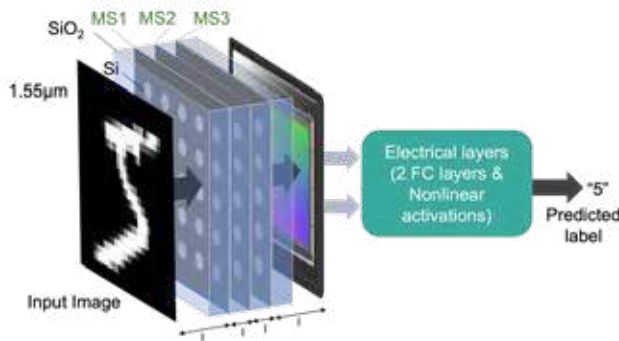


Fig. 1: Hybrid ONN with 3-layer MS serving as a convolutional layer and a lightweight digital decoder for two fully connected layers and nonlinear activation.

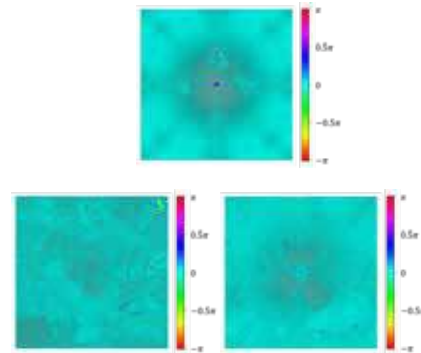


Fig. 2: Phase masks of MS1 (a), MS2 (b), and MS3 (c) after optimization.

In this work, we set $l = 0.7$ mm and employ 2048×2048 meta-atoms spaced at $0.7 \mu\text{m}$ in each MS layer. They are designed to generate eight 192×192 feature-map intensity distributions in spatially multiplexed regions of interest (ROIs) at the image sensor, corresponding to the positive and negative components of a four-kernel convolutional layer. We employ 28×28 images from MNIST and FashionMNIST datasets to encode the amplitude of the input light at 1550-nm wavelength. The feature maps are captured by the image sensor and sent to a lightweight digital electronic classifier composed of two fully connected layers and nonlinear activations.

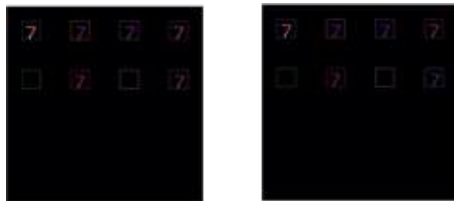


Fig. 3: Intensity distributions at the image sensor for an example case where digit

"7" is input. Left: Ground-truth intensity.

The four kernels with the size of 3×3 are first trained in the digital domain for each dataset. Then, they are used to optimize the phase shifts at each MS layer. In the simplest case where MS1 and MS3 are set to MLs with the focal length of l , we cannot implement arbitrary kernels unless we apply both amplitude and phase coding at MS2 [7], which induces undesirable optical losses. We therefore optimize MS1 and MS3 as well by adding small random perturbations to the initial ML design, so that the overall representational capability is enhanced. MS2 is initialized as a designed phase-only Fourier-plane mask, where the signed convolution kernels are decomposed into positive and negative components. A transfer function is synthesized in the spatial-frequency domain by projecting each pretrained kernel onto low-order spatial harmonics and applying linear phase shifts to spatially route the corresponding responses to designated ROIs. The phase of the resulting complex field is then encoded as the phase profile of MS2.

Result

Figure 2 shows the optimized phase distributions of the three MSs. Figure 3 shows the simulated feature-map intensity distributions at the image sensor for an example case. The normalized feature map intensities exhibit mean square errors (MSEs) of 5.1×10^{-3} compared to the target intensities.

Table 1 summarizes the classification performance of different optical front-end configurations for MNIST and Fashion-MNIST tasks. We compare three cases for our scheme: (i) when MS1 and MS3 are fixed to MLs and only MS2 is optimized, (ii) when MS1 is also optimized, and (iii) when all three MSs are optimized. We can confirm that accuracy consistently improves as we train more MS layers and reaches 97.7% and 87.4% for MNIST and Fashion-MNIST, respectively, when all three MSs are optimized. These values are comparable to the all-digital baseline, where fully digital CNN with identical configuration is assumed, implying that our scheme can reduce the total FLOPS in the digital domain by 38.4%, we also provide the case of classical 4f system, where the convolution layer is implemented by paired lenses and a linear spatial filter at the Fourier plane. We can confirm that our schemes of optimizing MS layers outperform this purely 4f-based system due to the enhanced representational capacity to enable more expressive feature extraction before digital classification.

Conclusions

In this work, we demonstrated a compact optical–electronic hybrid neural network using three phase-only MS layers as an optical convolution processor. Simulation results indicate that multi-layer MSs are a promising alternative for compact, low-power optical convolution.

Acknowledgement

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Table 1. Classification accuracy of optical front-end structures

Methods	MNIST	Fashion-MNIST
Digital baseline ^{a)}	97.3%	88.5%
4f system	95.8%	86.5%
Previous work ^[4]	96.5%	86.9%
(i) ML-MS-ML	94.2%	87.0%
(ii) MS-MS-ML	97.6%	87.1%
(iii) MS-MS-MS	97.7%	87.4%

^{a)} The digital baseline is built with 1 CNN layer with 4 kernels

PI-9

Low threshold InAs/InP quantum dot lasers on InP and Si

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Abstract Seven-stack InAs/InAlGaAs quantum dot lasers achieved low threshold current densities on InP and Si substrates, 180- μm cavity lasing on InP, and high-temperature operation up to 140 °C (InP) and 100 °C (Si).

Introduction

InAs/InAlGaAs QD lasers are promising candidates for C-/L-band optical communication and Si photonics because of their low threshold current density (J_{th}), high-temperature stability, and defect tolerance [1-3]. However, their performance is often limited by QD shape inhomogeneity, as well as the challenges of epitaxial growth on InP and Si substrates. In this work, a modified indium flush technique was employed to improve dot height uniformity and emission wavelength control [4]. Using this approach, high-performance seven-stack InAs/InAlGaAs QD lasers with low J_{th} and high-temperature operation were demonstrated on both InP and on-axis Si (001) substrates.

Low Threshold InAs/InAlGaAs Quantum Dot Lasers on InP

The laser structure was grown on an n-type (001) InP substrate by MBE, as shown in Fig. 1(a). The 7-stack QD laser sample exhibits an L-band room-temperature emission peak at 1604 nm with a narrow FWHM of 59.7 meV, as presented in Fig. 1(b). The AFM image in Fig. 1(c) reveals uniform uncapped QDs with a high density of $523/\mu\text{m}^2$ under optimized growth conditions. Broad-area FP lasers with a ridge width of 15 μm were fabricated and characterized under pulsed injection. Fig. 2(a) shows the L-I characteristics for devices with different cavity lengths, while Fig. 2(b) presents the temperature-dependent L-I characteristics of the 2000 μm device, exhibiting operation up to 130 °C. Fig. 2(c) shows CW temperature-dependent L-I curves of the 15 $\mu\text{m} \times 2000 \mu\text{m}$ device, demonstrating operation up to 35 °C.

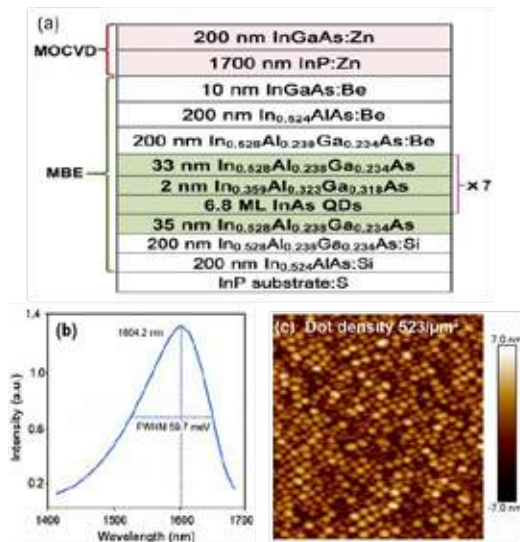


Fig. 1. Schematic epitaxial structure of the InAs/InP QD laser.

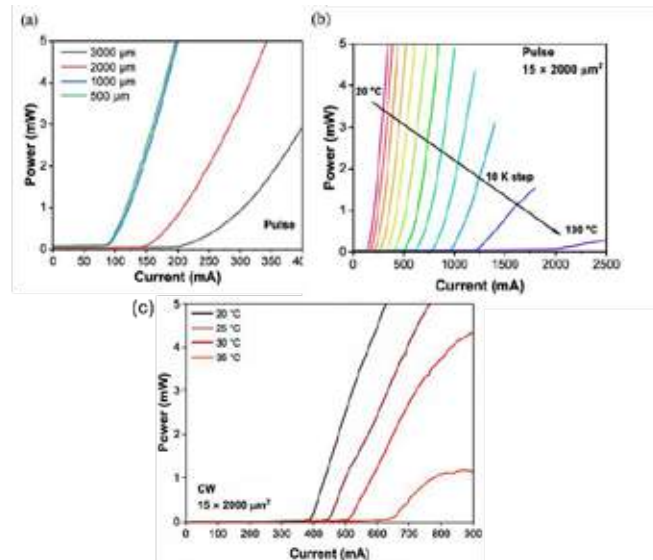


Fig. 2. (a) RT L-I for the InAs/InAlGaAs QD lasers with cavity width of 15 μm .

(b) Temperature-dependent L-I characteristics for the 15 $\mu\text{m} \times 2000 \mu\text{m}$ device.

(c) CW temperature-dependent L-I characteristics of the 15 $\mu\text{m} \times 2000 \mu\text{m}$ device.

High-Temperature and Ultra-Short Cavity Operation of InAs/InAlGaAs QD Lasers

To investigate the effect of reduced ridge width on temperature stability, 5 μm ridge devices were fabricated. As shown in Fig. 3(a), the 5 $\mu\text{m} \times 2000 \mu\text{m}$ device exhibited an I_{th} of 64.3 mA (J_{th} of 643 A/cm^2) and operated up to 140 °C under pulsed injection, which is 10 °C higher than the 15 $\mu\text{m} \times 2000 \mu\text{m}$ device. Fig. 3(b) shows the room-temperature L-I

characteristics of short-cavity QD lasers with cavity lengths down to 180 μm . Notably, the 180 μm device demonstrated lasing without facet coating, indicating the high optical gain of the InAs/InAlGaAs QD laser structure.

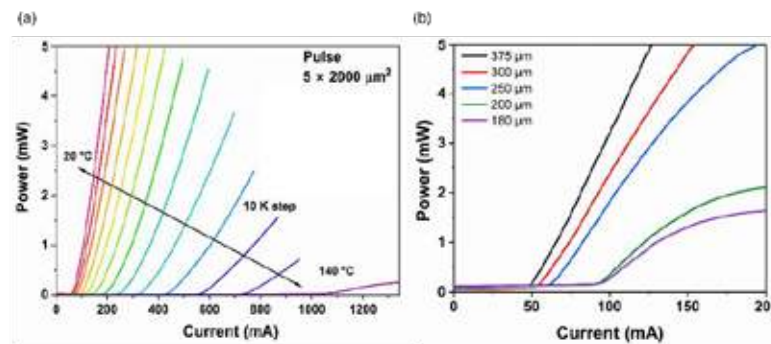


Fig. 3. (a) Temperature-dependent LI curves under pulsed injection for the 5 $\mu\text{m} \times 2000 \mu\text{m}$ device.

(b) RT LI characteristics for devices with cavity length less than 500 μm .

InAs/InAlGaAs QD Lasers Directly Grown on (001) Si Substrate

Based on the optimized InAs/InAlGaAs QD laser structure on InP, seven-stack QD lasers were directly grown on on-axis Si (001) substrates. FP lasers with ridge widths of 50 μm and 5 μm were fabricated and characterized under pulsed injection. The broad-area devices exhibited J_{th} values of 1.35–2.79 kA/cm^2 for cavity lengths ranging from 2000 to 350 μm . Temperature-dependent measurements were further carried out to evaluate device stability. As shown in Fig. 4, the 5 $\mu\text{m} \times 2000 \mu\text{m}$ device demonstrated lasing operation up to 100 $^{\circ}\text{C}$ under pulsed injection.

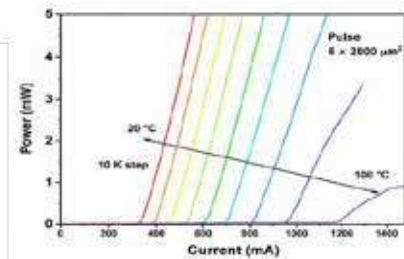


Fig. 4. Temperature-dependent LI curves.

Conclusions

This work demonstrates significant progress in InAs/InAlGaAs QD lasers on both InP and Si substrates through optimized QD growth and active region design. Seven-stack QD lasers on InP achieved of 63 A/cm^2 per QD layer and pulsed operation up to 140 $^{\circ}\text{C}$. In addition, electrically injected QD lasers directly grown on Si exhibited a low J_{th} of 1.35 kA/cm^2 and operation up to 100 $^{\circ}\text{C}$, highlighting their strong potential for optical communications and Si photonics.

Acknowledgment

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PI-10

All-Solid-State Anti-Resonant Fiber: A New Paradigm for Large-Mode-Area Ultrafast Laser Gain Media

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Abstract

We report an all-solid anti-resonant fiber as a novel photonic material with a 104- μm core, delivering 500- μJ ultrafast pulses and breaking the mode-area barrier for high-energy near-diffraction-limited fiber lasers.

Introduction

The pursuit of higher single pulse energy lies at the heart of ultrafast fiber laser research, because high energy ultrafast lasers are indispensable for applications that directly harness high pulse energy, such as strong field physics, high throughput precision micromachining, biomedicine, and remote sensing. However, the relentless pursuit of higher pulse energy in ultrafast fiber lasers is ultimately constrained by a fundamental physical barrier rooted in waveguide optics. In conventional large-mode-area (LMA) fibers, increasing the core diameter to suppress nonlinear effects inevitably weakens modal discrimination, leading to higher-order mode (HOM) competition and severe beam quality degradation. This "mode-area barrier" has long limited single-fiber ultrafast sources to pulse energies of around 100 μJ under near-diffraction-limited operation. Here, we introduce an all-solid anti-resonant fiber as a transformative photonic platform that decouples mode area from modal purity. Our silica-based Yb^{3+} -doped fiber, with a 104- μm core, leverages the anti-resonant cladding as a passive modal filter to resonantly eliminate higher-order modes while maintaining an ultra-large mode area.

Fabrication and Performance Characterization of AS-ARF

The fabricated AS-ARF was assembled via the rod-in-tube technique using the Yb^{3+} -doped active core rod and Ge-doped anti-resonant rods, followed by high-temperature fiber drawing. The final fiber cross-section, shown in Fig. 1a, exhibits an outer diameter of 275 μm , an inscribed core diameter of 104 μm , and a Yb^{3+} -doped active core diameter of 52 μm . The ultrafast amplification performance was evaluated using a MOPA system. As the pump power increased, the seed signal was amplified in the AS-ARF, ultimately delivering an average output power of 50 W with a pulse energy of 500 μJ and a peak power of 1.72 MW, corresponding to a slope efficiency of 55.5% (Fig. 1c). The output pulse duration was 289.4 ps (Fig. 1b). Fig. 1d shows that the relative RMS power fluctuation remained below 0.17% over 30 minutes at maximum output power, confirming excellent system stability. To our knowledge, this is the first demonstration of ultrafast pulse amplification based on an AS-ARF, achieving a pulse energy of 500 μJ that ranks among the highest in the field.

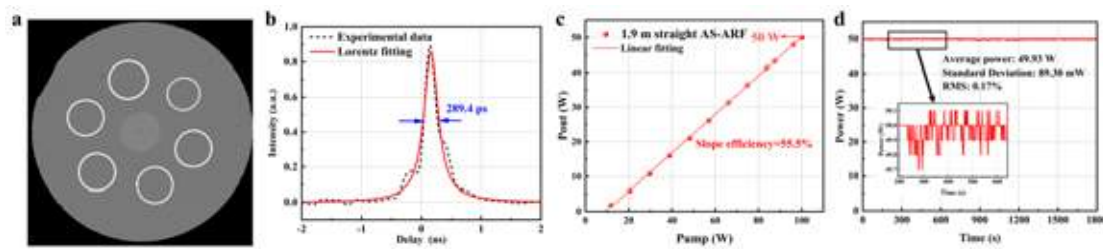


Fig. 1 Structures and ultrafast performances of AS-ARFs. **a**, Complete cross-section of the fiber. **b**, Pulse duration. **c**, Output power of the AS-ARF as a function of pump power. **d**, Power stability of the system over a 30-minute duration.

Conclusions

In summary, we have demonstrated a novel all-solid anti-resonant fiber as a transformative photonic material that successfully breaks the long-standing mode-area barrier. With a 104 μm core, the fiber delivers a record 500 μJ ultrafast pulse energy with near-diffraction-limited beam quality, while effectively suppressing nonlinear effects. This work not only fills the gap of Yb^{3+} -doped active AS-ARFs in high-power ultrafast systems but also opens a new physical pathway towards power-scalable, high-energy fiber lasers for future scientific and industrial applications.



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PI-11

Fabrication of a III–V–SiO/SiN Hybrid Cavity Incorporating a Single Stark-Tunable InGaAs Quantum Dot for High-Rate Single-Photon Generation on Silicon

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Abstract Deterministic integration of a Stark-tunable InGaAs quantum dot (QD) into a scalable III–V/dielectric hybrid cavity enables Purcell-enhanced emission and ultrafast single-photon generation. This CMOS-compatible platform represents a promising route toward high-brightness and coherent quantum light sources for scalable quantum photonic networks and integrated quantum technologies.

Introduction

The development and large-scale deployment of quantum photonic technologies, particularly secure quantum communication based on semiconductor quantum dots (QDs), critically relies on the on-demand generation of high-quality quantum light. Single photons with high brightness, purity, and indistinguishability are essential for scalable quantum networks and coherent quantum information processing. Consequently, ultrafast quantum emitters have become increasingly important for achieving high-speed operation. In addition, the integration of advanced quantum photonic devices on CMOS-compatible silicon platforms offers a promising pathway toward scalable and cost-effective quantum technologies [1].

However, the achievable repetition rate of QD-based single-photon sources is fundamentally limited by their intrinsic radiative lifetime, typically in the nanosecond range. To overcome this limitation, significant efforts have focused on integrating single QDs into photonic nanostructures that enhance the light–matter interaction, thereby increasing the Purcell factor and accelerating spontaneous emission dynamics [2]. Despite these advances, many existing implementations rely on complex alignment and wire-bonding procedures that are difficult to scale, limiting the practical integration of QD-based quantum photonic circuits.

Results

Figures 1(a) and (b) show schematics of the investigated samples. InGaAs QDs emitting in the telecom O-band were grown by MOCVD on (a) Si and (b) GaAs substrates. In both structures, the QD layer is positioned above an AlGaAs/GaAs bottom distributed Bragg reflector (DBR). For the GaAs-based structure, a dielectric SiO/SiN top DBR was additionally deposited, forming a vertical λ -cavity designed to enhance spontaneous emission via the Purcell effect. The electrical tunability of the QDs grown on Si is demonstrated in Fig. 1(c), which shows the emission wavelength of a single Stark-tunable QD as a function of the applied gate voltage. The emission can be tuned over 16 nm, enabling deterministic spectral alignment with the cavity mode. Figure 1(d) shows a representative μ PL spectrum of the same QD recorded at -0.5 V.

Figure 1(e) presents the low-temperature reflectivity spectra of the individual DBR mirrors: the AlGaAs/GaAs bottom DBR (black) and the dielectric SiO/SiN DBR (red). The dielectric DBR exhibits a significantly broader stopband (~ 250 nm) compared to the III–V DBR (~ 100 nm).

Combining both mirrors, as shown in Fig. 1(b), results in a pronounced cavity resonance within the stopband, as shown in Fig. 1(f). The cavity mode exhibits a full width at half maximum (FWHM) of approximately 2.7 nm at a resonance wavelength of 1319 nm, corresponding to a quality factor $Q \approx 477$ for a structure containing seven SiO/SiN DBR pairs. The cavity

performance could be further improved by increasing the number of dielectric DBR pairs.

The temperature dependence of the cavity properties is summarized in Fig. 1(g), which shows the cavity mode wavelength (black symbols) and the extracted quality factor (red symbols). With increasing temperature, the cavity mode exhibits the expected redshift, primarily caused by the temperature-dependent refractive index of the III–V cavity material, with a smaller contribution from thermal expansion. A gradual reduction of the Q factor is also observed at elevated temperatures, likely due to increased optical losses and absorption in the cavity materials.

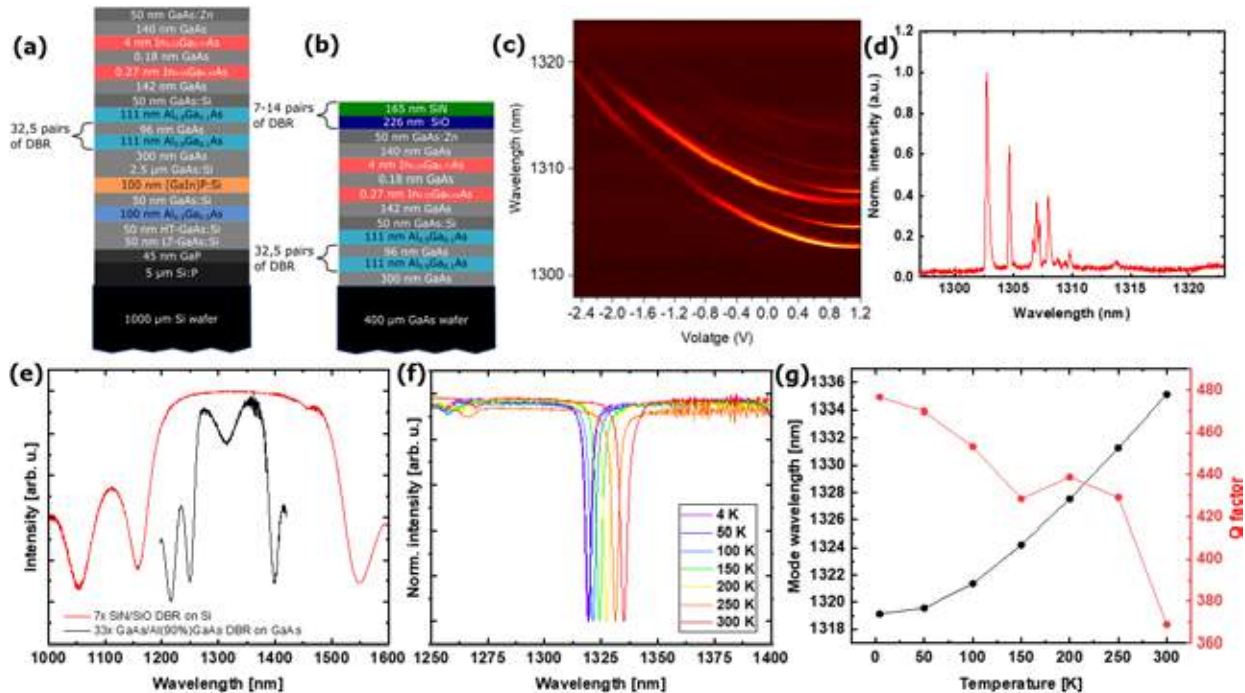


Figure 1: (a,b) Schematics of the QD samples grown on (a) Si and (b) GaAs substrates. In both structures, the QD layer is integrated above an AlGaAs/GaAs bottom DBR. The structure in (b) additionally incorporates a SiO/SiN top DBR, forming a λ -cavity. (c) Emission wavelength of a single Stark-tunable QD grown on Si as a function of the applied gate voltage. (d) Representative μ PL spectrum of the same QD recorded at -0.5 V. (e) Low-temperature reflectivity spectra of the individual DBR mirrors: the AlGaAs/GaAs bottom DBR (black) and the SiO/SiN top DBR (red). (f) Temperature-dependent reflectivity spectra of the full cavity structure shown in (b). (g) Temperature dependence of the cavity mode wavelength (black symbols) and the corresponding quality factor Q (red symbols).

Conclusions

We demonstrate a scalable hybrid cavity platform integrating a single Stark-tunable QD embedded in a p–i–n diode into a light-confining resonator consisting of an epitaxially grown III–V bottom mirror and a PECVD-deposited dielectric DBR. This hybrid design enhances the spontaneous emission rate via the Purcell effect, thereby reducing the radiative lifetime of the emitter. Deterministic positioning of the QD using in-situ electron-beam lithography (EBL) [3] ensures precise spatial alignment between the emitter and the optical mode, improving photon-extraction efficiency and emission coherence. Overall, this approach represents an important step toward scalable, high-brightness, and coherent quantum light sources, providing a promising foundation for next-generation integrated quantum photonic technologies.

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PI-12

Preferential Lasing through Mode-selective Gain sharing

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Abstract We demonstrate an asymmetric coupled-microcavity laser employing mode-selective gain sharing. A spectrally aligned auxiliary cavity redirects carrier-supported gain to the selected resonance while suppressing competing modes, achieving a 17-dB side-mode suppression ratio at pump levels.

Introduction

Power scaling in semiconductor microcavity lasers is commonly accompanied by enhanced modal competition and degraded spectral selectivity. Enlarging the pumped region increases the available carrier reservoir, but the additional gain is generally accessed by multiple cavity resonances. This gain-selectivity trade-off becomes particularly restrictive in compact resonators with dense spectral modes. Here, we demonstrate an asymmetric coupled-microcavity laser that addresses this limitation through mode-selective gain sharing.

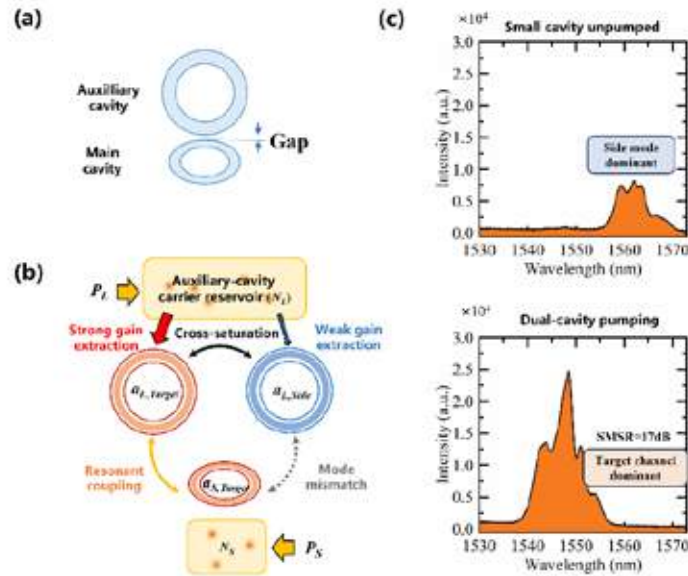


Fig 1. (a) Asymmetric coupled microcavity laser structure. (b) Mechanism of mode-selective gain sharing. (c) Experimental results.

Device Design and Operating Principle

The device consists of a large circular microcavity coupled to a smaller elliptical microcavity [Fig. 1(a)]. The two cavities are designed to exhibit partial isospectrality near the selected wavelength of approximately 1545 nm, while the large cavity additionally supports a competing resonance near 1560 nm. Under simultaneous pumping of both microcavities, the spectrally aligned resonance of the auxiliary cavity couples to the selected resonance of the large cavity. This coupling

establishes a preferred pathway through which the selected mode can utilize the carrier reservoir supplied by the enlarged pumped area.

As illustrated in Fig. 1(b), the mode-selection mechanism is not based solely on linear spectral filtering. Instead, the coupled target resonances share gain from the two carrier reservoirs, whereas the competing large-cavity mode experiences enhanced cross-saturation as the selected channel grows. Consequently, pump expansion preferentially strengthens the selected resonance while suppressing the competing mode.

Results and Discussion

Figure 1(c) compares the measured emission spectra under different pumping configurations. When the coupled microcavity system is fully pumped, the emission around 1545 nm becomes dominant, whereas the competing resonance near 1560 nm is substantially suppressed. A side-mode suppression ratio of approximately 17 dB is obtained for the selected emission. The lasing threshold is approximately 400 μ W under pulsed optical excitation.

These results indicate that the auxiliary microcavity does not merely introduce an additional resonance. Instead, its spectral alignment with the selected large-cavity mode enables coupling-assisted redistribution of the available gain. The resulting nonlinear modal competition favors the selected order under enlarged pumping conditions, despite the presence of competing resonances in the larger cavity.

Conclusions

We demonstrate mode-selective gain sharing in an asymmetric coupled-microcavity laser for preferential lasing. By combining partial isospectrality with coupled carrier-mediated modal competition, the device selectively reinforces the desired resonance while suppressing competing modes. This strategy provides a compact route toward power-scalable and spectrally selective on-chip coherent light sources.

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PI-13

Spiking Nanolasers for All-Optical Neural Networks

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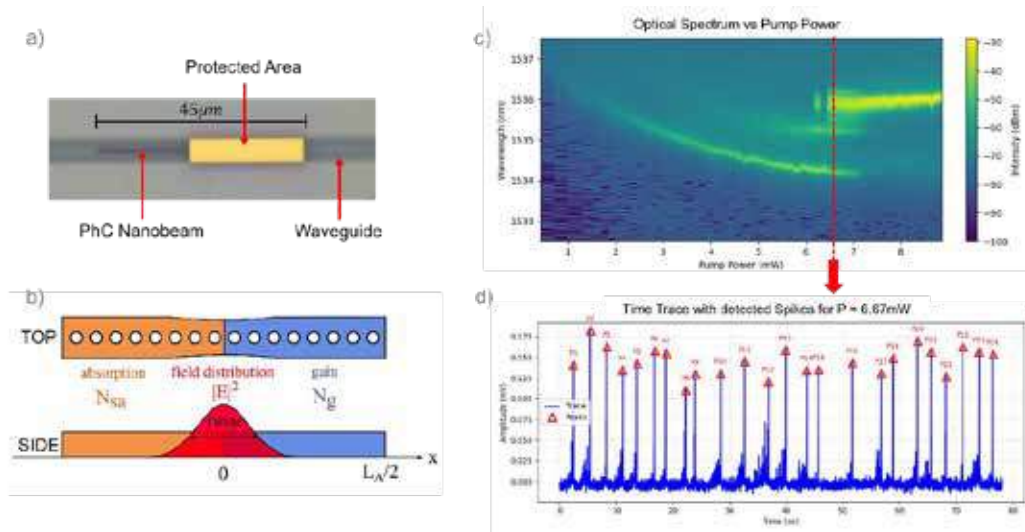
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We have developed spiking nanolasers with excitable non-linear dynamics, to be integrated in highly efficient, scalable and bio-plausible optical neural networks. They are realized in photonic-crystal nanobeams with small form-factor and high photon lifetimes

Introduction



The biological neuron is an example of an *excitable* system, and it stands out for its ability to perform complex computations when connected in a dense network, using only electro-chemical *spikes* to transmit information to its neighbors. This behavior is of great interest for applications in artificial neural networks, as it is believed that spike-based communication is responsible for the low energy consumption of the human brain (~20W) [1]. We have observed excitability with spike emission in photonic-crystal nano-lasers, through the addition of an intra-cavity saturable absorber. In the following sections

Figure 1 - An overview of the spiking nano-laser design and emission properties. a) Optical microscope image of the spiking nanolaser, composed of the PhC nanobeam, a protected area which acts as saturable absorber, all of it placed on top of an SOI waveguide. b) A schematic representation of the two sections of the laser, from the top and side views. c) The optical spectrum of the laser emission over the pump power. The broadening of the spectrum between 6mW and 7mW is associated with self-pulsing. d) A time-trace of the emission of the nanolaser, with labelled peaks, showing the spike emission

we will discuss insights into the design and fabrication of these devices, their emission properties in time and spectrum, and finally we will outline possible approaches for optical neural networks.

The spiking nanolaser

The spiking nanolasers presented in this work are pulsed lasers that operate under the same principle as many q-switching techniques. The starting point is a piece of III-V semiconductor material with a multiple-quantum-wells (MQW) structure, which is shaped into a nano-beam of sub-wavelength thickness and ~45µm length. The addition of holes which are etched vertically along the length of the nanobeam increases the confinement of one or multiple modes in the cavity following the

principle of distributed Bragg feedback. Such lasers have already demonstrated high quality factors, which leads to their high energy efficiency despite the compact scale [2].

To create a region that has saturable absorption, we passivate the nanobeam *selectively*, leaving one area un-passivated, and we cover the same area with a gold layer in the next fabrication step. This serves the dual purpose of respectively increasing the losses in the un-passivated area and preventing carrier injection by surface pumping. The goal is for carriers to be affected only by photons created in the gain-section of the cavity, and to keep a high ratio of differential gain between the sections. The interplay of many geometric and experimental parameters explains the challenge of achieving a stable self-pulsing device on such a small scale.

Conclusion

Excitable systems such as this one are of interest to optical neuromorphic computing applications due to their ability to respond quickly and bio-plausibly to external perturbations. There exist many proposed schemes on how to perform general purpose computations with spikes: some aim to exploit spike ordering in space and time [3, 4] to encode and process information, others leverage the stochasticity of the system for Bayesian inference on Boltzmann machines [5]. Regardless of the approach, integrated spiking nanolasers open the door for the prototyping of complex optical neural networks, with the promise of cascability and high-density integration on SOI circuitry.

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PI-14

Spatiotemporal Longitudinal Multi-Foci Femtosecond Laser for Manufacturing Large-Aperture, High-Damage-Threshold Metasurfaces

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Abstract Spatiotemporally shaped femtosecond laser introduces nanosecond-scale delays to suppress interactions between longitudinal foci. Multilayer structures with a high damage threshold can be fabricated in a single scan. This method enables the fabrication of large-aperture metasurfaces.

Introduction

Femtosecond laser demonstrates ultrahigh intensity and ultrashort irradiation periods, enabling precise modification and ablation of transparent materials¹. To date, femtosecond laser has been widely used in the manufacturing of a variety of optical modulation devices². In particular, direct writing of birefringent nanostructures in fused silica provides an effective route for processing metasurfaces with a high damage threshold³. However, the conventional femtosecond laser is limited by its single focus, thereby restricting the processing efficiency of processing and the aperture of metasurfaces⁴. The utilization of the spatial light modulators (SLMs) presents a promising avenue for addressing the aforementioned limitations. In this work, we demonstrate a spatiotemporal longitudinal multi-foci femtosecond laser processing strategy. Multiple longitudinally separated foci are generated through SLMs, and nanosecond-scale temporal delays are introduced between adjacent foci. These delays reduce transient interactions between the laser-induced optical filaments, allowing each focus to form birefringent structures independently. Consequently, multilayer structures with high damage thresholds could be fabricated in a single scan. This method provides an expandable approach for improving fabrication throughput and extending femtosecond laser processing to large-aperture metasurfaces.

Results and Discussion

The spatiotemporal longitudinal multi-foci femtosecond laser processing system is shown in Figure 1(a1). A three-foci configuration was used as a representative implementation. The incident laser was divided into three sub-beams, whose axial focal positions were controlled by spatial light modulators (SLMs). Optical path differences introduced nanosecond-scale delays between adjacent pulses. After recombination and polarization modulation, the sub-beams were focused into the sample to generate longitudinally separated foci. The temporal delays separate the transient optical filaments induced by adjacent foci, thereby reducing the interaction between the foci and enabling parallel writing of multiple modified layers within a single scan. Figure 1(a2) shows the cross-sectional morphology and elemental distribution of the modified region. Three spatially separated layers with comparable morphologies were formed along the same scanning trajectory. The O K α line profile exhibits three localized enhancement regions corresponding to Layers 1–3, confirming effective modification at each focal position. The consistent structure and element distribution indicate that the multilayer structure could be fabricated in parallel through a single scan. Although three foci were used here, additional longitudinal foci can be introduced through spatial and temporal control to further increase fabrication throughput.

To demonstrate the applicability of the proposed method to metasurface fabrication, a circular Airy-like beam generator with an aperture of 24 mm was fabricated, as shown in Figure 1(b1). The designed phase distribution is presented in Figure 1(b2), and the measured phase distribution is shown in Figure 1(b3). The measured distribution agrees well with the designed profile across the representative regions, confirming that longitudinal multi-foci processing preserves the spatially varying phase modulation required for metasurface fabrication. The damage threshold of the multilayer structures was evaluated using a 1064 nm laser with a pulse duration of 6 ns. As shown in Figure 1(c), the multilayer structures exhibit a 1-on-1 laser-induced damage threshold of 77 J/cm², corresponding to 84.6% of the 91 J/cm² threshold of the pristine fused-silica substrate. These results verify that spatiotemporal longitudinal multi-foci femtosecond laser processing enables parallel manufacturing of multilayer structures while preserving the high damage threshold of metasurfaces.

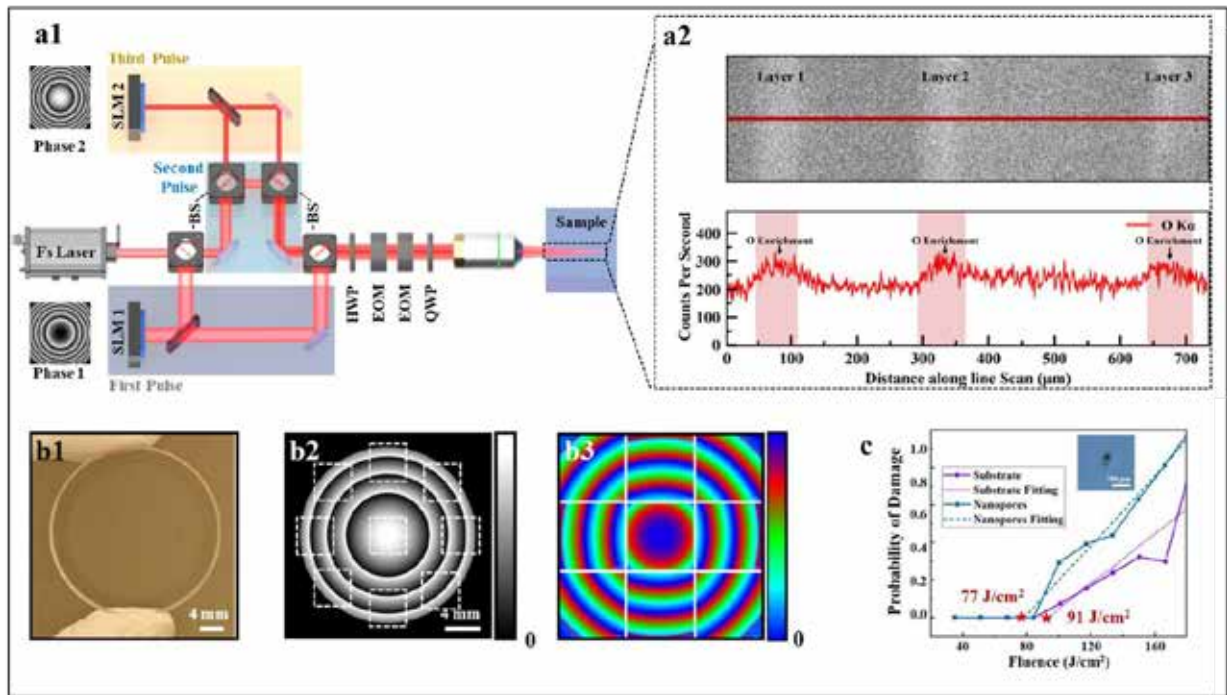


Fig. 1 Spatiotemporal multi-foci processing and characterization.

(a1) Spatiotemporal longitudinal multi-foci femtosecond laser processing system. (a2) Cross-sectional morphology and O K α line profile of the modified layers. (b1) A circular Airy-like metasurface. (b2) Designed phase distribution. (b3) Measured phase distribution. (c) Damage thresholds of the multilayer structures and the fused-silica substrate.

Conclusions

In summary, a spatiotemporally shaped longitudinal multi-foci femtosecond laser processing method was developed for single-scan fabrication of multilayer structures. Nanosecond-scale delays suppressed the interaction between the foci. A 24 mm aperture circular Airy-like metasurface was fabricated, and the modified structures exhibited a damage threshold of 77 J/cm². This method provides a scalable route toward large-aperture, high-damage-threshold metasurfaces.

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PI-15

Energy efficient MBE-grown wafer fused 1310 nm VCSELs

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Iqra Naeem and Julian Wagener (for consideration of Best Student Poster Award).

Abstract We demonstrate 1310 nm VCSELs with record-low EDR of 460 fJ/bit and 21 fJ/bit/km energy-to-distance-data-rate over 22 km transmission at 16 Gbps, with maximum data rates of 31 Gbps (NRZ).

Introduction

As the data traffic grows rapidly, the energy needed to transmit information is becoming a main topic of attention. 850-940 nm Vertical-Cavity Surface-Emitting Lasers (VCSELs) are the dominating solution for short-range links due to their combination of low cost and energy consumption, while providing good beam profile and high bandwidth [1]. Loss and dispersion in optical fibers restrict the practical length of these optical links. Conventional optical fibers favor longer wavelengths, with near-zero dispersion around 1300 nm and minimum absorption around 1550 nm. InP-based active regions enable efficient long-wavelength emission, while AlGaAs/GaAs DBRs provide high reflectance that overcomes the limitations of InP-based mirrors. These advantages are combined using wafer fusion (WF) technology to integrate both material systems to a high-performance VCSEL structure [2].

Data communication requires optimization of key VCSEL parameters for a particular application, to maximize output power, modulation bandwidth, and Side-Mode-Suppression-Ratio (SMSR), to minimize noise and power consumption.

We demonstrate, that post-fabrication tuning of the photon lifetime through altering the top Distributed Bragg Reflector (DBR) reflectance by applying a dielectric coating is an effective way to improve the VCSELs' performance [3], demonstrated for the first time for these types of lasers.

Device Structure

Present device heterostructures were grown using Molecular Beam Epitaxy (MBE) and bonded together using WF technology, having AlGaAs/GaAs DBRs. The cavity layers include an n-type InP bottom Intracavity (IC) contact layer, a thin, heavily doped n-type InGaAs bottom IC contact layer, an active region based on an InGaAs/InGaAlAs superlattice, designed for emission near 1310 nm, and a composite Buried Tunnel Junction (BTJ) for light and current confinement with a diameter of about 6 μm . The device was passivated by Si_xN_y layer and photon lifetime was altered through the deposition of SiO_2 on top of the structure [4].

Results & Discussion

The SiO_2 deposition changes the top DBR reflectance and consequently the mirror loss, thus altering the photon lifetime. These findings were derived with the Transfer Matrix Method. Experimentally, the coated configuration (120 nm SiO_2) shows a reduced threshold current and an improved modulation bandwidth in comparison to the uncoated device, ultimately resulting in improvement of the data rate and most importantly reduced energy consumption.

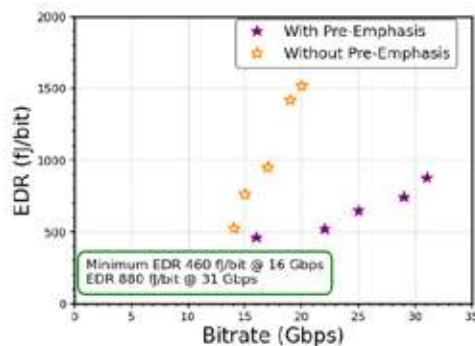


Fig. 1 Energy-to-Data ratio (EDR) versus with and without pre-emphasis (long photon lifetime, 1 m fiber length).

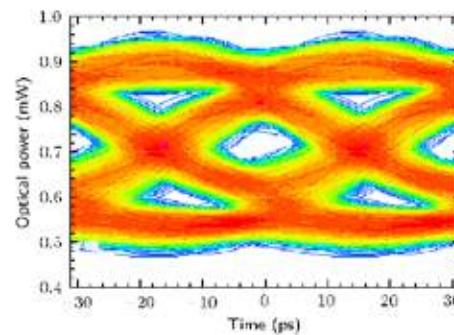


Fig. 2 Eye diagram at 31 Gbps, with a Q-factor of 3.43 (long photon lifetime, 1 m fiber length).

Fig 1 shows the Energy-to-Data-Ratio (EDR) vs. Bitrate for the device with increased photon lifetime. The experiments were conducted using varying optical fiber lengths at a temperature of 25 °C. Overall, an increase in the EDR with the data rate can be observed, reaching 1520 fJ/bit at 20 Gbps without pre-emphasis. With pre-emphasis an increased maximum data rate and reduced EDR of ~880 fJ/bit at 31 Gbps with a Bit-Error-Rate (BER) $< 10^{-12}$ was achieved. The eye diagram for this configuration is shown in Fig. 2. The lowest EDR values are 530 fJ/bit at 14 Gbps without pre emphasis and 460 fJ/bit at 16 Gbps with pre-emphasis, both at a bias current of 5 mA. These EDR values are noticeably lower in comparison to previously reported 1310 nm VCSELs (1064 fJ/bit [1]). The bitrate achieved at a fiber length of 22 km is 31 Gbps (BER $< 10^{-6}$) with a corresponding Energy-to-Distance-Data-Ratio (EDDR) of 40 fJ/bit/km. A record low EDDE of 21 fJ/bit/km was achieved at 16 Gbps (22 km).

Conclusion

We demonstrated 1310 nm VCSELs based on WF InP-based active regions and AlGaAs/GaAs DBRs, achieving record-low EDR. By post-fabrication tuning of the photon lifetime through dielectric coating of the top DBR, the device exhibit improvements in threshold current, modulation bandwidth, and energy efficiency. We demonstrate a lowest EDR of 460 fJ/bit and maximum data rates of 31 Gbps (NRZ). These results highlight photon lifetime engineering as an effective optimization approach for VCSELs and demonstrate the strong potential of this technology for future energy-efficient optical interconnects and data center communication systems.

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PI-16

Fabrication of High-Quality YIG Magneto-Optic Ceramics for Integrated Nonreciprocal Devices

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student

Abstract We demonstrate a YIG-on-insulator platform fabricated by ion-slicing of large-grain YIG ceramics. Combined with our previous work on Ti:SaOI and Nd:YAGOI, this platform offers low propagation scattering and high Faraday rotation, enabling compact on-chip magneto-optical isolators and modulators.

Introduction

The heterogeneous integration of diverse photonic materials on a single chip is essential for next-generation optical systems. Crystal-ion-slicing and bonding, which yield X-on-insulator (XOI) platforms, offers a versatile route to combine materials that cannot be epitaxially grown together. At the Shanghai Institute of Optics and Fine Mechanics (SIOM), we have advanced this technique by realizing active XOI platforms, including Ti:sapphire-on-insulator for broadband optical amplification and Nd:YAG-on-insulator for on-chip lasers. To complete the functional toolkit, a high-performance magneto-optical material in thin-film form is required. Yttrium iron garnet (YIG) is the ideal candidate, yet its integration as a low-loss single-crystalline thin film remains challenging. In the following sections, we summarize our published results on Ti:SaOI and Nd:YAGOI, present our earlier simulation-based comparative study of YIGOI against bulk single crystals and thick films, and finally introduce a critical material breakthrough: the fabrication of large-grain YIG ceramics with an average grain size of 2 mm. When combined with our established ion-slicing process, these ceramics are poised to yield YIGOI films with optical quality approaching that of single crystals, thereby enabling on-chip isolators and non-reciprocal devices in a scalable fashion.

Ion slicing of titanium-doped sapphire crystal and Nd:YAG laser ceramics

Ti:sapphire lasers are difficult to miniaturize due to low gain and short lifetime, demanding high pump power. that enabled sub-mW lasing and kW-level pulse amplification. However, that Ti:SaOI was realized by wafer bonding followed by polishing to control film thickness—a low-efficiency, high-cost process unsuitable for large-scale production. We addressed this via crystal-ion-slicing, where an ion-implanted Ti:sapphire crystal is bonded and exfoliated to yield a uniform single-crystalline film. Most recently, using this approach, we scaled the process to a 2-inch Ti:Sapphire/SiO₂/Sapphire wafer carrying a 1-μm-thick Ti:sapphire film (as figure 1 shown). The film exhibits sub-nanometer roughness and excellent thickness uniformity, showing that crystal-ion-slicing delivers wafer-scale Ti:SaOI while entirely avoiding waste from polishing, thus enabling mass-producible, high-performance Ti:sapphire integrated photonics.

In parallel, we extended crystal-ion-slicing to Nd:YAG ceramics, enabling submicron-thick gain films. Through an optimized stepwise annealing from 400 °C to 900 °C, we transferred Nd:YAG films onto sapphire (NYOS platform) with lateral dimensions up to hundreds of micrometers. TEM and photoluminescence imaging confirmed excellent crystallinity and luminescence. Together with Ti:SaOI, this establishes crystal-ion-slicing as a versatile route to wafer-scale laser-gain films for silicon photonics.

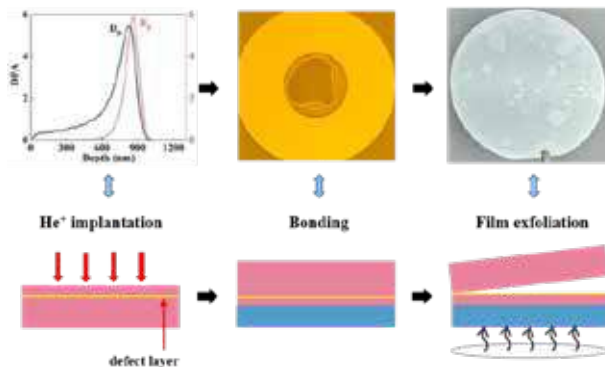


Fig. 1 Ti:Sa film formation process

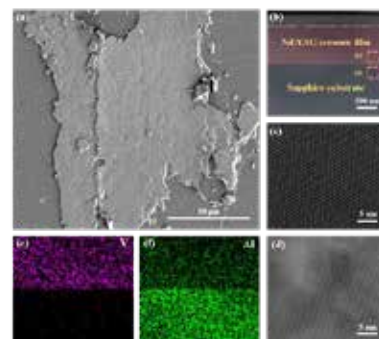


Fig. 2 SEM and EDS of Nd:YAG film

High-quality YIG Ceramics preparation and its devices application

We previously investigated the ion-slicing viability of commercial YIG single crystals, BIG, and YIG ceramics. While BIG films on silicon were transferred, their thickness and phase deviated; in contrast, YIG single crystals and ceramics both showed blistering after annealing, confirming their ion-slicing compatibility. Based on measured magneto-optical constants, we found that the nonreciprocal phase shift (NRPS) gap between BIG-on-Si and YIG-on-Si narrows drastically from 399% at 1.55 μm to only 26% at 2.1 μm. This drove the design of a YIG-ceramic-based TM-mode isolator with simulated insertion

losses of 2.78 dB at 1.5 μm and 0.35 dB at 2.1 μm , highlighting YIG as a strong candidate for mid-infrared on-chip isolation. However, practical implementation is limited by material availability: YIG single crystals are typically restricted to ~ 5 mm in diameter, and thick-film approaches struggle to simultaneously achieve sub-micrometer thickness, large area, and high crystalline quality. To bypass these constraints, we have recently fabricated YIG ceramics with an average grain size of 2 μm . The millimeter-scale grains are three orders of magnitude larger than the optical mode, effectively eliminating grain-boundary scattering and approaching single-crystal optical quality. Crucially, these ceramics can be produced with significantly larger lateral dimensions than single crystals, offering a scalable wafer-level material source. With these large-grain ceramics already in hand, we are now applying the same ion-slicing process to transfer sub-micrometer YIG films onto SiO_2 -on-silicon. The immediate goal is to realize the first large-grain-ceramic-based YIG-on-insulator platform, combining single-crystal-like propagation loss with macroscopic scalability and thus enabling CMOS-compatible on-chip isolators and non-reciprocal circuits in a truly practical format.

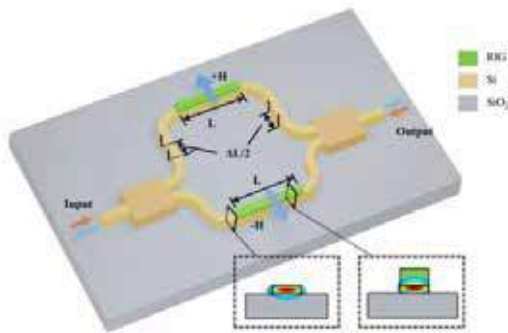


Fig. 3 Sketch of the proposed MZI magneto-optic isolator



Fig. 4 The image of large-grain YIG ceramics

Conclusions

In summary, we have demonstrated crystal-ion-sliced XOI platforms for broadband gain (Ti:SaOI) and on-chip lasing (Nd:YAGOI). Simulations verify that YIG ceramics are a viable route to low-loss mid-infrared isolators, and our newly fabricated 2 μm -grain YIG ceramics overcome the size limitations of single crystals, offering wafer-scale material without sacrificing optical quality. Immediate ion slicing of these ceramics will deliver the first large-grain YIGOI films, completing the XOI material suite and enabling practical, CMOS-compatible non-reciprocal magneto-phonic circuits.

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PI-17

Monolithic Multilayer Diffractive Neural Networks for Deep and High-Capacity Spectral Parallel Computing

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Abstract We demonstrate a monolithically integrated D²NN fabricated inside silica glass, combining aligned trilayer diffraction with spectral parallelism to perform four-wavelength, multi-dataset classification of 20 categories with 80% experimental accuracy, enabling scalable high-capacity optical computing platforms.

Introduction

Artificial intelligence driven by deep neural networks has created increasing demands for scalable and energy-efficient computing. Optical computing, with intrinsic parallelism, low latency, and low power consumption, offers a promising alternative. Among optical computing architectures, diffractive deep neural networks (D²NNs) enable all-optical inference through free-space propagation across passive diffractive layers.

Recently, metasurface-based D²NNs in the NIR and visible regimes have shown broad potential in image classification^[1] and quantum logic^[2]. However, existing systems still face major challenges in simultaneously scaling network depth and information capacity. Discretely assembled multilayer architectures suffer from cumulative alignment errors, while reported monolithic devices are mostly limited to shallow bilayer designs^[3-5]. Attempts to further increase depth often encounter optical crosstalk, off-axis aberrations, or reduced effective aperture. In addition, most D²NNs remain task-specific, and parallelization based on polarization^[3], direction^[6], or mechanical reconfiguration^[7] provides limited channel capacity and robustness. Spectral parallelism is attractive but highly sensitive to precise 3D alignment, yet the orthogonal nature of spectral information provides an additional degree of freedom for multi-information parallel processing and offers considerable potential for scalable information-capacity expansion.

Here, we propose a compact monolithically integrated multilayer D²NN combining cascaded diffractive layers with spectral-domain parallelism, enabling deep and high-capacity optical computing. Femtosecond-laser-induced birefringence nanopore arrays inside silica glass enable accurately aligned three-dimensional diffractive layers with large apertures and high pixel counts. As a proof of concept, we demonstrate a three-layer visible D²NN operating at four wavelengths, independently trained for multi-dataset object recognition. The system classifies 20 categories with 80% overall experimental accuracy and a peak channel accuracy of 86%, demonstrating a scalable route toward compact, high-density optical inference.

Results

As shown in Fig. 1, the monolithically integrated multi-layer D²NN (MIML-D²NN) combines volumetric layer integration with spectral parallelism on a single chip. Its core is a monolithic silica-glass processing unit containing three cascaded diffractive hidden layers, fabricated by femtosecond-laser-induced birefringence modification with geometric-phase nanopores for precise wavefront control^[8]. This in-situ writing method provides strong structural stability and sub-micron inter-layer alignment, eliminating the need for post-fabrication alignment and reducing performance loss from cumulative positioning errors. The monolithically integrated fabrication ensures precise layer positioning and enables accurate diffraction and phase control throughout the network.

The system consists of an input plane with transmissive amplitude masks, a monolithic diffractive processing unit, and an output plane divided into detection zones. By exploiting wavelength-dependent diffraction at 532, 570, 600, and 632 nm, the shared structure performs distinct optical mappings for different channels. The hidden-layer phase profiles are jointly optimized by error backpropagation across all wavelengths. Ten interleaved detection zones are shared among the four wavelength channels, enabling four independent five-class classification tasks in a compact, passive, and real-time optical system.

Conclusions

In this work, we have demonstrated the theoretical design, numerical validation, and experimental implementation of a MIML-D²NN empowered by spectral parallel for deep and high-capacity optical computing. By fabricating cascaded diffractive layers within a single transparent substrate via femtosecond-laser-induced birefringence modification, our approach fundamentally circumvents the stringent alignment prerequisites and mechanical instabilities that plague conventional free-space discrete setups. Through spectral parallel, multiple optical channels are efficiently integrated into the same architecture, thereby enhancing the information capacity and computational parallelism without increasing device footprint. Benefiting from these innovations, our network successfully performs multi-class classification tasks with a high experimental accuracy of 80%, closely matching the simulated prediction of 81% with a deviation of merely 1%. This demonstrates both the robustness of the multilayer spectrally parallel diffractive design and the reliability of the femtosecond-laser fabrication process. Importantly, the proposed approach provides a scalable and compact solution toward on-chip all-optical neural networks, with the potential to be extended to broader multiplexing modalities such as spatial, or orbital angular momentum channels.

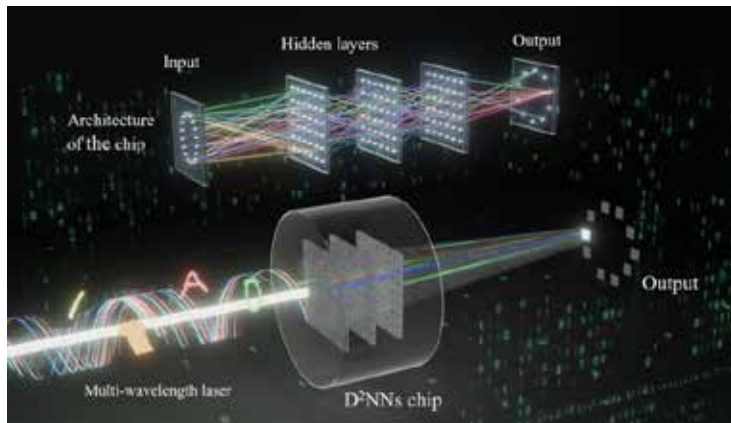


Fig. 1 Conceptual schematic of the MIML-D²NN. The architecture features a compact design where diffractive layers are embedded within a single silica glass via femtosecond laser direct writing. By leveraging spectral parallel, the system maps encoded inputs to spatially distinct detection regions through dense optical diffraction, enabling high-throughput, passive, and real-time classification.

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PI-18

Ultra-Narrow Linewidth Phonon Laser Based on Dissipation Dilution

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Abstract We demonstrate an on-chip phonon laser with a linewidth below 0.005 Hz by combining dissipation-diluted soft-clamped nanobeam resonators with active feedback, enabling ultracoherent mechanical oscillation for precision sensing and quantum technologies.

Introduction

Phonon lasers provide the mechanical analogue of optical lasers and are attractive for precision sensing, nonlinear dynamics and quantum technologies. Their practical impact is currently limited by linewidths that are usually broadened by environmental noise and intrinsic mechanical dissipation. This work addresses that bottleneck with a room-temperature, on-chip cavity optomechanical platform designed for extremely low mechanical loss.

Dissipation-diluted optomechanical resonator

We applied dissipation dilution theory to design nanobeam mechanical resonators with high quality factors. The device uses a high-stress stoichiometric silicon nitride nanobeam integrated with a zipper optomechanical crystal microcavity. A large aspect ratio enhances dissipation dilution, while a quasi-phononic-crystal soft-clamping region localizes the mechanical mode away from the supports to suppress bending losses. Ringdown measurements at room temperature show a mechanical resonance near 1.075 MHz with a high quality factor of 3.48×10^6 .

Feedback phonon lasing

Phonon lasing with ultra-narrow linewidth is realized through an active feedback loop. A probe laser is coupled into the optomechanical crystal microcavity for detection of the mechanical displacement, and an FPGA-based processor supplies adjustable delay and gain to drive an electro-optic modulator in the pump path. This process creates a modulated optical radiation pressure that is in-phase with the mechanical mode, providing negative damping to compensate mechanical loss. Phonon lasing occurs once the feedback gain fully offsets the losses. The corresponding spectra before and after the lasing transition are displayed in Fig. 2. Above the threshold, the signal intensity increases by over 30 dB, accompanied by a significant narrowing of the linewidth.

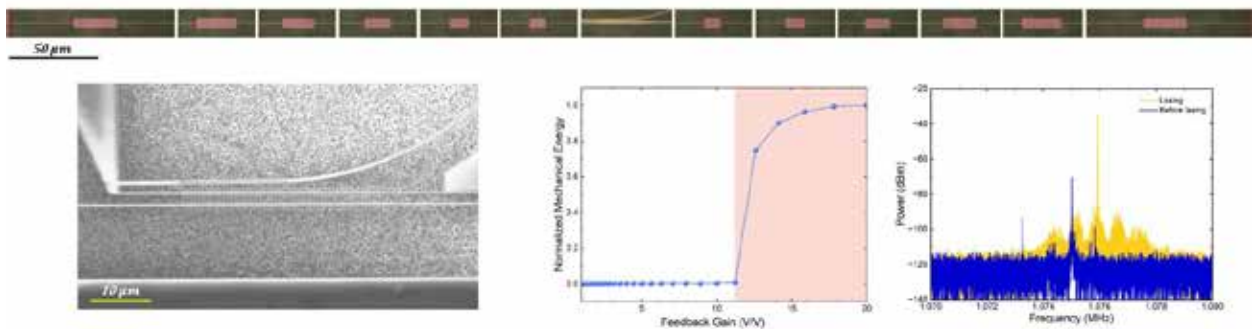


Fig. 1 Ultra-Narrow Linewidth Phonon Laser

Linewidth and stability

Frequency-stability measurements show strong suppression of phase fluctuations after phonon lasing. The phase-noise power spectral density decreases by approximately 50 dB above threshold, and Allan-deviation analysis indicates that the intrinsic linewidth is below 0.005 Hz. To the best of our knowledge, this is the narrowest linewidth reported for a phonon laser to date, with a reduction of three orders of magnitude compared to the existing.

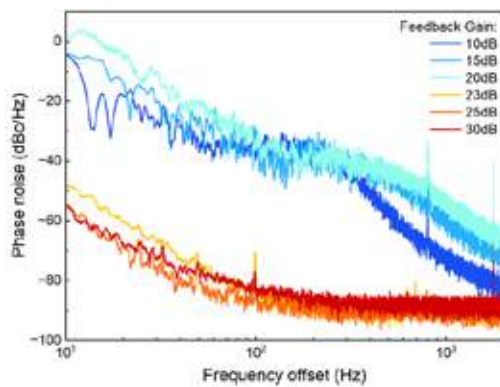


Fig. 2 Comparison of the phase noise power spectral density before and after lasing

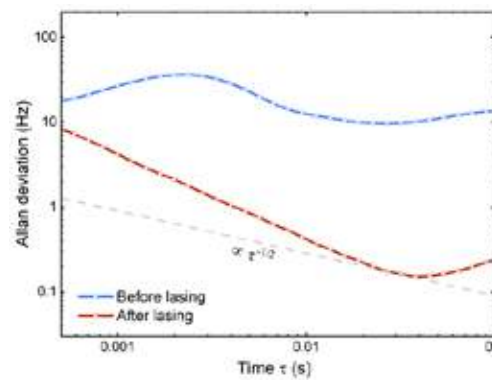


Fig. 3 Allan deviation of the mechanical signals before and after phonon lasing

Conclusions

In summary, we have demonstrated a phonon laser with an ultranarrow linewidth of less than 0.005 Hz, achieved by leveraging a high-Q mechanical mode combining with active feedback control. This approach establishes a novel architecture for generating highly coherent phonon sources.

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PI-19

Single-frame Motion Vector Imaging with Phonon-Engineered Perovskite Optoelectronic Synapses for Neuromorphic Visual Perception

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please indicate if Author 1 is a student (for consideration of Best Student Poster Award).

Abstract A lead-free perovskite neuromorphic imaging system enables single-frame motion vector imaging by integrating sensing, memory, and computation. Broadband photo-thermoelectric synapses directly encode trajectories and extract motion parameters, achieving efficient dynamic vision with ~300:1 sensor-level data compression.

Introduction

Conventional CMOS vision systems require high-frame-rate acquisition and multi-frame processing, resulting in redundant data transfer and computational burden [1-3]. Inspired by biological vision, we propose a single-frame motion vector imaging (SF-MVI) paradigm using neuromorphic optoelectronic synapses capable of simultaneously sensing, storing, and processing temporal information.

Material and Device Concept

The system is based on lead-free $(3\text{BPA})_3\text{Bi}_2\text{I}_6\text{Br}_3$ perovskite optoelectronic synapses. Strong acoustic-optical phonon coupling and soft lattice dynamics yield an ultralow thermal conductivity of $0.152 \text{ W m}^{-1} \text{ K}^{-1}$, enabling broadband photo-thermoelectric responses from 450 to 1342 nm. The devices exhibit synaptic plasticity, broadband photodetection, and intrinsic temporal relaxation suitable for motion encoding.

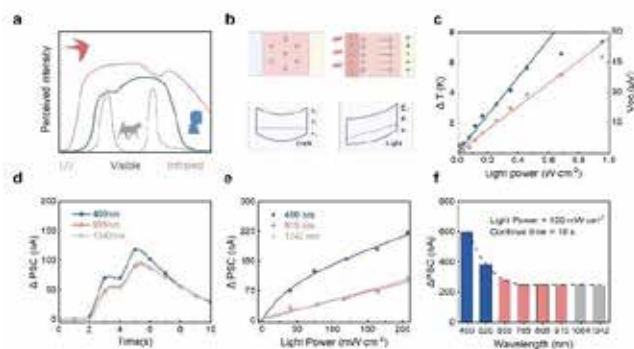


Fig. 1 Broadband photoresponse of the $(3\text{BPA})_3\text{Bi}_2\text{I}_6\text{Br}_3$ synaptic device. (a) UV-IR perception; (b) device structure and mechanism; (c) ΔT and V_{oc} versus light power; (d) transient photocurrent; (e) power-dependent photocurrent; (f) wavelength-dependent synaptic response.

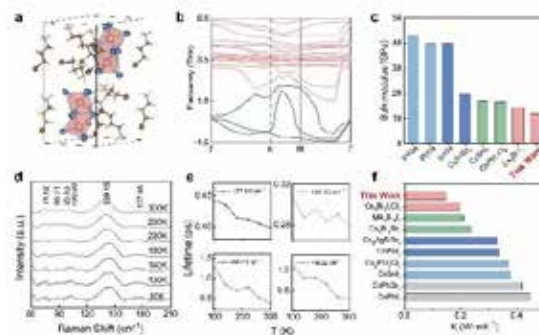


Fig. 2 Origin of ultralow thermal conductivity in $(3\text{BPA})_3\text{Bi}_2\text{I}_6\text{Br}_3$. (a) Crystal structure; (b) phonon dispersion; (c) bulk modulus; (d) Raman spectra; (e) phonon lifetime; (f) thermal conductivity comparison.

Neuromorphic Imaging and Motion Vector Extraction

A monolithic 64×64 active-matrix array (4096 pixels) was integrated with an a-Si TFT backplane. The array demonstrated excellent uniformity (PRNU = 4.06%) and robust visible/infrared imaging. By exploiting photocurrent decay dynamics ($\tau = 2.77 \text{ s}$), motion trajectories are compressed into a single spatiotemporal frame. Velocity, acceleration, and angular velocity

can be extracted directly from photocurrent gradients without conventional video reconstruction.

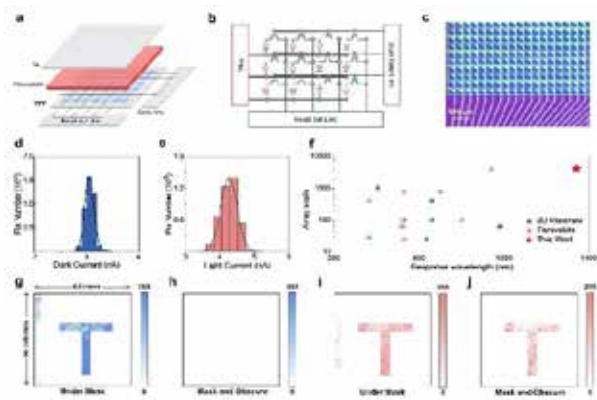


Fig. 3 Monolithic 64×64 neuromorphic imaging array. (a) Pixel structure; (b) addressing circuit; (c) array photograph; (d, e) pixel uniformity; (f) performance benchmarking; (g–j) visible and IR imaging demonstrations.

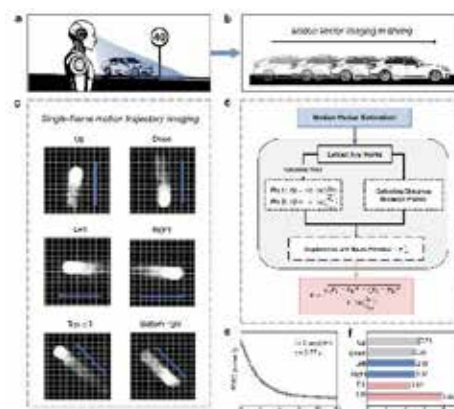


Fig. 4 Single-frame motion vector imaging and velocity extraction. (a) Vision sensing concept; (b) motion vector imaging principle; (c) representative trajectories; (d) velocity extraction method; (e) synaptic decay dynamics; (f) calculated velocities.

Results and Significance

The SF-MVI framework successfully recognized six representative motion directions with 100% classification accuracy using a compact neural network. Compared with conventional 30 fps imaging, the system achieves approximately 300:1 sensor-level data compression while preserving dynamic information. This work establishes a scalable platform for real-time motion perception, autonomous systems, and embodied artificial intelligence.

Conclusions

We demonstrate a broadband neuromorphic vision platform that directly encodes motion vectors within a single exposure. The combination of phonon-engineered lead-free perovskites, photo-thermoelectric sensing, and in-sensor computation provides an efficient route toward next-generation intelligent machine vision.

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PI-20

Halogen substitution in Lead-Free Double Perovskites toward Ultralow-Dose X-ray Detection and Signal Decoding

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Author 1 is a student and would like to be considered for the Best Student Poster Award.

Abstract Shielded X-ray communication is limited by detector sensitivity at low dose. Molecular halogen substitution stabilizes lead-free (I-PA)₄AgBiI₈, delivering record-low detection limit and reliable Morse-code/pixel-pattern decoding through 18.8 mm aluminum barriers for safer information transfer applications.

Introduction

Reliable wireless communication is essential in extreme environments, including shielded facilities and regions with severe electromagnetic interference. X-rays, with ultrashort wavelengths and high penetration capability, are promising for next-generation communication in such environments[2]. However, practical X-ray communication (XCOM) remains limited by the lack of ultra-sensitive, low-noise detectors that can operate under low-dose conditions. Lead-free two-dimensional double-metal perovskites containing Ag and Bi are attractive for X-ray detection because of their high-Z composition, structural tunability, and improved stability[3]. Nevertheless, their performance is often restricted by lattice distortion, insufficient dielectric screening, and limited charge-collection efficiency.

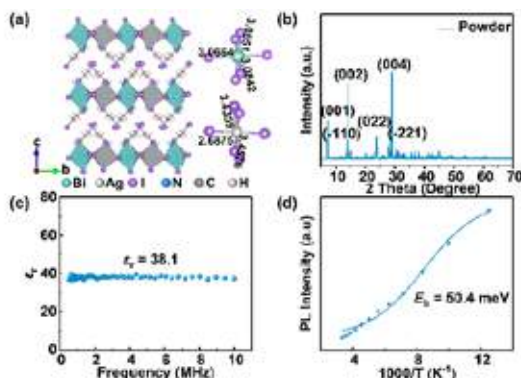


Fig. 1 Structural and photophysical characterization of (I-PA)₄AgBiI₈: (a) SCXRD structure, (b) PXRD pattern, (c) dielectric permittivity, and (d) exciton binding energy.

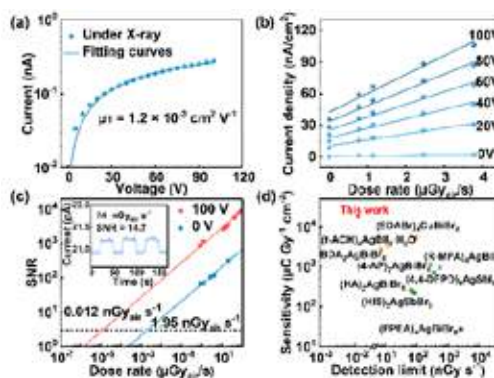


Fig. 2 X-ray detection performance of (I-PA)₄AgBiI₈: (a) bias-dependent photoconductivity and $\mu\tau$ product, (b) dose-rate-dependent current density, (c) SNR-derived detection limit, and (d) comparison with reported halide double-perovskite X-ray detectors.

Halogen Substitution with Enhanced Dielectric Response and Low Exciton Binding Energy

Herein, we report a molecular-level strategy to stabilize the lead-free double perovskite (I-PA)₄AgBiI₈ through terminal iodine substitution in the organic spacer[1]. This design increases molecular polarizability and strengthens iodine-involved intermolecular interactions, stabilizing the perovskite framework against competing low-dimensional phases. Single-crystal X-ray diffraction reveals a layered double-perovskite structure, in which Ag/Bi-I octahedral inorganic layers are separated by organic spacer cations. The compact crystal packing gives a high density of 3.452 g cm⁻³, favorable for X-ray absorption. Benefiting from enhanced dielectric screening, (I-PA)₄AgBiI₈ exhibits a high dielectric constant of 38.1 and an ultralow exciton binding energy of 50.4 meV, facilitating X-ray-induced free-carrier generation, separation, and extraction.

Exceptional X-ray Detection Sensitivity and Low Detection Limit

The charge-extraction capability of the detector was evaluated using the Hecht equation, yielding a mobility-lifetime product of $1.2 \times 10^{-3} \text{ cm}^2 \text{ V}^{-1}$. The device shows a linear photocurrent response over a broad dose-rate range and achieves a high sensitivity of $1.79 \times 10^4 \mu\text{C Gy}^{-1} \text{ cm}^{-2}$ under 100 V bias. Based on the signal-to-noise ratio criterion of $\text{SNR} = 3$, the detector reaches ultralow detection limits of $1.95 \text{ nGy}_{\text{air}} \text{ s}^{-1}$ at 0 V and $0.012 \text{ nGy}_{\text{air}} \text{ s}^{-1}$ at 100 V. In addition, temperature-dependent conductivity measurements reveal a large ion-migration activation energy of 735 meV, while long-term measurements confirm negligible dark-current drift and stable photocurrent response.

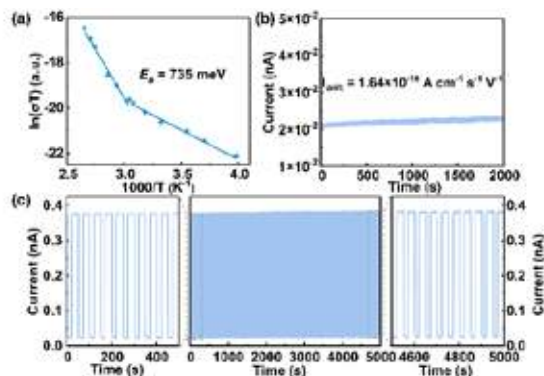


Fig. 3 Operational stability of the $(\text{I-PA})_4\text{AgBiI}_8$ X-ray detector: (a) temperature-dependent conductivity and activation energy, (b) dark-current drift under 100 V bias, and (c) long-term stability.

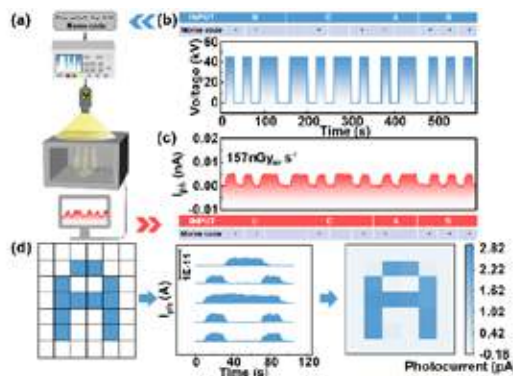


Fig. 4 Low-dose X-ray signal decoding using the $(\text{I-PA})_4\text{AgBiI}_8$ detector: (a) decoding setup, (b) Morse-code input for "UCAS", (c) decoded photocurrent output, and (d) pixel-pattern transmission.

Low-Dose X-ray Signal Decoding across Aluminum Shielding

To demonstrate application feasibility, proof-of-concept low-dose X-ray signal decoding was performed using the $(\text{I-PA})_4\text{AgBiI}_8$ detector. During Morse-code encoding, the X-ray emission was modulated into dot and dash pulses, and the detector successfully reconstructed the transmitted message. To emulate a strongly shielded environment, the X-ray beam was passed through an 18.8 mm-thick aluminum plate, reducing the dose rate to 157 nGy s^{-1} . Nevertheless, the detector maintained full decoding capability. Pixel-pattern transmission was further demonstrated by converting modulated X-ray signals into photocurrent outputs. These results verify the feasibility of radiation-minimized X-ray signal recognition in shielded environments.

Conclusions

In summary, we have developed a novel 2D double perovskite, $(\text{I-PA})_4\text{AgBiI}_8$, through halogen substitution, which simultaneously enhances structural stability and molecular polarizability. Benefiting from the high dielectric constant and low exciton binding energy, the resulting X-ray detector achieves exceptional sensitivity, an ultralow detection limit of $0.012 \text{ nGy}_{\text{air}} \text{ s}^{-1}$, and excellent operational stability. Importantly, the device further enables reliable ultralow-dose X-ray signal decoding, highlighting the potential of halogen-engineered lead-free perovskites for high-sensitivity X-ray detection and specialized communication technologies.

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PI-21

Momentum-Space Observation of Chiral Bloch Resonances in Supercell Photonic Crystals

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Abstract We experimentally observe chiral Bloch resonances in a C_3 supercell photonic crystal slab using momentum-space spectroscopy, revealing polarization-dependent reflection, circular dichroism, and opposite near-field phase vortices associated at opposite in-plane momenta.

Introduction

Photonic crystal slabs support radiative Bloch resonances whose dispersion, leakage channels, and polarization textures can be resolved in momentum space. These resonances provide a compact platform for engineering polarization-selective optical responses within subwavelength-thick planar structures. When Bloch modes couple asymmetrically to left- and right-handed circularly polarized light, their far-field spectra exhibit circular dichroism (CD), a direct signature of chiral resonant behaviour.

Recent studies have demonstrated that chiral resonances in photonic crystal platforms can be engineered through symmetry breaking [1], geometric perturbation [2], and Brillouin-zone folding [3], enabling control over chiral modes, Q factors, and light-emitter coupling. Establishing a systematic experimental connection between angle-resolved CD spectra, two-dimensional k-space imaging, and the corresponding Bloch-mode is therefore essential for identifying the modal origin of chiral resonances in supercell photonic crystals. Here, we design and fabricate a C_3 supercell photonic crystal slab and combine angle-resolved imaging spectroscopy with numerical analysis to observe chiral Bloch resonances in momentum space and link their modal origin to near-field phase-vortex textures.

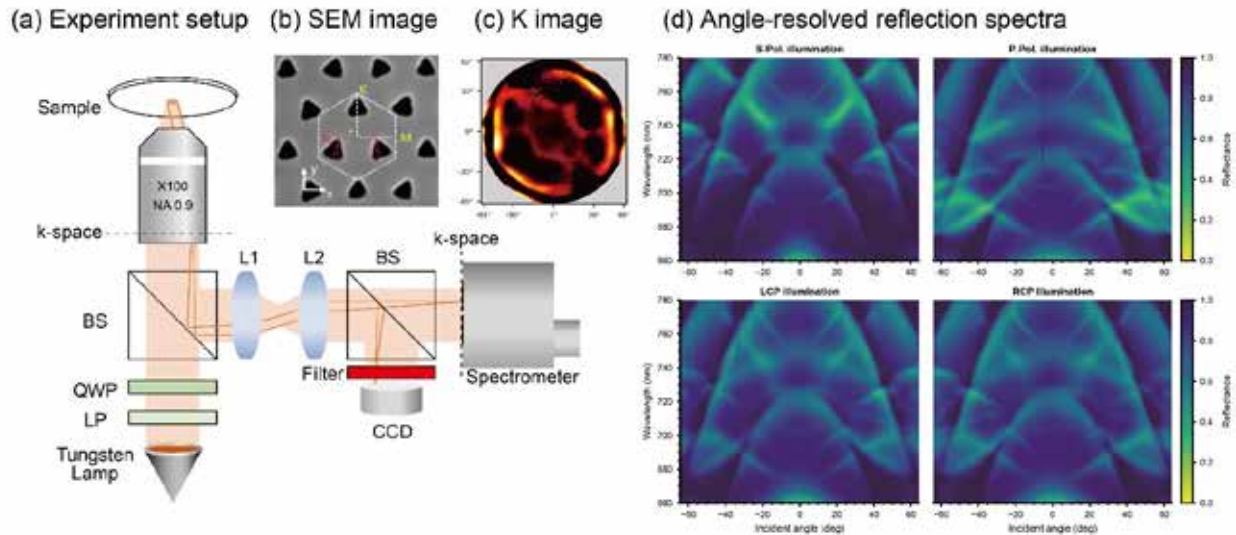


Fig. 1 Experimental setup and momentum-space characterization.

Supercell Photonic Crystal and Momentum-Space Spectroscopy

The investigated structure is a planar supercell photonic crystal slab composed of three triangular units arranged into a C_3 supercell [4]. The two lower triangles in each supercell are rotated in opposite in-plane directions, introducing a controlled structural degree of freedom while preserving the periodic supercell arrangement. A scanning electron microscopy image confirms the fabricated triangular-unit geometry and the long-range periodicity of the slab.

The polarization state of the incident light is controlled by a linear polarizer and a quarter-wave plate, allowing selective

excitation under linear, LCP, and RCP illumination. The back focal plane of the objective is imaged either onto a CCD camera to obtain two-dimensional k-space images or onto the entrance slit of a spectrometer to measure angle-resolved reflection spectra along high-symmetry directions. Wavelength-filtered k-space images further provide iso-frequency contours of the resonant radiation.

Polarization-Resolved Chiral Resonances

The angle-resolved spectra reveal resonant features whose reflection intensities depend strongly on the incident circular polarization and the sign of the in-plane momentum. Under LCP and RCP illumination, a pair of resonant branches at opposite momentum directions shows different reflection responses, indicating polarization-selective coupling to Bloch resonances. This asymmetric response gives rise to a measurable momentum-space circular dichroism.

The CD spectrum is calculated from the normalized difference between the LCP- and RCP-excited reflection spectra. Positive and negative CD signals appear at opposite momentum directions, showing that the chiral response reverses when the in-plane wave vector is reversed. Spectral slices taken at paired incident angles further confirm that the resonance enhanced under one circular polarization at positive momentum is enhanced under the opposite circular polarization at negative momentum.

Mode Assignment and Near-Field Phase-Vortex Textures

To identify the modal origin of the measured chiral resonances, we compare the experimental spectra with numerical simulations and photonic band calculations. Rigorous coupled-wave analysis and finite-difference time-domain simulations reproduce the main angle-resolved reflection features, while the calculated TE-like band structure assigns the observed resonances to a pair of counter-propagating Bloch modes in the supercell photonic crystal.

Near-field electromagnetic simulations further reveal that these modes carry distinct phase-vortex textures. The vertical magnetic-field phase distributions associated with the two resonant modes show opposite vortex handedness, consistent with the reversal of the far-field CD response at opposite momenta. This agreement between momentum-resolved spectroscopy, circular-dichroism measurements, band assignment, and near-field phase structure supports the interpretation that the measured signals arise from chiral Bloch resonances rather than from an isolated far-field polarization artifact.

Conclusions

We have experimentally observed momentum-space chiral Bloch resonances in a C_3 supercell photonic crystal slab. By combining k-space imaging, angle-resolved polarization spectroscopy, circular-dichroism analysis, and numerical mode assignment, we establish a direct connection between far-field chiral optical responses and near-field phase-vortex textures. These results provide a momentum-space characterization route for identifying chiral resonant modes in supercell photonic crystals and suggest a platform for controlling polarization-selective Bloch resonances through supercell symmetry design.

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Bo, Wang (Author3); Guangfeng, Wang (Author4); Xinyu, Liu (Author5); Yuning, Zhang (Author6) information not available at the time of submission.

PI-22

Surface-Plasmon-Polaritons-Assisted Cherenkov Radiation

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Abstract

Assisted by surface plasmon polaritons at a metal–dielectric interface, Cherenkov radiation is generated by grazing free electrons with enhanced efficiency, which is investigated via electron energy loss spectroscopy.

Introduction

The interaction of free electrons with materials gives rise to various radiation processes, including Cherenkov radiation^[1–3], transition radiation^[4], and Smith–Purcell radiation^[5], which provide diverse platforms for compact radiation sources. Among these mechanisms, enhancing the radiation efficiency remains a central challenge because the interaction between free electrons and electromagnetic modes is typically limited by the short interaction time^[6–8].

The interaction strength between free electrons and electromagnetic modes commonly depends on both phase matching and the effective interaction length^[3,7,8]. When the interaction time between electrons and electromagnetic modes is extended, the coupling strength can be significantly enhanced, leading to stronger free-electron radiation^[9]. Here we experimentally demonstrate a plasmonic-assisted approach to enhance Cherenkov radiation. When free electrons graze along a metal–dielectric interface, surface plasmon polaritons (SPPs) with high optical density of states are excited and co-propagate with the electrons, effectively prolonging the electron–field interaction time and intensity. This enhanced interaction increases the coupling strength and consequently amplifies the Cherenkov radiation.

Theory Analysis

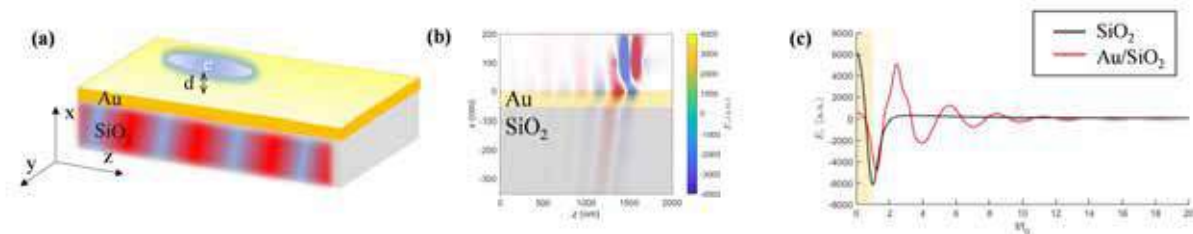


Fig. 1 Theoretical calculation results of SPPs-Assisted Cherenkov Radiation.

Figure 1(a) illustrates the mechanism of plasmonic-enhanced Cherenkov radiation. As free electrons graze along a thin Au film, SPPs are excited at the metal–dielectric interface. The excited SPPs co-propagating with the grazing electrons maintain strong electron–field coupling over an extended distance, while SPPs’ high density of optical states provides abundant electromagnetic modes for electron coupling, thereby enhancing the Cherenkov radiation emission in the SiO₂ substrate. Figure 1(b) shows the simulated electric-field distributions of plasmonic enhanced Cherenkov radiation. The far-field temporal response in Fig. 1(c) further confirms the mechanism that the plasmonic structure sustains the radiation for a much longer duration. For the bare dielectric structure, the radiation rapidly decays with time. In contrast, the Au-coated structure supports long-lived SPP modes, allowing the radiation to persist for approximately nine additional oscillation cycles. These results demonstrate that the SPP-mediated interaction effectively extends the electron–field interaction time and provides an efficient approach for enhancing Cherenkov radiation.

Experiment Results

To probe the above radiation process, we use an indirect detection approach by analyzing the electron energy loss spectrum (EELS) after electrons graze past a metal thin-film structure. Figure 2(a) presents the cross-sectional transmission electron microscopy (TEM) image, showing the position of the electron beam over the Au surface ($d=60\text{nm}$). And the energy-dispersive X-ray spectroscopy (EDS) measurement result of the sample shows the deposited Au thickness agrees well with the designed value.

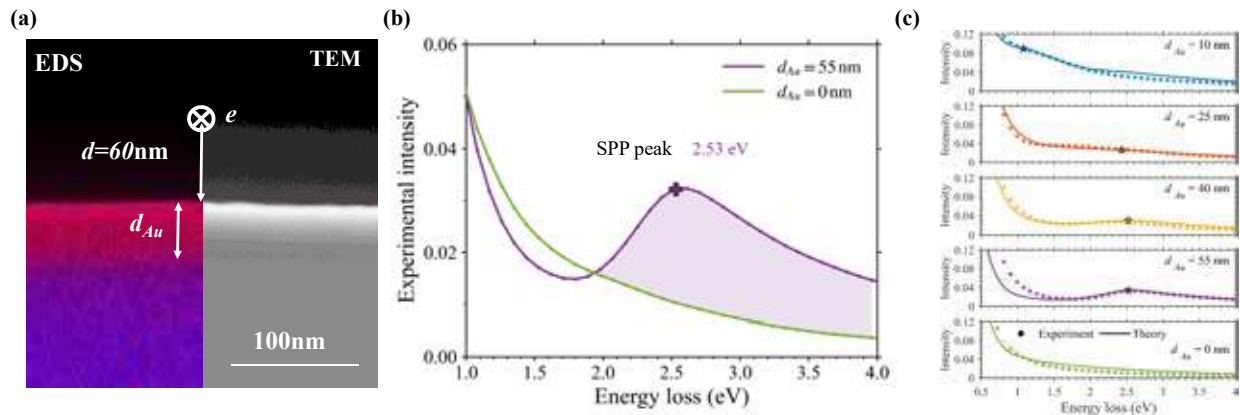


Fig. 2 Experimental results of SPPs-Assisted Cherenkov Radiation via EELS.

Figure 2(b) compares the EELS measured from samples with and without the Au film. Compared with the bare SiO_2 sample ($d_{\text{Au}} = 0$), the introduction of the Au film ($d_{\text{Au}} = 50\text{nm}$) produces a pronounced enhancement of EELS signal around 2.53eV , corresponding to SPP resonance peak and related SPPs-assisted Cherenkov radiation. Figure 2(c) presents the varied EELS with Au thicknesses and indicates the resonance peak shifts due to the change in the SPP dispersion relation as d_{Au} increases. It is obvious that the Au film ($d_{\text{Au}} = 10\text{nm}, 25\text{nm}, 40\text{nm}, 55\text{nm}$) produces a pronounced modification of the EELS spectrum. By varying the Au thickness, the measured resonance shift agrees well with the theoretical prediction based on the SPP dispersion relation, further supporting the SPPs-assisted Cherenkov radiation mechanism.

Conclusions

This work experimentally demonstrates the SPPs-assisted Cherenkov radiation with enhanced intensity. The enhancement mechanism stems from the high optical density of states of SPP and extended electrons-SPP interaction time. Our work provides a new strategy for manipulating free-electron radiation and facilitates the development of high-efficient free-electron light emitters.

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PI-23

Large Scale Universal Optoelectronic Hybrid Computing

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Ziyue Yang is a student.

Abstract: We have demonstrated a scalable and universal optoelectronic hybrid computing architecture (SUANPAN) formed by independent emitter-detector pairs. A 64-dimensional SUANPAN could achieve 88% accuracy in MNIST image recognition and successfully solve a 1024-dimensional Ising problem.

Introduction

Due to its natural characteristics of high speed, wide bandwidth and parallel propagation, light is promising to alleviate the computational burden in artificial intelligence (AI) applications caused by extensive vector multiplications. Various photonic computing architectures have been demonstrated to perform vector multiplications, i.e. Reck scheme [1], Stanford structure [2], deep diffraction architecture [3], micro-ring resonator array [4], etc. However, existing linear optical computing architectures usually rely on complex beam interactions to perform optical matrix transformations. The basic units in those computing architectures, i.e. liquid crystal cells, beam splitters, meta-atoms, etc. are highly coupled with each other. It is difficult to simultaneously achieve the requirements to be scalable and programmable in general-purpose AI computing. Therefore, such existing optical computing architectures are usually applied for specific tasks to minimize the programming of optical computing units, and there is an urgent need for a universal computing architecture.

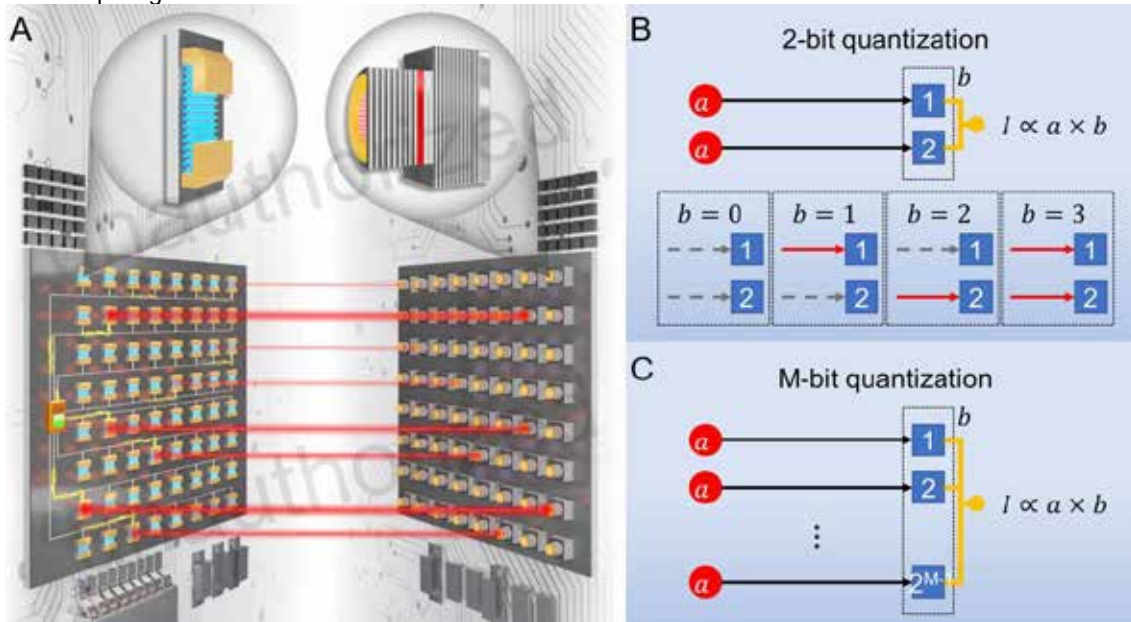


Fig. 1 A, The architecture of SUANPAN. B-C, The encoding scheme of 2-bit quantization and M -bit quantization

The SUANPAN Architecture

The SUANPAN architecture is promoted to address the aforementioned issues as shown in Fig. 1A. The emitter-detector pair is the independent fundamental computing unit to perform multiply-add operations. It employs a brand-new encoding method to perform digital-analog conversions without traditional digital-to-analog converters (DACs). As 2-bit quantization, two emitter-detector pairs should be combined as a set as shown in Fig. 1B. The two bits in the binary representation of multiplier b would be corresponding to the on-off states of the two emitter-detector pairs, and the photoresponsivity of the two photodetectors should be set as 2^0 and 2^1 . Further, M -bit quantization can be achieved with M emitter-detector pairs as shown in Fig. 1C. Therefore, the SUANPAN architecture can achieve multiply-add operations of arbitrary bit precision in theory. Since there is no interaction among the propagating light beams of all emitter-detector pairs, SUANPAN can be extremely scalable through simply duplicating such emitter-

detector pairs. At the same time, SUANPAN architecture greatly avoids the costs of delay, energy consumption and area introduced by DAC in traditional optoelectronic hybrid computing schemes.

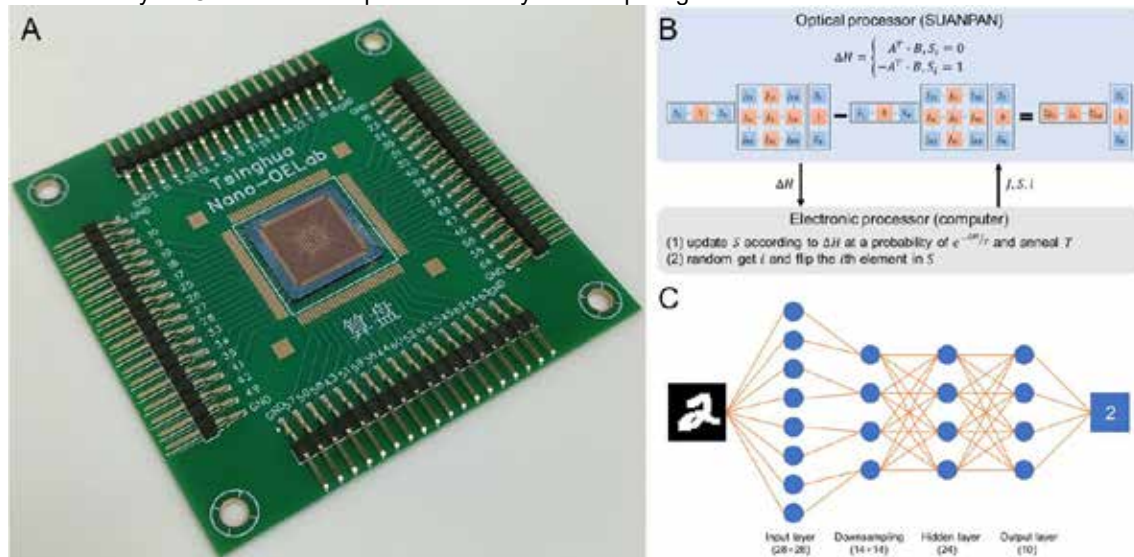


Fig. 2. A, The optical image of 64-dimensional SUANPAN. B, The framework of Ising machine application with SUANPAN. C, The neural network for MNIST image recognition.

Results

In the experiment, a 64-dimensional SUANPAN is demonstrated (Fig. 2A) through an 8×8 vertical cavity surface emission laser (VCSEL) array and an 8×8 MoTe₂ two-dimensional material photodetector array. A calculation fidelity of over 98% is achieved in the randomly generated vector inner product test of different bit precision, which is the foundation of universal AI computing. Furthermore, SUANPAN has performed two typical AI tasks, image recognition and Ising problem. For image recognition, A neural network is shown in Fig. 2C, where the linear vector multiplications are performed by the 64-dimensional SUANPAN and the nonlinear activation functions are calculated in an electronic processor. An experimentally accuracy of 88% is achieved in MNIST handwritten digit images recognition, which is consistent with the simulations. For Ising problem, the framework of the heuristic algorithm is shown in Fig. 2B, where the calculation of the Hamiltonian is performed by the SUANPAN and the nonlinear annealing process is performed in an electronic processor. 99% ground state convergence rate is experimentally achieved for a randomly generated 30-dimensional Ising problem. At the same time, a randomly generated 1024-dimensional Ising problem has been successfully solved, which is the highest dimensionality of optical Ising machine with the heuristic algorithm.

Conclusions

In this work, we have proposed a scalable and programmable optoelectronic hybrid computing architecture based on independent emitter-detector pairs as the basic computing units, and have promoted a brand-new encoding method for arbitrary bit precision without relying on the DAC. Further, a 64-dimensional SUANPAN is demonstrated and applied in two typical AI tasks to experimentally validated the potential for general-purpose AI applications.

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PI-24

Improvement of SiON Edge Coupler by Hybrid Inverse Design with Trident Geometry

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Abstract We proposed design improvement of silicon oxynitride edge coupler from a basic linear taper shape to a trident shape. The coupling efficiency is improved from -0.47 dB to -0.30 dB at 1.55- μ m wavelength

Introduction

Efficient fiber-to-chip coupling is essential for silicon photonic integrated circuits [1]. Silicon oxynitride (SiON) is a promising platform because of its low propagation loss and controllable refractive index by deposition conditions, which enables efficient mode matching with optical fibers. However, conventional inverse tapers have limited structural freedom, leading to insufficient control of mode evolution and radiation loss. Although trident edge couplers have been studied in other material platforms [2][3], their use in high-index single-layer SiON waveguides remains insufficiently explored. In this work, we propose a trident edge coupler optimized by hybrid inverse design to improve coupling efficiency in SiON photonic integrated circuits.

Device Structure and Optimization

The right figure of Fig. 1 shows the proposed SiON trident edge coupler with a 400-nm-thick core ($n = 1.9$) and SiO_2 cladding. Compared with the reference linear inverse taper (the left figure), two optimized side branches are introduced to control mode evolution. The geometry was designed using hybrid Bayesian–adjoint optimization with a 120-nm minimum feature-size constraint.

Simulation Results

Three-dimensional FDTD simulations were performed using Ansys Lumerical with a Gaussian beam waist radius of 1.05 μ m, which is the value for our lensed fiber. The conventional linear taper exhibits a coupling loss of 0.47 dB (90.0%) at 1.55 μ m, whereas the optimized trident structure reduces it to 0.30 dB (93.3%). Fig. 2 compares the optical leakage electric-field distributions of the inverse taper and trident coupler. The trident structure suppresses optical leakage and improves confinement inside the SiON core by redistributing the optical field and reducing lateral radiation, resulting in better mode matching with the incident Gaussian beam. In particular, the top/bottom leakage loss is reduced from 2.2% to 0.67%, and the side leakage loss is reduced from 2.0% to 0.2%, leading to improved simulated coupling efficiency. The remaining reflection loss at the input interface is approximately 4%, which could be further reduced by introducing an anti-reflection coating during fabrication. In addition, the optimized structure maintains a minimum feature size of 120 nm, indicating good compatibility with standard CMOS fabrication processes.

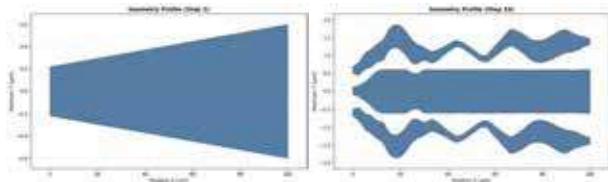


Fig. 1 (Left) linear inverse taper edge coupler. (Right)

Optimized trident edge coupler

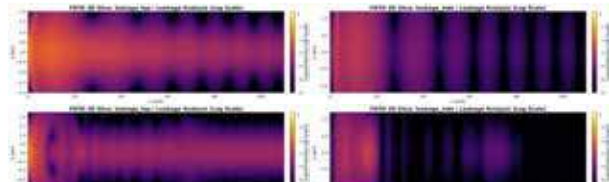


Fig. 2. Comparison of optical leakage field distributions:

inverse taper coupler (top) and trident coupler (bottom), showing top leakage (left) and side leakage (right).

Conclusions

A trident edge coupler for a single-layer SiON platform was optimized using a hybrid inverse-design framework. By appropriately tailoring the trident geometry, lateral radiation loss was suppressed and the coupling loss at 1.55 μm was improved from 0.47 dB to 0.30 dB. These results indicate that the trident concept can provide an effective solution for realizing low-loss SiON photonic integrated circuits. Owing to its fabrication-friendly geometry and low coupling loss, the proposed structure is promising for future high-density optical interconnect applications.

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PI-25

Compact Heterogeneously Integrated Thin-Film Lithium Niobate Coherent Modulator on Silicon Photonic Platform

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Abstract A wafer-scale heterogeneously integrated DP-IQ modulator on an 8-inch SiPh platform uses TFLN for EO and Si/SiN for passives. It features 4×3 mm² footprint and 640 Gbit/s DP-16QAM.

Introduction

Thin-film lithium niobate (TFLN) photonic integrated circuits have attracted increasing attention for high-speed optical communication owing to their strong Pockels electro-optic (EO) effect, broad optical transparency window, and excellent modulation performance[1, 2]. However, monolithic TFLN platforms still face limitations in compact passive integration, polarization management, thermo-optic tuning, and photodetection, mainly due to the optical anisotropy and relatively low refractive-index contrast of TFLN[3]. Silicon photonics (SiPh) provides mature wafer-scale fabrication, compact passive components, efficient thermo-optic phase shifters, and compatibility with process design kits[4]. Therefore, heterogeneous integration of TFLN on an 8-inch SiPh platform offers a promising route for coherent photonic integrated circuits.

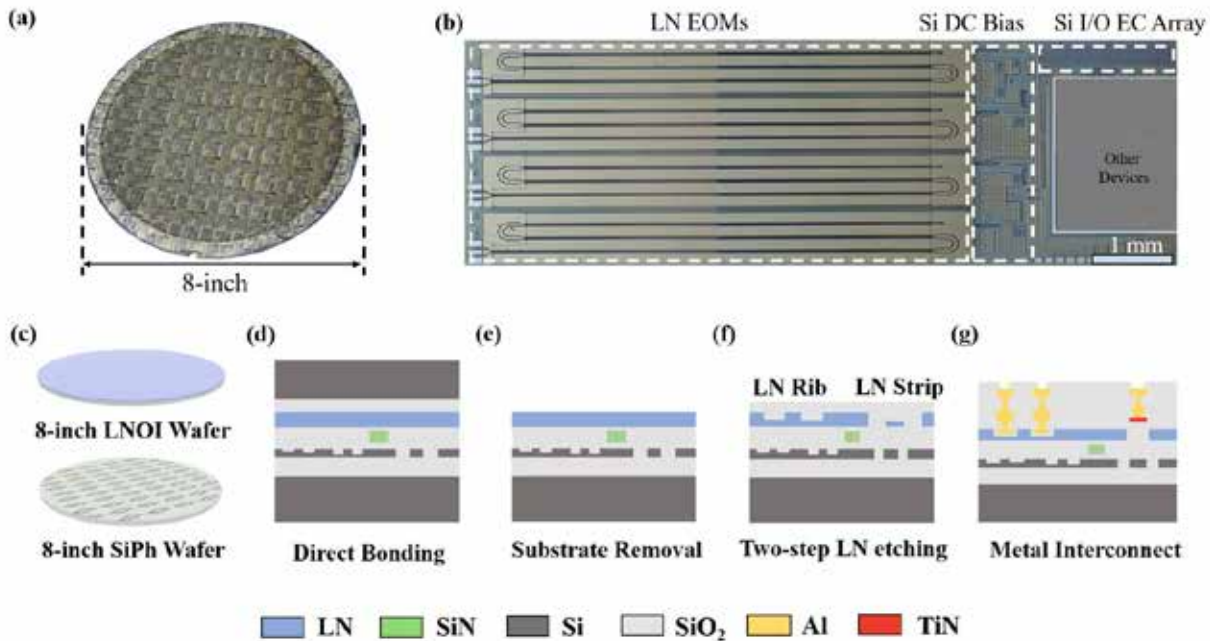


Fig. 1 (a) Photograph of the 8-inch TFLN-on-SiPh wafer. (b) Microscope image of the TFLN-on-SiPh DP-IQ modulators.

(c)-(g) Schematic diagram of the main process flows of the heterogeneous integrated TFLN-on-SiPh EO modulators.

Thin-Film Lithium Niobate (TFLN) Coherent Modulator on an 8-inch SiPh platform

As shown in Fig 1, we fabricate a compact heterogeneously integrated TFLN dual-polarization in-phase/quadrature (DP-IQ) modulator on an 8-inch SiPh platform. The device is fabricated by wafer-scale direct bonding of an 8-inch lithium-niobate-on-insulator wafer on a patterned SiPh wafer, enabling the co-integration of TFLN, silicon, and silicon nitride devices. In this platform, TFLN is selectively used for high-speed electro-optic modulation, while silicon and silicon nitride are employed for compact passive routing, multimode interferometers, polarization rotator-combiners, vertical adiabatic couplers, crossings, and thermo-optic phase shifters. A folded Mach-Zehnder architecture is adopted to reduce the device footprint while maintaining a long modulation length. Each constituent modulator contains three pairs of 3-mm-long TFLN modulation arms, providing an effective modulation length of 9 mm within a compact footprint of only 4×3 mm².

Result

As shown in Fig 2, the fabricated modulator exhibits a static extinction ratio of 24 dB and an on-chip insertion loss of 6.1 dB in the C band. At 1550 nm, the measured half-wave voltage is 3.3 V, corresponding to a $V_{\pi}L$ of 2.97 V·cm. The folded modulator shows a 3-dB EO bandwidth of 35 GHz while maintaining a return loss below -15 dB. High-speed coherent transmission experiments further demonstrate clear constellation diagrams for 100-Gbaud QPSK, 70-Gbaud 16-QAM, and 80-Gbaud 16-QAM signals, with the measured bit error ratios (BERs) remaining below the corresponding HD-FEC threshold for QPSK and SD-FEC threshold for 16-QAM.

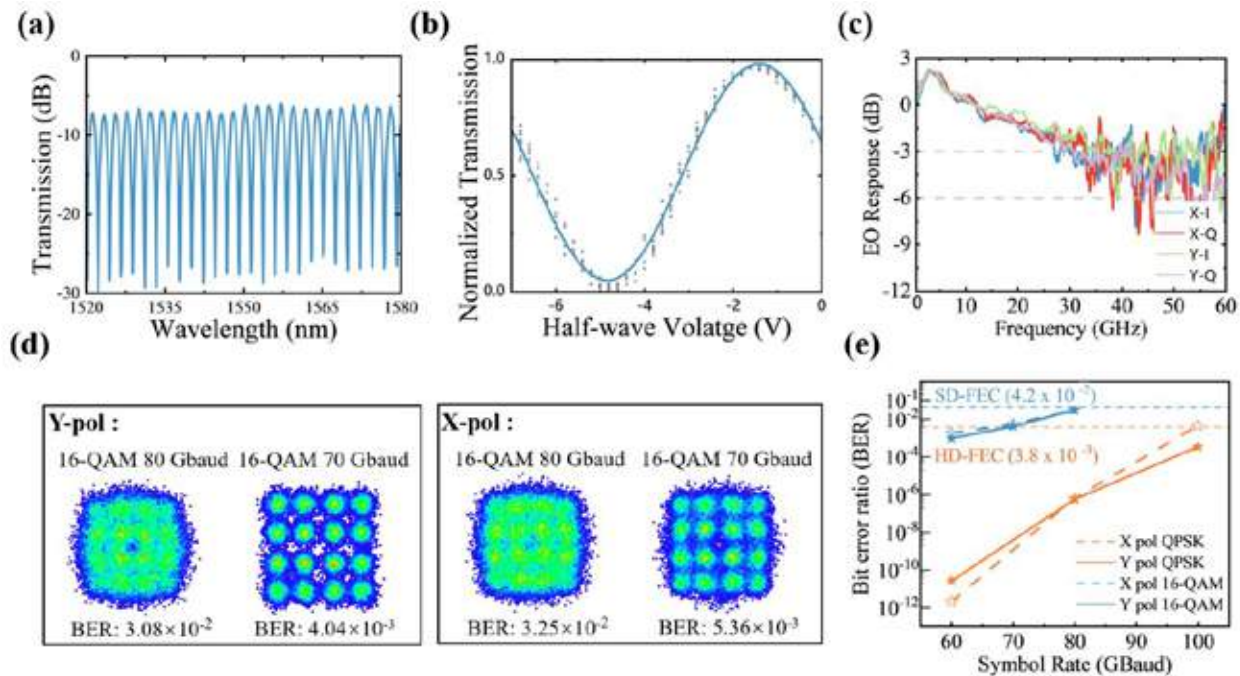


Fig.2 (a) Measured transmission spectrum of the constituent TFLN-on-SiPh modulators. (b) Normalized transmission with a 100-kHz triangular-wave voltage at 1550 nm. (c) Measured EO S21 response of the DP-IQ modulators at 1550 nm. (d) Measured constellation diagrams of the X-pol and Y-pol. (e) Measured BERs of X-pol and Y-pol.

Conclusions

We demonstrate a compact heterogeneously integrated TFLN-on-SiPh DP-IQ modulator. Benefiting from the folded architecture and compact SiPh passive components, the modulator with a footprint of only $4 \times 3 \text{ mm}^2$ achieves an effective modulation length of 9 mm. The fabricated device exhibits a low half-wave voltage of 3.3 V and a 3-dB EO bandwidth of 35 GHz with a return loss below -15 dB. High-speed coherent transmission is further demonstrated with 100-Gbaud QPSK, 70-Gbaud 16-QAM, and 80-Gbaud 16-QAM signals, all satisfying the corresponding FEC thresholds. This leads to a DP-16QAM data rate of up to 640 Gbit/s. These results highlight the potential of heterogeneous TFLN-on-SiPh modulators for compact, scalable, and high-performance coherent photonic integrated circuits.

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PI-26

A Wireless Optoelectronic System for Deep Brain Neural Activity Monitoring

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Author 1 is a student

Abstract We present a wireless photometric probe to monitor calcium dynamics during hippocampal seizures in freely moving mice. The miniaturized system integrates thin-film microscale optoelectronic devices and wireless circuits, offering a highly promising neuroscience research tool.

Introduction (Arial 9 pt Bold)

Monitoring deep-brain neuronal activities with high specificity and minimal invasiveness is crucial for understanding the nervous system. Genetically encoded calcium (Ca^{2+}) indicators enable cell-specific monitoring of neuronal activities^[1]. However, conventional fiber-based photometric systems rely on tethered instruments, constraining complex behavioral studies^[2]. Although wireless photometric probes exist^[3, 4], they can be further optimized using thin-film devices to mitigate tissue lesion and improved optical filters to enhance signal quality. Here, we present a fully wireless photometric probe system to capture Ca^{2+} dynamics during seizures in freely moving mice^[5].

Design, Fabrication, and Characterization of the Photometric Probe

The implantable probe integrates freestanding, thin-film optoelectronic devices transferred onto a flexible polyimide (PI) substrate (**Fig. 1a, b**). An indium gallium nitride (InGaN) blue micro-LED optically excites the GCaMP indicator, while an indium gallium phosphide (InGaP) photodiode records the green fluorescence. To minimize spectral crosstalk, we incorporated a custom short-pass filter on the micro-LED to cut off long-wavelength emissions, and a blue-absorbing dye filter on the detector. The rationally designed emission and detection spectra effectively match the GCaMP fluorescence profile while greatly minimizing LED interference (**Fig. 1c**).

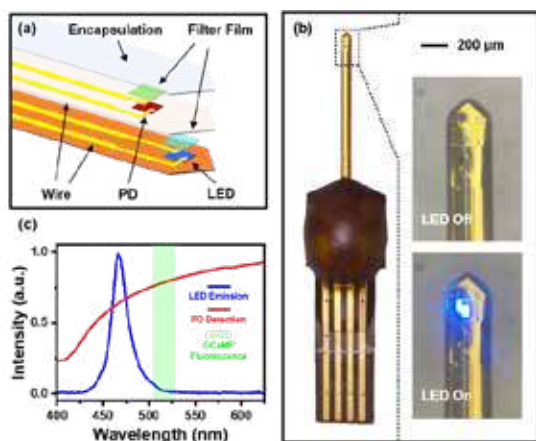


Fig. 1 (a) Schematic of the implantable probe structure. (b) Microscopic photograph of the probe. (c) Spectra of the blue micro-LED, photo-detector, and GCaMP demonstrating the spectral-selective design.

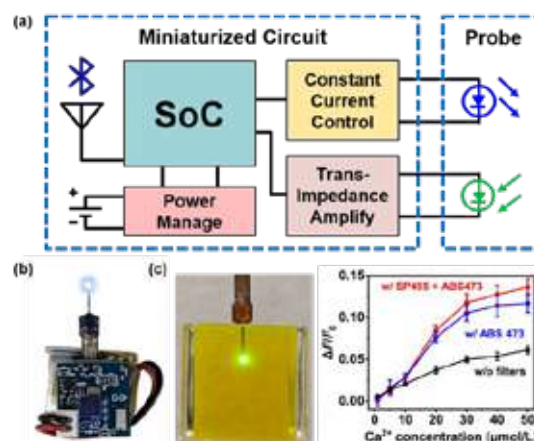


Fig. 2 (a) Block diagram of the wireless circuit system. (b) Photograph of the wireless module connected to the probe. (c) Relative Ca^{2+} fluorescence intensity change ($\Delta F/F_0$) comparing 3 different filter configurations.

Photometric System Design and In Vitro Characterization

The probe is powered and controlled by a customized, miniaturized circuit module (1.1 g) featuring a Bluetooth Low Energy (BLE) transponder and a rechargeable lithium battery (**Fig. 2a**). A photograph of the assembled wireless module connected to the probe is shown in **Fig. 2b**. This wireless system provides prolonged operational duration and a 5 m communication range with a sustained data throughput of 6 kbps. In vitro tests in aqueous environments validated the system's detection capability. The dual-filter design significantly enhanced the relative fluorescence response ($\Delta F/F_0$) compared to bare

devices (**Fig. 2c**), demonstrating excellent sensitivity for green fluorescence detection.

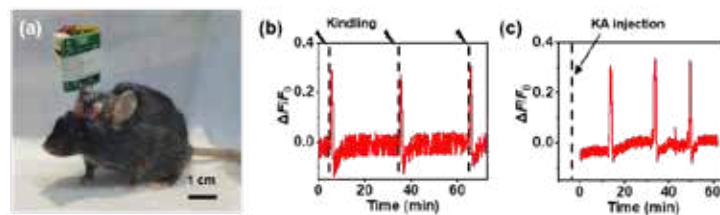


Fig. 3 (a) Photograph of a freely behaving mouse carrying the wireless module. Continuously monitored Ca^{2+} fluorescence in CA3 during (b) sequential electrical kindlings and (c) following kainic acid (KA) administration.

In Vivo Experimental Results

The lightweight wireless photometric probes were implanted into the hippocampus (CA3) of freely behaving mice expressing jRCaMP7b, successfully monitoring real-time Ca^{2+} fluorescence without interfering with animal locomotion (**Fig. 3a**). Histological analysis confirmed minimal tissue lesion ($\sim 200 \mu\text{m}$) after chronic implantation. Upon electrical stimulation (kindling) in the CA1 region, the probe reliably recorded strong Ca^{2+} fluorescence spikes ($\Delta F/F_0 > 0.2$) during sequential trials (**Fig. 3b**). Additionally, the system effectively captured sparse, synchronized Ca^{2+} activities following intraperitoneal kainic acid (KA) administration (**Fig. 3c**), validating its utility in tracking both electrical- and medication-induced seizure events.

Conclusions

We developed a wireless, miniaturized photometric probe system utilizing thin-film microscale optoelectronic devices and wavelength-selective filters. The system reliably records deep-brain Ca^{2+} dynamics during electrically and chemically induced seizures in freely moving mice^[5]. By eliminating tethering constraints and reducing tissue damage, this platform offers a powerful tool for investigating complex behaviors and neurological disease models.

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P11-27

Eliminating the confined dark-exciton qubit precession using an externally applied magnetic field

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Abstract We study dark excitons in an InAs/GaAs quantum dot under an external Voigt magnetic field. Varying field magnitude and direction controls the fine-structure splitting. We find conditions to nullify this splitting, stopping dark-exciton qubit precession.

Introduction

Semiconductor quantum dots (QDs) provide a robust platform for neutral spin qubits, which resist environmental electrostatic fluctuations better than charged carriers. While bright excitons allow for optical control, they are limited by nanosecond lifetimes. Dark excitons (DEs) offer microsecond lifetimes while retaining optical activity for initialization, control, and readout via weak state mixing [1]. The electron-hole exchange interaction lifts the spin degeneracy of neutral excitons; external magnetic fields can control their precession frequency when the magnetic energy matches the exchange splitting [2]. Here, we investigate the DE spin precession frequency under varying in-plane magnetic fields [3]. By employing polarization-resolved photoluminescence intensity autocorrelation, we extract electron and heavy-hole g -factor tensors to map DE spin evolution. This enables a complete characterization of the anisotropic exchange Hamiltonian and determines whether external magnetic fields can restore degeneracy in the DE spin eigenstates.

Method

The investigated structure consists of an InAs QD embedded within an asymmetric AlAs/GaAs planar microcavity on a [001] GaAs substrate. Held at 4 K, the sample resides inside 3D vector superconducting coils. A confocal setup excites a single QD and collects photoluminescence under an applied in-plane magnetic field (Fig. 1a). Emission is analyzed via polarization using liquid crystal variable retarders and passed through a transmission grating with 10 μ eV resolution. Superconducting nanowire detectors time-tag photons with 30-ps resolution. The short-range exchange interaction lifts the degeneracy of the DE $|\pm 2\rangle$ states and defines their coherent superposition phase. Resonant excitation forms a triplet biexciton composed of $|\pm 3\rangle$ superpositions. Optical selection rules restrict transitions between the $|\pm 2\rangle$ and $|\pm 3\rangle$ states to right and left circular polarizations. The energy levels of the bright exciton (BE) and DE, as well as the optical transition selection rules, are schematically illustrated in Figs. 1b and 1c.

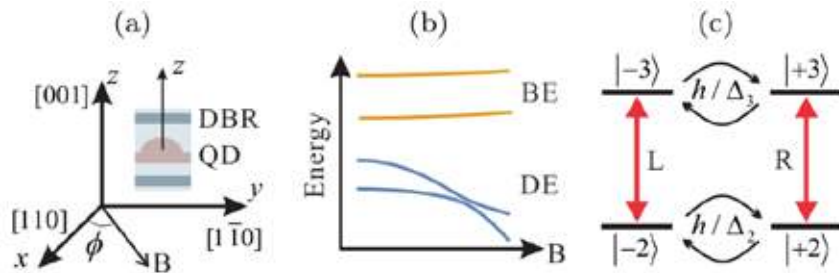


Fig. 1. (a) Schematic description of the self-assembled single QD, embedded in a planar microcavity formed by two distributed Bragg reflectors (DBRs). The growth direction is along the [001] axis which is parallel to the optical axis (z). An in-plane magnetic field (B) is externally applied at an angle ϕ relative to the cleavage plane [110] (x). (b) Schematic description of the energy levels of the bright exciton (BE) and the dark exciton (DE) as a function of the magnitude of the externally applied magnetic field. (c) Schematic description of the optical transition selection rules between the eigenstates $|\pm 2\rangle$ of the DE and the eigenstates $|\pm 3\rangle$ of the spin-blockaded biexciton.

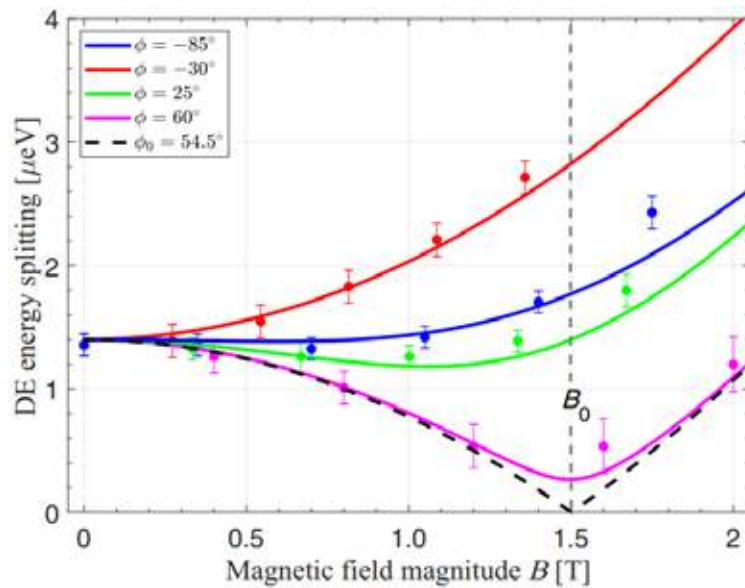


Fig. 2. The measured energy splitting between the DE eigenstates as a function of the in-plane magnetic field magnitude for various in-plane directions (ϕ). Solid circles with error bars represent the measured data, while solid curves represent the best fitted model.

Results

Figure 2 displays the measured DE energy splitting against magnetic field magnitude for various in-plane directions (ϕ). At $\phi = 60^\circ$ (magenta curve), we observe a clear minimum in DE splitting at $B_0 \approx 1.5$ T. This confirms that specific combinations of external field magnitude and direction can enforce degeneracy on the DE eigenstates. This behavior depends critically on QD symmetry; for QDs with symmetry lower than C_{2v} , "anticrossing" is expected, leading to a nonvanishing lower bound for the precession frequency. For this structure, DE-BE mixing yields a lower bound of 105 MHz.

Conclusions

We have demonstrated that the DE fine-structure splitting can be accurately controlled by varying the external magnetic field magnitude and orientation. Comparison with a model assuming C_{2v} symmetry for the exchange and Zeeman interactions of the confined charge carriers allows us to identify conditions for nullifying the energy splitting between the two DE eigenstates, effectively eliminating spin precession.

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Presenter's biography

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Optical close-to-atom-scale manufacturing for quantum chips

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Abstract Self-arresting laser-matter interactions can organize glass into compact quantum-chip platforms, combining nanometric modification, sealed cavities, optical engines, electrical interfaces and wafer-level packaging for scalable integration beyond conventional surface-bound layouts in transparent substrates.

Introduction

Quantum chips are becoming heterogeneous hardware that must co-locate optics, electrodes, traps, vapour or solid-state quantum media, cavities, sensors and package-level optical engines within a small and stable volume. Glass is attractive because it combines transparency, electrical insulation, mechanical rigidity, chemical durability and compatibility with wafer-level packaging. The difficulty is no longer simply whether glass can be locally modified, but whether a thick transparent solid can be turned into an internally wired, sealed and optically addressable chip platform.

This talk will discuss an optical manufacturing route in which ultrashort pulses are used less as miniature drill bits and more as programmable triggers of local structural change. The central question is how a broad optical focus can give rise to much smaller, self-arresting material transformations. Instead of relying only on spot size, the process uses nanoseeds, scattered fields, defects, thresholds and confinement conditions that switch the material response on and off within a sharply limited region. This viewpoint links nanoscale writing, internal slicing, tomographic facet formation and quantum-limit modification within a common manufacturing picture.

I will further outline how these mechanisms may support a glass-based technology stack for quantum chips. The stack includes internal sectioning, drilling and cavity formation, surface smoothing, joining and sealing, functional modification and buried optical routing. Special attention will be paid to photonic buried wiring, a three-dimensional optical interconnect concept that can route signals inside a transparent package and connect photonic, electronic, atomic, ionic and sensing modules, together with optical engines. In wafer-level packaging, such buried optical links could complement through-glass vias and metallized electrical routes, reducing surface congestion and enabling more compact chip architectures.

The message of the talk is that close-to-atom-scale optical manufacturing should not be viewed only as a resolution contest. Its broader value is to turn transparent solids into volumetric platforms where geometry, interfaces, optical paths and quantum functions can be co-designed.



Hong-Bo Sun received the B.S. and Ph.D. degrees in electronics from Jilin University, Changchun, China, in 1992 and 1996, respectively. He worked as a postdoctoral researcher at the Satellite Venture Business Laboratory, the University of Tokushima, Japan, from 1996 to 2000, and then as an assistant professor in the Department of Applied Physics, Osaka University, Japan. In 2004, he was promoted to full professor and Changjiang Scholar at Jilin University. Since 2017, he has been working at Tsinghua University, China. His research focuses on laser precision manufacturing. He has published more than 650 papers, which have received over 45,000 citations, with an h-index of 105 according to ISI records. He is editor-in-chief of PhotoniX and executive editor-in-chief of Light: Science & Applications. He is a Fellow of IEEE, Optica (OSA) and SPIE, and an academician of the Chinese Academy of Sciences.

Heterogeneous integration of photonic and optoelectronic materials and components

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Abstract This talk will review and discuss how to integrate heterogeneous optoelectronic materials and components on photonic integrated circuits in order to achieve more complete functionality and higher performance.

Introduction

Leveraging advantages such as ease of large-scale manufacturing, complementary metal-oxide-semiconductor (CMOS) process compatibility, high integration density, and low cost, silicon photonics have emerged as a core technological platform for photonics integrated circuits (PICs) used in AI data centers and on-chip/inter-chip optical interconnects. Meanwhile, emerging photonic integration platforms, such as thin-film lithium niobate (TFLN), are continuously being developed. However, there is a fundamental trade-off between achieving excellent passive photonic integration performance with low insertion loss and realizing highly efficient active optoelectronic functions, including light emission, modulation, and detection. Heterogeneous integration technology represents the cutting-edge research frontier for addressing this challenge.

Key Problems

Heterogeneous integration must overcome the following key problems.

1. **Material compatibility.** Different materials have different physical and chemical properties that can cause serious problems in the fabrication and application of heterogeneous PICs. For example, difference in thermal expansion coefficient can cause stress that results in failure.
2. **Optical coupling.** As light must be transferred between the heterogeneously integrated active components and the passive waveguides, high efficiency optical coupling is critical. Yet the high difference between the optical refractive indices of the active and passive waveguides can impede optical coupling, often requiring complicated mode converters that occupy large chip area.
3. **Process compatibility.** Silicon PICs are fabricated in highly controlled CMOS fabrication lines where incompatible chemicals are strictly banned. The integration or consolidation of different fabrication processes, including the sequence of fabrication (whether the heterogeneous integration is a front-end or back-end process to the silicon fabrication) as well as thermal load (the maximum process temperature allowed during subsequent processing steps that does not adversely affect prefabricated components), is a seriously complicate problem.

Technical Approaches

Several approaches are being developed, including:

1. **Hybrid integration of prefabricated optoelectronic components** (in particular semiconductor lasers and detectors) on silicon photonics or other PIC platforms. This approach has the advantage of using 'known good dies' (KNDs) that are pretested with known good performance and reliability. It also leverages existing optoelectronic components industry's mature fabrication capacity, requiring only modest capital equipment investment. On the other hand, it suffers from sub-micron high precision requirements in the hybrid integration process, typically by way of flip-chip bonding with pick&place (P&P) equipment, which results in slow alignment and low productivity.
2. **Transfer printing.** This approach also uses prefabricated optoelectronic components. But instead of individual P&P, it collectively pick up multiple components (known as coupons) in a formation that fits their final position on the PIC using a PMDS stamp, and place these on the PIC. The coupons attach to the PIC by van der Waals force or by an adhesive polymer such as BCB. Compared to hybrid integration, it improves productivity while retain the advantages of using KNDs, leveraging existing optoelectronic components industry's mature fabrication capacity and requiring only modest capital equipment investment. However, so far there is yet to be sufficient evidence of good yield, and the use of polymer can cause concerns in both lifetime and thermal performance.
3. **Die-to-wafer bonding.** This approach is typically implemented through collective die-to-wafer bonding (D2W), although can be implemented by individual D2W. In collective D2W, optoelectronic materials such as InP or GaAs epi-wafers, thin film lithium niobate (TFLN) wafers, etc, are first diced into suitably sized dies. These dies are then temporarily bonded onto a carrier wafer using a relatively low precision (several micron) P&P equipment to constitute a restructured wafer. After cleaning and surface activation, the restructured wafer as a whole is bonded with the silicon photonics (or other PIC) target wafer. The temporary carrier wafer is then removed, leaving the dies attached to the

target wafer. The substrate of the dies is then removed leaving only the active film. Active components are subsequently fabricated in the active film using precise lithography to achieve high alignment precision. D2W is a wafer-scale approach with high productivity by which successful commercial products have been developed. As this approach requires relatively high capital investment, the key to its success is to achieve high yield through rigorous process control in high volume production.

4. Heterogeneous epitaxy. Epitaxially grow compound semiconductors (InP, GaAs) on silicon is a wafer scale process that can be potentially very efficient and high yield. The key to heterogeneous epitaxy is how to eliminate defects caused by lattice mismatch and anti-phase boundary (APB). In blanket epitaxy, thick buffer layers are needed to transit from Si to high-quality III-V single crystal layers, which impedes optical coupling between active components and Si waveguides. Various selective area growth techniques have been developed. By growth in narrow vertical or horizontal trenches, it is possible to confine defects to a very thin layer (~100 nm) near the material boundary, with high-quality III-V structures successfully grown further away. High performance laser and detectors have been demonstrated. This approach holds good potentials for high-density integration. Process integration with the silicon photonics fabrication flow will be key to its future development.

Conclusions

Heterogeneous integration of active optoelectronic materials and components is being developed following several approaches. It is a rapidly developing area that will shape the future of photonic integrated circuits and the wider optical information technology.



Siyuan Yu received his BS degree from Tsinghua University, and his MS and PhD degrees from WRI and University of Glasgow, in 1984, 1987 and 1997, respectively, all in Electronic Engineering. He carried out research on physical photonics, photonic and optoelectronic components, photonic integrated circuits, optical communications systems and networks, optical computing, and optical signal processing. Prof Yu is a Fellow of OPTICA and currently serves as the editor-in-chief of Photonics Research.

Quantum Photonics Enabled by Semiconductor Quantum Dots

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Abstract Semiconductor quantum-dot light sources are emerging as key enablers of integrated photonics, offering unique advantages for silicon photonics, optical frequency combs, high-capacity optical interconnects, and quantum technologies. Their low-noise operation, broad gain spectrum, excellent feedback tolerance, and compatibility with silicon integration make them attractive candidates for both classical and quantum photonic systems. These exceptional properties pave the way toward scalable, energy-efficient photonic integrated circuits supporting next-generation optical communications, artificial intelligence, and quantum information processing.

Introduction

Semiconductor quantum dots (QDs) are enabling light sources for both next-generation classical optical communications and emerging quantum technologies. By combining the unique physical properties of QDs with the maturity and scalability of silicon photonics, the authors argue that QD-based devices are ideally positioned to meet the rapidly increasing demands of artificial intelligence, high-performance computing, optical interconnects, and quantum information processing [1]. Among the various semiconductor gain materials, InAs QDs offer unique advantages over conventional quantum well lasers. Their three-dimensional carrier confinement results in discrete energy levels, leading to low threshold currents, reduced temperature sensitivity, high optical gain, fast carrier dynamics, low relative intensity noise, enhanced nonlinear optical properties, and exceptional tolerance to optical feedback [2]. These characteristics make QD lasers attractive candidates for replacing conventional semiconductor lasers in integrated photonic systems. Furthermore, their broad gain spectrum, arising from inhomogeneous broadening, enables efficient multi-wavelength emission and frequency comb generation [3].

Integration and Silicon Photonics

The integration of QD lasers with silicon photonics represents one of the major technological opportunities. Silicon provides an outstanding platform for photonic integrated circuits due to its compatibility with CMOS manufacturing and its ability to support extremely dense photonic integration [1]. Since silicon cannot efficiently generate light because of its indirect bandgap, integrating III-V light sources remains essential. Two principal approaches are currently pursued: heterogeneous integration, where III-V epitaxial layers are bonded onto silicon wafers, and monolithic integration, where QDs are grown directly on silicon. Considerable progress has been achieved in both approaches, making QD lasers increasingly attractive for large-scale industrial deployment [3].

Another major focus concerns optical frequency combs (OFCs) generated by QD lasers. Compared with Fabry–Perot lasers or quantum well comb lasers, QD comb sources provide equally spaced optical modes, broader and flatter optical spectra, lower intensity noise, and excellent stability under optical feedback. Their fast carrier dynamics, high nonlinear susceptibility, and broad gain bandwidth enable efficient passive mode locking and the generation of stable combs suitable for coherent optical communications. Recent heterogeneous and monolithic QD-on-silicon comb lasers have demonstrated mode spacings around 60 GHz together with excellent spectral quality and strong robustness against on-chip reflections. These frequency comb sources naturally enable highly integrated DWDM communication systems. Instead of using large arrays of individual lasers, a single QD comb laser can simultaneously provide many wavelength channels, dramatically reducing footprint, power consumption, and system complexity. Recent demonstrations have achieved coherent transmission using 26 comb lines over 10 km of standard fiber, reaching an aggregate data rate exceeding 1 Tb/s using only two QD comb lasers operating respectively as transmitter and local oscillator. Such performances clearly demonstrate the potential of QD-based comb sources for future optical interconnects in AI clusters and data centers [4].

Quantum technologies

Semiconductor QDs behave as artificial atoms capable of generating deterministic single photons and entangled photon pairs, two essential resources for quantum communication, quantum computing, and quantum sensing. Beyond single-photon sources, they also constitute a promising platform for the generation of non-classical states of light. Strong exciton–photon interactions in quantum-dot microcavities, together with the large optical nonlinearities offered by QD materials, provide favorable conditions for the generation of quadrature-squeezed states [5]. At the device level, QD lasers also exhibit exceptionally low relative intensity noise, small linewidth enhancement factors, and excellent coherence, making them attractive candidates for integrated squeezed-light sources [6]. Recent

experiments have demonstrated broadband amplitude squeezing from electrically driven quantum-dot lasers operating at room temperature, highlighting their potential for practical implementations.

The combination of QD active devices with silicon photonics opens new opportunities for compact and scalable quantum integrated circuits capable of generating, manipulating, and distributing non-classical states of light. Such integrated platforms are expected to play an important role in continuous-variable quantum information processing, quantum key distribution, quantum sensing, and future fault-tolerant quantum photonic systems.

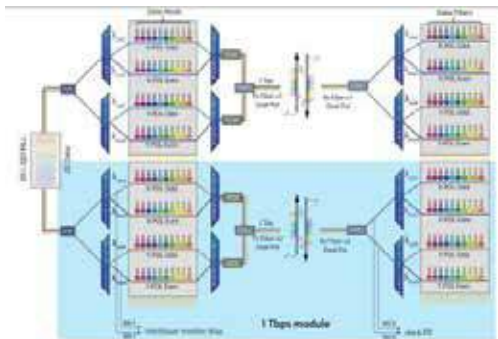


Fig. 1 Example of a coherent DWDM transceiver architecture enabled by QD frequency-comb light sources, illustrating the potential of QD comb lasers for massively parallel optical interconnects.

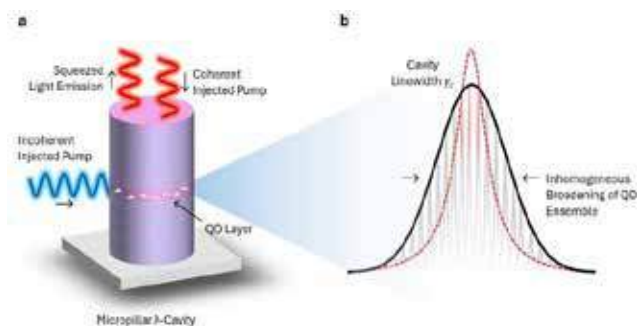


Fig. 2 (a) Microcavity containing an inhomogeneously broadened QD ensemble that is incoherently pumped and driven by a coherent seed to produce squeezed light. (b) A subset of emitters couples to the cavity mode.

Conclusions

QDs can be considered as a unifying technology bridging classical and quantum photonics. Their combination of low-noise operation, high stability, frequency-comb capability, compatibility with silicon integration, and ability to generate non-classical states of light makes them uniquely suited for future optical computing, high-capacity communications, and quantum information systems. Continued advances in QD epitaxy, device engineering, silicon integration, and photonic circuit design are expected to make QD technologies central components of next-generation information and communication infrastructures. Beyond their established role as high-performance semiconductor light sources, quantum dots are emerging as a unique technology capable of bridging classical optical communications and quantum information processing on a common integrated photonic platform.

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A metasurface waveguide for full-color AR displays

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Abstract : We report a novel full-color metasurface waveguide AR display combined with two inverse-designed metasurface couplers and a high refractive index glass waveguide. The metasurface waveguide optimizes compactness, dispersion correction, both color and angular uniformity to meet the high demands of AR applications. We built a proof-of-concept AR system, showing high quality full-color AR images. This represents a significant advancement in creating visually compelling AR experiences in compact and user-friendly AR glasses.



Dr. Xiao Wei Sun, Foreign Member of Russian Academy of Sciences, is a Chair Professor and the Executive Dean of the Institute of Nanoscience and Applications in the Southern University of Science and Technology (SUSTech), Shenzhen, China. He holds the honorary doctorate (PhD) degree from the Belarusian State University of Informatics and Radioelectronics. He is the founding Head of the Department of Electrical and Electronic Engineering of SUSTech. Before joining Southern University of Science and Technology, he had been working at Nanyang Technological University, Singapore as a Full Professor. He was awarded the Nanyang Award for Research and Innovation in 2009, and the Jacques Beaulieu Excellence Research Chair of INRS (Institut national de la recherche scientifique), Quebec, Canada in 2013. He was awarded the Slottow-Owaki Prize from the Society for Information Display (SID) in 2023, and SPIE Fumio Okano Best Paper Award in 2024. He is an Academician of the Asia-Pacific Academy of Materials, and fellow of several academic societies including IEEE, Optica (formerly OSA), SPIE, SID and Institute of Physics (IoP, UK). He is a Distinguished Lecturer of IEEE Nanotechnology Council and Chair of the IEEE Nanotechnology Council Guangdong Chapter. His main research is on wide bandgap semiconductors, semiconducting nanocrystals, ARVR, and display technologies. He is the founder of a quantum dot company Planck Innovation Pte. Ltd. in Shenzhen, which is now a key supplier of quantum dot films to some big brand TV manufacturers globally. He is also the co-founder of Moxwell Tech Pte. Ltd. which supplies AR metasurface waveguides. Professor Sun has authored over 600 peer-reviewed journal publications, and delivered numerous invited talks. His H-index is 106 (Google Scholar). He is an Elsevier Highly Cited Scholar.

Quantum Dot Lasers and SOAs for Modern Datacom and Optical Ranging

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Abstract AI-driven growth in computing is accelerating data center deployment and demand for optical interconnects. InGaAs/GaAs quantum dot lasers and SOAs, combined with silicon photonics, provide a cost- and energy-efficient solution for this rapidly expanding market.

Introduction

Computing demand has been growing exponentially in recent years and is expected to nearly triple between 2025 and 2030. This growth is driven primarily by the AI training boom, although traditional computing applications continue to account for a significant share of the demand. In response, the industry has made unprecedented investments in the construction of new data centres, with cumulative spending projected to reach USD 7 trillion by 2030 [1]. AI training clusters now comprise tens to hundreds of thousands of GPUs and TPUs (graphics and tensor processing units), which must be interconnected by ultra-high-bandwidth networks. The demand for optical interconnect bandwidth is increasing faster than the number of AI accelerators, driving the transition to higher-speed optical links and silicon photonics. The adoption of 800G, 1.6T, and 3.2T optical links, together with co-packaged optics and photonic integration, is considered essential for future AI infrastructure. Further scaling to clusters comprising up to one million GPUs is projected [2], requiring another major leap in optical scalability. The technology platform developed for optical interconnects in AI data centres can also be leveraged for other high-volume commercial applications, including FMCW LiDAR for automotive and robotics [3,4]. The large-scale deployment of data-centre photonics is expected to reduce manufacturing costs, accelerate technology maturation, and facilitate the adoption of these technologies in emerging markets.

QD lasers

The light sources currently used for optical interconnects in data centres are III-V semiconductor lasers, primarily VCSELs and InP-based DFB lasers, employing four-level pulse-amplitude modulation (PAM-4). Both types of lasers can be directly modulated by the injection current (directly modulated lasers, DMLs) and capable of operating up to 100G per lane. To further increase the per-lane data rate, an electro-absorption modulator (EAM) is monolithically integrated with an InP-based DFB laser, forming an externally modulated laser (EML). Alternatively, an external silicon photonic or other type of modulator are employed. In the latter approach, InGaAs/GaAs quantum dot lasers can successfully compete with conventional InP lasers owing to their unique advantages arising from both the three-dimensional carrier confinement and the material system itself. O-band InGaAs/GaAs quantum dot Fabry-Perot and DFB lasers can deliver optical output powers ranging from tens to hundreds milliwatts over a wide temperature range while exhibiting only a small variation in output power (Fig. 1). The power conversion efficiency exceeds 20% at the temperatures above 100 °C [5].

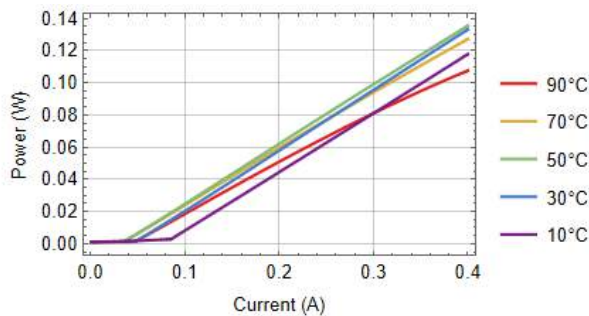


Fig. 1 Power of 1310nm QD DFB laser for pluggable TRx

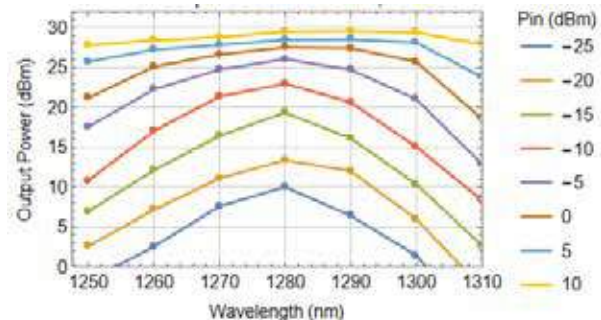


Fig. 2 Output power spectra of QD SOA for LiDAR

Another important feature of quantum dot lasers is their low linewidth enhancement factor (α -factor), which can be close to unity or even lower. This is a direct consequence of the intrinsically symmetric optical gain spectrum of quantum dots,

resulting in reduced phase noise and narrow optical line [6] that is useful for LiDARs and coherent data transmission, as well as significantly lower sensitivity to parasitic optical feedback compared with conventional quantum well lasers. As a result, the bit error rate (BER) remains essentially unaffected by parasitic reflections, enabling the use of quantum dot lasers in transceiver modules without optical isolators. This capability has been demonstrated in 1.6T pluggable transceiver modules by Genuine Optics and Accelink at OFC 2025, and in WDM transceiver modules by Aperion Technologies at OFC 2026. Moreover, this enables the integration of laser to Si Photonic chip by using butt coupling not being affected by parasitic reflection from interface and the internal optical components.

Today, most optical interconnects use a single wavelength per optical channel. Further scaling of link capacity can be achieved through wavelength-division multiplexing (WDM). Quantum dot mode-locked comb lasers provide an attractive multi-wavelength light source for WDM optical interconnects, replacing arrays of individual DFB lasers with a single compact device. A 24-channel flat-top comb with 100 GHz channel spacing has been demonstrated, supporting 106 Gb/s PAM4 transmission per channel and enabling aggregate data rates exceeding 2.4 Tb/s [7].

QD SOAs

Quantum dot semiconductor optical amplifiers (QD SOAs) complement quantum dot lasers by providing high output power and efficient uncooled operation in the O-band. Output powers exceeding 1 W have been demonstrated in the deep saturation regime [8] for LiDAR applications (Fig. 2). In the low-signal linear regime, QD SOAs exhibit superior performance in the amplification of modulated optical signals compared with conventional quantum well SOAs, owing to rapid carrier replenishment from the excited states. Their impact on transmission performance has been quantitatively analysed through bit-error-rate (BER) modelling and experimental investigations, demonstrating the feasibility of SOA-assisted WDM links without significant transmission penalties [9]. Together with quantum dot comb lasers, they enable compact multi-wavelength transmitter architectures supporting terabit-class DWDM optical interconnects [10].

Conclusions

InGaAs/GaAs quantum dot lasers and amplifiers offer several advantages that make them promising light sources for optical interconnects. Their key advantages include excellent temperature stability, enabling uncooled operation; low sensitivity to parasitic optical feedback, facilitating integration with silicon photonic circuits, and high reliability resulting from three-dimensional carrier confinement. Combined with silicon photonics, they provide a powerful platform for the next generation of optical interconnects for AI data centres and emerging applications.

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Scaling Augmented Reality Waveguide by Nanofabrication

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Abstract Augmented reality glasses are an emerging market. Surface relief grating waveguides are key components enabling lightweight virtual real image combining. Scaling production to 10 million units annually leverages modern nanofabrication processes with high precision throughput.



Yi Rao received his BS and MS degrees in Electrical Engineering from Tsinghua University in 2005 and 2008, respectively, and his PhD in Electrical Engineering from the University of California, Berkeley in 2012. After graduation, he joined the startup Bandwidth10, where he worked on high speed 1550 nm high contrast grating (HCG) VCSELs. He later pioneered the development of augmented reality glasses at Rokid before joining Goertek in 2019. He currently leads Goeroptics, a VR/AR company spun off from Goertek.

Optical Interconnect Evolution for AI Data Centers

Pan Cao
Huawei Technologies Co., Ltd.

Abstract To scale XPU clusters for AI workloads, optical interconnects will replace copper to breach bandwidth limitations. This presentation introduces lane speeds evolving from 100G to 200G and 400G through the continuous performance optimization of VCSEL, EML, SiP, and TFLN technologies. Moreover, NPO will replace pluggable modules as a pragmatic solution to support higher-density integration requirements, while CPO remains the long-term target after solving many technical and engineering challenges. These continuously evolving optical technologies will effectively support the high-density, large-capacity optical interconnects required for skyrocketing AI growth.



Dr. Pan Cao received his Ph.D. from Shanghai Jiao Tong University and has nearly 20 years of extensive experience in optoelectronic R&D. As a Technical Leader within Huawei's Optoelectronic Department, he currently heads an innovation team dedicated to advancing next-generation optical technologies for high-density AI interconnects. Extending from optoelectronic chips and advanced packaging to module architectures, his work spans the industry's generational shifts: including lane speeds from 100G/lane to future 400G/lane, form-factor transitions from traditional pluggable to NPO/CPO solutions, and module bandwidth scaling from 800G up to future 3.2T/6.4T+. Dr. Cao has delivered about 10 oral presentations at international conferences, authored 30+ papers in peer-reviewed journals and proceedings, and held over 20 active patents.

High-performance Semiconductor Lasers and Power Converters

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Abstract:

Laser-based power transmission technologies encompass free-space laser wireless power transmission (LWPT), power-over-fiber (PoF), and simultaneous wireless information and power transfer (SWIPT). LWPT enables long-range power delivery to unmanned aerial vehicles, remote platforms, satellites, and lunar exploration equipment; PoF is particularly suitable for sensors and electronic devices operating in high-voltage, explosion-hazardous, or electromagnetically sensitive environments; and SWIPT allows networked terminals to receive power and data through a shared optical link. However, the practical deployment of these technologies requires high-power, high-brightness transmitters and efficient receivers capable of scalable electrical output. This work presents an integrated transmitter–receiver architecture based on semiconductor lasers and wavelength-matched laser power converters (LPCs). At the transmitter, the epitaxial structure, carrier confinement, electrical resistance, temperature distribution, beam quality, packaging, and fiber-coupling efficiency were jointly optimized. At the receiver, monolithically series-connected vertical multijunction LPCs were developed to overcome the low output voltage and high current-related losses of conventional single-junction devices. By optimizing epitaxial uniformity, tunnel junctions, metamorphic buffers, subcell current matching, and optical absorption, device-level conversion efficiencies approaching 60% and kilowatt-level receiver-array output were achieved. The LPCs operate at 808 nm using GaAs-based structures, at 1064 nm using GaAs- and InP-based structures, and at 1310 and 1550 nm using InP-based structures. This wavelength coverage supports both free-space and fiber-based power transmission while enabling the simultaneous delivery of optical power and information.



Jun Wang is currently the Chief Technology Officer of Suzhou Everbright Photonics Co., Ltd., Suzhou, China, and a Distinguished Professor with the College of Electronics and Information Engineering, Sichuan University, Chengdu, China. His research interests include edge-emitting semiconductor lasers, surface-emitting lasers, photodetectors, and laser power converters.

Lab to Fab : On-chip Spectral Imaging and Sensing

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Abstract We demonstrated on-chip spectral imaging and in-sensor computing using freeform metasurfaces for diverse applications.

Introduction

Conventional spectral analysis techniques, which rely on traditional prism dispersion, grating diffraction, or Fourier transform principles, suffer from complex structures, large volumes, high costs, and the need for spatial or temporal scanning to obtain spectral information from different points in space.

In this work, we demonstrated an on-chip spectral imaging and in-sensor computing approach using metasurfaces composed of freeform-shaped meta-atoms. These meta-atoms are generated by an algorithm that enables controllable feature size and boundary curvature. Our results indicate that the proposed device holds promise for various applications, including medical diagnostics, precision agriculture, food quality inspection, and object detection.

Moreover, spectral imaging chip technology is rapidly evolving, with ongoing developments in spectral encoding, multidimensional light field computation and AI-driven reconstruction algorithms. Future advancements may include extending spectral bands into the infrared and ultraviolet ranges and exploring interdisciplinary applications. A promising direction for this technology is the development of in-sensor computing chips that are tailored for complex visual tasks. In the AI era, these chips could become fundamental modules for AI systems, enabling devices such as smartphones, robots and drones to perform advanced spectral sensing and computing tasks. With CIS as the most integrated optoelectronic detector array available, every pixel in a high-resolution camera could both sense and compute, opening the door to a new era of neural network chips with matter meta-imaging.

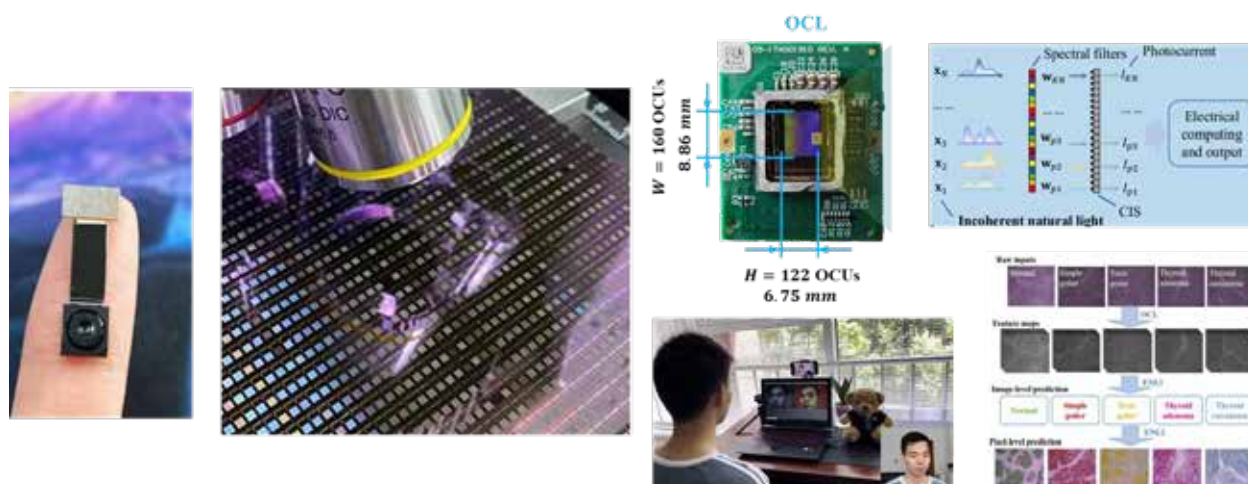


Fig.1 Spectral imaging chip and applications of in-sensor computing

Conclusions

We demonstrate an on-chip spectral imaging and in-sensor computing approach using algorithm-generated freeform metasurfaces, offering a compact, low-cost alternative to conventional spectrometry for medical, agricultural, and industrial applications.

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She is also the founder of Seetrum Corporation Limited, a company dedicated to bringing spectral imaging chips into high-volume application markets.

Exploring the Unique Properties and Application Potential of InAsP/InP Quantum Dots in Nanowires

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Abstract There will be presented the current status of developments of defect-free, zinc blende InAsP quantum dots in InP nanowires in view of their precise properties control and application potential in nanophotonics and quantum technologies.

Semiconductor quantum dots (QDs) is one of the most promising systems for development of devices in scalable technology which are able to outperform any of the existing solutions in various quantum technology applications for fiber-based quantum communication, quantum photonic integrated circuits, and photonic quantum information processing. It concerns especially near infrared sources of single photons [1] with record low multiphoton events probabilities [2], including the telecom range and on demand generation [3], and demonstrating simultaneously high photons' indistinguishability [4], but also in sources of entangled photon pairs [5] or cluster states generation [6].

One of the explored systems are QDs inside nanowires (NWs) formed epitaxially using the vapor-liquid-solid (VLS) growth mode. They have significant advantages over other QD-like materials concerning in particular precise control of the QD dimensions and spatial positioning (independently in the horizontal and vertical directions), NWs density, composition and even the material crystal phase [7]. Relaxation of the elastic strain in such systems allows combining highly lattice-mismatched materials and hence form waveguiding structures to tailor the light extraction efficiency.

Here, we report on the electronic and optical properties of such QD-NWs made of InAs_xP_{1-x} in InP by VLS in chemical beam epitaxy on Fe-doped InP(100) substrates. In the case of growth along the <100> direction, formation of defect-free zincblende wires occurs at larger catalyst gold nanoparticle diameters compared to more common and mature wurtzite counterparts [8], offering the in-plane QD size control in a broader range. Bright emission from such single QD-NWs of different sizes and composition could be obtained, tunable in a broad spectral range from below 1.1 to almost 1.6 μm [9], i.e. covering also the application-relevant second and third telecommunication bands. The spectral characteristics including the carrier dynamics have been compared to the results of band structure calculation in the 8-band k·p model for single particle states, combined with configuration interaction method to derive the energies of various excitonic complexes and conclude on their sensitivity to QD morphology, strain and composition. The model has been fed with structural parameters taken from transmission electron microscopy. Eventually, by tuning the growth parameters to balance between the axial and radial growth, we demonstrated the possibility to realize NW waveguides exhibiting enhanced extraction efficiency of photons emitted from the QDs by one order of magnitude [10] without a need of any pre-growth substrate patterning, nor selective-area epitaxy. Finite-difference time-domain simulations have been employed to design the optimal NW shape and InP shell thickness and confronted with the NW morphology observed experimentally by scanning and transmission electron microscopy and with the spectroscopic data.

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Deterministic generation of a large-scale multi-photon GHZ state

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Abstract We present a novel device based on a semiconductor quantum dot embedded in a photonic microcavity, which deterministically generate at gigahertz rate, strings of indistinguishable single photons in a Greenberger-Horn-Zeilinger (GHZ) multiphoton entangled state with entanglement length surpassing a dozen photons, providing valuable resources for quantum communication and computing.

Introduction

Quantum technologies witness rapid contemporary developments transforming from abstract scientific ideas and fundamental proof of principle demonstrations into systems of sufficient quality, enabling real applications in quantum information processing. Photonic quantum technologies, in particular, are playing pivotal role in these developments, since photons are quite robust, easy to detect, control and measure and thus to be used as flying quantum bits for carrying quantum information and distributing entanglement. The efforts invested in developing photonics-based quantum technologies stem from the maturity of the relevant classical technologies. Most relevant is the conceptual proof that a heralded quantum light source of only 3 entangled photons is sufficient for building a large-scale quantum computer using otherwise classical optical elements [1].

The quantum knitting machine with spin echo.

We present a novel device which deterministically generate at above a GHz rate, strings of entangled and indistinguishable single photons with entanglement length exceeding dozen photons. Our device is based on a semiconductor quantum dot embedded in an optical microcavity. The QD confines a heavy hole, precessing in a very weak, externally applied magnetic field in Voigt configuration [2-3]. The hole is resonantly excited periodically at an optimized rate of about 1.5 GHz, deterministically emitting a long string of single photons in a robust Greenberger-Horn-Zeilinger (GHZ) multi qubit entangled state [4].

The novelty in the device is in its natural spin echo, provided by the opposite precession-directions of the electron in the excited state before the photon emission and the hole in the ground state after the emission. The magnetic field independent optimized excitation rate is tuned to exactly nullify the acquired phase during both spin precessions. This high-rate and robust quantum light source of more than a dozen of entangled photons.

Conclusions

Our demonstration of this novel device concept, significantly reduces the overhead requirements for photonic measurement-based quantum computation [5] and communication [6], thereby bringing advanced photonic quantum technologies, closer to reality

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Photonic Integrated Circuits with Heterogeneous Materials Integration and Photonic-Electronic Co-design Technologies

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Abstract In this prestaton, photonic integrated circuits on Si-platform for photonic-electronic convergence, focusing on two topics; heterogeneous material integration of III-V and functional materials and EDA-based modulator/driver co-design are reviewed.

Introduction

The rapid evolution of generative artificial intelligence is increasing demand for computing and communication infrastructure, and has made photonics-electronics convergence a highly visible technology topic. Photonics is not merely an interconnect supplement to electronics; it is becoming a core technology for scaling information systems. This summary reviews two enabling technologies for such convergence: heterogeneous materials integration as a fabrication methodology, and photonic-electronic co-design as a design methodology.

Heterogeneous materials integration

Silicon is an excellent platform because large-diameter wafers are available and high-resolution fabrication is well established. However, silicon alone cannot efficiently provide all required optical functions, such as optical gain or high-speed, low-voltage refractive-index modulation. Heterogeneous integration addresses this limitation by adding III-V semiconductors, electro-optic films, and other functional materials to the silicon platform.

Figure1 shows an example of one-chip transceiver toward multi-Tbps era. Using this technology, several functions such as a tunable laser with a tuning range of over 100 nm can be realized by integrating C- and L-band gain chip into a single optical circuit. While basic bonding processes have become mature, several issues still remain, including how to couple light between silicon waveguide and bonded films [1], and how to integrate multiple films at high density without losing process compatibility [2].

Photonic-electronic co-design

Conventionally, optical and electronic components have been designed separately, with interface specifications agreed at the boundary; 50-ohm impedance matching is a typical example. If this boundary is removed and the entire function is optimized at once, the resulting photonic integrated circuit can be more efficient in terms of power, footprint, and bandwidth.

For this purpose, electronic design automation (EDA) environments must treat optical devices as design objects in the same way as transistors and interconnects. When compact optical models and electrode layouts are incorporated into EDA, devices such as silicon modulators can be co-designed with electrodes and drivers to realize lower power consumption and higher-speed modulation [3]. Figure 2 shows a Si modulator with SiGe BiCMOS drivers. A clear eye opening can be achieved using the co-design method. This also opens the door to AI-assisted optimization methods that are already being adopted for large-scale electronic circuits [4].

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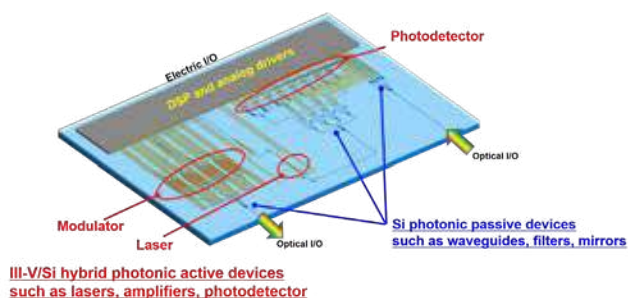


Fig. 1 Concept of a multi-Tbps transceiver.

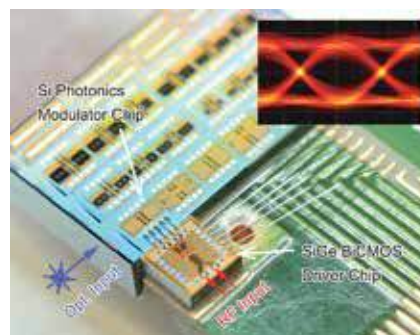


Fig. 2 Si slow-light modulator co-packaged with SiGe BiCMOS drivers.



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Ultra-High Bandwidth-Density Integrated Coherent Optics

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Abstract Integrated coherent silicon photonics enables unprecedented bandwidth density for future AI interconnects. Ultra-compact microring-based coherent transmitters achieve terabit-per-second data rates, multi-terabit-per-millimeter integration density, and scalable wavelength-multiplexed architectures toward petabit-class optical engines.

Introduction

As AI models continue to grow exponentially in computational complexity, optical interconnects have become a primary bottleneck for future computing systems. The continued scaling of AI clusters is driving demand for multi-terabit-per-millimeter optical bandwidth density together with ultra-low energy consumption.

Coherent optical communication provides an attractive solution by combining superior receiver sensitivity, higher spectral efficiency, longer reach, and compatibility with wavelength- and polarization-multiplexing [1]. While coherent transceivers have traditionally relied on millimetre-scale Mach-Zehnder modulators [2, 3], recent developments in silicon microring modulators have fundamentally changed the design space, enabling compact coherent transmitters with unprecedented integration density [4, 5].

Ultra-Compact Coherent Silicon Photonics

Microring-assisted Mach-Zehnder modulators (MRA-MZMs) combine the compact footprint of resonant modulators with the linearity of Mach-Zehnder interferometers [4]. Operating the two microrings in a push-pull configuration suppresses dynamic frequency chirp while preserving high electro-optic bandwidth, enabling coherent modulation at symbol rates previously unattainable using conventional resonant devices. Recent demonstrations have achieved coherent transmission exceeding 1 Tb/s per wavelength over 80 km using standard silicon photonic platforms, with modulation energies approaching 10 fJ/bit [4]. More importantly, the extremely compact footprint increases the shoreline bandwidth density from hundreds of Gb/s/mm to approximately 5 Tb/s/mm, representing more than an order-of-magnitude improvement in integration density.

For AI interconnects, O-band coherent optics offers additional advantages, including negligible chromatic dispersion, reduced digital signal processing complexity, and improved compatibility with existing data-center fiber infrastructure. Recent O-band MRA-MZM demonstrations achieved up to 400 Gb/s per wavelength and polarization with transmission over 7 km of standard single-mode fiber without chromatic-dispersion compensation [5].

Scaling Toward Petabit-Class Optical Engines

Beyond individual modulators, scalable coherent transmitters require efficient multi-wavelength architectures. A promising solution combines quantum-dot mode-locked laser frequency combs with SiN flat-top DWDM interleavers that distribute optical carriers across multiple waveguide buses [6]. This architecture enables efficient scaling to large channel counts while remaining compatible with dense silicon integration.

As a proof of concept, six comb lines carrying 100-GBaud QPSK signals achieved an aggregate net capacity exceeding 1 Tb/s over 5 km of standard single-mode fiber. Single-channel operation demonstrated 400 Gb/s using 120-GBaud 16-QAM while maintaining approximately 4 Tb/s/mm shoreline bandwidth density and only 10 fJ/bit modulation energy [6]. These results establish integrated coherent silicon photonics as a practical platform for compact optical engines targeting future co-packaged optics and resource-disaggregated computing systems.

Outlook

The next generation of AI infrastructure will require simultaneous scaling in bandwidth density, energy efficiency, and aggregate system capacity. Integrated coherent optics based on ultra-compact silicon modulators offers a compelling path forward by combining CMOS-compatible manufacturing, dense wavelength multiplexing, and advanced coherent modulation within an exceptionally small footprint.

Future research will extend these concepts beyond wavelength multiplexing toward multidimensional optical fabrics

integrating polarization, space-division multiplexing, optical switching, and frequency-comb sources on a common silicon platform. Such architectures could enable coherent optical engines exceeding 10 Tb/s per fiber and ultimately support petabit-class optical fabrics for large-scale AI clusters.

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Low-Coherence Biophotonic Imaging for Seeing the Unseen

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Abstract This presentation highlights advances in fiber-optic low-coherence biophotonic imaging, emphasizing improved resolution, contrast, imaging depth, and basic and clinical applications, while identifying key technical and translation challenges relevant to photonics researchers.

Introduction

Low-coherence biophotonic imaging technologies have advanced rapidly over the past two decades. OCT is among the most prominent examples [1], with ophthalmic OCT representing a highly successful clinical translation of optical imaging. Because tissue penetration is limited, miniature fiber-optic probes are essential for extending OCT and related technologies to internal organs.

Beyond **spatial resolution**, **imaging contrast** is probably more critical for revealing diagnostically useful tissue features. This presentation will review advances in imaging platforms and fiber-optic probes that improve resolution, contrast, and imaging depth, as well as recent progress in fiber-optic multiphoton microscopy if time permits.

Miniature Fiber-Optic Probes for Enabling Internal Organ Imaging

High-resolution optical imaging primarily relies on minimally scattered photons. Consequently, imaging depth in highly scattering tissues is generally limited to submillimeter-to-millimeter scales. Flexible fiber-optic probes are needed to overcome this limitation by providing access to internal organs through imaging needles, catheters, endoscopes, and other medical instruments.

In OCT, lateral resolution is determined by the numerical aperture of the focusing optics, whereas axial resolution Δz is governed by the coherence length of the light source and improves with broader spectral bandwidth and shorter center wavelength (i.e., $\Delta z = (2 \ln 2 \lambda_0^2) / (\pi \Delta \lambda)$, where λ_0 is the center wavelength and $\Delta \lambda$ is the 3dB spectrum bandwidth). Compared with conventional 1300-nm OCT, operation near 800 nm can improve axial resolution by approximately 2.5-fold [2]. More importantly, stronger tissue scattering at 800 nm can enhance imaging contrast by approximately 2.5–3-fold [3], enabling visualization of subtle pathological changes associated with early-stage diseases [4].

Operating OCT at 800 nm introduces substantial optical-design challenges, particularly chromatic aberration in miniature probes. Although miniature compound lenses (i.e., micro objective lens) can provide achromatic performance, their complexity and cost prohibit widespread clinical use. More economical approaches include miniature diffractive optics and optimized combinations of lens geometry and optical materials.

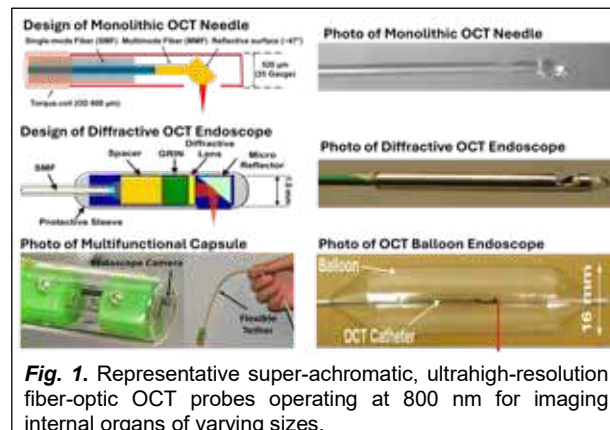


Fig. 1. Representative super-achromatic, ultrahigh-resolution fiber-optic OCT probes operating at 800 nm for imaging internal organs of varying sizes.

Representative probes (as shown in Figure 1) with super-achromatic performance will be presented, ranging from approximately 0.5-mm-diameter imaging needle to 12-mm capsule probes for imaging luminal organs of different sizes [5-8].

Challenges and Opportunities

Despite recent progress, several challenges remain. First, the bandwidth of fiber-optic interferometers, particularly fiber couplers, can limit the usable spectrum and therefore the achievable OCT resolution. Addressing this limitation offers a wonderful opportunity for collaboration between the biophotonics and fiber-optics communities.

Second, imaging depth remains restricted by tissue scattering. Refractive-index matching can reduce scattering by decreasing microscopic index variations within tissue [9]. Recent studies have demonstrated that strongly absorbing dyes may produce broad refractive-index changes that enable temporary optical clearing without proportionally increasing absorption [10]. Although promising results have been reported in skin, effective dye delivery and preservation of intrinsic imaging contrast remain important challenges.

Finally, clinical translation requires robust, manufacturable, and cost-effective probes; compatibility with existing clinical workflows; and rigorous validation of diagnostic value.

Conclusions

OCT near 800 nm can substantially improve imaging resolution and contrast compared with conventional 1300-nm systems. Combined with innovative miniature fiber-optic probes, these advances may enable earlier disease detection and expand high-resolution optical imaging to previously inaccessible internal organs.

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High-speed Miniaturized Two-photon Microscope

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Abstract We present high-speed miniaturized two-photon microscopes (2P miniscopes), with beam-multiplexing strategies or point-spread-function engineering. Using the 2P miniscopes, we imaged the neural activity in mouse cortex while the mice freely behaved in an open field.

Introduction

Miniaturized two-photon microscopes (2P miniscopes) are emerging transformative tools for studying neuronal activities in-vivo in freely-moving mice¹⁻⁷. These devices have a distinct advantage over conventional benchtop microscopes by enabling the recording of mice brain activity in natural settings. This advancement opens new avenues for novel scientific explorations, such as investigating the neural mechanisms of ethologically pertinent behaviors including social interactions and navigation. However, a major limitation of 2P miniscopes lies in their relatively low imaging speed, a consequence of the point-by-point excitation beam raster scanning mechanism, which restricts the optical recording throughput that can be achieved. Here, we present high-speed 2P miniscopes, using strategies of beam-multiplexing or point-spread-function (PSF) engineering. Using our miniscopes, we performed in vivo volumetric calcium imaging and voltage imaging in mouse cortex while mice were free to behave in an open field.

Beam-multiplexed 2P miniscopes

The beam-multiplexed 2P miniscopes were developed based on the open-source MINI2P⁴ and extend its imaging speed and throughput. Instead of a single laser focus, we deliver two focal spots onto the brain tissue and scan them across two different field-of-views (FOVs) through the microelectromechanical systems (MEMS) mirror. We implemented two different multiplexing strategies—temporal (TM-MINI2P) and computational (CM-MINI2P) multiplexing⁸. Both schemes share the same optical layout of the miniaturized microscope but have distinct benchtop optics optimizing each method and unique demultiplexing methods. In TM-MINI2P, a temporal delay is introduced between the two pulse trains toward the two FOVs and time gating at data acquisition is used to separate the signal. In CM-MINI2P, no temporal offset is required between the two pulse trains. It leverages the temporal dynamics of the neuronal activity to separate the two FOVs that appear overlapped during acquisition. Prior to a dual-path multiplexed recording, the individual FOVs were recorded where the spatial footprints of the neurons in individual FOV were extracted. This information is then used to extract the temporal activity of neurons in the simultaneous two-path recordings⁹.

With the beam-multiplexed 2P miniscopes, we demonstrated large-scale ($500 \times 500 \mu\text{m}^2$ FOV) multiplane calcium imaging in visual and prefrontal cortices of freely moving mice during spontaneous exploration, social behavior, and auditory stimulus. The increased speed of beam-multiplexed 2P miniscopes also enables 2P voltage imaging at 400 Hz over a $380 \times 150 \mu\text{m}^2$ FOV in freely moving mice (Fig. 1).

Short-line scanning 2P miniscopes

In short-line scanning 2P miniscopes, rather than illuminating the sample with a diffraction-limited spot, we shape the beam into a short line with $8 \mu\text{m}$ length along the slow-scanning-axis. The PSF is shaped into a short line along the slow-scanning-axis. This reduces the number of raster scanning rows to image each frame, and thus increases the imaging speed. The $8 \mu\text{m}$ length is smaller than the typical dimension of the cell body ($10\text{-}15 \mu\text{m}$), so we can maintain cellular resolution. We shape our beams through cylindrical lenses in two orthogonal directions. Using the short-line scanning 2P miniscopes, we performed fast volumetric calcium imaging in mouse secondary motor cortex over a volume of $500 \times 500 \times 300 \mu\text{m}^3$. Volumetric recordings enabled identification of neural populations tuned to different behavioral conditions such as movement, climbing, and grooming.

Summary

We have developed high-speed 2P miniscopes with two strategies: beam multiplexing and PSF engineering. Our miniscopes can perform fast population calcium imaging over a large brain volume and record voltage dynamics in freely moving mice. Our development broadens the application of miniaturized two-photon microscopes and provides a framework for further enhancement of their optical throughput.

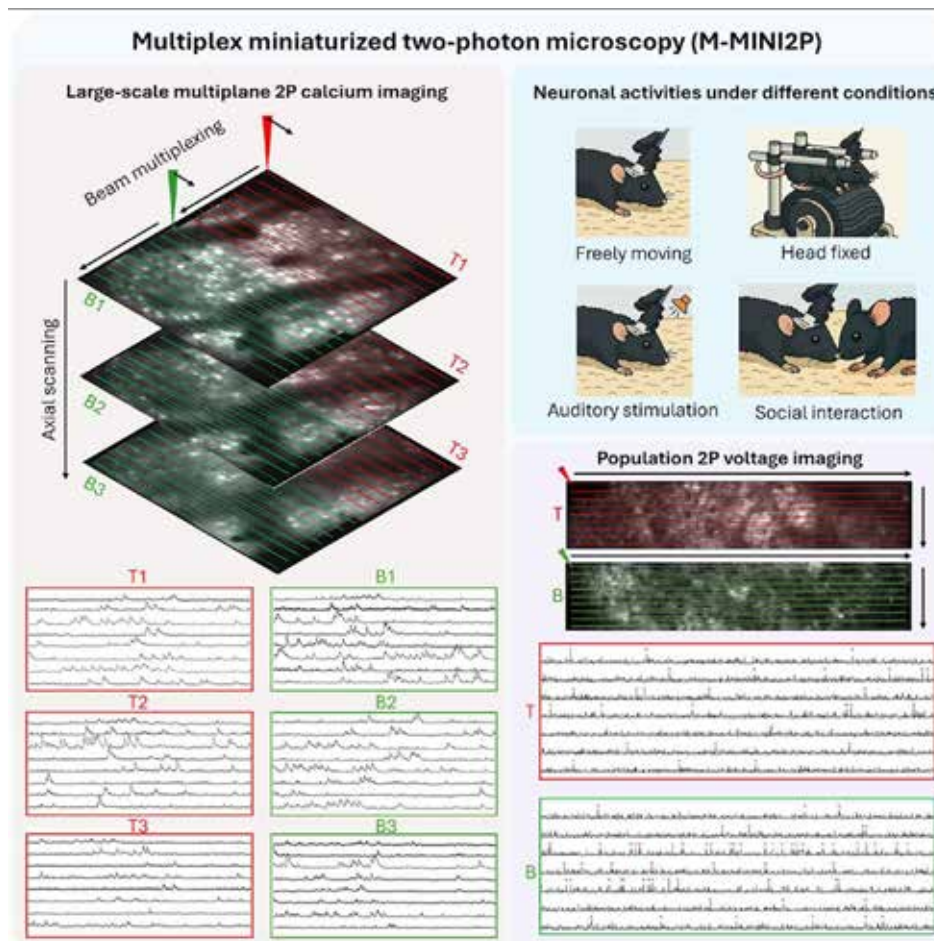


Fig. 1. Overview of the beam-multiplexed 2P miniscopes⁸. Figure adapted from Ref. ⁸.

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Photonics for Clinical Diagnostics: Cancer Margins, Bacterial Detection, and Pulse Diagnostics

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Abstract Photonics based technologies are attractive for point-of-care diagnostics in clinical settings due to their non-invasive nature and rapid decision time. Here, we discuss the applications of UV, visible and Terahertz imaging in bacterial detection, pulse diagnosis and cancer margin detection.

Introduction

Currently, clinical diagnostics require bulky, expensive equipment and typically an invasive blood test or a biopsy. This challenge is especially compounded in wound care applications and cancer margin detection which require a biopsy of the tissue followed by detailed culture test/examination of stained tissue under a microscope. This process is laborious and time consuming. In contrast, photonics based technologies that use excitation of light at specific frequencies such as UV, visible and Terahertz for analysing the tissue are non-invasive and can give rapid decision within minutes to an hour. Here we discuss three applications of photonics technologies in wound care, cancer margin detection and integrative health assessment.

Multi-spectral Autofluorescence for Bacterial Detection

Detection of bacteria in wound care such as diabetic foot ulcer is very important for understanding the infection levels which directly contribute to delayed wound healing. Currently, tissue swabs are taken and sent to culture test which can take anywhere from 1-2 days. An alternative approach is to leverage innate markers present in the bacteria such as NAD(P)H and Flavins. These native markers fluoresce under UV illumination. By analysing the spectral response of the bacteria to various UV excitation wavelengths and using AI, bacteria can be detected along with their gram-type with >90% accuracy [1]. Based on this principle, we have developed a multi-spectral fluorescence imaging device, Illuminate, which is a FDA approved device that performs optical biopsy and can be used in point-of-care settings.



Fig. 1 Bacterial detection device Illuminate which uses multi-spectral auto-fluorescence imaging.

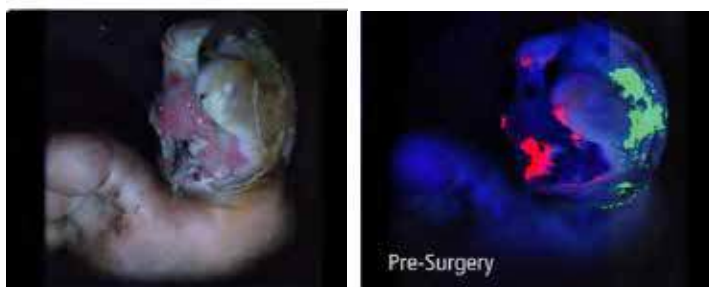


Fig. 2 Example of bacteria detected on the wounds using multi-spectral imaging combined with AI.

Cancer Margin Detection

Breast, oral, head and neck cancers are increasing at a rapid pace and affecting millions of people world-wide. Detection of cancer in surgical settings require a tissue biopsy followed by staining and examination under a microscope. Recently, Terahertz imaging has emerged as an attractive technology for non-invasive cancer margin detection due to differential scattering and water absorption properties of cancerous tissues. Here, we demonstrate the results of a Terahertz probe for in-situ cancer margin detection [2].



Fig. 3 Terahertz imaging system for cancer margin detection.

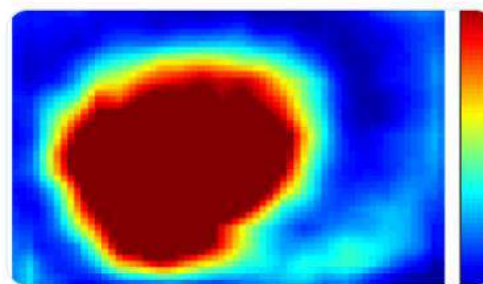


Fig. 4 Terahertz image of a cancer sample.

Pulse Diagnostics for Integrative Health applications

Pulse diagnostics is very important for understanding the cardiovascular health. Conventional PPG sensors utilizing multiple wavelengths typically measure heart rate and oxygen saturation. In ancient medicinal systems such as Traditional Chinese Medicine and Ayurveda, pulse diagnostics is used to understand deeper integrative health markers. Here, we show how full blood pulse waveforms collected from PPG sensors can be used to understand integrative health parameters.

Conclusions

Photonics based multi-spectral imaging technologies enable a wide range of clinical diagnostic applications ranging from optical biopsy to integrative health assessment.

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Photonics-Electronics Convergence : Oscillation, Computation and Integration

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Abstract This report presents our recent advances in photonic-electronic convergence, covering novel optoelectronic oscillators (OEOs), a fully programmable optical analog processor and photonic-electronic Ising machine, and high-speed integrated optical interconnect devices and system.

Introduction

As high-speed communication and computing systems demand higher bandwidth, lower latency, and improved energy efficiency, conventional electronics face fundamental limitations. Microwave photonics, optical computing, and integrated optoelectronics provide promising alternatives. This report highlights our recent progress in optoelectronic oscillators (OEOs), programmable optical analog processors, and high-speed optical interconnect chips for future high-performance systems.

Optoelectronic Oscillator

OEOs are microwave photonic feedback loops capable of generating ultra-low-phase-noise, high-frequency signals for radar, communication, and sensing applications. We have proposed several novel OEO architectures [1], including frequency-scanning Fourier domain mode-locked, parity-time symmetric, parametric, and broadband random OEOs, demonstrating strong signal generation capabilities. We further developed compact integrated OEOs [2], including all-optical InP, hybrid-integrated, and coupled configurations with reduced footprint and enhanced performance.

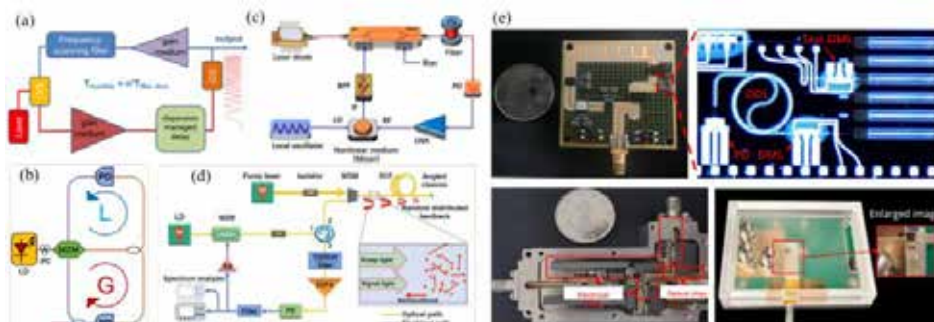


Fig. 1 Novel and integrated OEOs [1-2]. (a) Fourier domain mode-locked OEO, (b) parity-time symmetric OEO, (c) parametric OEO, (d) broadband random OEO, and (e) chip-scale integrated OEOs.

Optoelectronic Computing

A photonic-electronic Ising machine based on parametric oscillation achieves a 1.5 h coherence time, 4096×4096 connectivity, and 2-3 orders-of-magnitude speedup over von Neumann systems [3]. In addition, photonic intelligent computing chips were developed using WDM-assisted multimode interference to address scalability. A hybrid optical-microwave multiplexing and wavelength-tunable weight-loading scheme enables 3D tensor convolution with 14× higher compute density than NVIDIA H100. An optoelectronic closed-loop CNN achieves 8-bit equivalent inference accuracy [4].

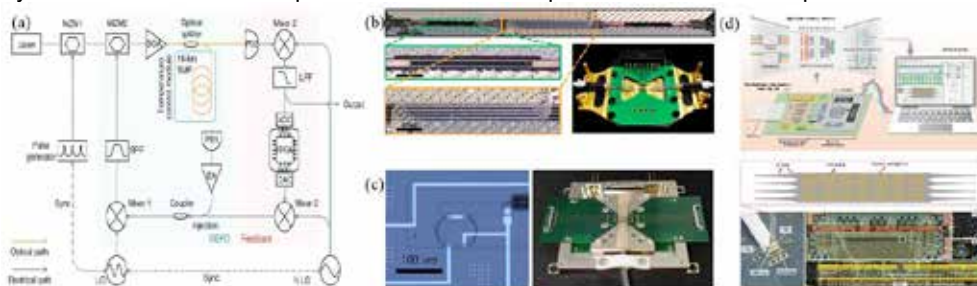


Fig. 2 Optoelectronic computing schemes [3-4]. (a) photonic-electronic Ising machine, (b) WDM-assisted multimode interference scheme, (c) hybrid optical-microwave multiplexing tensor processing scheme, and (d) high equivalent inference accuracy optoelectronic closed-loop optimized scheme.

Optoelectronic Integration

We developed high-performance silicon photonic building blocks and a PDK for a 12-inch silicon photonics platform, along

with a universal end-to-end simulation model for efficient technology transfer. Photonic–electronic co-design enabled a monolithic optical interconnect OI/O chip with 256 Gb/s bandwidth and 2.85 pJ/bit energy efficiency [5], and a 3D-packaged receiver with 200 Gb/s per channel. A PZT electro-optic modulator with 66 pm/V efficiency and 70 GHz bandwidth was also demonstrated [6].

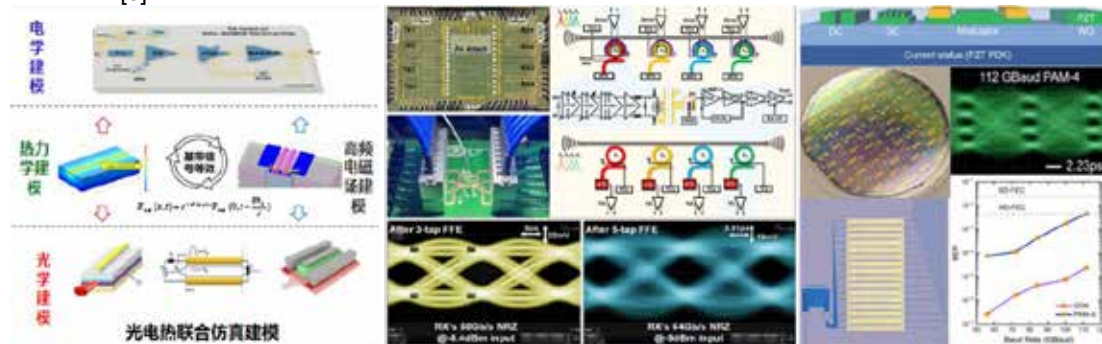


Fig. 3 Photonic-electronic co-Simulation system, monolithic OI/O chip and novel PZT platform [5-6].

Conclusions

These results demonstrate the strong potential of photonic-electronic convergence to overcome the fundamental limits of conventional electronics, enabling scalable, high-speed, and energy-efficient computing and interconnect systems. The advances in OEOs, optical computing architectures, and integrated photonic devices collectively provide a viable pathway toward next-generation information processing platforms and large-scale deployment in future data centers and intelligent systems..

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Deterministic telecom-wavelength quantum-dot devices for scalable quantum photonics

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Abstract Telecom-wavelength semiconductor quantum dots integrated with nanophotonic resonators enable efficient single-photon generation, photon indistinguishability, and spin-photon interfaces, providing scalable building blocks for fiber-based quantum networks and photonic cluster-state sources.

Introduction

As high-performance sources of single photons, epitaxial semiconductor quantum dots can be considered a semiconductor launchpad for quantum photonic technologies [1,2]. Their deterministic emission, compatibility with nanophotonic integration, and potential access to spin-photon interfaces make them particularly attractive for quantum communication, photonic quantum information processing, and distributed quantum networks. However, realizing sources of single or entangled photons with simultaneously high brightness, low multi-photon, indistinguishability, and scalability remains a central challenge, especially directly in the telecom C-band.

Telecom quantum dots in circular Bragg gratings

Here, we present an overview of recent developments in our group on III-V semiconductor quantum-dot single-photon sources grown by molecular beam epitaxy and integrated into nanophotonic resonators. By embedding InAs/InAlGaAs quantum dots into circular Bragg grating resonators, Purcell-enhanced single-photon emission with a Purcell factor of approximately 7 in the telecom C-band was achieved [3]. Low multi-photon emission probabilities and Hong-Ou-Mandel two-photon interference were demonstrated, establishing circular Bragg gratings as an efficient platform for telecom quantum-dot single-photon sources.

Deterministic integration and polarization control

For an unweighted mapping of the quantum-dot polarization state directly into the outcoupled photon polarization, a symmetric cavity and a well-positioned quantum dot are essential. In circular Bragg grating resonators, even a displacement of the emitter with respect to the cavity center of a few ten nanometers can strongly influence the polarization characteristics, because the symmetry of the coupled quantum-dot-cavity system is broken and the quantum dot couples differently to the degenerate fundamental resonator modes [4]. We therefore employ deterministic placement techniques also for telecom C-band quantum dots.

Photon indistinguishability in the telecom C-band

By further improving epitaxial growth and photonic design, telecom quantum-dot sources have recently reached substantially improved two-photon interference performance. In earlier devices, record two-photon interference visibilities of approximately 72% were obtained in the telecom C-band. More recently, deterministic InAs/InAlGaAs quantum dots integrated into circular Bragg grating resonators demonstrated raw two-photon interference visibilities up to $(91.7 \pm 0.2)\%$ [5]. This represents an important step towards bringing telecom-wavelength quantum-dot sources into a performance regime relevant for entanglement swapping, quantum networking, and photonic quantum information processing.

Spin-photon interfaces at telecom wavelengths

Beyond single-photon generation, charged telecom quantum dots provide access to spin-photon interfaces. Recent work on InAs/InAlGaAs quantum dots integrated into deterministically placed circular Bragg gratings at $1.55 \mu\text{m}$ demonstrated optical access to a confined hole spin qubit. Polarization-resolved measurements of positively charged excitons allowed electron and hole g-factors to be extracted, and pulsed two-photon correlation measurements enabled heralding of the hole spin with an inhomogeneous dephasing time of $T_2^* = (15.9 \pm 1.7) \text{ ns}$ [6]. These results establish key ingredients for coupling stationary spin qubits to telecom photons without external frequency conversion.

Photonic cluster-state generation in the telecom C-band

Building on this spin-photon interface, we recently demonstrated the deterministic generation of a spin-photon-photon cluster state directly in the telecom C-band [7]. The experiment implements the Lindner-Rudolph protocol using a confined hole spin as a stationary entangler qubit, which is sequentially coupled to emitted photons by repetitive optical excitation and controlled spin precession in an external magnetic field. Such deterministic emitter-based entanglement generation is

particularly relevant for scalable photonic quantum technologies, where probabilistic construction of large resource states quickly becomes inefficient [8]. We characterize the cluster-generation process by reconstructing the process map of one circuit building block, consisting of spin precession and spin-dependent photon emission, and obtain a fidelity of $F = 0.71 \pm 0.01$ with respect to the ideal process. As part of this characterization, we observe spin–photon polarization entanglement by full quantum-state tomography. The emitted photons exhibit approximately 80% indistinguishability, and polarization tomography through optical fiber underlines the compatibility of the generated cluster states with existing telecommunication infrastructure [7].

Conclusion and outlook

Together, these results show that telecom-wavelength semiconductor quantum dots have progressed from efficient single-photon sources to active generators of multi-qubit photonic resource states. Circular Bragg grating resonators provide efficient and Purcell-enhanced photon extraction, improved material quality and device design enable highly indistinguishable photons in the telecom C-band, and charged quantum dots provide optical access to stationary spin qubits. The deterministic generation of a telecom-C-band photonic cluster state combines these ingredients and marks an important step towards scalable quantum networking and optical quantum information processing with semiconductor quantum dots. Future improvements in photon extraction, Purcell enhancement, charge control [9], and spin coherence are expected to further increase cluster-state fidelities and enable longer entangled photon strings directly in the low-loss telecommunication window.

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Metasurface Devices for Optical Communication and Interconnects

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Abstract Ultrathin metasurfaces with silicon nanoposts were employed to realize spatially scalable receivers, multi-input multi-output vectorial mode converters, and dense pitch-converting couplers. Furthermore, active metasurfaces with organic electro-optic materials were developed to demonstrate >Gbps data modulation.

Metasurface (MS) is an engineered array of dielectric or metallic subwavelength structures on a planar substrate that enables flat wavefront-shaping devices [1]. We have been developing various functional devices based on passive [2–8] and active [9–13] MSs operating at 1550-nm wavelength for high-speed optical communication and interconnects.

Using passive MSs composed of dense arrays of Si nanoposts, we have demonstrated high-speed Stokes vector receivers [2], coherent receivers [3,4], multi-modulation-format one-chip receivers [5], and IQ modulators [6]. In [5], an ultrathin MS layer was successfully integrated with high-speed (> 70 GHz) InP/InGaAs membrane photodetectors on a single chip to realize a compact surface-normal receiver, capable of detecting highly parallelized signals in various modulation formats. Furthermore, multi-stage reflective and transmissive MSs were employed to realize multi-input multi-output (MIMO) vectorial optical mode converters [7] and dense pitch-converting multi-channel couplers [8]. Such devices should be useful for the next-generation space-division-multiplexed (SDM) optical transmission systems, high-density optical interconnects, and co-packaged optics (CPO).

By embedding organic-electro-optic (OEO) materials inside subwavelength structures, we have also demonstrated various types of active MS devices, whose reflectance and/or transmittance properties could be modulated at high speed. In [10], a Si-organic-hybrid (SOH) dimerized grating structure was employed to achieve >Gbps data modulation with sub-volt driving voltages. Towards higher-speed operation, we have also demonstrated use of InP [13] and plasmonic [9, 11, 12] nanostructures, enabling modulation bandwidths beyond 10s of GHz. Such high-speed surface-normal devices should find diverse applications for dense optical interconnects, free-space optical (FSO) communication, high-speed beam-steering, and scalable optical computing.

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Engineering Polariton Dispersion: Reversed Cherenkov Radiation and Flatland Wakes

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Abstract. We engineer anisotropic van der Waals polaritons to realise analogue reversed Cherenkov radiation, directional flatland wakes, and electrically tunable nanoscale transport, revealing how dispersion transforms confined light into programmable emission and routing for integrated nanophotonics.

Introduction

Cherenkov radiation offers a direct route from moving charges to electromagnetic waves, yet conventional media impose a velocity threshold and largely fix the emission geometry. Hyperbolic media relax these constraints by providing large optical momenta and strongly anisotropic energy flow. Integrated artificial hyperbolic structures have therefore enabled threshold-free free-electron radiation on a chip [1]. Natural van der Waals crystals provide a complementary platform: their low-loss phonon polaritons are deeply confined, directionally dispersive, and tunable by stacking or electrostatic control. We use these properties to connect three functions—analogue reversed Cherenkov emission, directional flatland wakes, and programmable nanoscale transport—within a common dispersion-engineering framework.

Analogue reversed Cherenkov radiation in natural crystals

In the type-I hyperbolic band of $\alpha\text{-MoO}_3$, the phonon-polariton group velocity is negative, allowing energy to flow backwards relative to the wave vector. To overcome the momentum mismatch between free electrons and these highly confined modes, a propagating plasmon on a metal nanowire is used as an optical analogue of a moving charge. Scattering-type scanning near-field optical microscopy directly resolves the resulting reversed wake [2]. Rotating the nanowire relative to the crystal axes reshapes the radiation symmetry, while adding hBN modifies the isofrequency contour, increases the reversed emission angle, and raises the quality factor by approximately 60%. The experiment is an analogue polaritonic realisation, rather than direct free-electron emission, but it reveals how a natural crystal can determine both the existence and direction of Cherenkov-like radiation.

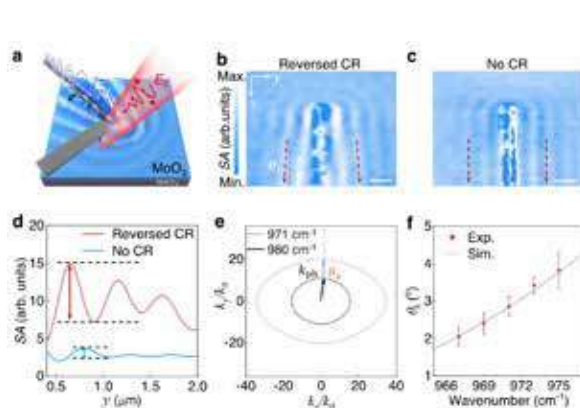


Fig. 1. Near-field observation and dispersion control of analogue reversed Cherenkov radiation in $\alpha\text{-MoO}_3$ [2].

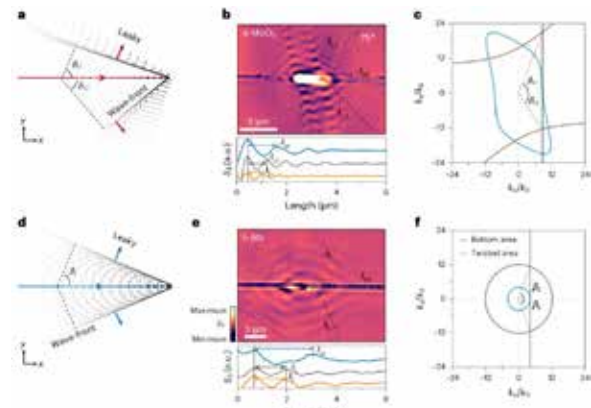


Fig. 2. Directional flatland wakes generated by leaky hyperbolic polaritons in mixed-dimensional van der Waals structures [3].

Flatland wakes from leaky hyperbolic polaritons

We next translate motion-induced radiation into a fully planar geometry. A nanoscale van der Waals strip placed on a polaritonic film forms a mixed-dimensional waveguide. Its confined mode lies within the continuum of modes supported by the underlying film and therefore leaks energy at a well-defined angle. Constructive interference between successive leakage events creates a highly directional two-dimensional wake [3]. The crystal orientation controls the symmetry of the wake, ranging from asymmetric emission to a symmetric Cherenkov-like pattern. A thickness gradient in the upper waveguide continuously changes the local phase velocity, producing accelerating or decelerating wavefronts. These flatland wakes provide a direct conversion between confined guided modes and directional in-plane polaritons without conventional antennas or bulky optical elements.

Towards programmable polariton transport

Radiation becomes a circuit function only when its dispersion can be actively reconfigured. In graphene/ α -MoO₃ heterostructures, electrostatic doping reshapes the polariton isofrequency contour and switches the refraction response, including electrically controlled negative refraction [4]. Together with orientation-controlled wakes, this suggests a modular route from generation to routing: engineered dispersion selects whether a mode is emitted, anisotropy directs its energy, and electrical or structural control reprogrammes its path. The same extreme field confinement may ultimately support compact active functions for source–route–modulate–detect architectures. Key challenges remain in coupling efficiency, propagation loss, high-speed electrical control, and scalable integration.

Conclusions

Hyperbolic polaritons turn Cherenkov radiation from a fixed cone into a designable nanoscale transport phenomenon. Dispersion determines whether radiation is allowed, anisotropy determines where energy flows, and active control converts that flow into a programmable on-chip function.

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Biography

Qing Dai is Dean and Distinguished Professor of the School of Materials Science and Engineering at Shanghai Jiao Tong University. He received an MEng from Imperial College London and a PhD in Materials Engineering from the University of Cambridge. His research focuses on polaritonics, van der Waals materials, near-field infrared nanoscopy, and programmable light–matter interactions.

III-V Ternary Nanowires: Building Blocks for Quantum Information Technologies

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III-V ternary nanowires and heterostructures of different types within such nanowires, including quantum dots in nanowires, are currently considered as potential candidates for Si-based photonics and sources of non-classical light for quantum information technologies. In this talk, we review the recent achievements in the compositional modeling [1-4], MBE growth [5-7] and experimental studies of optical properties [6-9] of III-V ternary nanowires based on group III and group V intermix and hybrid III-V nanowires heterostructures of different types. It will be demonstrated how the vapor-solid distributions of III-V ternary nanowires transition from the equilibrium shapes containing the miscibility gaps to the kinetic Langmuir-McLean shapes with the suppressed miscibility gaps by simply changing the total V/III flux ratio at a constant temperature [1,4]. We will discuss the origin of spontaneous core-shell nanowire heterostructures in MBE growth of AlGaAs [5] and InGaN [7] nanowires on Si substrates and the bright red photoluminescence from InGaN at 650 nm [7]. It will be shown that the GaAs quantum dots inserted into the core-shell AlGaAs nanowires emit single photons, with the corresponding anti-correlation function $g^2(0)$ of ~ 0.1 [8,9]. The results of correlation measurements of the single photon emission using a setup that comprises a laser-excited fluorescence microscope equipped with a Brown-Twiss intensity interferometer as one of the detection systems [8,9] will also be presented.

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Frontiers of Intelligent Metamaterials and Metamaterials Intelligence

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Abstract AI and metamaterials converge into two paradigms: algorithm-driven intelligent metamaterials and wave-matter computation-based metamaterial intelligence. This synergy transforms static devices into autonomous agents with integrated sensing, decision-making, and actuation for next-generation electromagnetic systems.

Introduction

The convergence of artificial intelligence (AI) and metamaterials is reshaping electromagnetic science, evolving from static functional devices toward dynamic, intelligent systems. This review systematically surveys two bidirectionally coupled paradigms: Intelligent Metamaterials (AI for Metamaterials) and Metamaterials Intelligence (Metamaterials for AI). The former leverages data-driven algorithms for inverse design and adaptive regulation, while the latter embeds computation directly into physical structures, utilizing electromagnetic waves as carriers for high-speed, low-latency information processing. We adopt a unified “physical mechanisms–algorithmic synergy–system applications” framework to analyze core principles, recent advances, and future challenges. Ultimately, these directions converge to create “metamaterial intelligent agents” capable of perception, decision-making, and execution, bridging the gap between physical hardware and digital intelligence.

Intelligent Metamaterials: Algorithm-Driven Adaptation

Intelligent metamaterials enhance the design efficiency and environmental adaptability of electromagnetic systems by integrating external AI algorithms with reconfigurable hardware. The physical foundation relies on dynamic metasurfaces utilizing varactor diodes, phase-change materials (VO₂, GST), liquid crystals, and MEMS to provide the degrees of freedom necessary for real-time modulation of amplitude, phase, and polarization. Algorithmically, deep learning architectures—including multi-layer perceptrons and convolutional neural networks (CNNs)—have superseded traditional parameter scanning, significantly accelerating forward prediction and inverse design. To address the inherent non-uniqueness of inverse problems, advanced frameworks such as tandem networks, generative models (VAEs, GANs), and “generate–eliminate” strategies ensure physical feasibility. Furthermore, reinforcement learning (RL) enables autonomous closed-loop control, allowing systems to explore optimal strategies in unknown environments, while transfer learning facilitates rapid adaptation across diverse frequencies and tasks. These synergies have driven breakthrough applications: in stealth technology, deep learning-driven cloaks achieve real-time scattering cancellation under dynamic conditions, evolving from static covers to active “invisibility spaces”; in communications, Reconfigurable Intelligent Surfaces (RIS) actively shape wireless environments for 6G by integrating sensing and communication to track users and optimize beamforming. Consequently, large-scale systems now demonstrate homeostatic behaviors, managing wireless channels autonomously without iterative external intervention.

Metamaterials Intelligence: In-Situ Physical Computation

Distinct from algorithm-assisted design, Metamaterials Intelligence (or Neuro-Metamaterials) embeds computation directly into the physical substrate. By exploiting wave propagation physics, these structures naturally perform linear transformations such as matrix multiplication and convolution, while nonlinearities required for activation functions are introduced via the Kerr effect or active feedback. This enables all-optical neural networks that operate at the speed of light with ultra-low energy consumption. The design paradigm shifts to topology optimization, where differentiable physics models and end-to-end training map abstract computational tasks directly to structural parameters. Advanced techniques, including online learning and reinforcement learning, further allow these physical networks to adapt their structural states in real-time, evolving from static processors into trainable hardware. Practical implementations demonstrate significant potential: diffractive deep neural networks (D²NN) achieve ultra-fast image classification without electronic sensors, while twisted diffraction networks facilitate high-density holographic storage. Furthermore, all-optical logic gates and programmable nonlinear networks are paving the way for photonic AI chips capable of executing complex inference tasks, such as gesture recognition and signal processing, with nanosecond latency.

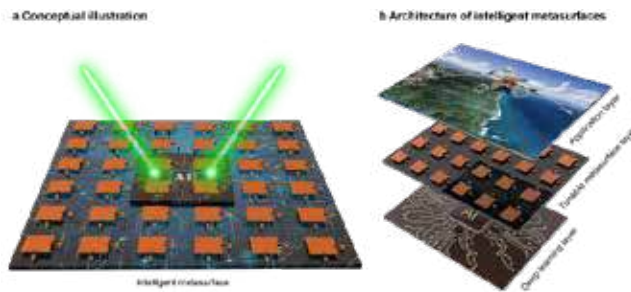


Fig. 1 Intelligent metamaterials.

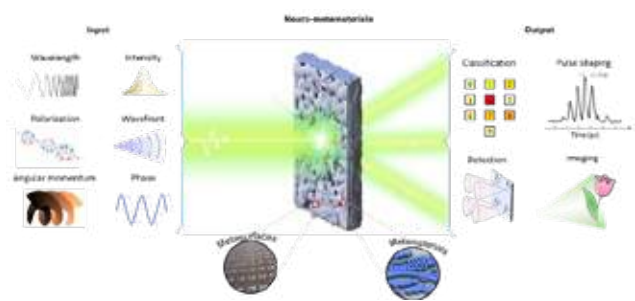


Fig. 2 Metamaterial intelligence

Conclusions

The fusion of intelligent metamaterials and metamaterials intelligence transforms passive components into active “metamaterial agents,” offering unprecedented latency, parallelism, and energy efficiency. By integrating algorithmic decision-making with in-situ physical computation, this paradigm fundamentally advances next-generation communication, sensing, and stealth technologies.

Future Outlook

Key challenges remain in bridging the simulation-to-reality gap caused by fabrication errors and noise, necessitating physics-informed neural networks. Future progress depends on developing robust nonlinear materials, few-shot online learning, and hybrid architectures that co-design physical hardware with digital control for deployable systems.

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Nanxuan Wu received her BS degree from Zhejiang University, in 2021, respectively, all in Information Engineering, and is currently pursuing his PhD at Zhejiang University in electronic science and technology. His research interest focuses on intelligent metamaterials, inverse design, and electromagnetic stealth technologies. He has authored 9 papers in leading technical journals and conferences. Best Student Paper Award at the PIERS2024.

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Optical nanofibers for extreme photonics

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Abstract Optical nanofiber are ideal structures for exploring extreme photonics. Here, we introduce our recent progresses in high-power transmission, atomic-level light confinement, ultra-long-range optical pulling, and ultra-sensitive optical sensing based on optical nanofibers.



Limin, Tong (Author1) received his BS in physics, MS in optics and PhD in Material Science and Engineering from Zhejiang University in 1991, 1994 and 1997, respectively. His research interest has been in the area of nanophotonics and light-matter interaction. He has authored more than 300 papers in leading technical journals and conferences. He received the National Science Foundation for Outstanding Young Scholars (China) in 2004, the WANG Daheng Optics Prize (Chinese Optics Society) in 2007, the Chang Jiang Scholars (Ministry of Education, China) in 2012. He is a fellow of Optica, and a New Cornerstone Investigator.

Meta-optics 3.0: On-chip Metasurface for Revolutionary Applications

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Abstract In this talk, I would like to report new progresses of on-chip metasurface mounted with CMOS sensor for compact microscope, wavefront sensor and LiDAR applications.

Introduction (Arial 9 pt Bold)

Optical metasurface, as a new kind of optical design with 2D architecture, has enabled versatile functionalities towards new conceptual optical devices and systems. Thanks to its extremely high flexibility in structural design and powerful capability in optical wave tailoring, optical metasurfaces are revolutionizing both newly-emerging technologies and conventional optical techniques. In optics regime, we would like to term the bulk metamaterials as meta-optics 1.0, the ultra-thin metasurface as meta-optics 2.0. Now, when metasurface is tightly integrated with optoelectronic device to work for well defined applications, we call meta-device as meta-optics 3.0.

Compact Meta-microscope

Metasurface is well recognized for its ultra-thin and ultra-light feature. In fact, flat architecture enables it well compatible with CMOS Image Sensor (CIS), which possibly revolutionizes the conventional imaging system. In this talk, I would like to first introduce our progresses in developing ultra-compact meta-microscope by directly integration metalens to the CIS chip. Here, large field-of-view (FOV) meta-microscope will be mainly addressed, which is composed of metalens array that breaks the Space-Bandwidth Product limitation in conventional microscope [1]. Then, neuro network is employed to such a compact large FOV meta-microscope to further improve the resolution [2]. More recently, we developed the meta-microscope for Quantitative Phase Imaging (QPI) [3,4], which show great advantage in miniaturizing complex optical system by meta-devices.

On-chip Metasurface for Wavefront Sensing

In area of wavefront sensing, conventional Shack–Hartmann sensors usually have limitations in dynamic range. Here, we present, for the first time, a chip-integrated metasurface Shack–Hartmann sensor operating directly on a CIS chip, enabled by a dual-encoding strategy. Orientation-encoded double-helix point spread functions extend the dynamic range to $\pm 9.4^\circ$ per channel without degrading localization accuracy. The architecture inherently supports vectorial wavefront sensing, enabling reconstruction of polarization-phase distortions. We demonstrate high-fidelity 3D localization of point source, high-precision lens profilometry, and video-rate dynamic wavefront monitoring, establishing a scalable platform for alignment-free, high-performance metrology [5].

On-chip Metasurface Enabled LiDAR application

In this third part, we also show metasurface enhanced LiDAR functions. First, in the all-solid scanning component, we developed optical phase array (OPA) chip based the thin film Lithunibate (TFLN) platform, showing its fast scanning rate with low power-consuming [6]. By integrating metasurface in the output port, the scanning FOV is greatly improved according to the polarization splitting effect [7,8]. Moreover, in a very recent work, we show a metasurface empowered polarization FMCW LiDAR, which enables not only the detections of distance and velocity of objects, but also the material property. In particular for instances, it can distinguish an object to be whether a virtue image from a mirror or a real one.

Conclusions

finally, I would like to address some new perspectives to future development of metasurface technology, including the deep combination of AI with meta-technology.

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Tao Li received her BS degree and his PhD degrees from Nanjing University in 2000 and 2005, respectively, all in Physics. Tao Li's research interest has been in the area of optical metamaterials, Integrated photonics and topological photonics. He has authored over 150 papers in leading technical journals and conferences like Nature, Nature Nano., Nature Commun., Science Advances, PRL, etc, which received more than 10000 citations. He has won the "Top Ten Optical Advances of China" for 4 times and "Top Ten Optical Industry Technologies in China" once.

Energy-Efficient High-Speed Vertical-Cavity Surface-Emitting Lasers

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The explosive growth of AI and hyperscale data centers demands ultra-fast, energy-efficient optical interconnects, where VCSELs play a pivotal role. To meet Tb/s aggregate capacities while reducing power consumption, single-mode VCSELs in the 850–940 nm window offer a clear solution by eliminating modal dispersion and enabling dense wavelength multiplexing.

Photon lifetime engineering has been proven to optimize the trade-off between bit rate and energy per bit (EDR) in VCSELs [1]. Building on this concept, we demonstrate 940-nm single-mode VCSELs with a 15-nm gain-to-cavity offset and optimized mirror/QW designs [2,3]. By optimizing photon lifetime, these devices achieve record EDRs of 69 fJ/bit at 100 Gb/s and 85.6 fJ/bit at 108 Gb/s under PAM4 modulation, with a maximum 3 dB bandwidth of 33 GHz and SMSR >40 dB, enabling error-free transmission over 100 m OM5 fiber.

To further mitigate thermal saturation and increase rollover current, output power and bandwidth, we developed Multi-Hole Aperture (MuHA) VCSELs with gold-filled holes [4] and rings [5], which reduce thermal impedance and series resistance while providing more homogeneous current injection. Combining MuHA structures into Multi-Aperture VCSELs (MAVs) yields pseudo-single-mode emission with 8-10 mW output power [6]. These advanced VCSEL architectures represent a key step toward energy-sustainable AI-driven data centers.

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Poster Session II

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PII-01

Record Energy-Efficiency of Single-Mode VCSELs for Next-Generation Dense Wavelength Multiplexing Optical Links

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Xing-Chen Ai (for consideration of Best Student Poster Award).

Abstract 940 nm single-mode VCSELs based on deep-oxide-flanked QWs show a record energy efficiency of 69/85.6 fJ/bit at 100 Gbps/108 Gb/s across 100 m OM5 fiber, enabling dense wavelength multiplexing for Tb/s links.

Introduction

The power consumption of data centers is exploding, driven amongst others by AI proliferation. By 2026, data centers worldwide are expected to consume more than 1,000 TWh of electricity annually, equal to Japan's total energy consumption, up from 460 TWh in 2022 [1]. This increase drives the demand for low-power, cost-effective optical interconnects. Additionally, the demand for much larger data rates in the Tb/s range must be met. While 850 nm VCSELs dominate currently short-reach links, IEEE has already previously standardized coarse wavelength multiplexing combining 850, 880, 910 and 940 nm multi-mode sources in the same fiber. Dense multiplexing large data rate lasers would enable aggregated lane capacities in the Tbit/s range, directly matching the scaling objectives of the upcoming IEEE P802.3dj standard framework [2]. Sufficiently high-power, single-mode VCSELs in this wavelength window eliminate fiber dispersion, present the technologically easiest basis to meet the future IEEE standard and provide a clear architectural pathway advantage. Here we present our latest results on energy-efficient 940 nm single-mode VCSELs, demonstrating the feasibility of our approach towards Tb/s lane rates.

The lasers and thermal impact on VCSEL electro-optical characteristics

Various types of wafers are grown along [001] on GaAs substrates via MOCVD. The QWs are sandwiched between 2 closely flanking deep oxide layers. We fabricate 2-3 μm size oxide apertures having the advantages: (1) enhancing current injection efficiency into the active region, thereby reducing the threshold current and improving energy efficiency. (2) increasing the photon density, allowing the bandwidth to rise rapidly with increasing current. Our devices exhibit stable single-mode operation, effectively suppressing modal dispersion. Some of them are processed with surface gratings, leading to single-polarization operation, eliminating polarization switching noise. At 25°C, a typical 2 μm oxide aperture VCSEL type A features a 0.175 mA threshold at 2 V and 2.09 mW maximum power at rollover current of 4.75 mA. Above threshold, the SMSR exceeds 30 dB (41.05 dB maximum). A Crosslight PICS3D model was developed to investigate the influence of self-heating effects on performance. As shown in Figure 1, the measured LIV data diverge from the isothermal prediction above a few milliamperes due to self-heating. The simulated slope efficiency is 1.01 mW/mA, larger than the measured value of 0.69 mW/mA. Figure 2 demonstrates that self-heating reduces the simulated isothermal bandwidth from 41.61 GHz to 33.32 GHz, close to our best experimental results.

Large Data Rates and Energy Efficiency

NRZ EDRs of type A lasers with grating are 105.85/126.68 fJ/bit at 65 Gbps ($Q > 3$) and 85.6/121.1 fJ/bit at 60 Gbps ($Q > 3.4$) for 1 m / 100 m OM5 MMF. For PAM4 modulation EDRs are 85 - 87 fJ/bit at 106-108 Gbps. At 100 Gbps, EDRs are 67 - 69 fJ/bit for 1 m and 100 m transmission, and 690 fJ/(bit-km) EDDR. Figure 3 shows these results and eye diagrams. Figure 4 compares our results with the literature data under PAM4 modulation.

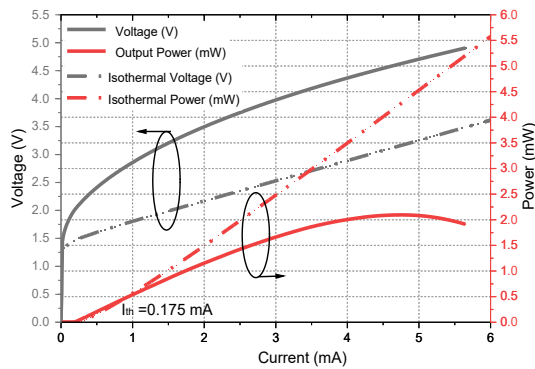


Fig. 1 Isothermal Simulation vs Experimental LIV

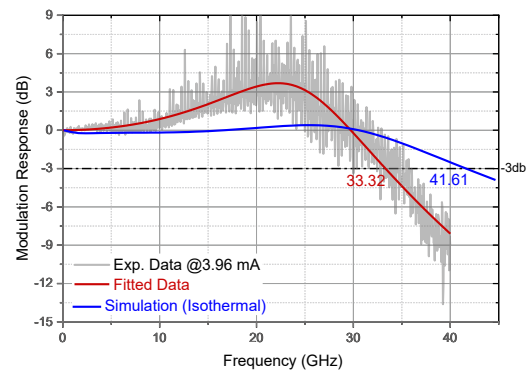


Fig. 2 3dB bandwidth at 3.96 mA, type B without grating

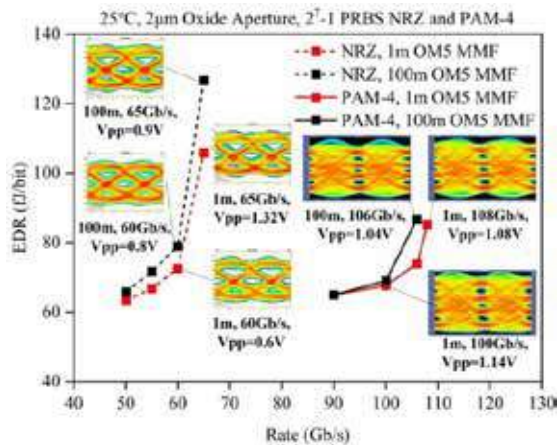


Fig. 3 EDR vs data rate, and corresponding eye diagrams (type A)

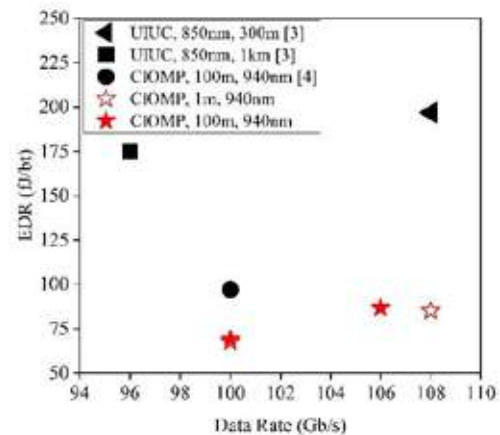


Fig. 4 Comparison of single-mode EDR values under PAM-4 modulation [3][4]

Conclusions

We report a record energy efficiency for 940 nm single-mode VCSELs based on a proprietary design showing EDR values of 69 fJ/bit at 100 Gb/s across 100 m, and 85.6 fJ/bit at 108 Gb/s across 1m OM5 fiber.

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PII-02

Direct current modulation of 2D Photonic Crystal Nanolaser-diode

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Abstract: We report modulation bandwidth measurements of electrically-injected hybrid III-V/Si 2D photonic crystal nanolasers. Using a custom electro-optic bench, direct modulation bandwidths up to 10 GHz are demonstrated, with >20 GHz targeted in ongoing doctoral work.

Introduction

The rapid growth of data-intensive computing workloads - driven by AI requirements - is pushing on-chip electrical interconnects toward fundamental physical limits in bandwidth density and energy efficiency. Copper interconnects face an intrinsic energy-per-bit floor that rises with signaling rate, making further scaling energetically prohibitive [1]. Integrated optical interconnects offer a path to overcome this bottleneck, thanks to CMOS-compatible on-silicon laser sources [2]. Among the candidate architectures, hybrid III-V/Si photonic crystal nanolaser diodes are particularly compelling: PhC nanocavities bonded onto SOI waveguides enable electrically injected lasing at room temperature with sub-100 μ A threshold currents [3,4], and direct modulation up to 10 Gbit/s has been demonstrated on complete silicon photonic links [5].

2D Photonic Crystal Nanolaser Platform

The studied structure is shown in Fig.1. It consists of an InP/InGaAsP MQW membrane bonded onto an SOI substrate via a BCB adhesive layer. A 2D array of air holes etched into the III-V membrane defines a photonic bandgap; a linear defect on one side forms a waveguide and the optical cavity. The lasing mode is laterally confined by the PhC bandgap on one side and by total internal reflection on the other, and vertically by index guiding in the III-V slab. Evanescent coupling through the BCB layer links the PhC waveguide to the underlying SOI circuit. A vertical P-i-N junction provides electrical injection, with the intrinsic MQWs region aligned with the optical mode. The same structure can operate as a photodetector

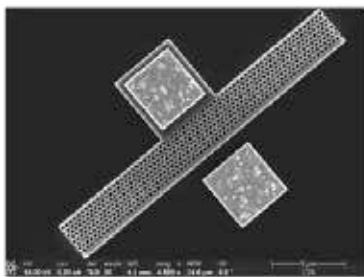


Fig. 1 - SEM image of the studied 2D PhC cavity

under reverse bias.

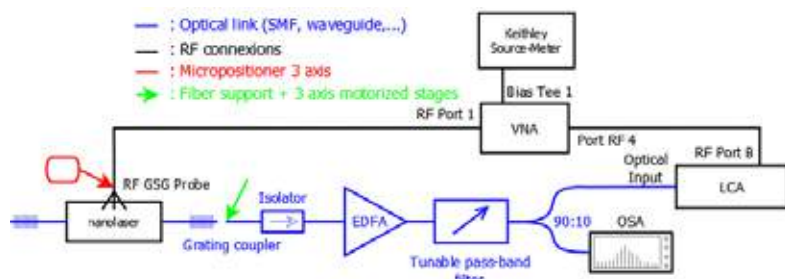


Fig. 2 – Experimental setup for Nanolaser bandwidth characterization

Electro-Optic Characterization bench

We developed a broadband E/O bandwidth characterization bench covering up to 67 GHz (Fig. 2). A vectorial network analyser (Keysight PNA N5227A) modulates the injection current via a bias tee and GSG RF probe. The optical output is collected through a grating coupler into a single-mode fiber, amplified by an EDFA, filtered by a tunable bandpass filter, and detected by a lightwave component analyser (Keysight N4373D). The S_{41} parameter directly yields the E/O frequency response after calibration of the bench response. Instrument control and data acquisition are automated in Python.

Results

The measured devices exhibit threshold currents in the 100–300 μA range and single-mode emission across 1500–1600 nm. Fig. 3 illustrates a continuous redshift of the emission wavelength (~ 3 nm over 200–550 μA) for an increasing pump current. The E/O small-signal frequency response (Fig. 4 inset) shows a relaxation oscillation peak characteristic of the rate-equation small-signal model, whose frequency increases with pump current before decreasing at higher drive levels, attributed to thermal effects as evidenced by the wavelength redshift. Bandwidths above 7 GHz are routinely measured; on the best-performing cavities, 10 GHz is demonstrated.

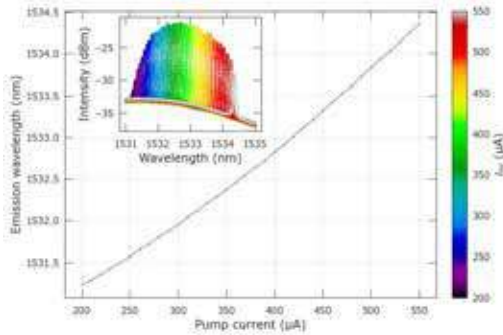


Fig. 3 – Laser emission wavelength as a function of pump current. (Inset) Emission spectra for different pump current.

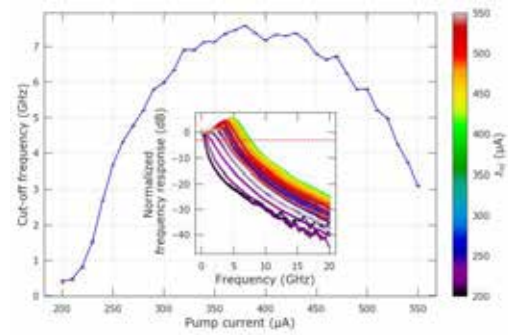


Fig. 4 – Extracted -3 dB bandwidth as a function of pump current. (Inset) Normalized E/O frequency response for pump currents from 200 to 550 μA .

Conclusions

Direct modulation bandwidths up to 10 GHz have been measured on hybrid 2D-PhC III-V/Si nanolasers, validating both the theoretical framework and the E/O characterization platform. These results form the starting point of an ongoing industrial PhD thesis (NcodiN/INPHYNI) with three objectives: (i) PhC cavity design optimization (increasing Q factor and mode volume) through FDTD simulation; (ii) fabrication improvement, especially passivation; (iii) advanced characterization toward >20 GHz direct modulation for chip-scale optical interconnects.

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Raphaël Amerette information not available at the time of submission.

Fabrice Raineri information not available at the time of submission.

Bruno Garbin information not available at the time of submission.

Patricia Loren information not available at the time of submission.

Ayman Kamel information not available at the time of submission.

François Gustave information not available at the time of submission.

Zubair Iftikhar information not available at the time of submission.

Jonathan Peltier information not available at the time of submission.

PII-03

Cascaded four-wave mixing decorated supercontinuum with discrete colorful rings during filamentation

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Zhiwenqi An is a student for consideration of the Best Student Poster Award.

Abstract

Colored rings in femtosecond laser filamentation are interpreted via cascaded four-wave mixing. The model reproduces wavelength-dependent divergence angles, clarifying supercontinuum formation and guiding efficient spatial-spectral generation of multi-wavelength ultrashort pulses from ultraviolet to infrared ranges.

Introduction

Femtosecond laser filamentation in transparent optical media, typically driven by Ti:sapphire pulses near 800 nm, produces strong spectral broadening and a bright white-light core surrounded by concentric colored rings. The central white-light supercontinuum has been widely attributed to self-phase modulation, self-steepening, and medium ionization. However, the surrounding colored rings, usually referred to as conical emission, remain incompletely understood. Existing models, including Cherenkov radiation, conventional four-wave mixing, and X-wave formation, can explain certain aspects of conical emission but cannot quantitatively reproduce the discrete colors, wavelengths, and divergence angles observed in experiments.

Cascaded four-wave mixing *CFWM* of intersecting femtosecond beams provides an efficient route for generating multi-wavelength ultrashort pulses. Inspired by the similarity between CFWM-induced discrete colored rings and those observed during filamentation, this work investigates whether CFWM can explain the spatial-spectral structure of filamentation-induced colored rings. By combining systematic measurements with phase-matching analysis, we show that CFWM accurately predicts the correlation between ring color and divergence angle.

Experimental Results

The experiment employed 50 fs, 800 nm Ti:sapphire laser pulses with pulse energies up to 4 mJ and a repetition rate of 500 Hz. The beam was focused into a fused silica sample using lenses with focal lengths of 10, 20, and 30 cm. The generated white-light supercontinuum and colored rings were recorded on a screen 20 cm behind the glass center, while spatially resolved spectra were measured using a fiber probe connected to a spectrometer.

Energy-dependent measurements showed that the appearance of colored rings is closely related to filamentation. At about 0.16 μJ , a bright white spot with a weak diffused ring appeared. At 0.1 μJ , the signal weakened significantly, and at 0.08 μJ the spectrum approached that of the pump laser. This agrees with the calculated self-focusing threshold in fused silica, confirming that the colored rings originate from nonlinear filamentation dynamics.

The spatial-spectral measurements further show that the colored rings are discrete in wavelength and angle. For focal lengths of 10, 20, and 30 cm, continuous white-light emission was accompanied by short-wavelength colored rings with measurable divergence angles. A shorter focal length produced larger conical divergence angles, indicating that the ring structure is governed by focusing geometry and nonlinear phase accumulation.

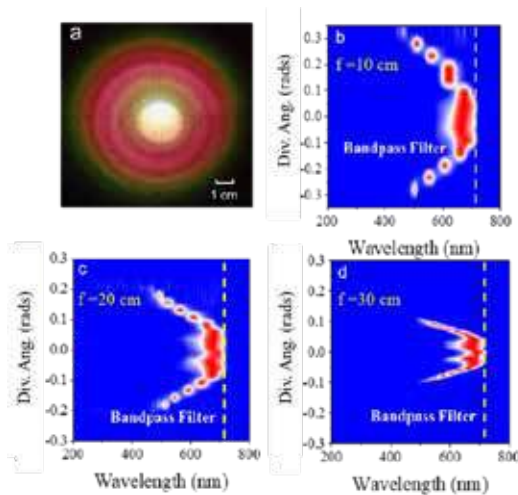


Fig. 1 Spatial and spectral patterns of supercontinuum and colorful rings for different focus lengths

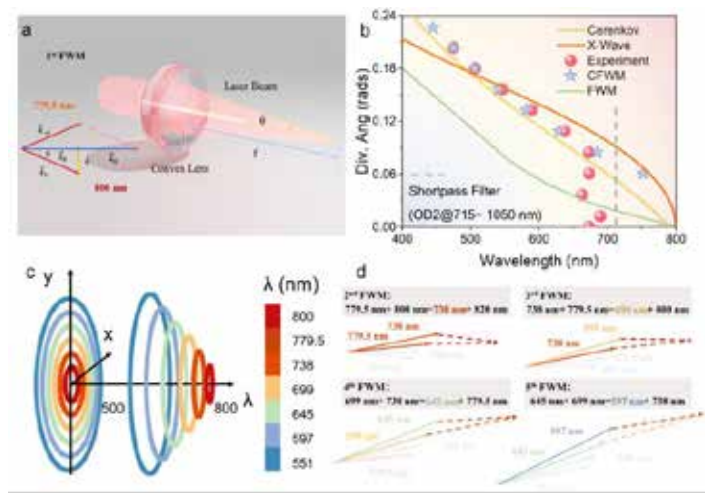


Fig. 2 CFWM based physical scenario of discrete colorful rings during filamentation

CFWM Model and Physical Picture

The observed ring structure is interpreted using a CFWM model. During filamentation, forward degenerate four-wave mixing first amplifies weak spatial side modes from the fundamental 800 nm beam. These side modes then participate in cascaded frequency conversion processes, generating a series of anti-Stokes components. In this picture, the first generated sideband appears near 779.5 nm, followed by higher-order CFWM components such as 738 nm, 699 nm, 645 nm, 597 nm, and 551 nm.

Both energy conservation and momentum conservation must be satisfied in each CFWM step. The divergence angle of each generated wavelength is determined by the transverse wave-vector component associated with maximum nonlinear gain. Therefore, the model naturally links the spectral position of each colored ring with its spatial emission angle. Compared with Cherenkov, X-wave, and conventional FWM models, CFWM not only reproduces the wavelength-dependent divergence angles but also explains why the rings appear as spatially discrete structures.

Phase-Matching Analysis

To verify the CFWM mechanism, the relative wave-vector mismatch was calculated as a function of wavelength and divergence angle. Efficient CFWM occurs when the mismatch is sufficiently small. The experimentally observed peak wavelengths and emission angles fall within the predicted phase-matching regions for different focal lengths, supporting the CFWM interpretation.

For a focal length of 10 cm, the pump divergence angle was about 69.8 mrad, corresponding to a calculated first-stage CFWM wavelength of 759 nm. For a focal length of 30 cm, the pump divergence angle decreased to about 23.3 mrad, corresponding to a first-stage wavelength of 790 nm. These results confirm that the CFWM model remains valid under different focusing geometries and can quantitatively describe the formation of discrete colored rings during filamentation.

Conclusions

This work demonstrates that discrete colored rings accompanying femtosecond laser filamentation in fused silica are predominantly governed by cascaded four-wave mixing. The CFWM model quantitatively reproduces the relationship between wavelength and divergence angle and explains the spatially discrete nature of the ring structure. These results deepen the understanding of supercontinuum generation during filamentation and provide guidance for controlling the spatial-spectral configuration of multi-wavelength ultrashort optical pulses.

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PII-04

VCSELs: Characterization by Optical Impulse Response and Direct Observation of Spectral Hole Burning

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Abstract The impulse response of a 1060 nm InGaAs VCSEL obtained by injecting a 300-fs pulse at 1030-nm reveals a parasitic free bandwidth above 30 GHz and a direct observation of spectral hole burning.

Introduction

VCSELs are key components in short-reach optical interconnects, with state-of-the-art devices achieving modulation rates of up to 50 Gbit/s NRZ and well over 100 Gbit/s using the PAM 4 format. Standard S21 characterization captures the full small signal electro-optical response, which includes contributions from electrical parasitics such as device capacitance and series resistance introduced by current injection through the top P-type DBR. These parasitics mask the intrinsic carrier dynamics and limit the assessment of the inherent bandwidth. In all semiconductor lasers, the inherent bandwidth is limited by the nonlinear gain. A key contribution to the nonlinear gain is spectral hole burning (SHB) yet no direct optical measurement of SHB in VCSELs has been demonstrated. We present a characterization approach based on ultrashort-pulse excitation of a 1060 nm InGaAs VCSEL using a 1030 nm 300 fs pulse from a Yb fiber laser. This enables both direct measurement of the intrinsic impulse response, free from electrical parasitics, while at the same time, a direct observation of spectral hole burning.

Experimental Setup

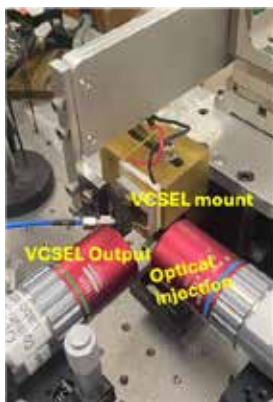


Fig. 1 – Experimental set up

The excitation source is a mode-locked Yb-doped fiber laser emitting at 1030 nm. Its short pulses are coupled into the 1060 nm InGaAs quantum well VCSEL, driving carrier dynamics directly without involving the electrical contacts.

Since the top DBR reflects at 1030 nm, we couple the pulses from the side of the VCSEL. A photograph of the system is shown in Fig. 1.

The VCSEL output is captured using a high-speed photodetector. Electro-optic S21 measurements, shown in Fig. 2 serve as a baseline.

Results

The S21 measurement yields a maximum modulation bandwidth of roughly 20 GHz (Fig. 2), reflecting the combined response of intrinsic carrier dynamics and electrical parasitics including device capacitance and P-DBR series resistance. The impulse response is shown in Fig. 3. It reveals two significant details. First, the impulse response is 32 ps wide which represents an equivalent bandwidth of roughly 30 GHz, well above the bandwidth measured electrically (Fig. 2). This proves the significance of performing parasitic free optical modulation. Moreover, the impulse response is preceded by a negative signal with a width of 20 ps. This signal is unresolved by the 42 GHz detector used in the experiment. This

negative response represents a direct observation of spectral hole burning.

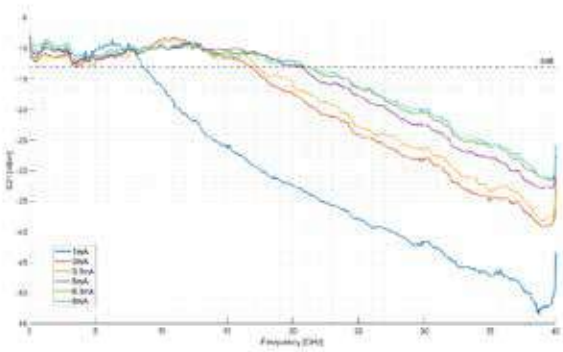


Fig. 2 S21 measurements of VCSEL in varying bias currents

The carrier distribution within the VCSEL gain spectrum contains carriers at energy levels higher than that of the oscillating wavelength of 1060 nm. A short pulse at 1030 nm interacts with the corresponding carrier and induces a spectral hole in that corresponding energy. This modifies the balance of carrier injection to the oscillating energy leading to a reduction of the power output at 1060 nm. Once the spectral hole recovers, the VCSEL response to the pulsed excitation and reveals the 32 ps pulse which represents roughly 30 GHz bandwidth.

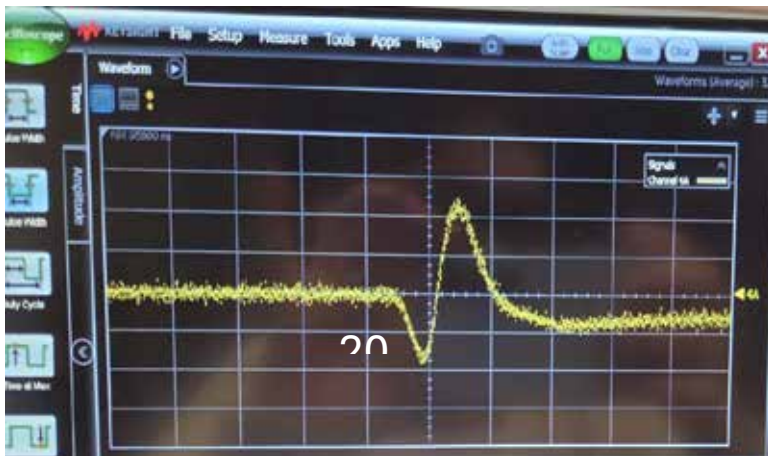


Fig. 3 – Impulse response

Conclusions

Optical impulse response characterization using a 1030 nm, 300 fs pulse from a Yb fiber laser reveals intrinsic carrier dynamics in a 1060nm InGaAs VCSEL exceeding 30 GHz, compared to roughly 20 GHz measured in traditional techniques— directly quantifying the bandwidth penalty from electrical parasitics. At the same time, the optical pulse excitation reveals directly spectral hole burning in the form of a negative pulse at 1060 nm. This approach enables the first direct optical measurement of spectral hole burning in a VCSEL, providing access to ultrafast gain dynamics on a sub-picosecond timescale that is inaccessible to conventional electrical characterization methods.

The spectral hole burning pulse in Fig. 3 is unresolved with the 42 GHz detector used in the experiment. It has to be characterized using electro optic sampling which is ongoing. The electro optic sampling scheme will serve also to characterize the intrinsic impulse response in VCSELs whose bandwidth is significantly wider than the present laser.



Roni, Bar received her BS degree from Technion, in 2025, in Electrical Engineering.

PII-05

High-Efficiency Interlayer Coupler between Si and Low-index (~ 1.6) SiON Waveguide with Low Polarization Dependent Loss

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Abstract We demonstrate a Si–SiON interlayer coupler using low-refractive-index SiON for multilayer photonic integration. Simulations and measurements confirm efficient, low-polarization-dependent interlayer coupling with sub-0.5 dB/coupler insertion losses for both TE and TM modes.

Introduction

The advancement of multilayer integration is essential for realizing high-density optical interconnects [1]. In such multilayer photonic integrated circuits, interlayer couplers are crucial elements for optical coupling between different layers and are therefore required to achieve high coupling efficiency, large alignment tolerance, and low polarization dependence for robust operation under random polarization states. To meet these requirements, we design, fabricate, and characterize a high-efficiency Si–SiON interlayer coupler. By using low-refractive-index SiON ($n = 1.6$) as the upper-layer waveguide instead of a conventional SiN waveguide [2], the proposed structure is expected to reduce polarization-dependent loss and improve alignment tolerance. In this report, simulation and measurement results of fabricated device are presented and discussed.

Design and Fabrication

Fig. 1 shows the proposed SiON interlayer coupler and its optimized geometric parameters for achieving high coupling efficiency while maintaining low polarization dependence. Based on the calculation results reported previously [3], a SiON waveguide width of $2.2\ \mu\text{m}$ and height of $0.6\ \mu\text{m}$ was adopted to achieve high interlayer coupling efficiency and large fabrication tolerance. Fig. 2 shows an optical microscope image of the fabricated interlayer couplers. The key fabrication steps are formation of metal lift-off marks for precise electron-beam lithography alignment and chemical mechanical polishing for planarizing the SiO_2 surface before SiON deposition.

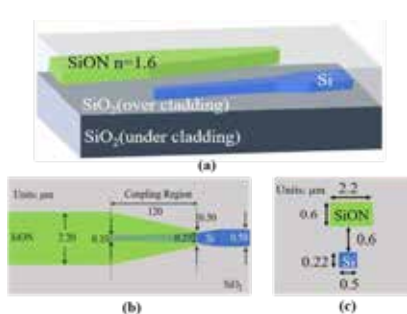


Fig. 1 SiON-Si interlayer coupler, (a) Whole structure, (b) Top view, (c) Cross-sectional view

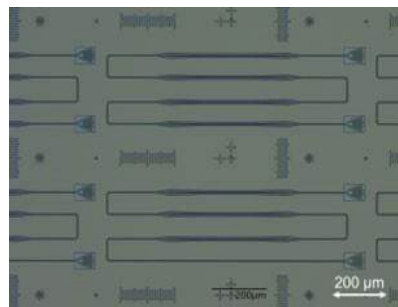


Fig. 2 Optical microscope image of the fabricated interlayer couplers

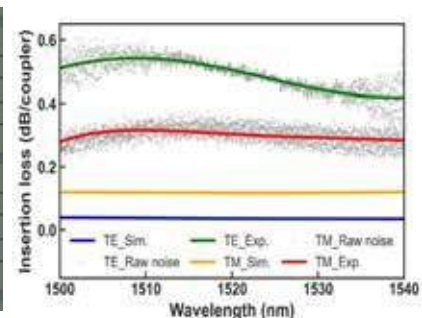


Fig. 3 Simulated and measured insertion loss of the coupler for TE and TM mode

Results

As shown in Fig. 3, the simulated interlayer insertion loss was 0.04 dB/coupler for the TE mode and 0.13 dB/coupler for the TM mode across the C-band under the optimized design conditions. Experimentally, the fabricated Si–SiON interlayer coupler exhibited an insertion loss of 0.26 dB/coupler for the TE mode and 0.45 dB/coupler for the TM mode at $1.525\ \mu\text{m}$, as shown in Fig. 3. The measurable wavelength range was limited by the wavelength range of the fabricated grating couplers. The measured insertion loss per coupler was extracted by comparing devices with different numbers of interlayer couplers. Furthermore, the calculation results confirmed that a coupling efficiency of more than 90% can be maintained even with a horizontal misalignment of $1\ \mu\text{m}$.

Conclusions

We demonstrated a Si-SiON interlayer coupler using low-refractive-index SiON for multilayer photonic integration. The simulations predicted low interlayer insertion losses of 0.04 dB/coupler for the TE mode and 0.13 dB/coupler for the TM mode across the C-band, as well as a coupling efficiency above 90% under a horizontal misalignment of 1 μm . The fabricated device achieved insertion losses of 0.26 dB/coupler for the TE mode and 0.45 dB/coupler for the TM mode at 1.525 μm . These results indicate that the proposed structure is a promising approach for efficient and lowpolarization-dependent interlayer optical coupling.

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P11-06

High-brightness single-lateral-mode quantum dot HiBBEE lasers for LiDAR light sources at 1.2- 1.3 μm

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Abstract Quantum dot based high-brightness vertical broad-area edge-emitting lasers based on square corrugated waveguides for the wavelength window 1.2 – 1.3 μm are demonstrated for the first time. Such lasers are advantageous for automotive applications.

Introduction

The output power of semiconductor lasers used for automotive applications is limited by the eye safety standard DIN EN 60825-1. The maximum allowed cw output power at emission wavelengths between 1200 and 1400 nm is ~ 20 times larger than at the presently used 905 nm wavelength. In addition, atmospheric transmission is nearly 100% between 1200 nm and 1300 nm. LiDAR systems operating at these wavelengths can control much larger distances and are of similar or lower cost as present systems, as long as they are based on GaAs/InAs QD-lasers emitting in this wavelength range.

High beam quality and temperature stability simplify the optical system and reduce ownership costs. Most conventional ridge waveguide lasers suffer from an asymmetric beam profile, poor beam quality and of astigmatism in the case of high-power trapezoidal lasers. We combine here two patented approaches: HiBBEE epitaxy greatly reducing the far-field divergence angle of the laser and increasing the brightness [1,4,] with corrugated waveguides increasing the single mode output power on the expense of higher order modes [2,3]. Here we present for the first time corrugated-waveguide HiBBEE laser diodes on GaAs substrates with densely stacked InGaAs QD layers as the active region.

Device design and Results

In previous work, we have verified the validity of our concept combining the HiBBEE vertical design with the corrugated lateral design, using quantum wells for the active area by comparing several different corrugation designs and finding the optimum. We reported, that square shape corrugations are optimum in suppressing the emission of higher-order modes, feeding power to the fundamental lateral mode. Furthermore, by utilizing HiBBEE vertical structures, a significant reduction of vertical far-field divergence was achieved, with a divergence angle of 10° at FWHM. A schematic diagram of a square-shaped corrugated waveguide HiBBEE lasers is shown in Fig 1.

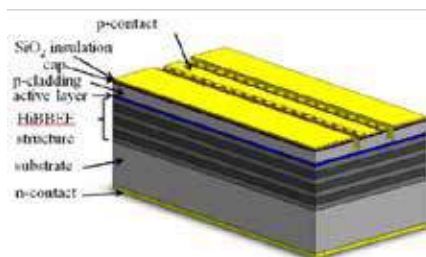


Fig.1 schematic diagram of a square-shaped corrugated waveguide HiBBEE laser

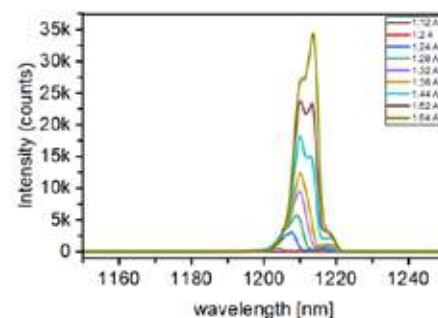


Fig. 2 lasing spectra at different currents of the fundamental mode

Since laser emission at 1.2 μm from defect-free GaAs QW-lasers was until now not demonstrated, we designed GaAs-based quantum dot lasers to realize lasing at 1.2 μm . Our laser structure includes 5 QD layers and 6 HiBBEE layers for

the lower waveguide cladding. Fig. 2 shows lasing spectra at different currents. The details of the MOCVD grown structure, along with the refractive index profile and near-field distributions of the fundamental and the first two higher-order modes, are shown in Fig. 3, left. The broad expansion of the fundamental mode gives rise to a narrow full width at half maximum vertical divergence angle of 12° as shown in Fig. 3, right.

Then, a ridge waveguide of $15\ \mu\text{m}$ width combined with $5\ \mu\text{m}$ square corrugations was formed by etching down to the bottom of the p-cladding layer. After depositing a SiO_2 insulating layer, the electrode contact area was etched out. The p- and n- type electrodes were then evaporated separately. The wafer was cleaved into individual chips with a $2\ \text{mm}$ cavity length. The lasers received AR/HR coatings and a passivation layer on the AR side. Finally, they were mounted p-side down on C-mount copper heat sinks for better heat removal. The lasers are characterized in CW mode at a heatsink temperature of $T = 20^\circ\text{C}$.

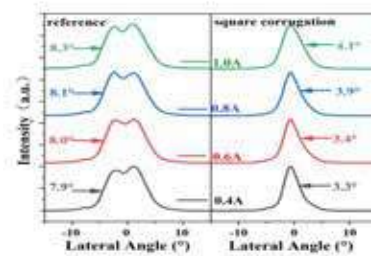
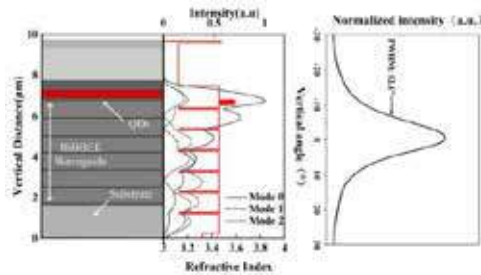


Fig.3 Left: schematic diagram of the HiBBEE structure, refractive index profile and simulated near-field amplitude of the fundamental and first two higher-order modes; right simulated far-field distribution of the fundamental mode

Fig. 4 Far-field distributions in the lateral direction of a reference laser (left) and of a square corrugated laser (right)

We have compared the brightness of our single mode QD $1210\ \text{nm}$ lasers to those of the omnipresent $905\ \text{nm}$ single mode lasers used for LIDAR and found an increase by more than 100%.

Conclusions

We have realized a QD HiBBEE lasers at $1210\ \text{nm}$ wavelength. The HiBBEE structure can extend the optical field across the vertical direction, thus decreasing the vertical divergence angle. The square-shaped corrugated waveguides can introduce more losses to the higher-order modes compared to the fundamental mode, therefore increasing single transverse mode output power, improving beam quality, and the brightness of the devices. These still preliminary results present a proof of concept for novel lasers for LIDAR applications in the shortest wavelength eye safety window.

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- 4 Cheng-Kun Wu, *et al.*, APL Photonics, 9 (2024) 126113.



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PII-07

Spectral Localizer in Valley Photonic Crystals

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Abstract Spectral Localizer (SL) is a real-space based operator for diagnosing topological states. In this work, SL is utilized to analyze two disordered Valley photonic systems: topological Anderson phase transition and robust topological edge states.

Introduction

Introducing disorder into valley photonic crystals (VPCs) can drive a topological Anderson transition between topologically trivial and nontrivial phases. A direct way to identify such a transition is to examine the existence of edge states. For example, one can introduce disorder into an initially topologically trivial interface and check whether robust edge states emerge.

However, this phenomenological approach lacks a quantitative characterization of topological localized states. More importantly, it is difficult to determine whether the observed edge-state-like response originates from a genuine disorder-induced topological phase transition or is merely a consequence of Anderson localization. In disordered systems, conventional momentum-space topological invariants defined within band theory are no longer directly applicable. Therefore, a real-space topological diagnostic is required.

The spectral localizer method provides such a framework by combining the system Hamiltonian with position operators into a finite-dimensional Hermitian localizer matrix. This method has been widely adopted because it is compatible with finite-size and disordered systems and provides a quantitative real-space criterion for identifying topological localized state [1]-[3]. Therefore, we employ the spectral localizer method to quantitatively analyze disorder-induced topological phase transitions in VPCs.

Since the systems studied in this work operate in the TM modes, the corresponding spectral localizer can be written as:

$$L(Y, H) = \begin{pmatrix} 0 & (H - E\mathbf{1}) - i\kappa(Y - y_0\mathbf{1}) \\ (H - E\mathbf{1}) + i\kappa(Y - y_0\mathbf{1}) & 0 \end{pmatrix}$$

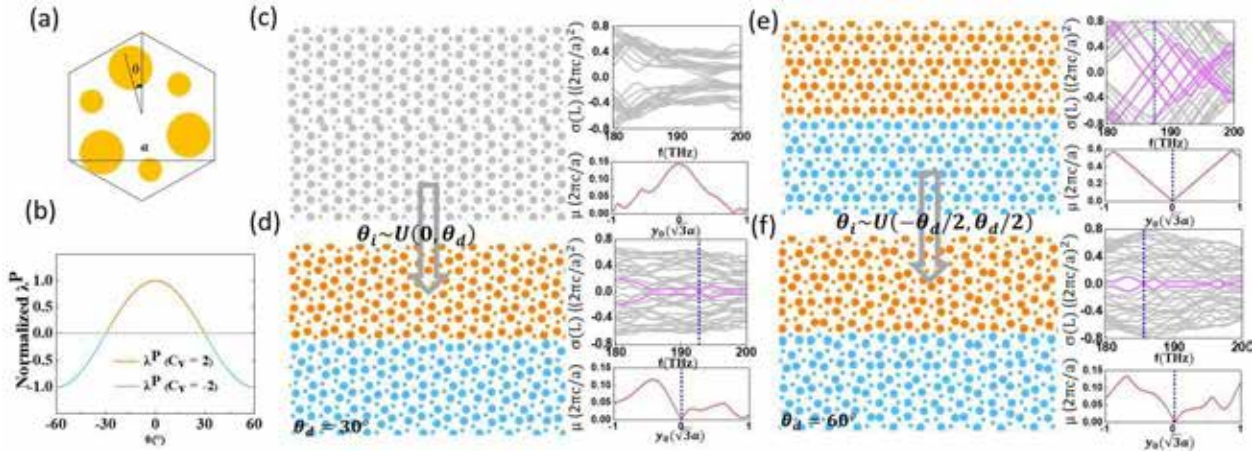
$$H = -M^{-1/2}WM^{-1/2} \quad E = (2\pi f)^2 \quad \kappa = 0.01(2\pi c)^2/\alpha^3 \quad (1)$$

$$\mu_{(y, f_0)} = \sqrt{\min(|\text{spec}[L(y, f_0)]|)}$$

where α is a tuning coefficient used to ensure consistent units and comparable contributions of operators H and Y , M is the matrix of relative permittivity $\epsilon(x, y)$, W is the discrete Laplacian matrix, Y is the y position operator, $\mathbf{1}$ is the identity, and f is the frequency of the mode. The position y_0 and energy E (or frequency f) are the inputs of the spectral localizer $L(Y, H)$, and the spectrum of the $L(Y, H)$ quantifies whether the system exhibits a topological edge state approximately localized at (y, E_0) . If there are eigenvalues crossing zero, related to the local gap $(y, E_0) = 0$, then a localized state could exist at (y, E_0) .

Topological properties of VPC

The structure of C3-symmetric VPC is shown in Fig. 1(a), where the atoms can be rotated by angle θ . The topological invariant of valley Chern number could be determined by λ^P . The phase diagram is shown in Fig. 1(b).



Localized topological properties of the disordered VPC

This work has focused on two aspects of topological phase transition in VPC.

Firstly, we have used SL to verify the low-threshold emergence of topological edge state. We start with an interface composed of two parts of VPC with phases of $\theta = 30^\circ$. Since the two phases have a valley Chern number $C_v = 0$, they correspond to topological trivial phases and there should not support topological edge states. Disorder is then introduced by randomly rotating the Si rods in each unit cell, with the random rotation angle following the uniform distribution of $\theta_i \sim U(0, \theta_d)$, where θ_d represents the disorders strength. When θ_d increases, more cells on both sides of the interface acquire opposite valley Chern numbers, leading to topological phase transition. The scan diagrams of initial and disordered VPC are shown in Fig. 1(c)(d). These results show that local gap $(y E_0)$ vanishes at interface $y_0 = 0$ with disorder $\theta_d = 30^\circ$, indicating the occurrence of a topological phase transition and the emergence of topological edge state.

Secondly, we have studied the robustness of topological edge states against disorder. Different from the above case, the initial VPC consists of two parts with $\theta = 0^\circ, 60^\circ$, corresponding to valley Chern number $C_v = \pm 2$; therefore, topological edge state should exist at the interface. Then introduce disorder of $\theta_i \sim U(-\theta_d/2, \theta_d/2)$. Fig. 1(e) shows that the local gap $(y E_0)$ vanishes at $y_0 = 0$ in the initial VPC, which corresponds to the conventional topological edge state between non-trivial topological phases. While Fig. 1(f) shows that the local gap $(y E_0)$ also vanishes at $y_0 = 0$ with disorder $\theta_d = 60^\circ$, indicating that the valley topological properties of the VPC are preserved within a disorder range of 60° . These results demonstrate that VPC are robust against strong rotational disorder.

Conclusions

In this work, we have used spectral localizer to quantitatively diagnose disorder-induced topological phase transitions in VPC. The results reveal both the low-threshold emergence of topological edge states from trivial interfaces and the strong robustness of valley edge states against rotational disorder.

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PII-08

A Six-Degree-of-Freedom Heterodyne Grating Interferometer for Atomic-level Precision Measurement

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Abstract We present a six-degree-of-freedom (DOF) heterodyne grating interferometer for atomic-level precision measurement. By integrating a dual-frequency laser and a common-mode-rejection architecture, the system achieves multi-dimensional measurement with a remarkably high signal-to-noise ratio and exceptional environmental stability at the atomic scale.

Introduction

High-precision multi-dimensional displacement measurement is crucial for advanced manufacturing, such as semiconductor lithography and atomic-scale fabrication. The grating interferometer has become a mainstream metrology technology because it relies on the physical grating pitch as a stable benchmark, offering strong anti-interference capabilities and facilitating multi-DOF expansion. However, existing multi-DOF solutions typically rely on stacking multiple single-axis or low-DOF sensors. This approach inevitably introduces catastrophic Abbe errors, increases system volume, and complicates optical alignment. To address this bottleneck, our work proposes a single-probe six-DOF heterodyne grating interferometer. This unified architecture completely eliminates spatial alignment redundancies and minimizes Abbe errors, providing a highly significant multi-dimensional positioning benchmark for precision industry.

Principle of Linear and Angular Measurement

To contextualize the multi-degree-of-freedom (multi-DOF) metrological challenges in high-end industrial systems, Figure 1 illustrates the schematic diagram of a multi-DOF positioning wafer stage within a semiconductor lithography scanner. Conventional sensor stacking configurations within such a confined envelope inevitably exacerbate spatial constraints and introduce catastrophic alignment Abbe errors. To overcome these bottlenecks, the development of a single-probe six-DOF metrology paradigm is of paramount significance. To resolve this limitation and achieve uncoupled six-DOF tracking, a highly integrated single-probe symbiotic optical layout is proposed, as detailed in Figure 2.

In a conventional single-axis grating interferometer, the linear displacement Δx induces a proportional phase shift in the diffracted beam relative to the physical grating pitch g , governed by the grating encoding equation:

$$\Delta\varphi = \frac{2\pi}{g} \Delta x$$

For three-axis linear displacement (x, y, z) measurements, the digitized heterodyne phase variations undergo a common-mode rejection operation to eliminate target-independent disturbances, such as laser frequency drift:

$$\bar{\varphi}_i = \varphi_i - \varphi_{ref} (i = x, y, z)$$

By mathematically inverting this coupled matrix, the fully decoupled linear displacements are explicitly resolved in a closed form:

$$\begin{aligned} x &= \frac{g}{2\pi n} \bar{\varphi}_x - \frac{g(1 + \cos\theta)}{4\pi n} \bar{\varphi}_z \\ y &= \frac{g}{2\pi n} \bar{\varphi}_y - \frac{g(1 + \cos\theta)}{4\pi n} \bar{\varphi}_z \\ z &= \frac{\lambda}{4\pi n} \bar{\varphi}_z \end{aligned}$$

where n is the air refractive index, λ is the laser wavelength, g is the grating pitch, and θ is the first-order diffraction angle. Concurrently, three-axis angular displacements (R_x, R_y, R_z) are tracked utilizing quadrant photodiodes, which monitor the spatial intensity centroids of the back-reflected diffracted beams. Angular tilts induce coordinate variations $(\Delta A, \Delta B, \Delta C, \Delta D)$ in the spot centroids. Through a deterministic geometric optical model, the rotational angles are directly mapped as:

$$R_x = \frac{-\Delta B}{2f}, \quad R_y = \frac{\Delta A + \Delta C}{4f}, \quad R_z = \frac{\Delta B - \Delta d}{f \tan\theta}$$

where f denotes the focal length of the collection lens. This symbiotic architecture achieves instantaneous, closed-form decoupling of six-DOF motions without requiring iterative optimization algorithms.



Fig. 1 Schematic diagram of a multi-DOF positioning sensor used in lithography wafer fabrication.

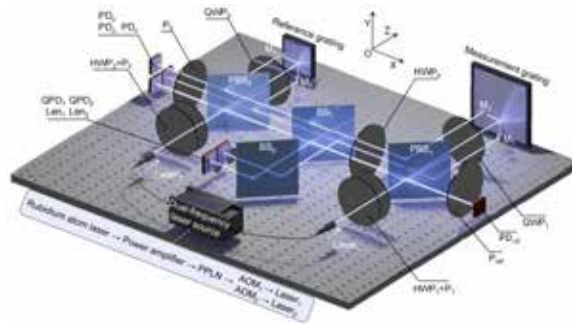


Fig. 2 The comprehensive 3D optical design of the six-DOF heterodyne grating interferometer.

Conclusions

We have successfully demonstrated a single-probe six-DOF heterodyne grating interferometer. Experimental validations confirm that the system covers an in-plane range of > 25 mm and an out-of-plane range of approximately 5 mm. Within this envelope, the system achieves a linear resolution of < 0.8 nm and an angular resolution down to $0.9 \mu\text{rad}$. Reliability tests indicate a repeatability of < 1 nm for linear axes and $< 1 \mu\text{rad}$ for rotational axes. Furthermore, the system exhibits long-term stability superior to 6 nm over 1000 s and $1.5 \mu\text{rad}$ over 300 s. This system provides a highly stable and robust metrological solution for next-generation precision manufacturing.

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PII-09

Cyclical Noise Squeezing in Quantum Dot SOAs Due to Rabi Oscillations

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Abstract

Short pulse excitation of quantum dot gain media induces Rabi oscillations which modify, in turn, the noise accompanying the amplified signal.

Homodyne characterization reveals noise squeezing during the Rabi cycle when the quantum dots exhibit gain.

Introduction

The propagation of optical pulses in quantum dot (QD) gain media, in the form of QD SOAs with durations smaller than the coherence time which is roughly 1 ps, induce a variety of coherent interaction such as Rabi oscillations [1].

The properties of the pulses emerging from the SOA have been studied for the past decade using X-FROG characterization accompanied by a comprehensive semi-classical model.

The coherent quantum interaction between the QDs and the optical pulse affect also the noise. These noise properties are addressed in this paper using homodyne measurements.

We demonstrate **a unique interplay between squeezing of the noise accompanying the pulse and the Rabi oscillations that the QDs undergo**. Specifically, we show that the noise is squeezed only during the part of the Rabi cycle when the QD experience gain while at all other times, the noise exhibits the properties of a coherent state.

Experimental Setup and Conduct

Fig. 1 shows the experimental system. A 100-fs pulse at 1540 nm feeds a QD amplifier inducing Rabi oscillations. It broadens to roughly 1 ps upon propagation along the 1.5 mm long amplifier. A replica of the 100-fs excitation pulse serves as the local oscillator (LO) in the homodyne detection system. The phase of the LO is scanned over 2π radians some 1000 times yielding a histogram of the uncertainty in the noise photon number. The histogram is translated into a Wigner function using the Inverse Radon Transformation [2].

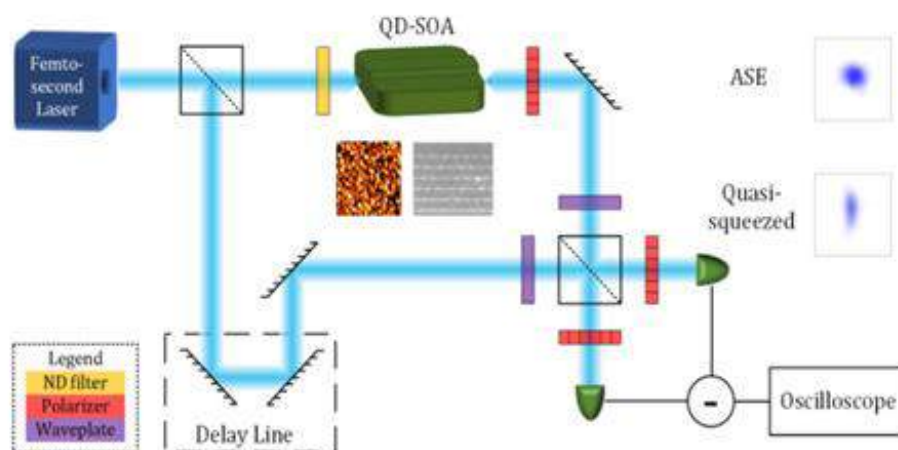


Fig. 1: The experimental setup

Results

The dependence on pulse excitation energy was examined in detail as described in Fig. 2.

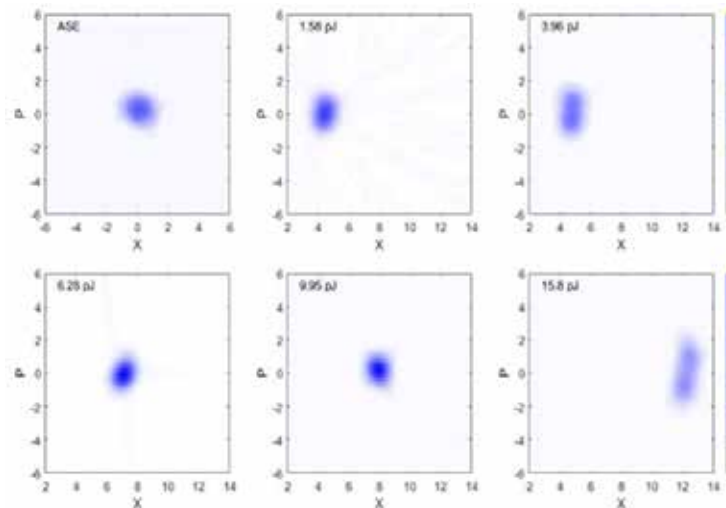


Fig. 2: Excitation energy dependent Wigner functions

The upper left panel shows a wide, circular Wigner function corresponding to a thermal state, obtained because no input was introduced into the SOA, meaning that the measured signal consists of amplified spontaneous emission (ASE). Noise squeezing occurs at 3.96 pJ (displaced squeezed thermal state) and 15.8 pJ (squeezed coherent state). This is a fourfold increase in energy which amounts to an increase in pulse area of 2π . For all other excitation energies, the Wigner function is once again circular, and its standard deviation is bigger than that of a vacuum state, describing a displaced thermal state. This behavior is observed over a large range of excitation energies up to 145 pJ maintaining the cyclical nature wherein increases of a factor of four yield an elliptic Wigner function, corresponding to an appearance of noise squeezing.

Conclusions

To conclude, we have demonstrated a direct relationship between Rabi oscillations and noise squeezing in a QD optical amplifier. For input pulse energies that differ by factors of four, the noise is squeezed since such energies represent a full circle around the Bloch sphere. For all other energies, the output state is a displaced thermal state.

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P11-10

Interplay of quantum dot size, composition and nanowire geometry indetermination of emission dynamics of a novel zincblende $\text{InAs}_x\text{P}_{1-x}$ - x/InP system

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Abstract Exciton lifetime in novel zincblende $\text{InAs}_x\text{P}_{1-x}$ quantum dots in InP nanowires grown by chemical beam epitaxy in vapour-liquid-solid mode is studied experimentally and theoretically to determine its dependence on quantum dot size, composition, and nanowire geometry.

Introduction

A single photon source (SPS) is a fundamental building block of various quantum technologies, including quantum computing and quantum communication. An important parameter influencing the application potential of an SPS is its radiative lifetime, which constitutes a fundamental limitation on photon generation rate. Short radiative lifetimes enable high repetition rates, while also reducing the influence of dephasing processes and timing jitter. This is beneficial for high overall device speed and effectiveness of quantum protocols realisation. Epitaxial quantum dots (QD) have potential to be the best SPSs, characterised by high brightness, on-demand operation and mature technology, with potential for scalable integration. Of particular interest are QDs engineered to emit in the telecommunication spectral range (1.3–1.55 μm), where optical fibre losses are minimized and enabling long-distance transmission of quantum information through the existing silica-based fibre-optic infrastructure. In recent years, QDs in nanowires (NW) have emerged as a promising platform for a high quality SPS, as they offer several advantages over conventional self-assembled QDs. The growth method enables deterministic positioning of a single or multiple QDs along the NW axis, ensuring optimal coupling to a single guided optical mode. The properly designed NW acts as a photonic waveguide, reducing radiative losses due to the dielectric screening effect and significantly enhancing light extraction efficiency upwards [1]. Furthermore, nanowire-based structures provide exceptional flexibility in material composition and heterostructure design, allowing control of the emission wavelength in a wide spectral range, including the telecom bands [3-5]. A common approach is to grow InAsP QDs in InP NWs in the wurtzite crystal structure using selective-area epitaxy in vapour-liquid-solid growth (SAE-VLS) within chemical beam epitaxy system (CBE) [4-5]. However, this growth requires prefabricated substrates, it is burdened with high probability of defects and imposes strict constraints on the gold colloid size serving as the nucleation centre. In contrast, those problems are lifted for novel zincblende structures [2-3]. Here, we present studies on emission dynamics of $\text{InAs}_x\text{P}_{1-x}/\text{InP}$ QD/NWs grown without defects in the zincblende phase by means of CBE in VLS mode along the $\langle 100 \rangle$ direction on a bare Fe-doped InP(100) substrate. In particular, we analyse the influence of QD size and composition, as well as QD photonic environment on exciton radiative lifetime to assess the structures application potential as an SPS.

Results

In order to experimentally determine the influence of both QD and NW parameters on emission dynamics, three samples were prepared: one with a thick 150 nm InP NW shell and a 2 nm high QD, one with the same QD but a thin 50 nm InP NW shell and one with a thick 150 nm InP NW shell and a 10 nm QD with slightly smaller As content, emitting in the telecom C-band. The 150 nm InP NW shell thickness was chosen to guarantee optimal single mode waveguiding, while the thin one was chosen to be too small for optical mode confinement to observe Purcell effect. The NW geometry and quality of all samples were analysed by means of Scanning Electron Microscopy. The exact QD size and As composition in the range of $x=0.69-0.76$ was determined using High Resolution Scanning Transmission Electron Microscopy and Energy Dispersive X-ray Spectroscopy. The structural data were then used to design realistic models for theoretical calculations. Finite-difference time-domain simulations were performed to study the influence of the photonic environment on radiative lifetime without focusing on the QD details. The Purcell factor was calculated as a function of emission wavelength and NW shell thickness. It was shown that for the sample with the thin NW shell a strong Purcell emission inhibition is expected, decreasing radiative lifetime by a factor of 10. For both samples with the thick NW shell the Purcell factor was calculated to be roughly constant, varying between 0.8 and 1. To study how QD details affect radiative lifetime, 8 band $k\cdot p$ calculations with configuration-interaction model were implemented. The results are shown in Fig.1. The radiative lifetime increases with QD size and As content due to changes in confinement regime and wavefunctions overlap.

The experimental time-resolved photoluminescence measurements were performed on a QD/NW ensemble to ensure sufficient signal intensity. The measured decay time dispersion is presented in Fig. 2., with an inset showing an exemplary fitted mono-exponential decay curve for each sample. The general trends turned out to be in agreement with calculations. The exact lifetime values for samples with thick shell are elongated, as compared to calculations, due to Purcell factor slightly below 1. The sample with the thin shell exhibits decay time longer by a factor of 2. The deviation from expected 10 value is due to the fact that the measurements were performed on an ensemble of thousands of QD/NWs, with contributions coming from various excitonic complexes and possibly excited states, with shorter lifetimes than ground state exciton.

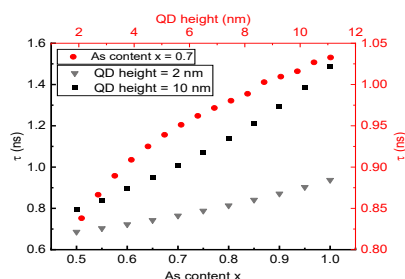


Fig. 1 Calculated radiative lifetime and emission energy as a function of QD size and As composition

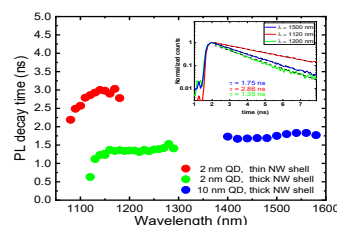


Fig. 2 Decay time dispersion for all studied samples and exemplary fitted decay curves

Conclusions

We have shown that in the QD/NWs with the thin shell the dominant factor influencing lifetime is the Purcell inhibition. In the case of samples with thick NW shell the increase in lifetime originates mostly from changes in QD potential due to the increased QD size. We also note that the average decay time in the telecom spectral range for the thick shell samples is below 2 ns so lower than the literature values for InAsP/InP QD/NW grown in the wurtzite phase [4-5].

Acknowledgements

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PII-11

Electrical Wavelength Tuning of InAs Quantum Dots Towards Tunable Single-Photon Sources

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Abstract We demonstrate quantum-confined Stark tuning of the excitonic emission of InAs/InAlGaAs quantum dots embedded in nin-diode structures at 1.25 μm , paving the way towards electrically tunable single-photon sources.

Introduction

The optical properties of semiconductor quantum dots (QDs) make them promising building blocks for secure quantum communication, quantum computing, and future quantum networks [1,2]. Many of these applications rely on single-photon sources with a high degree of quantum-mechanical indistinguishability between emitted photons. However, the epitaxial growth of QD ensembles inherently introduces variations in size, shape, and composition, such that no two dots emit at exactly the same energy. External electric fields can be used to overcome this inhomogeneity by tuning the emission energy via the quantum-confined Stark effect (QCSE), enabling the spectral matching of remote emitters [3]. To this end, the dots are embedded in electrically contactable nin-diode structures, in which a vertical electric field can be applied through metallic contacts to tune the excitonic emission energy and to control the charge state of the QD.

Electrical control of InAs quantum dots via the QCSE

The InAs/InAlGaAs quantum dots are embedded in vertical nin-diode structures, in which a vertical electric field is applied through metallic contacts to tune the excitonic emission via the QCSE. The dots investigated here emit around 1.25 μm . By sweeping the bias voltage applied to the nin-structure, a continuous redshift of the excitonic lines of ~ 0.2 meV (corresponding to ~ 0.3 nm) is observed, consistent with the expected QCSE.

The field-dependent μPL spectra are fitted with double Lorentzians, and the resulting excitonic energies are described by $E(F) = E(0) + \beta F^2$, where F denotes the electric field at the QD. This field is directly related to the applied bias voltage V shown in Fig. 1(b) and is estimated as $F \approx V/d$ from the $d = 142$ nm thick intrinsic region. The fits yield polarizabilities of $\beta/e \approx -28$ to -29 nm²/V for two lines attributed to different charge states of the same QD, in good agreement with previously reported values for InAs/GaAs QDs [4], while a third line, attributed to a different dot, exhibits a markedly larger polarizability of $\beta/e \approx -63$ nm²/V. Since the polarizability is predominantly governed by the QD height [5], this is attributed to a more asymmetric dot geometry, which enables a greater displacement of the electron and hole wavefunctions along the growth direction.

Comparison with band-structure simulations

To support the experimental results, the conduction and valence band profiles of an InAs/InAlGaAs QD subjected to a vertical electric field are simulated self-consistently using a Schrödinger–Poisson solver. Modelling the dot as a truncated pyramid embedded in the nin-structure, the simulated QCSE tuning reproduces the experimentally observed behavior and yields a polarizability of the same order of magnitude. By adjusting the simulated QD dimensions to match the measured transition energies, the size of the experimentally investigated dot is estimated to a base width of ~ 10.6 nm and a height of ~ 3 nm, illustrating how the combined experimental and theoretical analysis provides insight into the effective QD

geometry.

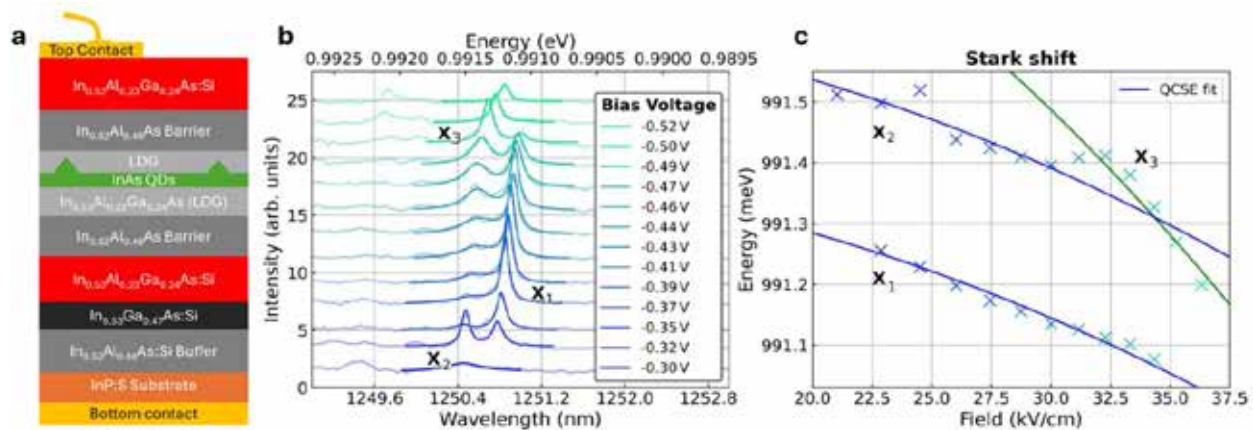


Fig. 1 (a) Schematic of the vertical nin-diode layer stack with the $\text{InAs}/\text{InAlGaAs}$ QDs embedded in the intrinsic region. (b) Bias-dependent μPL spectra showing the tuning of the excitonic emission lines via the QCSE; spectra are vertically offset by 20 kcts/s for clarity, and each line is tuned by ~ 0.2 meV, corresponding to a wavelength shift of ~ 0.3 nm. (c) Stark shift of the excitonic energies as a function of the applied electric field, fitted with a parabolic QCSE model to extract the polarizabilities. X_1 and X_2 are attributed to different charge states of the same QD, while X_3 originates from a different dot and exhibits a markedly larger polarizability. All measurements at ~ 5 K under above-band excitation.

Conclusions

We have demonstrated electrical wavelength control of the excitonic emission of $\text{InAs}/\text{InAlGaAs}$ quantum dots embedded in nin-diode structures, achieving a continuous quantum-confined Stark tuning of ~ 0.2 meV at $1.25 \mu\text{m}$. The extracted polarizabilities are consistent with literature values for InAs -based QDs and with self-consistent band-structure simulations, which additionally provide an estimate of the effective dot dimensions. As a next step, the tuning scheme will be applied to larger, telecom C-band-emitting dots of the same material platform and combined with holey circular Bragg gratings, towards scalable, fiber-compatible single-photon sources for quantum networks.

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P11-12

Coherence Properties of Kerr Frequency Combs Under Noisy Injection and Optical Feedback

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Abstract We study coherence of Kerr microcombs under continuous-wave and pulsed injection. Analytical and numerical results quantify phase noise and timing jitter from the pump, while optical feedback improves coherence.

Introduction

Solitons in nonlinear optical systems play a central role in modern photonics, offering exceptional stability and enabling transformative applications in high-precision frequency comb generation, ultrafast optics, and optical communications. Kerr microcavities, described by the Lugiato-Lefever Equation (LLE) [1–3], provide a powerful platform to study soliton dynamics. The LLE captures the essential physical ingredients of these systems, including dispersion, Kerr nonlinearity, cavity losses, and external driving, making it a cornerstone model for understanding frequency comb formation.

This work investigates analytically and numerically the combined impact of phase noise and injection pulse timing jitter on soliton dynamics in synchronously pumped Kerr microcavities, using the LLE as the governing model. We perform an asymptotic analysis of the impact of external injection noise and intracavity thermal noise on soliton phase noise and timing jitter.

We consider the dynamics of the intracavity field $A(x,t)$ in a synchronously pumped Kerr microcavity, described by a stochastic version of the LLE. After rescaling and setting the dispersion coefficient to one, the governing equation becomes:

$$\frac{\partial A}{\partial t} = -A - i[\theta + \sigma(t)]A + i\frac{\partial^2 A}{\partial x^2} + [v + \beta(t)]\frac{\partial A}{\partial x} + A_{in}[x + \xi(t)]e^{i\phi(t)}, \quad (1)$$

where $A(x,t)$ is the slowly varying envelope of the intracavity field satisfying periodic boundary condition $A(x,t) = A(x+L,t)$, where t (x) is the slow (fast) time, and L is the cavity round trip time. The term $A_{in}[x + \xi(t)] \cdot e^{i\phi(t)}$ is the injected pulse, subject to timing jitter $\xi(t)$ and phase noise $\phi(t)$. The noise processes $\xi(t)$ and $\phi(t)$ are Brownian motions, described by Langevin equations.

Microcavity with Pulsed Injection

To simulate the LLE with pulsed injection we employ the general form of Eq. (1), where the injection term A_{in} is defined as:

$$A_{in} = A_0 e^{\frac{-(x-\xi(t))}{2w^2}} e^{i\phi(t)}. \quad (2)$$

By modelling Eq. (1) with an injection term from Eq. (2), we obtained the corresponding optical and RF. Notably, the linewidth of each comb tooth increases with harmonic order as a result of a timing jitter. Based on these results, we further analyze the dependence of the linewidth. Following the approach of Haus and Mecozzi, and taking into account phase dynamics, we define the linewidth $\Delta\nu$ as $\Delta\nu = \frac{D_\phi}{\pi}$. The graphical representation of the linewidth dependence on the harmonic number (Fig. 1) clearly follows the quadratic trend observed in mode-locked lasers [4]. This allows us to quantify

timing jitter in high-repetition rate frequency combs and indicates that LLE exhibits behavior similar to that of a mode-locked laser in the presence of timing jitter.

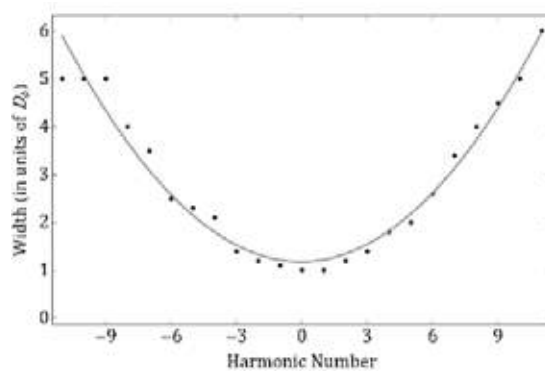


Fig. 1 Dependence of linewidth of each tooth on the harmonic number, obtained from the optical spectrum calculated with the LLE under pulsed injection.

Effect of the Optical Feedback

We demonstrated that increasing the noise amplitude leads to the destruction of the soliton, which in turn disrupts the output frequency comb. Phase noise causes the comb to vanish, resulting in an optical spectrum with a single frequency component. However, it has been experimentally shown that optical feedback from the microresonator to the laser can restore the frequency comb [5]. To investigate this effect, we extend the framework introduced by Lang and Kobayashi [6] to describe semiconductor laser with optical feedback. However, in our case the laser field couples to the microcavity, and the fraction of the microcavity output field is re-injected into the laser. We therefore replace the injection term A_{inj} from Eq. (1) by the complex envelope of the electric field $F(t)$ emitted by a single-mode laser.

Conclusions

We have analyzed the coherence properties of Kerr frequency combs generated in optical microresonators under noisy injection and optical feedback, using both analytical and numerical methods within the framework of the LLE. Numerical simulations of synchronously pumped microcavities confirm theoretical results, revealing a quadratic dependence of the optical and RF linewidths on the harmonic order, a characteristic signature of timing jitter known from mode-locked lasers. Increasing the amplitude of phase noise destabilizes the soliton, leading to its suppression. Finally, by coupling the LLE to semiconductor laser rate equations, we showed that coherent optical feedback can restore soliton stability and narrow the linewidth of comb lines. This work was supported by the HYBRIDCOMB project, funded by the ANR and the DFG (No. 491234846).

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PII-13

Full-Stokes Broadband Hyperspectral Imaging Chip Empowered by AI-Designed Freeform Metasurfaces

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Abstract We report a CMOS-compatible hyperspectro-polarimetric imaging(HSPI) chip based on AI-designed freeform metasurfaces. Demonstrating leading-level performance across all benchmarks, the comprehensive platform simultaneously achieves snapshot, broadband, full-Stokes megapixel imaging with sub-nanometer spectral resolution.

Introduction

High-dimensional optical sensing can provide richer physical fingerprints for AI perception, but compact systems that simultaneously capture spectrum, polarization and spatial information remain limited. Metasurfaces offer a route to integrated light modulation[1]. Guided by our Compressive Sensing Basis (CSB) theory to resolve encoding limits, we utilize a generative AI model for freeform metasurface inverse design, and implement two CMOS-compatible HSPI chips. They show versatile performance and enable abundant applications with or without our reconstruction method.

Principle and Approach

The optical transmission of hyperspectro-polarimetric imaging (HSPI) is projecting the wavelength-dependent full-Stokes vector s into intensity measurements I by encoding, as in a matrix form $I = Ms$, where

$$M = \begin{bmatrix} m_0^{1\lambda_1} & \dots & m_0^{1\lambda_M} & m_1^{1\lambda_1} & \dots & m_1^{1\lambda_M} & m_2^{1\lambda_1} & \dots & m_2^{1\lambda_M} & m_3^{1\lambda_1} & \dots & m_3^{1\lambda_M} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ m_0^{N\lambda_1} & \dots & m_0^{N\lambda_M} & m_1^{N\lambda_1} & \dots & m_1^{N\lambda_M} & m_2^{N\lambda_1} & \dots & m_2^{N\lambda_M} & m_3^{N\lambda_1} & \dots & m_3^{N\lambda_M} \end{bmatrix}, \quad s = \begin{bmatrix} s_0^{\lambda_1} & \dots & s_0^{\lambda_M} | s_1^{\lambda_1} & \dots & s_1^{\lambda_M} | s_2^{\lambda_1} & \dots & s_2^{\lambda_M} | s_3^{\lambda_1} & \dots & s_3^{\lambda_M} \end{bmatrix}^T$$

Our CSB theory interprets each matrix column of M as a basis vector, and concluded that spectral and polarization states become distinguishable when basis vectors remain separated beyond the uncertainty imposed by sensor noise. Therefore, reducing column correlation increases the resolution limits under the same signal-to-noise ratio.

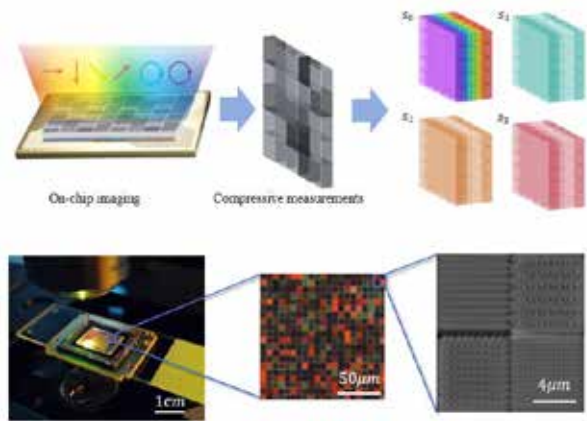


Fig. 1 Principle and fabrication of HSPI chips

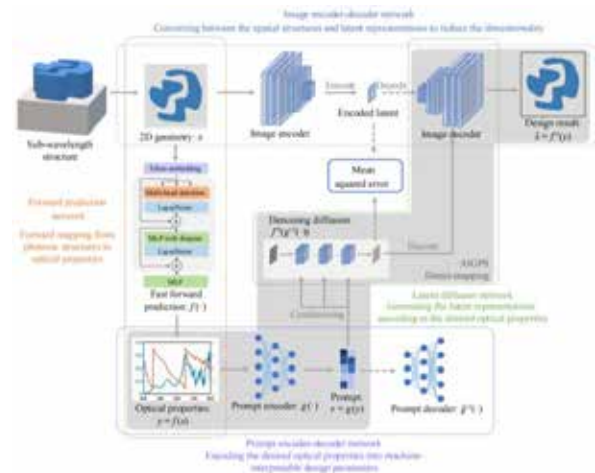


Fig. 2 AIGP for HSPI chip inverse design

Metasurface Design and Fabrication

Guided by CSB theory, we use an AI-driven evolutionary design flow to generate freeform meta-atoms with broadband polarization-sensitive transmission spectra[2]. A generative inverse-design model maps target full-Stokes spectral responses to manufacturable nanostructures, while genetic search selects units that reduce sensing-matrix coherence over the visible and near-infrared bands. The optimized structures are fabricated on single-layer silicon-on-sapphire metasurfaces by one-step lithography and bonded onto commercial CMOS image sensors, preserving CMOS compatibility and large-area scalability. Principles, methods and results are shown in Fig.1 and Fig.2.

Chip Performance, Reconstruction and Applications

The same metasurface design is integrated with two CMOS sensors to form complementary HSPI chips, whose experimentally measured performance is summarized below in Tab.1. For image-level reconstruction, a deep-unfolding ADMM-Net[3] reconstructs full-Stokes hyperspectral cubes from the two-dimensional measurement and the calibrated sensing matrix, and it supports dividing measurements into sub-images for efficient inference. This method offers exceptional operational flexibility for different hardware configurations without the need for model retraining.

Metric	HSPI1	HSPI2
Operating band	400-1000 nm	400-1500 nm
Spectral resolution	0.62 nm	2.16 nm
Central wavelength error	0.51 nm	1.82 nm
Full-Stokes error	<0.021	<0.025
Spatial pixels	10.8 megapixels	5.0 megapixels

Tab. 1 Performance of HSPI chips

The HSPI platform supports multidimensional machine vision tasks, including non-contact stress visualization in transparent samples and suppression of surface reflection. And treating the metasurface as a physical convolutional layer[4], we implement material classification without reconstruction. Our approach outcores conventional RGB imaging in these applications, indicating a compact route toward real-world robust imaging and edge AI perception.

Conclusions

Our CMOS-compatible HSPI platform enables broadband snapshot high-fidelity 4D imaging. The analysis of CSB theory and AI generative optimization provide a methodology applicable to diverse compressive optical systems. Demonstrated applications in stress detection, artifact suppression, and material classification indicate a rapid and compact route toward scientific imaging and intelligent perception, broadening the dimensionality of vision sensing.

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PII-14

Fabrication-constrained Inverse Design of a Broadband 2- μm Perfectly Vertical Grating Coupler

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Abstract: We present a fabrication-constrained perfectly vertical grating coupler operating at 2- μm wavelength band via hybrid continuous-discrete inverse design, achieving -2.17 dB coupling efficiency at 2000 nm and a 1-dB bandwidth of 92 nm.

Introduction

Benefiting from low transmission losses of hollow-core photonic bandgap fibers [1] and broad gain bandwidth of thulium-doped fiber amplifiers [2], the 2- μm waveband has become a promising communication band. Due to the mode field diameter mismatch, efficient fiber-to-chip coupling remains a key challenge for 2- μm waveband photonic integrated circuits (PICs) [3]. Edge couplers (ECs) can achieve high coupling efficiency and broad bandwidth, but suffer from the constraints of post processing and fixed coupling position [4]. Grating couplers (GCs) support wafer-level testing and flexible placement with limitations including high coupling loss and narrow bandwidth [5]. Perfectly vertical grating couplers (PVGCs) are attractive for large-scale PICs due to their low packaging complexity and ease of integration [6]. In this work, a hybrid continuous-discrete inverse design method was proposed to optimize the heights of individual grating segments of PVGC, achieving a peak coupling efficiency of -2.13 dB at 1979 nm, and 1-dB bandwidth of 91 nm numerically.

Grating Coupler Structure and Inverse Design Principle

The optimized grating coupler is implemented on a standard 220-nm silicon-on-insulator (SOI) platform, as illustrated in Fig. 1 (a). Both the buried oxide layer and top cladding layer have a thickness of 3 μm . The grating region is divided into $N = 100$ segments with a fixed segment length of 100 nm, giving a total grating length of 10 μm . Each segment height is restricted to one of three physical levels, 0 nm, 150 nm, and 220 nm for fabrication process compatibility after optimization. A standard single-mode fiber is placed normal to the chip surface at the centre of the grating region.

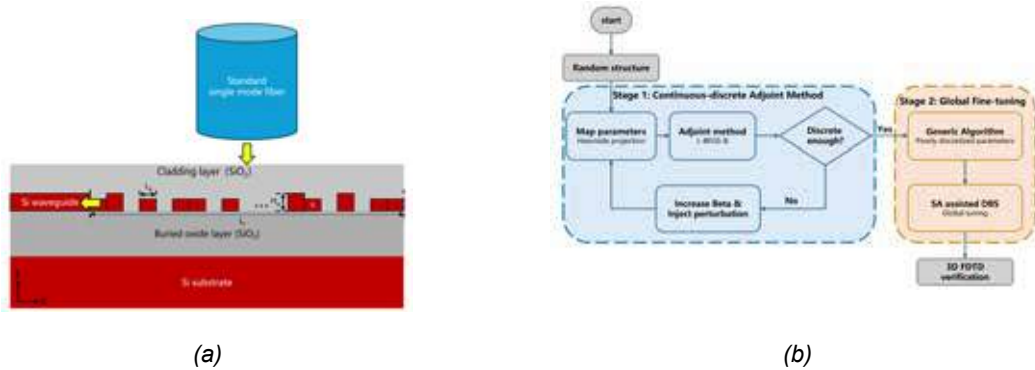


Fig. 1 (a) 2D cross-section view of the perfectly vertical GC with design variables. (b) Flow chart of the continuous-discrete hybrid inverse design method.

The proposed design flow combines a continuous-discrete adjoint method stage with a discrete heuristic refinement stage, as shown in Fig. 1(b). The performance of the designed grating coupler is evaluated using 2D finite-difference time domain (2D FDTD) and verified by 3D FDTD. In the first stage, the height of the i -th grating segment is represented by a normalized continuous variable $\rho_i \in [0,1]$. To map the continuous variables toward three manufacturable, etch levels, a double-threshold smooth projection is applied as

$$P(\rho, \eta) = \frac{\tanh(\beta\eta) + \tanh[\beta(\rho - \eta)]}{\tanh(\beta\eta) + \tanh[\beta(1 - \eta)]}, \quad (1)$$

where β controls the steepness of the projection and η is the threshold. With two thresholds η_1 and η_2 , the physical height of the i -th segment (H_i) is obtained as

$$H_i = h_{low} + (h_{mid} - h_{low})P(\rho_i, \eta_1) + (h_{high} - h_{mid})P(\rho_i, \eta_2), \quad (2)$$

where h_{low} , h_{mid} , and h_{high} correspond to the 0, 150 nm, and 220 nm, respectively. The broadband coupling efficiency

performance is evaluated by a weighted figure of merit (FOM),

$$FOM = \frac{\sum_{i=1}^{N_\lambda} W(\lambda_i) T(\lambda_i)}{\sum_{i=1}^{N_\lambda} W(\lambda_i)}, \quad (3)$$

where $T(\lambda_i)$ is the coupling efficiency at the i -th sampled wavelength, and $W(\lambda_i)$ is a Gaussian weighting function centred at 2 μm over the target bandwidth. The continuous variables are first updated using the adjoint method. During this stage, β is gradually increased to enhance discreteness, and small random perturbations are introduced to variables trapped near the projection thresholds.

After the adjoint method stage, well-discretized segments are locked to the nearest allowed height, while poorly discretized segments are further optimized by a genetic algorithm. Finally, a simulated annealing (SA) assisted direct binary search (DBS) is applied to all discrete segments, allowing the search to escape local optima.

Simulation Results and Discussions

The optimized heights of each segment are shown in Fig. 2 (a). All segments are strictly assigned to 0, 150 nm, or 220 nm, confirming that the continuous variables are successfully converted into a fabrication-compatible three-level-height structure. The aperiodic three-level height profile indicates that the inverse-designed structure enables spatially varying control over the local scattering strength and phase response along the propagation direction, rather than relying on a conventional periodic Bragg-grating configuration. As shown in Fig. 2(b), the 3D FDTD-simulated spectrum exhibits a peak coupling efficiency of -2.13 dB at 1979 nm, while the coupling efficiency remains -2.17 dB at the target wavelength of 2000 nm. The negligible difference indicates a flat-top spectral response around the 2- μm wavelength band. The 1-dB bandwidth is approximately 92 nm around the target wavelength of 2000 nm, demonstrating that the broadband weighted objective and subsequent discrete refinement effectively preserve high coupling efficiency over the targeted 2- μm communication window.

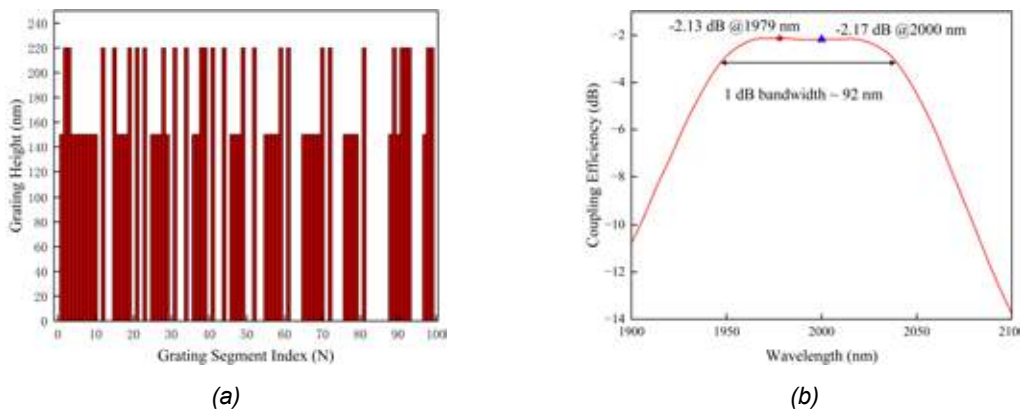


Fig. 2 (a) Optimized structural parameters. (b) 3D FDTD-simulated coupling efficiency spectrum.

Conclusions

A hybrid continuous-discrete inverse design method has been developed for a perfectly vertical grating coupler compatible with standard fabrication process. The numerically demonstrated 2- μm waveband perfectly vertical grating coupler has a coupling efficiency of -2.17 dB at 2000 nm and a 1-dB bandwidth of ~92 nm, making it a promising fiber-to-chip interface for broadband 2- μm photonic integrated circuits.

Acknowledgment

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PII-15

Radiative Non-Hermitian Coupling for Power-Scalable Single-Mode Photonic-Crystal Surface-Emitting Lasers

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Abstract We propose DBR-mediated non-Hermitian radiation engineering for PCSELS. By controlling the vertical round-trip phase of reflected radiation, passive leakage is transformed into mode-selective coupling, enabling simultaneous power extraction and finite-size mode stabilization.

Introduction

High-power single-mode semiconductor lasers are highly desired for LiDAR, free-space optical communications, and high-brightness photonic systems. Photonic-crystal surface-emitting lasers (PCSELS) provide an attractive route toward large-area coherent emission [1-3]. However, their power scalability is fundamentally constrained by the competition between radiation extraction and modal stability. Modes with nearly vanishing radiation loss can exhibit high quality factors, but they usually suffer from inefficient power extraction, low slope efficiency, and high lasing threshold. To obtain efficient surface emission, previous works mainly focus on increasing emission area or radiation strength, however, competing finite-size modes can approach the lasing condition, leading to multimode oscillation and degraded beam quality.

Non-Hermitian radiation engineering

The design principle is illustrated in Fig. 1. In this work, the leakage channel is converted into a controllable non-Hermitian coupling mechanism. The upward radiated wave and the DBR-reflected downward wave interfere with each other after a vertical round trip. Therefore, the effective radiation loss experienced by each finite-size mode depends on the phase relation between the photonic-crystal radiation and the reflected field. This phase-sensitive process provides a physical mechanism for mode-selective loss engineering. When the round-trip phase satisfies a constructive condition for the selected fundamental mode, the radiation constant can be enhanced, supporting efficient surface emission. Meanwhile, the competing higher-order modes can experience a different radiation phase condition due to their distinct spatial field distributions and coupling strengths. As the p-cladding thickness varies, the radiation constants of the fundamental mode and the first higher-order mode exhibit clear oscillatory behaviour. This oscillation originates from phase-sensitive non-Hermitian process.

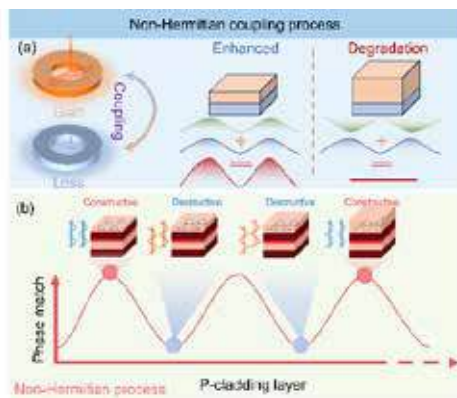


Fig. 1 Non-Hermitian PCSEL design principle.

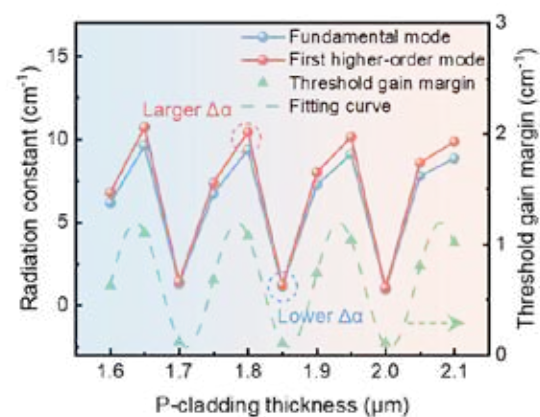


Fig. 2 Numerical analysis of mode-selective non-Hermitian coupling by 3D-CWT [4-5]

Experimental verification of finite-size mode control

To verify the proposed strategy, PCSELS with varying non-Hermitian coupling constants were fabricated and characterized. The measured spectra and far-field patterns are summarized in Fig. 3. A strong dependence of modal behaviour on p-cladding thickness is observed, confirming that the vertical radiation phase plays a decisive role in finite-size mode

selection.

For non-optimized phase conditions, the devices exhibit multiple spectral peaks and distorted far-field profiles, indicating that competing modes are not sufficiently suppressed. In particular, the presence of fragmented far-field patterns suggests that higher-order finite-size modes participate in the lasing process. By contrast, under optimized DBR-mediated non-Hermitian coupling, the device shows a dominant lasing peak together with a stable single-lobe far-field pattern. This transition from multimode and spatially degraded emission to clean single-mode-like operation demonstrates that the vertical radiation channel can be deliberately used to control modal competition.

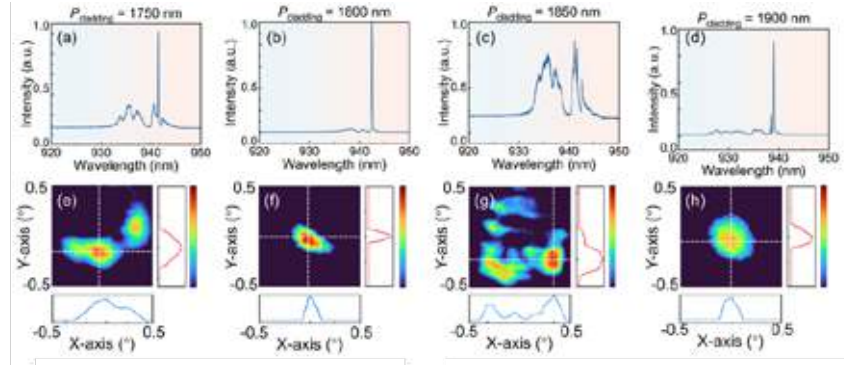


Fig. 3 Experimental verification of finite-size mode control.

Conclusions

Here we bridge this gap by introducing DBR-mediated vertical radiation engineering, which converts radiation leakage from a passive loss channel into a controllable mode-selective coupling mechanism. By tuning the scalable non-Hermitian coupling, we control the vertical round-trip phase of the DBR-reflected radiation. This strategy transforms radiation leakage from a passive out-coupling loss into a controllable non-Hermitian coupling mechanism for selectively redistributing modal losses.

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P11-16

Stochastic processes in nonlinear optics

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Abstract We present methods to engineer and shape spatial coherence in second harmonic generation, including object-induced coherence synthesis, generation of incoherent vortex and Airy beams, and a nonlinear van Cittert-Zernike theorem for pump- and crystal-controlled coherence.

Introduction

Optical coherence is a central statistical property of light [1], but nonlinear frequency conversion has traditionally been discussed mainly with highly coherent laser fields [2]. Here we present a complementary view: spatial coherence itself can be engineered during second harmonic generation (SHG). As summarized in Fig. 1, we study two related strategies. The first synthesizes desired second harmonic coherence by designing the input speckle ensemble [3]. The second shapes the coherence through a nonlinear extension of the van Cittert-Zernike (VCZ) theorem [4,5], where the source distribution and nonlinear susceptibility jointly determine the generated coherence.

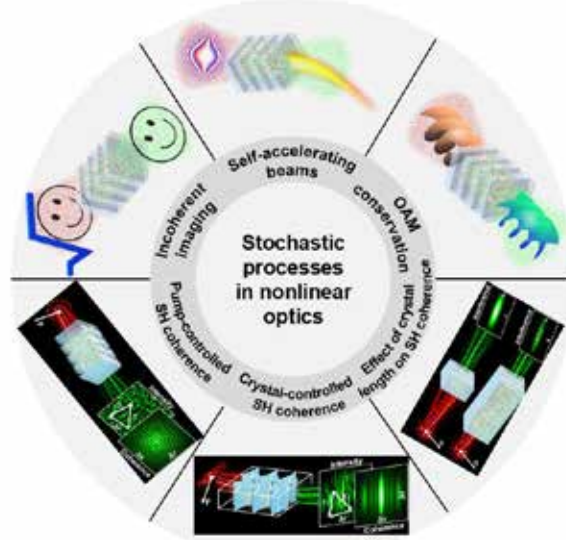


Fig. 1 Overview of two coherence-control routes in SHG. Upper circle: coherence synthesis from designed speckle ensembles. Lower circle: coherence structuring by the fundamental source and nonlinear structure.

Results

Figure 2(a)-2(d) shows the object-induced coherence synthesis result from the first method. In this experiment, a smiley-face object illuminated by an incoherent source is represented by 800 retrieved fundamental speckle fields. Each field is square-root filtered, converted into a phase-only hologram, and sent to a short $\chi^{(2)}$ crystal for SHG. Although each second harmonic frame is random, the averaged intensity gradually reconstructs the smiley face as more frames are accumulated (1, 8, 80, and 800 frames), confirming that the object-induced coherence is synthesized at the second harmonic.

For coherence structuring, the nonlinear VCZ relation shows that second-harmonic coherence is proportional to the Fourier transform of the nonlinear source term:

$$g_{2\omega}^{(1)}(\Delta\mathbf{r}) \propto \int \left| \chi_{\perp}^{(2)}(\mathbf{p}) E_{\omega}^2(\mathbf{p}) \right|^2 e^{-ik_{2\omega}\Delta\mathbf{r}\cdot\mathbf{p}/z} d^2\mathbf{p}.$$

Here $g_{2\omega}^{(1)}(\Delta\mathbf{r})$ is the first-order coherence in the second harmonic at far-field separation $\Delta\mathbf{r}$; $\mathbf{p}$ is the source-plane coordinate; $E_{\omega}(\mathbf{p})$ is the fundamental pump field; $\chi_{\perp}^{(2)}(\mathbf{p})$ is the transverse nonlinear susceptibility; $k_{2\omega}$ is the SH wave

number; and z is the propagation distance. Thus, the second harmonic coherence is set by *both* the squared pump field and the nonlinear pattern. In Figs. 2(e)-2(m), an incoherent elliptical Gaussian pump and an HG₀₃ ferroelectric domain pattern make the coherence of the second harmonic follow the Fourier transform of the nonlinear structure, producing Cartesian Laguerre-Gaussian coherence. Double-slit measurements with 1-mm PPKTP and 50-mm LBO further show stronger fringes in the second harmonic after long propagation, revealing coherence growth.

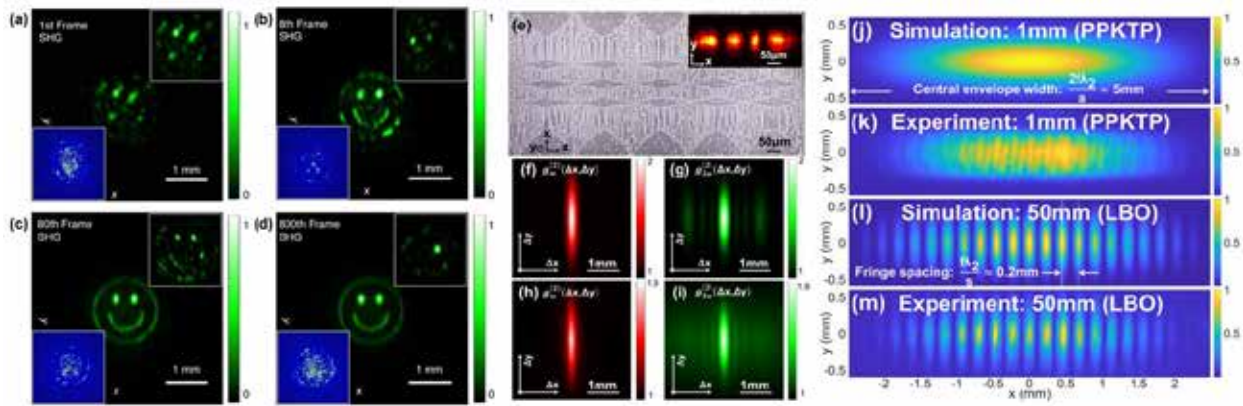


Fig. 2 Main results. (a)-(d) Object-induced coherence synthesis in SHG: accumulated second-harmonic speckle intensities from 1, 8, 80, and 800 hologram frames progressively reconstruct a smiley-face coherence pattern. (e) HG₀₃-patterned nonlinear crystal. (f)-(i) Simulated and measured coherence profiles showing crystal-shaped second harmonic coherence. (j)-(m) Double-slit measurements showing stronger second harmonic fringes after long-crystal propagation, evidencing coherence growth.

Conclusions

Overall, nonlinear optics can synthesize and structure optical coherence. The results demonstrate object-induced coherence transfer, crystal-shaped coherence, and propagation-induced coherence growth at the second harmonic.

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PII-17

Integrated waveguide-coupled nanolaser arrays in non-Hermitian regimes

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Abstract We investigate two integrated waveguide-coupled semiconductor nanolasers within the framework of non-Hermitian photonics. This study enables the exploration of nonlinear dynamical regimes and associated phenomena, including directional emission control and ultrafast optical switching mechanisms for integrated photonic applications.

Introduction

Loss engineering in optical systems and coupled resonators has attracted growing interest, though on-chip realization demands precise control over the nanodevice properties. Here, we study both the modal properties and the nonlinear dynamics of waveguide-coupled nanolasers, a regime with only a few experimental demonstrations in non-Hermitian photonics [1,2].

Phase-coupled nanolaser

In this work, we investigate the interaction between two integrated semiconductor nanolasers. The InP-based photonic-crystal nanolasers are distantly coupled through a common silicon-on-insulator waveguide (Fig. 1). The coupled-mode analysis of this configuration provides the rate equations for the cavity amplitudes. The coupling phase acquired by the light propagating between the two cavities through the waveguide directly governs the coupling regime [3].

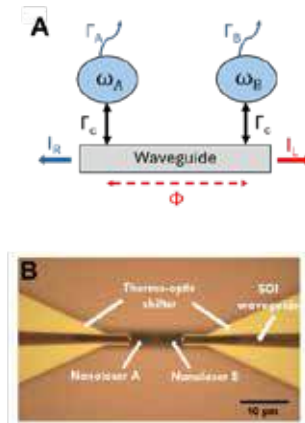


Fig. 1 Two waveguide-coupled nanocavities with independent loss rates and frequencies (A). Microscope image of two coupled III-V nanolasers with integrated gold nanowires for frequency tuning (B).

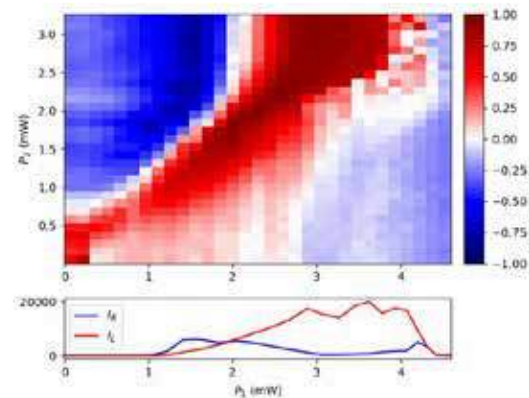


Fig. 2 Top: Constant between the left and right emission flux (red and blue respectively), shown as a function of the pump powers P_1 and P_2 . Bottom: Output powers as a function of P_1 , for $P_2 = 2.5$ mW.

Directional light propagation near exceptional points is a promising feature for photonic devices [3]. In our system, it arises from the phase difference between the fields emitted by the two cavities into the waveguide and can be controlled through the pump powers (Fig. 2). We further explore the impact of stimulated emission, carrier dynamics, and gain saturation on the resulting nonlinear and locking regimes.

Nonlinear dynamics and bistability effects

In coupled laser or resonator systems, the mutual optical feedback between interacting cavities enriches this nonlinear response, enabling the system to switch abruptly between a low- and a high-transmission state as a control parameter is varied [4]. In our structures, bistability is observed in both emission directions. These bistable behaviors occur when both cavities are capable of lasing independently. This static characterization provides valuable insight into the system dynamics,

although a complete understanding of the phenomenon will require complementary spectral investigations and dynamic characterization of the bistable regime.

Conclusion

Waveguide-coupled nanolasers provide a versatile platform for exploring non-Hermitian and nonlinear photonic phenomena. The observed directional emission and bistability open promising perspectives for integrated optical routing, switching, and memory functionalities [5].

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PII-18

Grating Optimization of single-mode DFB laser based on Genetic Algorithm

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Abstract

A high-power single-mode distributed feedback (DFB) semiconductor laser with a specific phase-shift grating structure and with high-reflection (HR) and anti-reflection (AR) coatings. With grating optimized by genetic algorithm, the device enjoys even photon density distribution within the cavity and high margin of threshold gain difference.

Introduction

The high-power distributed feedback (DFB) laser is widely applied in optical communication, sensor and LiDAR as light source. Hence the demands for stable single-mode output, high side mode suppression ratio (SMSR), and high slope efficiency are always concerned. While the spatial hole burning comes from inhomogeneous photon density distribution within the cavity¹. Moreover, introduced random phase from cleaving causes periodically power fluctuation among chips along the bar². These situations have hindered the further improvement of yield. In this paper, a grating optimization method based on Genetic Algorithm (GA) is adopted, seeking for the ideal grating structures with lower flatness factor and higher gain difference. The results show the flatness of photon density distribution within the cavity and power robust among chips is effectively improved.

Analysis Based on Genetic Algorithm

The optical field modulation of grating is stated by transfer matrix method (TMM) method^{3,4}.

Single-mode performance is affected by photon density distribution and threshold gain difference. To evaluate the distribution, the flatness factor index (F) is defined¹:

$$F = \frac{1}{L} \int_0^L (I(z) - I_{\text{avg}})^2 dz,$$

where $I(z)$ is the normalized photon intensity along the cavity:

$$I(z) = |E_s(z)|^2 + |E_r(z)|^2,$$

where $|E_s(z)|$ and $|E_r(z)|$ are the electric field intensities at forward and backward directions. Besides, to prevent power fluctuating acutely, the exported design is confined with the photon intensity mean value as 1. The smaller the flatness factor is, the more even the photon density distribution will be. The threshold gain margin difference is assessed by $\Delta\alpha L_g$, extracting from the difference value between main mode and main side mode in calculated gain spectrum. In DFB laser, the higher the $\Delta\alpha L_g$ magnitude is, the higher single-mode yield will be. To simulate the cleaving deviation such as non-perpendicular crack and length offset, random phase at facets is introduced. And probabilities of crossover and variation are inserted to manipulate the combining and dereferencing among the parameters.

Set up duty, length L_g and inserting position of the grating z_0 as the variation to be optimized, importing in GA (Fig. 1). During iterating, only if $F < 0.03$ and $\Delta\alpha L_g > 1$ are fulfilled simultaneously, the structure can pass the filtration. The parameters above is settled as a populatio and the pass rate is define as evaluation factor Q.

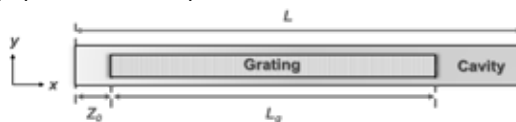


Fig. 1 Key parameters in grating

The cavity length L is fixed as 1 mm, period is 200 nm, with 99% high-reflection (HR) and 0.05% anti-reflection (AR) coatings. As generations accumulating, Q is going to converge to 0.75 gradually because of the existing of random

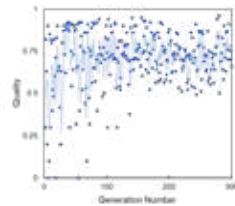


Fig. 2 The statistic data of quality with generations increasing, gradually converge at 0.75 after 200 generations

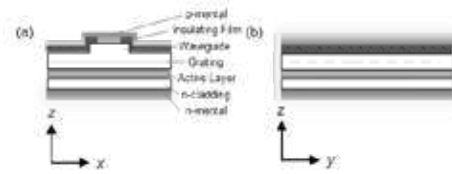


Fig. 3 The schematic diagram of the HR-AR DFB laser with grating structure designed by GA at x-z(a) and y-z(b) cross-sections

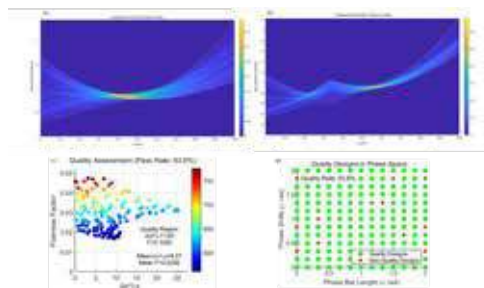
shift (Fig.2).

Device Design

Shown as Fig. 3, a high-power single-mode DFB lasers employed the optimized grating and a ridge waveguide is designed. Considering application requirement, $\kappa L_g = 0.6$ throughout the work.

Firstly as a $\pi/2$ phase shift inserted, intensity fluctuation is suppressed while the distribution becomes predictable (Fig. 4(a)(b)). Referring to GA, grating parameters are determined as duty=0.5, $L_g=800$ nm, $z_0=1$ μm . The design has relatively high passing rate, with mean F as 0.029 and $\Delta\alpha L_g$ as 8.27. The influence from random phase shifts can be available hold under the structure. By optimizing, the power fluctuation of the device reduces from original ± 10 mW to ± 5 mW, while SMSR is maintained as high as 53.6 dB.

Fig. 4 Quality characteristic analysis of modified grating structure. The longitudinal intensity frequency through the cavity of uniform grating (a) and single phase shift grating (b). Flatness and gain margin assessment (c). The relationship between random phase shifts and yield quality (d).



Conclusions

In this work, optimized grating supporting high-power single-mode DFB lasers is established, while GA providing a feasible design approach in grating research. By adding a phase shift and adjusting grating parameters such as duty, length and inserting position, the optical distribution within cavity becomes more even and the gain difference between modes is enhanced.

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PII-19

Hyperspectral Imaging for Deterministic Quantum-Dot Device Fabrication in the Telecom C-Band

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Abstract Hyperspectral imaging enables deterministic selection of quantum dots for precise positioning of nanophotonic resonators. Combining spatial and spectral mapping, this technique provides a high device yield with a strong mode coupling to the emitter resonance.

Introduction

The controlled integration of individual emitters such as semiconductor quantum dots into photonic devices is a key requirement for high-quality quantum light sources. We present the principles and practical advantages of hyperspectral imaging as a spatial and spectral measurement technique for pre-selecting randomly distributed InAs quantum dots suitable for the fabrication of cavity-enhanced quantum light sources in the telecom C-band. Building on recent work demonstrating the deterministic placement of circular Bragg grating resonators for emitters at 930 nm, hyperspectral imaging enables an overall process accuracy (from pre-selection to device fabrication) of (15 ± 11) nm [1], offering a substantial improvement to recent selection strategies relying on probabilistic placement. For 1550 nm, we expect this to scale linearly with $\lambda/(2NA)$ according to the Abbe diffraction limit.

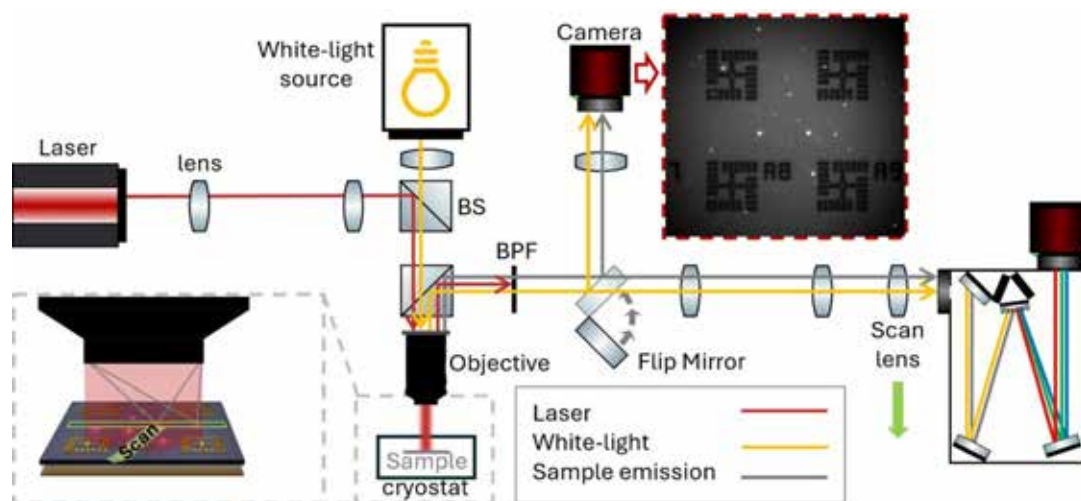


Fig. 1 Schematic of the setup for hyperspectral imaging. The sample surface and markers are illuminated by a 1550 nm LED. Simultaneously, a 730 nm continuous-wave laser excites a large area of the sample. The white-light reflection and

QD emission pass through a bandpass filter and is projected onto a CCD screen to localize the quantum dots and markers. With a flip mirror, the sample emission is focused on the entrance slit of the spectrometer. Using a motorized mounted scan lens, the spectral resolution of the photoluminescence emission can be analyzed strip by strip
[Adapted from 1].

Data Acquisition

The measurement technique combines wide-field optical microscopy with wavelength-resolved detection, recording a full emission spectrum at every spatial pixel. By mapping photoluminescence intensity as a function of both position and wavelength, hyperspectral imaging provides a multidimensional dataset that allows precise identification of the location of a quantum dot, its emission energy, and its linewidth in a single acquisition. In addition, hyperspectral imaging enables automated screening of large areas. A high yield of high-quality devices is ensured by subsequently performed image corrections necessary for the accurate placement of cavities keeping emitted photons unpolarized crucial for quantum applications.

Image Distortion and Tilt Correction

Optical distortions and sample tilt induce significant systematic errors in QD localization. To improve the placement accuracy of the CBGs, all camera images are corrected based on Zhang's method [2] together with a correction of sample tilt. Calibration patterns on the sample are used to determine distortion correction parameters while periodic marker fitting is applied for tilt correction. Together, these methods enable an overall high device yield of 68% [1], surpassing all previously reported techniques [3].

Displacement induced Polarization

Recent studies have shown that a spatial offset of the QD from the circular Bragg grating cavity center is the main source of polarization, as it breaks the cylindrical symmetry of the resonator modes [4]. In this context, a placement accuracy of ≤ 50 nm results in sufficiently low polarization suitable for quantum photonic applications.

Conclusions

Hyperspectral imaging transforms quantum-dot device fabrication from a stochastic into a deterministic process. The combination of spatial and spectral QD mapping with the image correction enables precise cavity placement and results in high fabrication accuracy and device yield. This advantages makes hyperspectral imaging a powerful tool for deterministic fabrication of devices for various applications in quantum photonics.

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Buchinger, Quirin (Author2), Krause, Constantin (Author3), Peniakov, Giora (Author4), Reum, Yorick (Author5), Helal, Mohamed (Author6), Damasceno, Barbara Souza (Author7), Sauter Mathias (Author8), Pfenning, Andreas (Author9), Huber-Loyola, Tobias (Author10), Höfling, Sven (Author11)

Information not available at the time of submission.

P11-20

Terahertz multidimensional on-chip manipulation based on liquid crystal-integrated metadevices

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Author 1 is a student for consideration of Best Student Poster Award.

Abstract This work takes the advantages of plasmonic metasurfaces and liquid crystal phased arrays to address the key issues of insufficient on-chip regulatory parameters and the lack of dynamic programmability for terahertz surface fields.

Introduction

In the post-Moore era, on-chip intelligent integrated photonic circuits have emerged as a promising route for next-generation devices and computing architectures. Surface plasmons confine optical fields to near-field interfaces far below the diffraction limit, facilitating the development of novel ultra-compact devices. Additionally, terahertz (THz) surface waves can overcome the limitations of weak confinement and high loss in the microwave and visible bands. However, THz surface plasmonic devices still face challenges in terms of multiplexing, reconfigurability, and multifunctionality.

An on-chip coherent synthesis mechanism

The coherent synthesis mechanism for surface fields is proposed, enabling the remarkable evolution that surface focusing from single-frequency excitation to broadband control (>270 GHz), surface vortices from pure-state to interference-state excitation (>4 modes), and even from a single field to the simultaneous near-/far-field generation (12 near-/far-field vortices).

A joint symmetry breaking strategy

The joint symmetry breaking is fully exploited to realize the on-chip manipulation across multiple dimensions, including time, space, frequency, and spin-orbit angular momentum.

A spatio-temporally programmable modulation technique

The spatio-temporally programmable modulation technique is proposed based on liquid crystal (LC)-graphene transparent electrode integration. The manipulation with multi-level external electric bias drives (n levels) and multi-pixelations (m pixels) enables an exponential increase of the surface field states ($> n^m$ states).

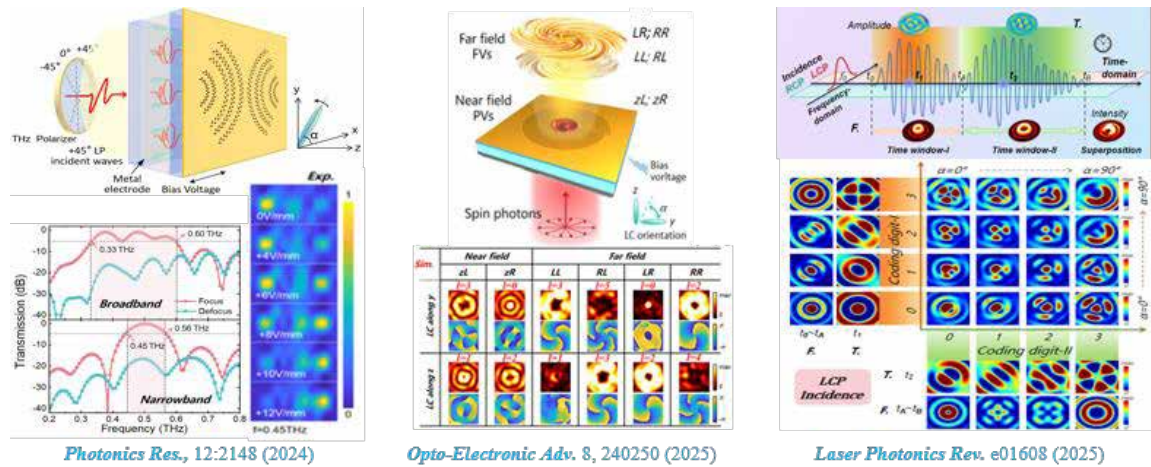


Fig. 1 Schematic diagram of THz LC-integrated metadevices for broadband on-chip focusing, multi-mode vortex generation and encoded surface vortex interference.

Conclusions

These works offer transformative potential for cutting-edge applications in intelligent perception, high-density photonic communication and computing.

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P11-21

Integration of Erbium Oxychloride Nanosheets via Silicon Slot Waveguides with Enhanced Light-Matter Interaction

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Abstract We investigate a silicon slot waveguide integrated with ErOCl nanosheets, achieving a 52.7% confinement factor. It has the potential to achieve >1 dB gain within a 10-μm footprint, facilitating ultra-compact on-chip integrated active devices.

Introduction

Silicon photonics has emerged as a promising platform for high-density optical integration. However, the realization of efficient on-chip active devices remains a challenge due to the indirect bandgap of silicon. A widely adopted solution to this limitation is the integration of rare-earth ions into waveguide structures, which enables telecom-band absorption and amplification. This has facilitated the development of erbium-doped waveguide amplifiers (EDWAs) and lasers (EDWLs) [1,2]. Despite this advancement, conventional doping techniques are limited by the relatively low erbium concentrations to avoid ion clustering, leading to modest absorption and gain coefficients that require device lengths on the millimeter-to-centimeter scale.

Two-dimensional van der Waals erbium oxychloride (ErOCl) has recently emerged as a promising alternative gain medium [3]. Owing to the stoichiometric crystalline structure, ErOCl nanosheets exhibit an erbium concentration orders of magnitude higher than traditional doped waveguides, demonstrating strong absorption and gain coefficients at C-band wavelengths. In this work, we present a heterogeneous integration scheme utilizing a longitudinal slot structure to enhance the overlap between the optical field and the low-index ErOCl nanosheets on silicon waveguides. This approach provides a route toward ultra-compact active photonic devices with enhanced light-matter interaction.

Device design

Conventional integration of two-dimensional materials with photonic waveguides typically relies on evanescent coupling, where the nanomaterial is transferred directly onto the waveguide surface. However, this configuration suffers from limited mode-field overlap with the active material, restricting the effective light-matter interaction strength. To address this limitation, we propose a longitudinal slot architecture that embeds the ErOCl nanosheet within the silicon waveguide structure, as shown in Fig. 1.

The hybrid integration structure can be realized by the following fabrication steps: dry-transferring ErOCl nanosheets onto silicon-on-insulator (SOI) substrates; depositing an amorphous silicon (a-Si) capping layer; patterning the hybrid stack by inductively coupled plasma (ICP) and focused ion beam (FIB) milling; and final encapsulation with a silicon dioxide (SiO₂) cladding.

Simulation results

The fundamental TM mode profile of the hybrid slot structure is shown in Fig. 2(a). The structure consists of an a-Si capping layer ($n=3.94$), an ErOCl nanosheet ($n\sim 1.7$), and a crystalline silicon (c-Si, $n=3.47$) substrate, all surrounded by silicon dioxide ($n=1.44$) cladding. Owing to the significant refractive index contrast between the silicon and the ErOCl layer, the fundamental TM mode is predominantly confined within the lower-index ErOCl layer.

We quantify the light-matter interaction using the active-region confinement factor Γ , defined as the fraction of the optical power residing in the ErOCl nanosheet to the total guided power:

$$\Gamma = \frac{\iint_{\text{slot}} |E(x,y)|^2 dx dy}{\iint_{\text{total}} |E(x,y)|^2 dx dy}, \quad (1)$$

where the numerator integrates the electric field intensity over the ErOCl nanosheet cross-section, and the denominator integrates over the entire computational domain.

Using Lumerical FDE solver, we calculate the confinement factor Γ for the fundamental TM mode at 1536 nm. As shown in Fig. 3, when the waveguide width is greater than 520 nm and the ErOCl thickness is greater than 180 nm, the fundamental TM mode exhibits a confinement factor exceeding 50% in the active region. For example, for a waveguide width of 550 nm with 120-nm c-Si, 200-nm thick ErOCl nanosheet, and a 100-nm a-Si capping layer, the fundamental TM mode exhibits a high confinement factor of 52.7% in the active region, significantly surpassing the confinement factors in conventional integration schemes, which yield only 13.2% for the fundamental TE mode and 32.7% for the fundamental TM mode (Fig. 2(b) and 2(c)). Notably, the total silicon thickness of 220 nm is intentionally chosen for compatibility with

standard 220-nm SOI platforms. These results confirm that the longitudinal slot geometry effectively concentrates the optical mode within the ErOCl gain medium.

Based on the reported absorption coefficient of 1934 dB/cm and a gain coefficient exceeding 2000 dB/cm at 1536 nm [3], we estimate that a single 10- μ m-long ErOCl nanosheet can provide >1 dB of net absorption or optical gain. This substantial enhancement in light-matter interaction offers a promising pathway toward ultra-compact, chip-integrated active photonic devices. Fabrication of the proposed slot-integrated devices is currently underway, with experimental characterization and performance validation expected in the near future.

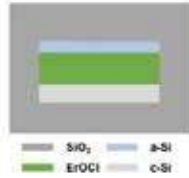


Fig. 1. Waveguide structure.

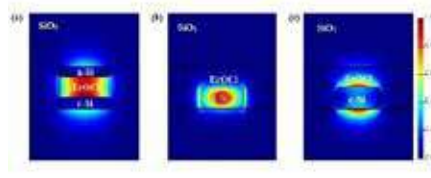


Fig. 2. Simulation results.

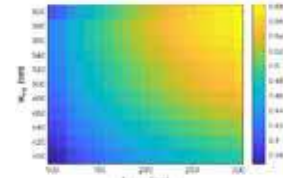


Fig. 3. Calculated confinement factor.

Conclusions

We proposed an ErOCl-integrated silicon slot waveguide that achieves a 52.7% confinement factor in the active region. The enhanced light-matter interaction suggests the potential for >1 dB gain within a 10- μ m footprint, enabling ultra-compact on-chip active photonic devices.

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PII-22

A Non-Local Holographic Structured-Illumination Super-Resolution Method for Micro- and Nanoscale Structure Measurement

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Abstract

We propose a non-local holographic structured-illumination super-resolution concept for integrated-circuit micro- and nanoscale structure measurement, exploring SIM-based frequency translocation for high-frequency information acquisition over larger fields of view and depths of field.

Introduction

As integrated circuit manufacturing continues to advance toward smaller feature sizes, the demand for high-precision and large-area measurement of micro- and nanoscale structures has become increasingly prominent. Conventional optical microscopic measurement is constrained by the diffraction limit, making further improvement of lateral resolution difficult. Structured illumination microscopy (SIM) can achieve an approximately two-fold improvement in spatial resolution through a frequency-domain translocation mechanism. However, typical SIM implementations rely on high-numerical-aperture and high-magnification microscope objectives, leading to a small practical field of view and limited depth of field. These characteristics make conventional SIM difficult to directly adapt to large-area, high-throughput, and three-dimensionally tolerant inspection in integrated circuit manufacturing.

Principle of Structured-Illumination-Based Super-Resolution

The core principle of SIM is to illuminate the specimen with a structured pattern of known spatial frequency. For a sinusoidal illumination pattern, the intensity distribution can be written as

$$I_{\theta,\phi}(r) = I_0 \left[1 - \frac{m}{2} \cos(2\pi p_\theta \cdot r + \phi) \right]$$

where $r = (x, y)$ denotes the spatial position, p_θ is the illumination spatial frequency vector, ϕ is the phase shift, and m is the modulation factor. Under such structured illumination, the detected image can be modeled as

$$D_{\theta,\phi}(r) = [S(r)I_{\theta,\phi}(r)] \otimes H(r) + N(r)$$

Where $S(r)$ is the specimen distribution, $H(r)$ is the point spread function of the imaging system, and $N(r)$ denotes additive noise. This expression indicates that the specimen is first modulated by the structured illumination in the spatial domain and then blurred by the optical system.

In the frequency domain, the modulation produces a mixing effect between the specimen spectrum and the illumination frequency. The Fourier transform of the detected image can be expressed as

$$\tilde{D} * \theta, \phi(k) = \left[\tilde{S}(k) - \frac{m}{2} \tilde{S}(k - p * \theta) e^{-i\phi} - \frac{m}{2} \tilde{S}(k + p_\theta) e^{i\phi} \right] \tilde{H}(k) + \tilde{N}(k)$$

This equation shows that the captured spectrum contains not only the central component $\tilde{S}(k)$, but also two shifted components $\tilde{S}(k - p_\theta)$ and $\tilde{S}(k + p_\theta)$. Therefore, high-frequency information of the specimen that originally lies beyond the cut-off range of the optical transfer function can be translocated into the observable frequency band through structured illumination. By acquiring images with multiple phase shifts and orientations, these translocated frequency components can be separated and restored to their original positions in reciprocal space, thereby improving the lateral resolution beyond the limit of conventional wide-field imaging.

Proposed Holographic Structured Illumination Approach

To address the small field of view and limited depth of field of conventional SIM, this work proposes a holographic structured-illumination super-resolution concept for non-local measurement scenarios. In the proposed approach, interference fringes are employed as structured illumination with a known spatial frequency. Compared with projection-based structured illumination, interference fringes can maintain relatively stable fringe contrast and spatial periodicity over a larger spatial range, enabling structured illumination modulation over a larger field of view and an extended depth of field.

The proposed method still follows the fundamental super-resolution mechanism of SIM. Holographic interference fringes provide a known spatial frequency to translocate high-frequency structural information of the specimen into a lower-frequency band, allowing it to be acquired by an imaging system with a lower numerical aperture or a larger field of view. Unlike conventional high-NA fluorescence SIM, which is mainly oriented toward localized microscopic imaging, holographic structured illumination offers design flexibility in fringe period and modulation range. This may improve high-frequency information acquisition for micro- and nanoscale structures while maintaining a relatively large field of view and depth of field.

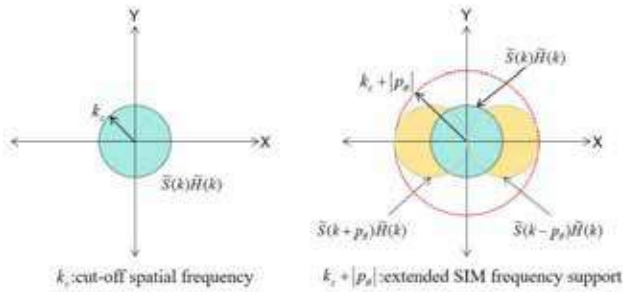


Fig. 1 Frequency translocation mechanism in SIM

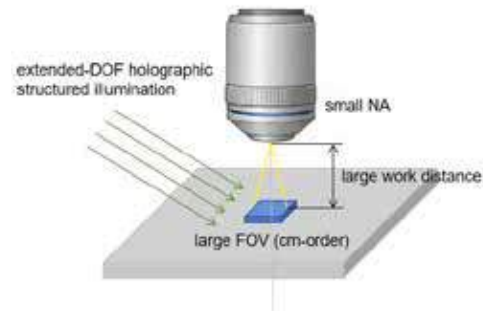


Fig. 2 Conceptual illustration of non-local holographic structured illumination for micro- and nanoscale structure measurement.

Conclusions

This work proposes a non-local holographic structured-illumination super-resolution concept for integrated-circuit micro- and nanoscale structure measurement. Based on the frequency translocation mechanism of SIM, the proposed method attempts to extend the effective modulation range of structured illumination using holographic interference fringes, thereby mitigating the field-of-view and depth-of-field limitations of conventional high-NA microscopic SIM.

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PII-23

Coating-Free 10.55 μm Quantum-Cascade DFB Laser with an Asymmetric Phase Shift for SF_6 Sensing

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Abstract We demonstrate a coating-free 10.55 μm DFB quantum-cascade laser with an asymmetric phase shift. The device combines low-power operation with enhanced single-facet output, improved reproducibility, and stable single-mode emission for SF_6 sensing applications.

Introduction

Distributed-feedback quantum-cascade lasers (DFB-QCLs) are attractive light sources for trace-gas spectroscopy because they provide wavelength-selective emission within strong molecular absorption bands. For SF_6 sensing near 10.55 μm , stable single-mode operation, sufficient output power, and low-power performance are required. While the DFB grating selects the lasing mode, selected-facet output still requires coatings, which provide the cost of possible reliability concerns at long mid-infrared wavelengths.

Here we demonstrate a coating-free 10.55 μm DFB-QCL with an asymmetric phase shift. By tailoring the longitudinal field distribution, the design enhances selected-facet output while maintaining low-threshold operation and improving device reproducibility.

Design and Simulation

For coating-free DFB-QCL, high selected-facet output cannot be imposed by facet coatings and must instead be controlled by the internal cavity design. We therefore investigated how the phase-shift position modifies the longitudinal mode and output distribution. A transfer-matrix model was used to scan the normalized phase-shift position and evaluate the threshold gain, selected-facet output fraction, side-mode selectivity, and field nonuniformity.

The simulation shows that moving the phase shift away from the cavity center can substantially enhance the right-facet output fraction. Among the scanned positions, an asymmetric phase shift at 0.20L provides a favorable balance: it gives high selected-facet output while maintaining low normalized threshold gain. Compared with the center-QWS design, it also avoids severe field localization. However, this output enhancement is obtained at the cost of reduced side-mode selectivity and increased field nonuniformity compared with the uniform DFB structure.

Facet-phase ensemble simulations were further used to assess the robustness of the coating-free design. The 0.20L asymmetric-phase-shift structure shows smaller variations in the calculated optical metrics than the uniform DFB cavity, indicating reduced sensitivity to cleaved-facet phase uncertainty. These results suggest that the asymmetric phase shift provides an effective route to high single-facet output and improved reproducibility in coating-free DFB-QCLs.

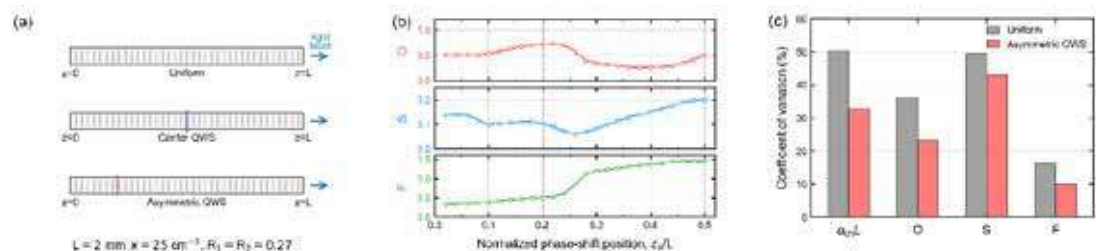


Fig. 1 Simulated phase-shift design for coating-free DFB-QCLs. (a) Uniform, center-QWS, and asymmetric-QWS grating configurations. (b) Dependence of output fraction, side-mode selectivity, and field nonuniformity on the phase-shift position. (c) Coefficient of variation of optical metrics under facet-phase ensemble simulations.

Device Characterization

Uniform DFB-QCLs and asymmetric-QWS DFB-QCLs were fabricated and characterized under the same conditions. Both

structures exhibit low and comparable threshold currents, which can be attributed to the large- κ L grating design and the resulting strong distributed feedback. In contrast, the asymmetric-QWS device shows higher selected-facet output power, with the representative peak power increasing from 53.6 mW to 60.4 mW.

Multi-device measurements further confirm the advantage of the asymmetric-QWS design. While the threshold current remains nearly unchanged, the selected-facet slope efficiency and peak output power are increased. The smaller spread of the measured data also indicates improved device reproducibility, consistent with the simulated reduction in facet-phase sensitivity.

Temperature-dependent spectra confirm stable single-mode emission over the measured range. The emission wavenumber shifts from 947.525 to 944.587 cm^{-1} as the temperature increases from 5 to 45 $^{\circ}\text{C}$, covering the spectral region relevant to SF_6 absorption. These results verify that the coating-free asymmetric-QWS DFB-QCL combines low-threshold operation, enhanced selected-facet output, improved reproducibility, and stable single-mode emission.

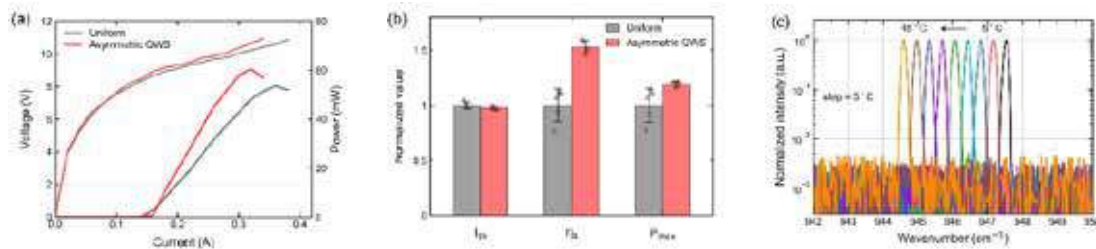


Fig.2 Experimental characterization of coating-free DFB-QCLs. (a) LIV curves of uniform and asymmetric-QWS devices. (b) Multi-device comparison of threshold current, selected-facet slope efficiency, and peak output power, normalized to the uniform DFB mean. (c) Temperature-dependent single-mode spectra of the asymmetric-QWS device.

Conclusions

We demonstrated a coating-free 10.55 μm DFB-QCL with an asymmetric phase shift for SF_6 sensing. The asymmetric phase shift enhances selected-facet output and improves device reproducibility without compromising low-threshold operation. Stable single-mode emission near the SF_6 absorption region further supports this design as a practical approach for compact mid-infrared gas sensing.

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PII-24

DBR-Enhanced Ge/GaAs Uni-Travelling-Carrier Photodiodes for High-Speed 1550 nm Detection

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Abstract A DBR-enhanced Ge/GaAs UTC photodiode is numerically investigated for 1550 nm detection, achieving 54 GHz bandwidth, 0.5 A/W responsivity and 117 nA dark current, indicating a scalable, lower-cost route for high-speed photonic receivers at C-band.

Introduction

Uni-travelling-carrier photodiodes (UTC-PDs) are key devices for C-band optical receivers, microwave photonics and sub-terahertz generation because their carrier transport is dominated by electrons rather than holes. This unipolar transport scheme suppresses hole-induced transit-time delay and mitigates space-charge effects, enabling high-speed operation [1,2]. A persistent challenge, however, is to achieve high responsivity, low dark current and large 3-dB bandwidth on a material platform that is scalable beyond costly InP substrates. Ge/Si UTC-PDs are compatible with silicon photonics, but their bandwidth and responsivity are constrained by the lower electron mobility of Si relative to III-V collector materials [3,4]. Here, we numerically investigate a front-illuminated Ge/GaAs UTC-PD for 1550 nm operation. Ge is selected as the C-band absorption layer, whereas GaAs provides a high-mobility electron-collection layer. The small lattice mismatch between Ge and GaAs further supports the formation of high-quality heterostructures. By integrating a GaAs/AlGaAs distributed Bragg reflector (DBR), the design aims to improve absorption without increasing carrier transit length, thereby addressing the responsivity-bandwidth trade-off on a potentially scalable platform [5,6].

Device Design and Simulation Method

The device consists of a p-type Ge absorption region and an n-type GaAs collection region. The Ge stack includes a heavily doped anode contact, a diffusion-barrier layer, a graded p-type absorption region and an undoped Ge layer. The graded doping profile establishes a quasi-electric field that assists electron transport toward the GaAs collector. At the heterointerface, a 10 nm undoped $\text{Al}_{0.05}\text{Ga}_{0.95}\text{As}$ spacer mitigates band discontinuity, while a 10 nm n-doped GaAs cliff layer enhances the local electric field and promotes electron injection into the 150 nm undoped GaAs collection layer [1,2]. The cathode side incorporates a ten-pair GaAs/ $\text{Al}_{0.8}\text{Ga}_{0.2}\text{As}$ DBR. In the front-illuminated configuration, the DBR reflects unabsorbed 1550 nm light back into the Ge absorber, increasing the effective optical path length while leaving the electrical transit distance unchanged. This optical-recycling strategy is preferable to simply thickening the absorber, which would increase absorption at the expense of speed [7,8]. Optical generation was calculated using ANSYS Lumerical FDTD and imported into CHARGE simulations to extract dark current, photocurrent, responsivity, electric-field profiles and small-signal frequency response for circular devices with diameters of 5-8 μm .

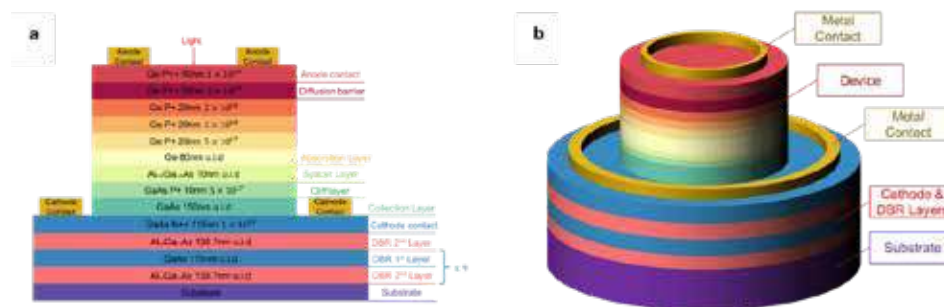


Figure 1. Schematic of the proposed Ge/GaAs UTC-PD. (a) Cross-sectional structure showing the layer sequence, thicknesses, doping levels and materials. (b) Three-dimensional schematic of the circular front-illuminated device.

Results and Discussion

The simulated band and electric-field profiles indicate that the spacer and cliff layers smooth the Ge/GaAs heterointerface and sustain a strong reverse-bias field across the active region. At -2 V, the 5 μm -diameter device achieves a 3-dB bandwidth of 54 GHz, a photocurrent of 2.25 mA, a responsivity of 0.5 A/W and a dark current of 117 nA. Increasing the

diameter from 5 to 8 μm raises the responsivity from 0.5 to 0.7 A/W and the photocurrent from 2.25 to 2.89 mA, while reducing the bandwidth from 54 to 30 GHz because of the larger capacitance and active area. The DBR contribution is substantial: for the 5 μm device, responsivity increases from 0.176 A/W without DBR to 0.5 A/W with DBR, and photocurrent increases from 0.89 to 2.25 mA. Relative to a previously reported vertical Ge/GaAs photodetector, the simulated bandwidth and responsivity indicate a clear design-level improvement [5].

Table 1. Simulated performance of Ge/GaAs UTC-PDs with and without DBR layers at 1550 nm under -2 V bias.

Bias voltage -2 V		5 μm	6 μm	7 μm	8 μm
With DBR layers	Photocurrent (mA)	2.25	2.39	2.62	2.89
	Responsivity (A/W)	0.5	0.53	0.59	0.7
Without DBR layers	Photocurrent (mA)	0.89	1.01	1.08	1.12
	Responsivity (A/W)	0.176	0.193	0.235	0.248

Conclusions

A DBR-enhanced front-illuminated Ge/GaAs UTC-PD has been numerically evaluated for 1550 nm operation. The simulations show that optical recycling through the GaAs/AlGaAs DBR improves responsivity without increasing carrier transit length, enabling the 5 μm device to reach 54 GHz 3-dB bandwidth and 0.5 A/W responsivity at -2 V. Across 5-8 μm diameters, the design offers a controllable trade-off between speed and sensitivity, with the 8 μm device reaching 0.7 A/W responsivity. These results support Ge/GaAs as a credible material system for lower-cost high-speed photodetectors and provide a basis for subsequent epitaxial growth, fabrication and waveguide-coupled UTC-PD development.

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PII-25

High Time-frequency Resolution Time-stretched LiDAR with Modified Synchrosqueezing Transform

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Abstract A modified Synchrosqueezing transform is applied to time-stretched coherent LiDAR, realizing high time-frequency resolution and cone of influence mitigation at frequency transition point. Dispersion-limited lateral resolution and accurate phase change extraction along frequency ridge is realized simultaneously.

Introduction

Time-stretch spectral interferometry enables ultrafast 3D imaging by encoding spatial information into a broadband spectrum and mapping it to a temporal waveform via dispersive Fourier transformation (DFT) [1, 2]. However, extracting the interference frequency using the standard short-time Fourier transform (STFT) introduces a Heisenberg uncertainty-dictated trade-off, while widening the temporal window improves frequency resolution but inherently degrades temporal resolution [3]. This compromise is especially severe when interrogating targets with abrupt topographies. Alternative derivative-based methods like the Hilbert transform avoid windowing but are hypersensitive to noise and fail on non-stationary signals due to phase singularities.

To overcome these fundamental limitations, we present an ultrafast Synchrosqueezing transform (SST)-enabled phase-sensitive time-stretch light detection and ranging (LiDAR) system. SST sharpens time-frequency representations by reassigning energy to precise instantaneous frequency ridges, effectively decoupling axial and lateral resolution constraints [4, 5]. Furthermore, to eliminate spectral blurring caused by the cone of influence (COI) at sharp frequency transitions in standard SST, we modified algorithm to dynamically reallocate the wavelet. This approach ensures that the time-frequency representation maintains high spectral sparsity even at the boundaries of transition, effectively laying a solid foundation for precise phase extraction along the frequency ridges. By performing quantitative phase imaging (QPI) along these continuous frequency ridges, we experimentally achieved an axial resolution of 10.79 nm (theoretical 4.70 nm) and a lateral resolution of 88.39 μm at a 30.72-MHz linescan rate. This approach successfully circumvents the conventional resolution trade-off. This integration of ultrafast speed and high precision opens up new avenues for the high-definition 3D inspection of complex industrial and biological surfaces.

Experimental Setup and Working Principle of Modified SST

The schematic diagram of the proposed time-stretch spectral scanning LiDAR is shown in Fig. 1(a). The setup consists of three parts. In the laser generation part, a tailor-built dissipative soliton fiber laser operates a self-starting nonlinear polarization evolution (NPE) with steep spectral edges and large frequency chirps, providing a 20.86-nm 3-dB optical bandwidth and a 30.72-MHz repetition rate. The time-stretch processor is comprised by a dispersion compensating module (DCM) with a total dispersion coefficient of -1338.04 ps/nm. The stretched pulse is subsequently amplified by a picosecond pulse EDFA (AEDFA-PS-01-1000-23-B-FA, Amonics), maintaining low peak power to suppress nonlinear effects. In the Michelson interferometer, the laser light is split into two arms by a beam splitter. A transmission grating (T-940CL,

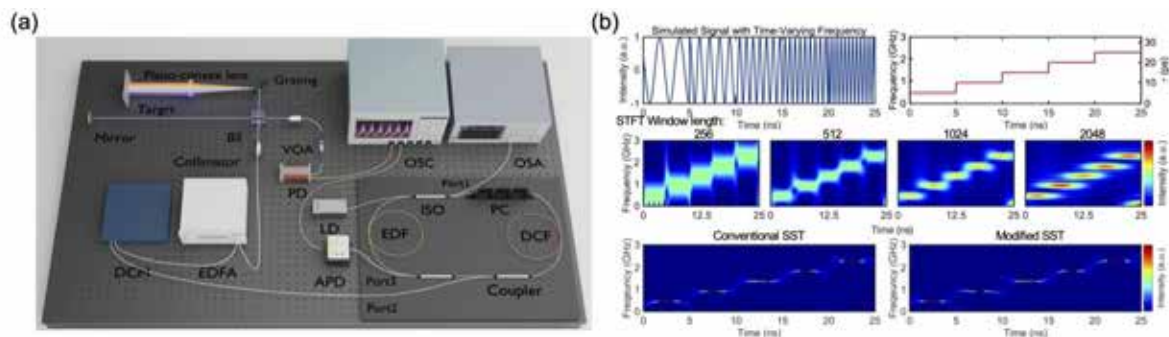


Fig. 1 (a) Schematic diagram of the proposed time-stretch LiDAR with tailor-built dissipative soliton fiber laser source. (b) Comparison of STFT, SST and modulated SST for frequency extraction on simulated time-varying frequency signal.

Lightsmyth, 940.07 grooves/mm) serves as the spatial disperser in the measurement arm, while the laser beam is directly reflected by a mirror in the reference arm. After wavefront reflection by a 500-mm focal length plano-convex lens, the light from the target recombines with the reference beam at the beam splitter and is coupled back into the single-mode fiber

(SMF) via the collimator. The combined signals then interfere at a 25-GHz bandwidth photodetector (UPD-15-IP2-FC, ALPHALAS). The interference signal is converted into an electronic signal and digitized by a high-speed oscilloscope (MSO73304DX, Tektronix).

In the SST-based frequency extraction stage, the interference signal first goes through the continuous wavelet transform (CWT) of the acquired temporal signal $s(t)$, defined as $W_s(a, b) = \int s(t) a^{-\frac{1}{2}} \psi(\frac{t-b}{a}) dt$, where ψ is an appropriately chosen mother wavelet, a is the scale factor, and b is the translation factor. It is then transferred from the time-scale plane to the time-frequency plane by reassigning the diffused energy to intrinsic instantaneous frequency ridges. The continuous version of the SST is expressed as $T_s(\omega, b) = \int_{A(b)} W_s(a, b) a^{-\frac{3}{2}} \delta(\omega(a, b) - \omega) da$, where $A(b) = \{a; W_s(a, b) \neq 0\}$ and δ is the Dirac delta distribution. To mitigate COI, we modified the SST by estimating the changing point and reallocating the wavelet to avoid it to be positioned at the frequency transition point, as shown in Fig. 1(b).

Experimental Results and Discussions

As a proof of concept, a USAF 1951 resolution test chart was used as target. Based on the grating and lens parameters, the theoretical lateral resolution, limited by the spatial dispersion, is calculated to be 111.56 μm . Fig. 2(a) depicts a 3D image of line pairs from group 0 to group 3 was acquired by performing QPI along the SST-extracted frequency ridge while using a 5- μm step-size translation stage for the orthogonal direction. As shown in Fig. 2(b), the system achieves an 88.39- μm lateral resolution, since the line pairs are considered to be indistinguishable when the contrast drops below 15%, while 150-nm thickness coating resolvable through the colorbar. To further evaluate the ultimate axial resolution limit of the proposed system, we probed a home-made target with a 10-nm-thick silver coating, as shown in Fig. 2(d). The phase-based reconstruction shows an averaged step height of 12.63 nm, while a parallel measurement conducted by a commercial mechanical step profiler exhibits an averaged step height of 10.79 nm, as shown in Fig. 2(c). The 1.84-nm discrepancy shows a high measurement accuracy comparing to the 4.70-nm theoretical axial resolution.

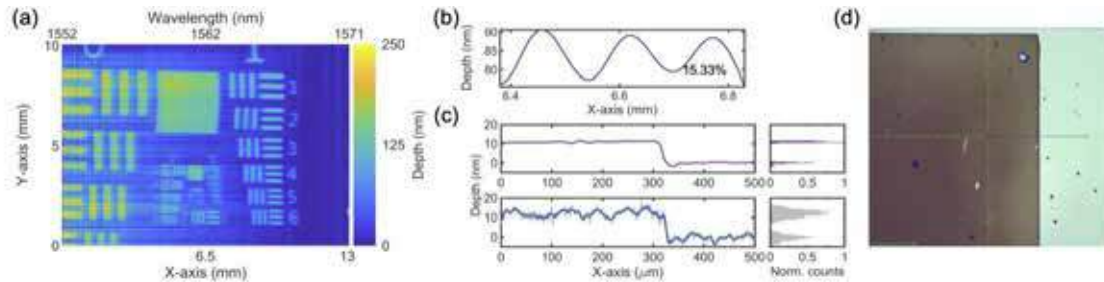


Fig. 2 (a) 3D imaging result of USAF 1951 resolution test chart. (b) Surface relief profile of the slits located at element 4 from group 2. (c) Cross-sectional depth profiles and corresponding depth histograms of the target, measured by the proposed LiDAR system (top, purple) and a commercial step profiler (bottom). (d) Optical micrograph of the fabricated target.

Conclusions

A modified SST is proposed to break the trade-off between axial resolution and lateral resolution in the time-stretched coherent LiDAR for the first time. The experimental results demonstrate a 30.72-MHz ultrafast imaging capability with 88.39- μm lateral resolution and 10.79-nm axial resolution, validating the high-fidelity performance of the proposed system in both dimensions, paving the way for high-definition, real-time 3D inspection of intricate industrial components and dynamic biological surfaces.

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Generation of High Dimensional Quantum Light and Its Application in Communication, Sensing and Computing

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Abstract Spatially entangled photons can be generated by spontaneous parametric down conversion using structured nonlinear crystals and shaped pump beams. These biphotons are then used in quantum key distribution, in super-resolved sensing and in quantum computation.

In the process of spontaneous parametric down conversion, a pump photon spontaneously splits inside a quadratic nonlinear crystal to signal and idler photons. By either structuring the nonlinear coefficient of a crystal or by shaping the pump beam, it is possible to control the correlations of the down-converted signal and idler photons in different degrees of freedom. In my presentation, I will focus on generation and application of spatially encoded entangled photons.

Specifically, we have fabricated structured nonlinear crystals for direct generation of spatially entangled signal-idler pairs, including a bi-photon Bell state in the Hermite-Gauss basis [*Science Advances* **9**, eade7968 (2023)]. Alternatively, by shaping the pump beam, we generated bi-photon qubits and qutrits in the Laguerre-Gauss basis. The bi-photon qutrit was used to demonstrate three-dimensional entanglement-based quantum key distribution [*Optica Quantum* **4**, 179-188 (2026)], as illustrated in Fig. 1.

Shaped pump beams were also used for generating high brightness N00N states [*Optics Express* **30**, 21535-21543 (2022)], which were then used for super-resolved quantum rotation sensing [*APL Photonics* **9**, 106116 (2024), *Lasers and Photonics Reviews* e020709 (2026)]. Here we used two opposite spiral phase plates with topological charge of up to 128 in order to convert mechanical rotation to wavefront phase shift, enabling to obtain, using a 4-photon state, up to $4 \times 128 = 512$ -fold improvement in resolution, see Fig. 2.

Finally, I will also briefly discuss the advantages of using spatial optical qudits for realizing quantum computing algorithms. In this case, a multiplane light converter can be used to perform arbitrary unitary transformations of different spatial qudits, and the inner product of the final state with the base vectors can be realized by spatial light modulator and optical Fourier transformation with a lens.

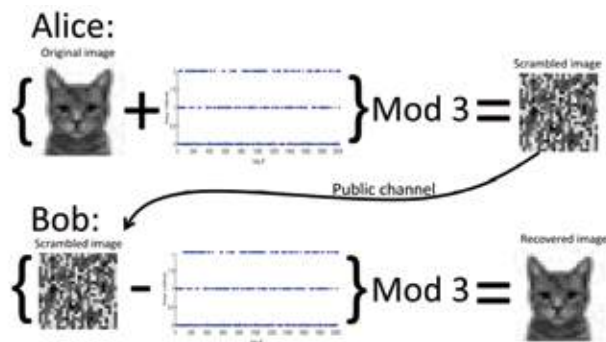


Fig. 1 Encrypting and decrypting a grayscale image of a cat.

The encryption key was generated by simultaneous measurements, made by Alice and Bob, of spatially entangled qutrits [*Optica Quantum* **4**, 179-188 (2026)]

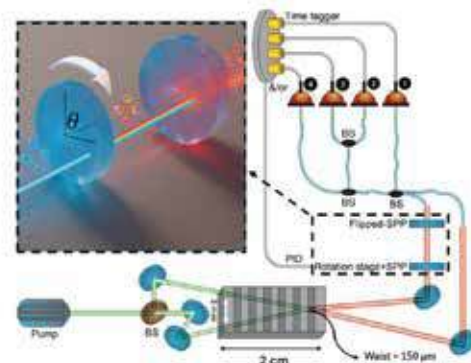


Fig. 2 Experimental setup for measuring mechanical rotation, using entangled 4-photon state and two spiral phase plates [*Lasers and Photonics Reviews* e020709 (2026)].



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Free-Electron Radiation with Micro/Nanostructures

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Abstract Via the interaction of free electrons with micro/nanostructures, we observe several novel free-electron radiation phenomena, including threshold-less Cherenkov radiation, vortex Smith–Purcell radiation, and pump-induced Smith–Purcell radiation featuring super-narrow linewidths.

Introduction

Cherenkov radiation (CR) and Smith-Purcell radiation (SPR) are electromagnetic waves emitted by moving charges passing through dielectric media or interacting with grating structures. They play important roles in physics research, medicine, and free electron light sources. Driven by advances in nanofabrication technologies, various artificial optical materials/structures and interesting phenomena have emerged, which promote the research interest of studying the interaction of free-electrons with micro/nanostructures for radiation generation. Here, the threshold-less CR, Vortex SPR, and pump-induced SPR with novel radiation characteristics are demonstrated.

Threshold-less Cherenkov Radiation^[1,2]

To generate CR, moving charges passing through dielectric media must travel with velocities exceeding a specific threshold. We show the integrated threshold-less CR source with a planar electron emitter on hyperbolic metamaterial (HMM). It is demonstrated that, with low-energy electrons (0.25-1.4keV), the CR is generated covering $\lambda_0=500\sim900\text{nm}$. The electron energy generating CR experimentally is three (two) orders of magnitude lower than that in natural media, while the output power of 200nW is two orders of magnitude higher than that generated by the high-energy electrons (tens to hundreds of keV) in the nanostructures.

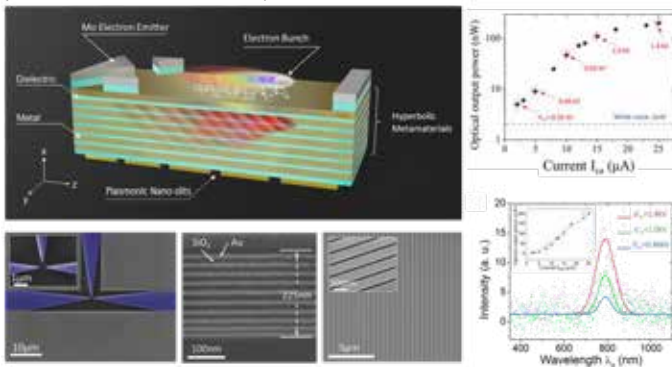


Fig. 1 Threshold-less Cherenkov Radiation

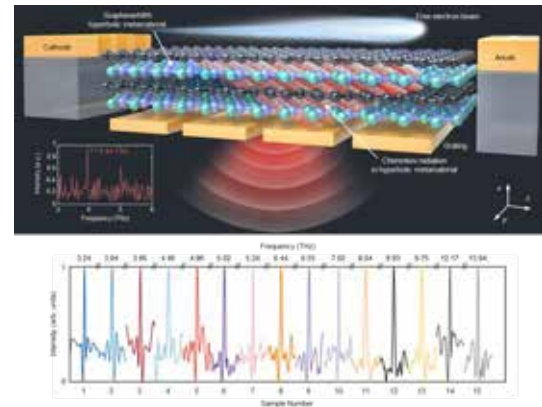


Fig. 2 Cherenkov Radiation in THz region

Furthermore, by constructing a hyperbolic metamaterial with graphene and hexagonal boron nitride, on-chip, free-electron-based terahertz Cherenkov radiation is observed and the frequency tunable range spans 3.2 to 14 THz in a hundred-micron-scale dimension. Compared with other free-electron terahertz sources, the chip size is over three orders of magnitude smaller, and the tunable range is one of the widest.

Vortex Smith–Purcell radiation^[3]

An integratable method for generating vortex Smith-Purcell radiation (VSPR), namely SPR carrying OAM, is proposed and investigated by having free electron bunches pass on planar holographic gratings. The VSPR generated by different electron energy, with different topological charge of OAM, radiation angles, and frequencies are demonstrated numerically. It is also found that, for high order radiation, its topological charge of the OAM wave will be multiplied by the radiation order. This work introduces a new way to generate SPR with OAM and provides a method to achieve an integratable and tunable free-electron OAM wave source at different frequency.

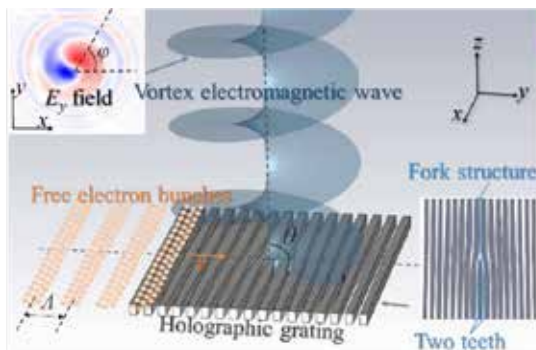


Fig. 3 Vortex Smith-Purcell radiation

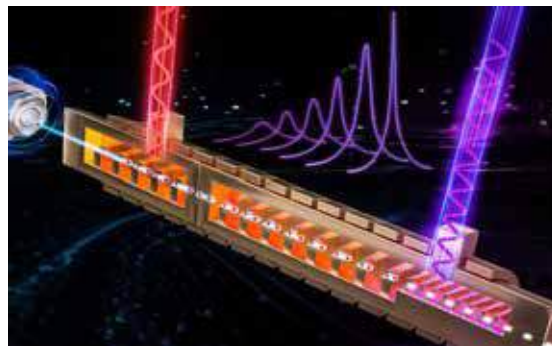


Fig. 4 Pump-induced Smith-Purcell radiation

Pump-induced Smith-Purcell radiation^[4]

The superradiant Smith-Purcell radiation (S-SPR) in terahertz frequency band with ultra-narrow and continuously tunable linewidth in a compact device. By proposing a new effect of pump-induced stimulated S-SPR (PIS-SPR), the spectral linewidth could be reduced to 0.3 kHz @ 291.7 GHz, which is about two–six orders of magnitude narrower compared with those obtained by accelerators and other electron devices. Meanwhile, the wide range of continuously tunable spectral linewidth spanning 0.3–900 kHz is observed for the first time. This work provides a way to greatly narrow the spectral linewidth of free electron radiation and to achieve high-order harmonic of S-SPR in a compact device, and offers a platform to study the interaction between free electron bunches and different micro/nanostructures.

Conclusions

This work investigates the novel micro/nanostructure-enabled free-electron radiations. We realize integrated threshold-less CR with drastically lowered electron energy, and fabricate chip-scale broadband tunable terahertz Cherenkov sources. An integratable vortex SPR scheme carrying controllable OAM is numerically validated. Moreover, PIS-SPR with record-narrow continuously tunable linewidth is reported. These compact, tunable light sources advance miniature integrated photonic devices from visible to terahertz bands.

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Nanoscale electrooptical studies of nanowires and nanoLEDs

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Abstract Self-assembly of nanomaterials has enabled advanced nanoscale devices. I will focus on the field of compound semiconductors nanowires for nanoelectronics and nanophotonics and bottom-up growth of sub- μm sized InGaN nanoLEDs based on relaxed InGaN templates.

Introduction

Progress in electronics and opto-electronics is often the result of novel materials approaches, for instance new ways to grow crystals and devices. Enablers of the breakthroughs for compound materials resulting has come from the development of molecular beam epitaxy (MBE) and Metal-Organic Vapour Phase Epitaxy (MOVPE). These growth methods allowed the development and exploration of novel areas such as quantum wells (QWs), nanowires (NWs) and quantum dots (QDs), all based on the important concepts for semiconductor heterostructures, as pioneered by Herbert Kroemer more than 50 years ago. I will here concentrate on how we have realized nanowires and other nanomaterials by MOVPE for their potential use in electronics and opto-electronics.

Development of ideal III-V nanowires

Some of the most original efforts in growth of NWs were performed by Kenji Hiruma and his team at Hitachi, back in the late 80's and early 90's, demonstrating that by seeding growth by nanoparticles of gold, also the first to demonstrate that it is possible to form heterostructures between different III-V's. With the efforts set up in my group at Lund University for NW growth, and effort that was started late 90's, we made a strong effort in combining the NW growth with a pre-patterning using electron-beam lithography, by which we were able to control lateral and axial dimensions as well as the exact positioning of each of the NWs, which opened the way to real device explorations.

Understanding nanowire growth mechanisms

The general understanding of how NWs grow date back to the 60's when the vapour-liquid-solid (VLS) mode of growth was proposed and demonstrated. The principle is that a catalytic gold particle forms a eutectic alloy, for instance with metallic gallium, as provided for instance as tri-methyl-gallium (TMG), and that this alloyed metallic particle reacts with suitable precursor molecules containing arsenic (for growth of GaAs), such as arsine (AsH_3). Given the right conditions, this can in a very controlled manner lead to the outgrowth of a single-crystalline NW with its diameter governed by the catalytic particle size and the orientation being vertical from a 111-oriented substrate like GaAs. Many efforts were spent in the time 2004-2008 in fundamental studies of NW growth and how the actual crystalline structure of the NWs could be controlled, either cubic (zinc-blende) or hexagonal (wurtzite). Indeed, we also explored how controlled switching between these forms may lead to interesting steps in the conduction and valence bands, influencing optical properties as well as both thermal and electronic transport.

Controlled design of axial and radial heterostructures

I took the initiatives for this research around the year 2000 primarily to realize quasi-one-dimensional hetero-structured semiconductors, as low-dimensional heterostructure physics devices. Our first studied was that of heterostructures between InAs and InP which were selected as potentially highly abrupt interphases, since it is possible to change the group-V atoms from As to P extremely abruptly. Our first highly noticed study of these kind of NW heterostructures was published in 2004 in Nano Letters, with the descriptive title "One-dimensional steeple chase for electrons realized", demonstrating that electrons in the conduction band of InAs, when encountering the new segment containing InP, experienced a potential step, as a barrier of more than 0.5 eV's. We also showed that for a very thin segment of InP, this appears as an ideal tunnelling barrier while, for longer segments, the electrons could, via thermionic excitation, overcome this one-dimensional barrier. Obviously, these results generated a novel toolbox for exploration of known heterostructure systems but now converted to the low-dimensional NW world.

Nanowires for electronics and opto-electronics applications

Two InP barriers located in an InAs NW, could define a QD in between them. By this scheme, we were able to produce highly perfect single-electron transistors (SETs) as well as resonant tunnelling devices (RTDs), in both case as the first

such one-dimensional heterostructure devices. A very recent addition is a “Hot carrier nanowire transistor at the ballistic limit”. Beside these “physics devices” we were very active in exploring how the traditional gating of planar transistors could be replaced by a NW device where a wrap-gate-all-around could ideally allow the continued down-scaling of transistors, in a way we today see in the newest nodes of integrated circuits.

A QD of a smaller bandgap material located inside a NW offers quite ideal systems for single photon on demand. I will also give examples of how III-V NWs are ideal for solar cell applications. We could demonstrate how a perfectly designed array of NWs can capture almost all incoming solar light even if the NWs only cover about 10% of the surface, because of nanophotonic antenna effects. Finally, I will for this subject area show examples of how GaN-based NWs can ideally function as light-emitting diodes (LEDs), which we explored also in close collaboration with our spin-out company GLO, first established in Lund, later transferred to Silicon Valley.

Market pull for μm -sized RGB-emitting microLEDs

The field of microLEDs is attracting much attention, because of their extreme brightness and long-term stability, with important applications for advanced displays and for inter-chip optical communication. In high-demanding display applications, as for smart-phones and AR/VR-applications, the pixel size needs to reduce to about $1\mu\text{m}$, for all three RGB-colors. For miniLEDs and large-sized microLEDs, the blue and green colors are made from III-Nitrides, while red is made from AlGaInP/GaAs. For pixel sizes approaching $10\mu\text{m}$, and below, top-down processing of AlGaInP wafers lead to un-acceptable defects killing the efficiencies. Although the III-Nitrides are less prone to defects and carrier diffusion, efficient Red is still extremely hard to achieve, due to large lattice-mismatch between InGaN quantum well (QW) and the GaN substrate. Damage from top-down processing strongly reduces the efficiency, suggesting bottom-up growth.

Recent progress in highly ideal RGB-emitting microLEDs

I will first present a survey of approaches to enable all RGB-colors by III-Nitrides also for extremely small-pixel microLEDs. I will then describe how we are able to replace the GaN substrate with extended platelets of relaxed InGaN, thus reducing the lattice mismatch. Using bottom-up crystal growth, from seeding of GaN nanowires, we create extended platelets of InGaN, freely separated from the GaN substrate and the growth mask. On top of these relaxed and dislocation-free InGaN platelets we can form the entire micro/nanoLED structure having IQE-values typically 60%, also for device sizes below $1\mu\text{m}$, i.e. pixel-sizes as required for advanced AR/VR applications. I will show various examples of electro-optical studies of these unique devices, as developed jointly with the spin-out company Hexagem AB in Lund.

Conclusions

I hope that my talk will inspire some young researchers participating in iNOW2026, with the general thematic approach, to create advanced nanomaterials and nanodevices by innovative epitaxial crystal growth method and to apply various materials and device characterization methods to verify the performance and, very important, to provide feed-back to the epitaxy and processing which produce the structures and the devices.

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Lars Samuelson got his PhD in Physics at Lund in 1977. After Post-doc at IBM, CA, he set up the first MOCVD in Northern Europe. Full Prof. from 1986 and in 1988 he initiated NanoLund, today with >400 researchers. Since 2021 Chair Prof. and Institute Director at SUSTech. He is author of ≈ 750 articles with h-index 92 at Web-of-Science (h-index 112 at Google Scholar), listed among the 1% most highly cited researchers by Web-of-Science. Member of Swedish Academy of Science, of Swedish Academy of Engineering Sciences and Foreign member of Chinese Academy of Sciences.

Transmission over Anti-resonant Hollow-core Fibers

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Abstract

In recent years, anti-resonant hollow-core fibers (AR-HCFs) have made remarkable progress, surpassing the loss limit of conventional silica solid-core fibers and achieving attenuation as low as 0.04 dB/km. Due to their low latency, negligible nonlinearity, and broad transmission bandwidth, AR-HCFs have attracted significant attention from both academia and industry, positioning them as a foundational technology for optical communications over the next half-century.

We demonstrated the first-ever 1-Tb/s s/λ signal transmission over 10,000 km without regeneration. A 146.77-km recirculating loop of low-IMI and ultra-low-loss DNANF-5 fiber was used. A DP-36QAM-PCS signal with an entropy of 3.96 was modulated and transmitted after 73 loops at 23-dBm launch power. The total transmission distance reached a record 10,714.28 km. IMI and attenuation ripple replaced the nonlinearity as the dominant penalty contributors.

The air-guiding mechanism of AR-HCF not only brings ultra-low loss but also results in ultra-low Rayleigh backscattering, allowing for the direction to be treated as an independent dimension. We demonstrated co-frequency co-time full-duplex (CCFD) S+C+L-band WDM transmission over 100 km AR-HCF. The capacity of one direction was experimentally measured to be 188.8 Tb/s under a bidirectional transmission configuration, corresponding to an equivalent aggregate bidirectional capacity of 377.6 Tb/s over 100-km AR-HCF.

However, large-scale industrial production of AR-HCFs remains underdeveloped, and prior research has been largely confined to laboratory-scale experiments using short fiber segments, failing to fully explore their performance potential or identify deployment-related challenges. To address this gap, we presented the field deployments of four structurally distinct AR-HCF cables spanning 10-42.7 km. Post-deployment measurements demonstrated an average link loss reduction from 0.599 dB/km to 0.113 dB/km, with the lowest recorded span loss reaching 0.065 dB/km, making it the world's first fiber cable deployment to break the 0.1 dB/km level. Leveraging these deployed links, we conducted real-time coherent transmission experiments at 800 Gb/s to 1.2 Tb/s across S-, C-, and L-bands, validating the feasibility of co-time co-frequency full-duplex (CCFD) transmission in hollow-core fibers and characterizing the impact of gas absorption (e.g., CO₂ and H₂O) on system performance. Despite these impairments, we achieved the first field demonstration of real-time terabit-scale coherent transmission over the S+C+L band, delivering a record aggregate capacity of 114.9 Tb/s over 137.36 km using 105 channels.

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Zhangyuan Chen received the BS, M.S., and Ph.D. degrees from Peking University of China, in 1991, 1994, and 1997, respectively. Since 1999, he has been with the State Key Laboratory of Photonics and Communications at Peking University as an Associate Professor (1999-2004) and Professor (2004-present) of Electronics Engineering. He was the Director of the State Key Laboratory from 2019 to 2023. He spent time as a visiting scholar in COMELEC Department of Ecole Nationale Supérieure

des Telecommunications of France in 1998 and in the EECS Department of UC Berkeley from 2005 to 2006. His main research interest is in the area of optical communication and photonics.

Coherent Coupling of Semiconductor Lasers for Energy-Efficient Frequency Combs and High-Bandwidth Sources

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Abstract



Guillaume Huyet received the M.Sc. degree from ENS Lyon, Lyon, France, and the PhD degree from the University of Nice, Nice, France. After postdoctoral positions in Mallorca, Spain, Cork, Ireland, and Glasgow, U.K., he became a Lecturer at University College, Cork, Ireland. In 2002, he became a Senior Research Fellow at University College. He is currently the Science Foundation Ireland Principal Investigator at the Tyndall National Institute and the Head of the Center of Advanced Photonics and Process Analysis (CAPPA), Cork Institute of Technology, Cork. Since January 2017 he is research director at CNRS and head of the Institut de Physique de Nice (INPHYNI). His research interests include semiconductor devices for applications in communications and life science. Dr. Huyet received the Science Foundation Ireland Principal Investigator Award in 2002.

Topological Photonic and Phononic Crystals: A Synthetic Universe of Waves

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Abstract Topological photonic and phononic crystals provide a versatile platform as a “synthetic universe” where some fundamental physics questions can be emulated, visualized, and addressed, enabling robust wave transport and a wide range of novel functionalities.

Introduction

Topological photonic and phononic crystals originated from the effort to emulate the quantum Hall effect, or Chern insulator, characterized by a nonzero Chern number. Over the past two decades, they have evolved into two vibrant and enduring research fields in their own right. In this talk, I will highlight several recent advances in both directions.

In topological photonics, we have developed a series of three-dimensional (3D) topological photonic crystals that serve as analogues of electronic 3D topological insulators. The first is a time-reversal-invariant system realizing a weak 3D topological insulator. The second is a 3D Chern insulator, in which the Chern number is generalized to a three-component topological invariant. The third is a photonic axion insulator (Fig. 1), whose surfaces carry half-quantized Chern numbers of $\pm 1/2$. As a consequence, unidirectional chiral hinge states emerge and propagate through three-dimensional space, giving rise to robust 3D topological transport.

In topological phononics, we introduce the concept of a synthetic dimension by treating the spatial coordinate x as an effective time axis t (Fig. 2). Under this mapping, acoustic wave propagation along x can be interpreted as the time evolution of a wave function. This framework enables the realization of an effective Floquet time-periodic system using static acoustic structures. Leveraging this approach, we observe a novel type of phase transition that transcends both the Landau–Ginzburg paradigm and conventional topological phase transitions. In particular, we demonstrate a topology-enforced multicritical point at which the entanglement entropy (von Neumann entropy) exhibits an additive behavior, revealing an unexpected interplay between topology and criticality.

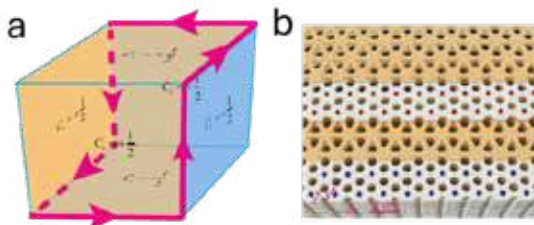


Fig. 1 A photonic axion insulator. (a) Every surface of this photonic crystal takes a half quantized Chern number $\pm 1/2$. So the hinges support unidirectional chiral states propagating in 3D. (b) The photonic crystal construction. The little black dots are gyromagnetic YIG rods.

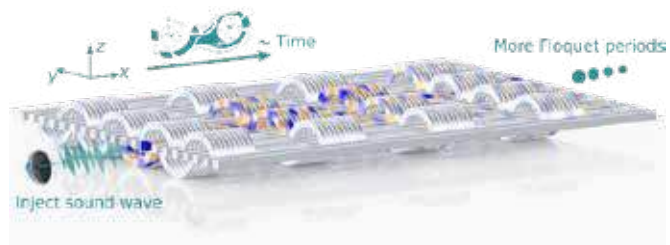


Fig. 2 A phononic crystal simulating a periodically driven one-dimensional dimerized lattice model (the Floquet SSH α -chain). This Floquet system undergoes a topological phase transition in the critical regime, which we refer to as critical topological phase transition.



Zhang, Baile received her BS and MS degrees from Tsinghua University, and his PhD degrees from MIT in 2003, 2006 and 2009, respectively, all in Electrical Engineering. He is currently President's Chair in Physics at School of Physical and Mathematical Sciences, Nanyang Technological University, Singapore. He was a recipient of TR 35 Global Innovators award in 2012. He was awarded Singapore's President Science Award with two colleagues in 2020. He is a Clarivate Highly Cited Researcher in Physics.

Metasurface Nanophotonic Devices Based on Superhard Materials

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Abstract

Superhard materials, represented by silicon carbide (SiC) and diamond, combine high refractive indices, wide bandgaps, excellent thermal conductivity, and outstanding mechanical robustness, offering attractive material platforms for high-performance nanophotonic devices. In this report, SiC is primarily investigated as a representative superhard material platform, with diamond-related work briefly discussed as an extension toward more extreme material and device performance.

Focusing on SiC metasurface devices, this report presents studies on metalenses and AR diffractive waveguides. To address thermally induced focal shift under high-power laser irradiation, a thermally stable SiC metalens is developed for long-term near-diffraction-limited focusing. Through the co-optimization of structural design and process compensation, a high-numerical-aperture achromatic metalens is constructed. Furthermore, an ultrathin and lightweight single-layer diffractive waveguide is proposed, enabling full-color, large field-of-view display while effectively suppressing rainbow artifacts. These studies provide a promising route for developing superhard-material-based metasurface nanophotonic devices.



Prof. Min Qiu holds the Guoqiang Chair Professorship in Optical Engineering at Westlake University. As a recipient of Special Government Allowance from the State Council, he serves as Vice President of the university, Dean of the School of Engineering, and Director of the Westlake Institute for Optoelectronics. He is a Foreign Member of Academia Europaea, a Foreign Member of European Academy of Sciences and Arts and a recipient of the National Science Fund for Distinguished Young Scholars. He is also a Fellow of several prestigious professional societies, including: IEEE Fellow (Institute of Electrical and Electronics Engineers), Optica Fellow (formerly OSA, The Optical Society of America), SPIE Fellow (International Society for Optical Engineering), COS Fellow (Chinese Optical Society), CSOE Fellow (Chinese Society of Optical Engineering) and CIE Fellow (Chinese Institute of Electronics). Prof. Qiu actively contributes to the academic community through leadership roles, serving as a Standing Council Member of the Chinese Society of Optical Engineering (CSOE), Deputy Director of both the Micro- and Nano-Optics Committees of CSOE and the Chinese Optical Society (COS), as well as Vice President of the Zhejiang Optical Society and the Zhejiang Institute of Electronics.

Prof. Qiu's main research interest is micro-nano optoelectronics, including micro-nano fabrication technology and instrumentation, micro-nano photonics theory and optoelectronic devices, key theories and technologies for smart applications, etc.

Triple-lattice Photonic Crystal Surface Emitting Lasers

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Abstract Triple-lattice structure PCSEL was proposed and demonstrated in the 905nm, 940nm, 1.3μm GaAs-based quantum well (QW) and quantum dot (QD) PCSELS, and 1.55μm InP based QW PCSELS.

Introduction

Photonic crystal surface-emitting lasers (PCSELS) have recently attracted much attention as novel semiconductor lasers because of the extreme brightness and narrow spectral linewidth. These lasers use two-dimensional photonic-crystal resonators to achieve optical feedback, and light amplification and lasing are realized at the band edge by forming a broad-area standing wave in the lateral direction, with the light extracted from the normal direction by first-order diffraction. Recently, a narrow-divergence far-field pattern was achieved due to the broad-area coherent resonance with a record output power above 50 W [1], which indicates the enormous potential of PCSELS. However, it is difficult for PCSEL to be applied for high-speed direct modulation due to the limitation of large device size and high threshold current. In this work, a triple-lattice photonic crystal structure was proposed to enhance the optical feedback of in-plane for the operation under a short cavity with low threshold current.

Use of the template is mandatory.

Methods and Results

Using triple-lattice photonic crystal structure, a three-fold increase in in-plane 180° coupling compared to a normal single-lattice structure was realized and hence the threshold current density decreased. The triple-lattice PCSELS were demonstrated experimentally based on 905 nm, 940 nm InGaAs/GaAs QWs, 1.246μm InAs/GaAs QD and 1.55μm InP based QW material [2-8]. The low threshold current ~ 29 mA was realized in 940nm PCSEL [7], which is comparable with traditional DFB lasers. The continuous wave (CW) operation of 1.246μm InAs/GaAs QD [8] and 1.55μm QW PCSEL were realized with emission power of a few milliwatts. Our structure provides a new strategy for the miniaturization of photonic crystal lasers and will contribute to the development of high-performance PCSELS in the future.

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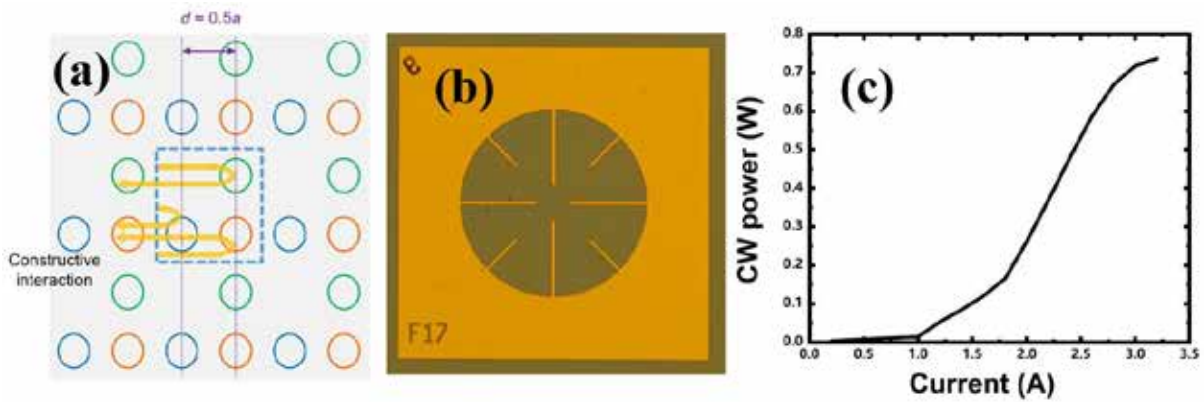


Figure 1. (a) Principle of triple-lattice PCSELs, (b) top-view of PCSEL chip, (c) CW power performance of 940 nm PCSEL fabricated by nano-imprint.



Tong Cunzhu received his BS and MS degrees from applied physics, and his PhD degree from institute of Semiconductors, Chinese Academy of Sciences in 1999, 2002 and 2005, respectively, He is a winner of the National Science Fund for Distinguished Young Scholars. His research is mainly engaged in laser diode technology, including high-brightness laser diode, surface-emitting lasers and disc laser. He was awarded the first prize of Jilin Provincial Science and Technology Award, Wang Daheng Optical Award. He has presided over 25 projects, including key national research and development programs, key projects of the Natural Resources Foundation, and projects commissioned by Trumpf and Huawei, and has published more than 140 papers, authorized 32 Chinese invention patents and 4 USA patents.

Semiconductor Cavity Quantum Electrodynamics

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Abstract We present our recent research activities on semiconductor cavity quantum electrodynamics based on epitaxial quantum dots deterministically coupled to on-chip microcavities.

Introduction

Semiconductor quantum emitters, especially epitaxial quantum dots (QDs) with large optical oscillator strength, are one of the most promising candidates for exploring fundamental quantum physics in solid-state and building quantum photonic devices on-chip. However, the deterministic creation and eventual scalability of single QD devices greatly suffer from the random nature of the QDs produced in their self-assembled growth.

Result

In this talk, I will present the breakthrough of scalable and deterministic cavity quantum electrodynamics (cQED) systems based on single-photon hyperspectral imaging[1]. With deterministically coupled QD-microcavity systems, we 've investigated fundamental quantum physics [2-4], advanced hybrid integrated quantum photoincs [5,6] and developed high-dimensional quantum light sources [7-9].

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Jin Liu received his BS degree from South China Normal University, and his PhD degree from Technical University of Denmark in 2007 and 2012, respectively, all in Photonics Engineering. Before moving back to China, he worked with Dr. Kartik Srinivasan at National Institute of Standards and Technology (NIST) to develop integrated quantum photonic technologies. His current research activities cover integrated quantum photonics and nanophotonics by utilizing molecular beam epitaxy, semiconductor nanofabrication and cryogenic optical characterizations.

Integrated Photonics for LiDAR

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Abstract This talk gives the evolution of LiDAR toward highly integrated photonic platforms. By resolving fundamental hardware bottlenecks and advancing algorithmic data fusion, we present a comprehensive vision for next-generation, intelligent 3D sensing.

Introduction

As a three-dimensional (3D) sensor, light detection and ranging (LiDAR) has emerged as one of the most eye-catching fields in optoelectronic systems due to its unique capabilities in long-distance and high-precision ranging. To address the inherent limitations of traditional mechanical assemblies, LiDAR is evolving rapidly toward chip-scale systems based on photonic integrated circuits (PICs) [1]. Integration offers a compact form factor, reduced cost, improved stability, and the potential for large-scale manufacturing.

Because 3D sensing depends largely on the beam scanner, achieving inertia-free, solid-state beam steering is a critical industry bottleneck. Spectral-scanning techniques provide a highly effective solution by utilizing diffractive components alongside a wavelength-swept laser source. The inherent passive beam deflection of optical diffraction facilitates exceptional beam-steering performance, with reported maximum scanning rates reaching the GHz level [2].

Our research group has been deeply engaged in the field of spectral-scanning LiDAR [3-5]. We have proposed a four-dimensional (4D) frequency-modulated continuous-wave (FMCW) spectral-scanning LiDAR that combines a dispersive grating with a mechanical rotator, achieving a panoramic field-of-view (FoV) with simultaneous ranging and velocity capabilities [6]. The application of a vertical cavity surface emitting laser (VCSEL) provides the system with a compact size and low cost. However, a major technical pain point is that VCSELs exhibit increased frequency-swept nonlinearity compared to other laser sources, which fundamentally degrades FMCW ranging precision. To mitigate this hardware limitation, we developed robust algorithms to correct the nonlinearity effect using pre-distortion and CNN-based deep-

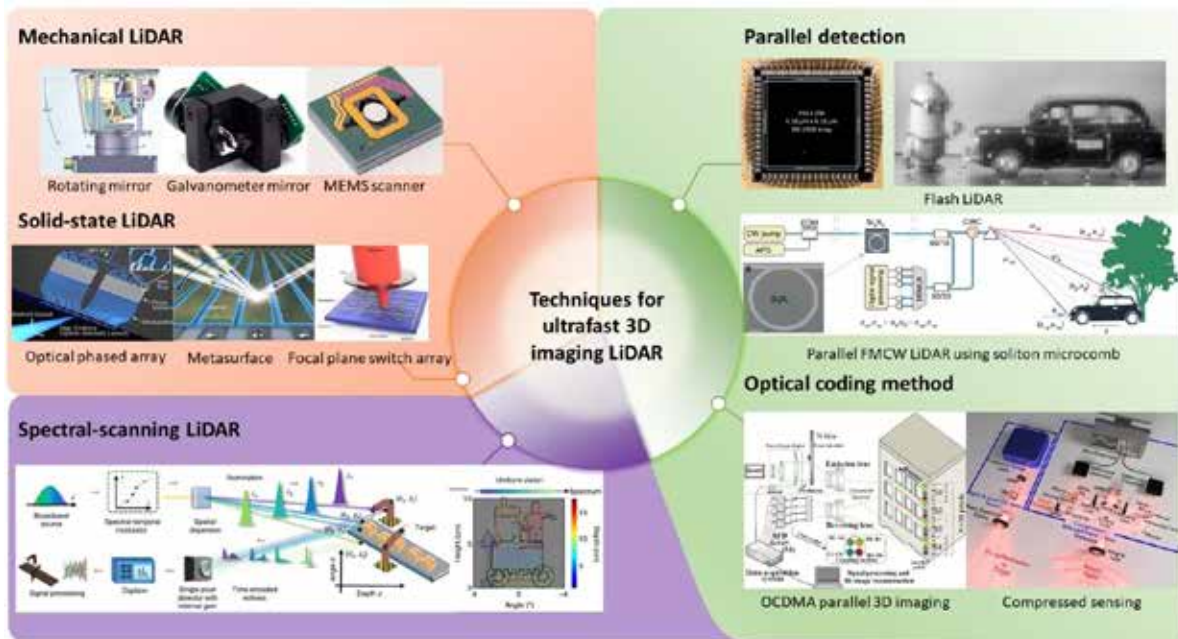


Fig. 1 Techniques for ultrafast 3D imaging LiDAR.

learning methods, providing a data-efficient, model-free solution [7].

Beyond system-level source optimization, we are also pushing the boundaries of component integration by embedding metasurface-based components into silicon photonic platforms [8]. In FMCW LiDAR systems, metamaterials open new avenues for non-mechanical beam steering, spectral multiplexing, and polarization diversity. These are critical features for

building robust, high-resolution 3D imaging systems. Our results demonstrate that metamaterial-enabled designs significantly enhance the functionality and integration level of LiDAR systems.

Finally, to provide a complete research flow from physical sensing to intelligent perception, our group has developed robust algorithms to process LiDAR point clouds and resolve cross-modal geometric alignment issues. By proposing an ego-motion-conditioned hierarchical fusion framework for motion-aware multi-modal 3D semantic segmentation, we bridge the gap between raw optical data and practical autonomous applications.

In this talk, I will review our recent, comprehensive advances in LiDAR technology—spanning from novel hardware and AI-assisted signal processing to multi-modal perception. Building on these existing research achievements, I will also discuss the future trajectory of photonic integration and envision the next generation of intelligent sensing platforms.

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Hongyan, Fu is currently a tenured-associate professor, and in charge of Nano-fabrication Platform, Tsinghua Shenzhen International Graduate School (SIGS), Tsinghua University, Shenzhen, China. He received the B.S. degree in electronic and information engineering from Zhejiang University and the M.S. degree in electrical engineering with specialty in photonics from Royal Institute of Technology (KTH), Sweden, and the Ph.D. degree from the Department of Electrical Engineering from Hong Kong Polytechnic University. His research focuses on integrated photonics and its related applications in communications and sensing, including optical wireless communication and LiDAR.

From 2005 to 2010, he was a research assistant and then research associate with Photonic Research Center, the Hong Kong Polytechnic University. From 2010 to 2017, Dr. Fu was a founding member and leading the advanced optic communications research at Central Research Institute, Huawei. He was the project manager of All-Optical Networks (AON), which was evolved to a company-wide flagship research project that covers whole aspects of next generation optical communication technologies to guarantee Huawei's leading position. He was also a representative for Huawei at several industry/academic standards/forums. He was an active contributor at IEEE 802.3 Ethernet and Optical Internetworking Forum (OIF) where he was an OIF Speaker from 2012 to 2013. He actively participates in organizing several photonic conferences, such as co-chair of International Nano-Optoelectronics Workshop (iNOW2019) and technical program co-chair of the 2022 Asia Communications and Photonics Conference (ACP2022). He is Optica fellow, senior member of IEEE, and life member of SPIE. He is the founding advisors of Optica/IEEE Photonics Society/SPIE Student Chapters at Tsinghua SIGS, Tsinghua University. He serves as the associate editor of Frontiers in Photonics and reviewers for Nature, Science, etc. He has authored/coauthored over 350 journal or conference papers, 3 book chapters, over 80 granted/pending China /Europe/Japan/ US patents.

Holographic Lithography for Grating Fabrication and Atomic-scale Characterization of Gratings

Xinghui Li, Shuonan Shan

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Abstract

This paper reviews recent advances in holographic lithography for precision grating fabrication and atomic-scale characterization, highlighting technological evolution from laser interference lithography to multiscale, SI-traceable metrology for next-generation precision gratings.

Introduction

Diffraction gratings are fundamental optical components for precision metrology, optical encoders, and advanced photonic systems. Increasing demands for positioning accuracy and measurement range have driven both grating fabrication and characterization toward the atomic scale. Among various fabrication techniques, laser interference lithography has emerged as a key technology, while advances in interferometric metrology have significantly improved the accuracy and traceability of grating characterization. This paper reviews recent developments in these two complementary areas, focusing on holographic lithography for precision grating fabrication and atomic-scale characterization techniques, as summarized in Fig. 1.

Holographic Lithography for Grating Fabrication

Laser interference lithography (LIL) is a maskless fabrication technique that records the interference pattern of two or more coherent laser beams in a photoresist, followed by development and pattern transfer to generate diffraction gratings. The grating period is determined by the laser wavelength and the interference angle, $\Lambda = \lambda / (2 \sin \theta)$, enabling flexible and accurate period control. Benefiting from its high throughput, excellent periodicity, and inherent large-area capability, LIL has become one of the most effective approaches for precision grating fabrication.

The development of holographic lithography has been driven by the continuous expansion of fabrication capability, from two-dimensional grating patterning to high-fidelity exposure, large-area stitching, and multifunctional grating fabrication. Early efforts focused on extending interference lithography from one-dimensional to two-dimensional grating patterning, where Li et al. developed a two-dimensional Lloyd's mirror configuration for high-precision crossed gratings. This capability was further strengthened by the introduction of spatial polarization tracing and polarization modulation, which substantially improved interference-field uniformity and exposure fidelity for large-area fabrication. The subsequent incorporation of interference-fringe locking enabled seamless stitching of multiple exposure fields, overcoming the intrinsic field-of-view limitation of conventional holographic lithography while maintaining nanoscale pattern continuity. More recently, holographic lithography has been extended beyond conventional periodic structures through hybrid lithography strategies, allowing periodic gratings and non-periodic encoding patterns to be integrated on a single substrate and paving the way for multifunctional cross-scale grating devices.

Atomic-scale Characterization of Gratings

With the continuous improvement of grating fabrication accuracy, characterization techniques have evolved from global form evaluation toward traceable atomic-scale dimensional metrology. Early grating characterization relied on Fizeau interferometry for non-contact evaluation of pitch uniformity and surface flatness. The subsequent development of self-calibration and synthetic aperture interferometry extended quantitative characterization to large-scale variable-line-spacing gratings, demonstrated by the successful evaluation of a 105 mm linear scale using a 100 mm-aperture Fizeau interferometer. Subsequent advances shifted the focus from global morphology to atomic-scale dimensional characterization. The metrological large-range AFM developed by Gaoliang Dai and co-workers at PTB established SI-traceable measurements of grating pitch and surface profiles, reducing the calibration uncertainty to 0.3 nm with a repeatability of 0.02 nm, thereby providing a benchmark for atomic-scale grating metrology. More recently, laser interferometer-based metrology systems developed by Xinbin Cheng's group at Tongji University have further strengthened traceable grating characterization by establishing dual traceability chains referenced to both the laser wavelength and grating pitch, enabling sub-nanometer displacement calibration directly linked to the SI definition of the metre.

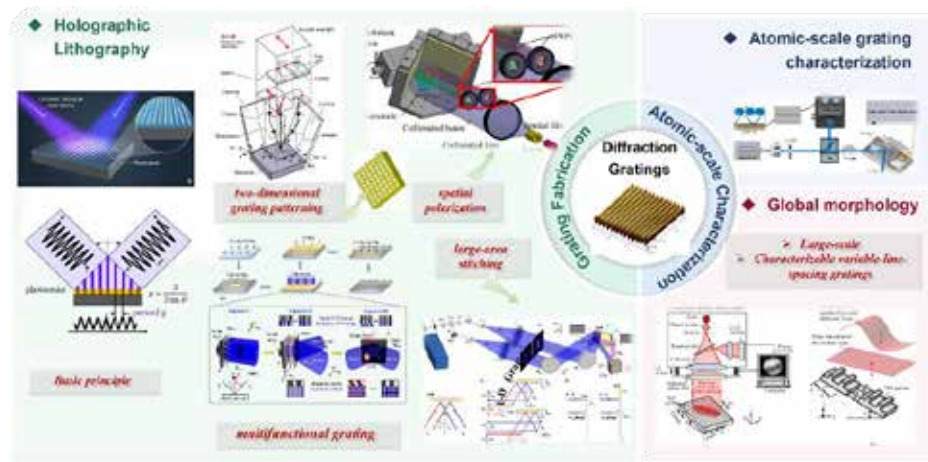


Fig. 1 Overview of holographic lithography for grating fabrication and atomic-scale characterization.

Conclusions

The rapid development of holographic lithography and grating metrology has continuously pushed the achievable fabrication accuracy from periodic pattern generation toward atomic-scale structural control. Meanwhile, advances in multiscale characterization have provided increasingly reliable quantitative feedback for process optimization and dimensional traceability. Future developments are expected to further integrate intelligent fabrication, real-time process monitoring, and traceable atomic-scale metrology, enabling deterministic manufacturing of increasingly complex grating architectures for precision positioning, semiconductor metrology, and emerging photonic systems.

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Shuonan Shan received the B.S. degree from Southeast University, Nanjing, China, in 2021, and the M.S. degree from Tsinghua University, Beijing, China, in 2024. She is currently pursuing the Ph.D. degree with Tsinghua University. Her research interests have been in the areas of precision grating fabrication, holographic lithography, and optical precision metrology.



Note





Note





Note

Venue Introduction



Venue 1: Conference Centre of UCAS

Conference Center of the University of Chinese Academy of Sciences is located at UCAS Yanqihu Campus, Huairou District, Beijing, overlooking Yanqi Lake with picturesque mountain views.

As an official CAS designated conference venue, it boasts complete modern audio-visual equipment and diverse meeting spaces ranging from small breakout rooms to a 500-seat grand lecture hall. The center provides all-in-one supporting services including on-site guest accommodation, multi-style catering, business and recreational facilities, perfectly suited to host international academic conferences, workshops and invited speaker forums.



Venue 2: Hilton Tianjin Eco-City

Sino-Singapore Tianjin Eco-City Investment and Development Co., Ltd founded in July 2009, the Sino-Singapore Tianjin Eco-City Investment and Development Co., Ltd. (SSTEC) is the master developer of the China-Singapore Tianjin Eco-City (the Eco-City). As the master developer, SSTEC works closely with the governments and private sectors of China and Singapore, as well as other international partners, to plan and develop the Eco-City. SSTEC is committed to building a sustainable Eco-City that is ecologically friendly, socially harmonious and resource efficient.

SSTEC will continue to play four important roles of the platform for bilateral collaboration, the Eco-City's master developer, the project developer and the business park operator, seize the new opportunities brought about by China's "dual carbon" development strategy, promote urban development of the Eco-City continuously, strive to bring the Eco-City to even greater heights as a leading low-carbon and smart city in China, and open up a new chapter for bilateral cooperation between China and Singapore.

The Eco-city provides superior conditions for high-tech innovation and sponsors the establishment of IEIT (the Institute for Electronics and Information Technology in Tianjin of Tsinghua University) in 2015. Besides, the Eco-city also attracts the industries of cultural creation, environment protection technology, customer finance, information technology service, etc. All these guarantee a promising future of the Eco-city.

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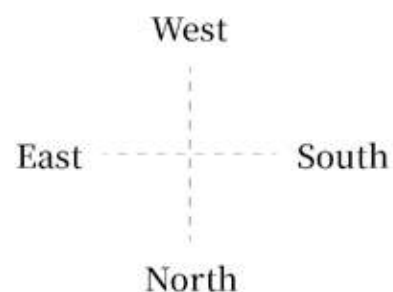


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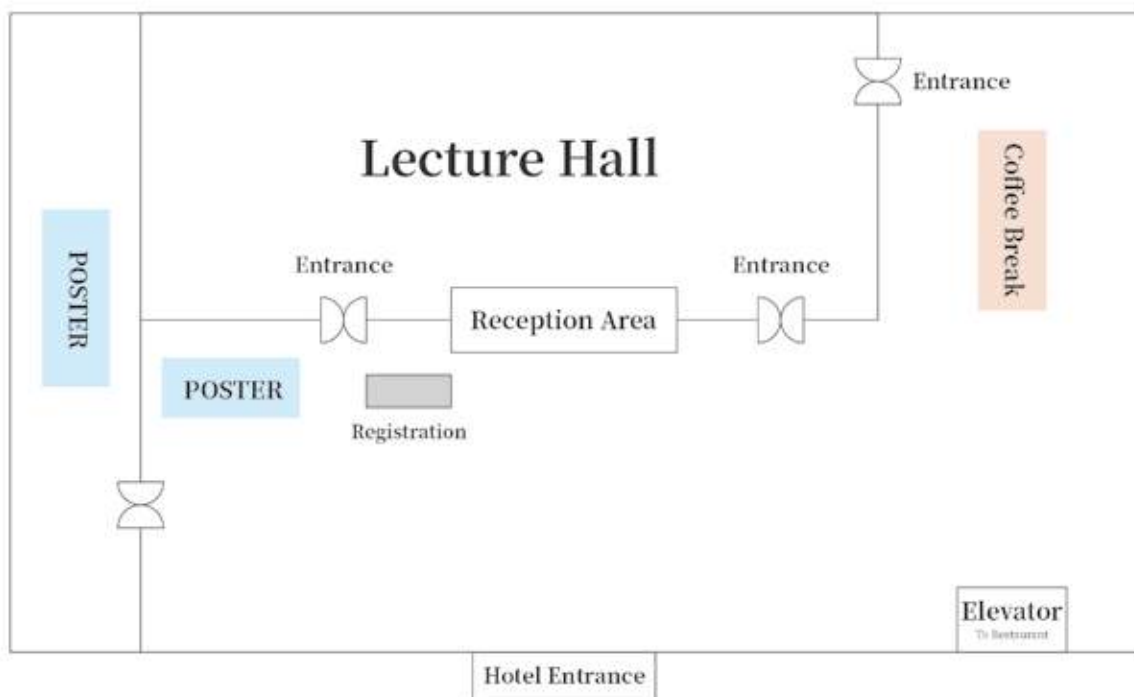
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Maps

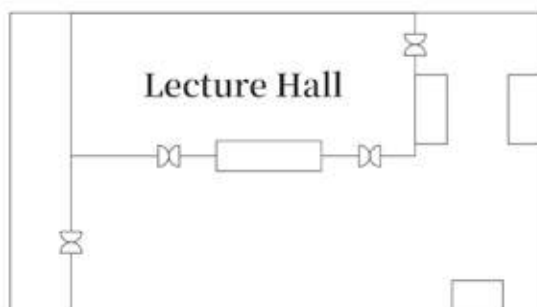
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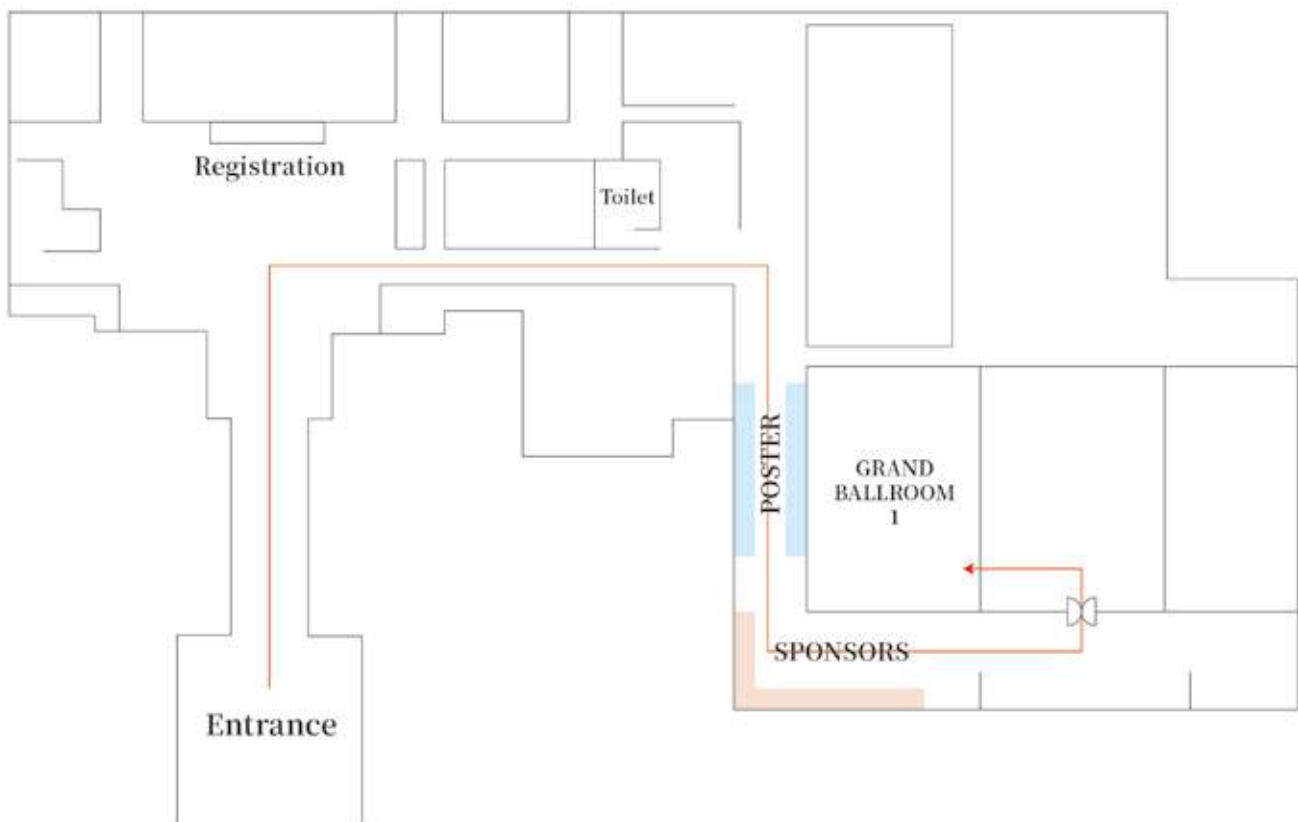
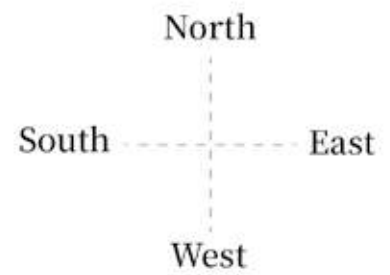


Outdoor



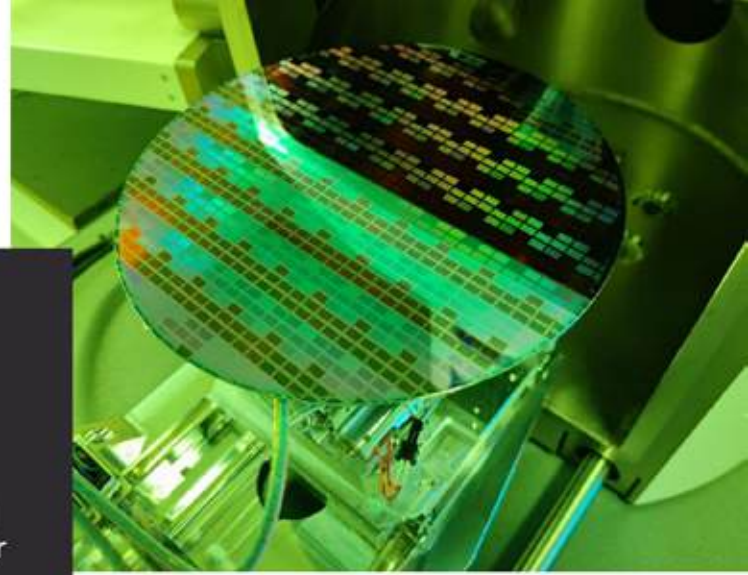
Maps

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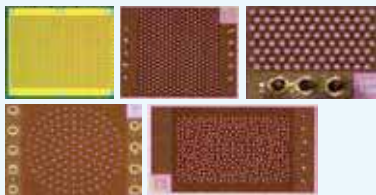
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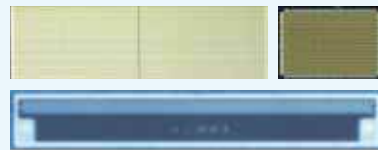
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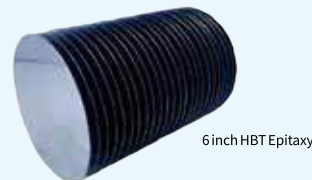
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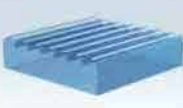
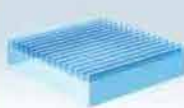
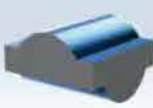
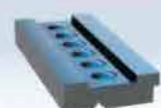
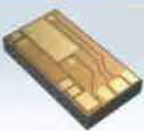
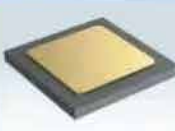
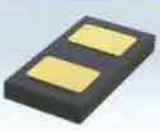
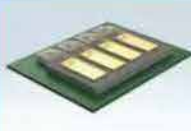
530+
硕博人数

120+
授权专利

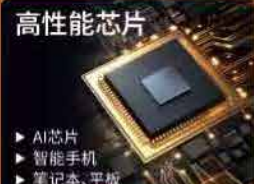
600+
研发人员

20%
研发投入占比

SUNA产品矩阵

					
硅透镜	石英透镜	光栅	双面正交柱透镜	透镜棱镜组件	多通道FAV槽
					
硅IPD/硅基板	打线电容	硅电容	差分电容	硅排容	多端子硅电容

SUNA应用场景

 光通信 ► 数据中心 ► 云计算中心 ► 电信网络	 高性能芯片 ► AI芯片 ► 智能手机 ► 笔记本、平板	 消费电子 ► 红外测温、红外成像 ► 人体感知、人脸识别	 汽车电子 ► 激光雷达 ► 红外成像	 工业制造 ► 工业激光 ► 仪器设备 ► 医疗健康
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主营业务 Main Business

应用于电力电子与Micro-LED的 大尺寸硅基氮化镓外延材料

Dedicated to providing high quality
GaN epiwafers for Power electronics
and Micro-LED applications



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Developing GaN Epitaxial Materials



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Professional GaN Material Manufacturer

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Micro-LED 外延材料。

World's leading company providing 12" GaN-on-Si epi wafers for
HV power application and Micro-LED.

可根据客户需求进行不同尺寸(2"-12")、
不同衬底(硅、蓝宝石等)、不同结构产品的定制。

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substrate types, and with various epi stacks.



✉ info@enkris.com

🌐 www.enkris.com

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📍 苏州市工业园区旺家浜巷2号

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Enkris Semiconductor

 **晶湛半导体**
Enkris Semiconductor




4" GaN-on-Sapphire
Epi Wafer (up to 6")


6" GaN-on-HR_Si
Epi Wafer (up to 12")


8" GaN-on-Si
Epi Wafer (up to 12")

为工业过程的监测与分析提供光电技术解决方案

光函数科技有限公司 | 北京海淀 / 浙江绍兴 / 四川绵竹 / 山西运城

关于我们

光函数科技有限公司专注于工业检测设备的研发，用先进的光电技术和领先的人工智能技术为工业生产过程检测提供解决方案。光函数是清华大学科研成果转化公司，核心技术来源于清华大学电子工程系微纳光子学实验室，拥有多项发明专利。公司已获得国家高新技术企业、中关村高新技术企业、国家科技型中小企业、北京市创新型中小企业等资质认定。

**8000m²**

公司总占地面积

20+

核心研发人员

20+

合作头部企业

50+

申请专利



光谱工业动态监测系统

Funclight QuantSpec Monitor

基于国际首创的CMOS光谱芯片，融合行业领先的光谱分析大模型，对转炉炼钢等工业过程中的关键参数进行实时、非接触式动态监测。其中温度误差15℃以内，碳含量误差0.05%以内，精准指导炉前精细化调控与工艺决策，支撑钢厂降本增效与智能化升级，可推广至其他冶炼、化工、煤炭等场景的关键参数实时监测。



手持式材料成分检测仪

Funclight QuantLIBS Analyzer Air

以激光诱导击穿光谱技术为核心，集成高精度光谱成像芯片与人工智能算法，兼具轻巧便携与快速精准的光谱解析及成分反演能力。可对钢铁、合金等材料进行全元素精准分析，平均检测误差可达0.01%，有效缩短检测周期、降低质控成本，可推广至食品健康、环境保护等领域的现场成分检测。



快捷式工业材料检测设备

Funclight QuantLIBS Analyzer Pro

融合激光诱导击穿光谱技术与高分辨光谱解析算法，专用于冶炼炉渣、工业灰分等复杂副产物的快速高精度分析，1分钟内即可完成全指标现场检测。有效攻克复杂基体效应带来的定量干扰，检测相对误差在5%以内。为造渣工艺及固废资源化利用提供定量依据。可推广至矿物加工、固废回收等复杂基体样品的成分快速分析。



珠海 中国 | 总部



太仓 中国 | 子公司



成都 中国 | 子公司

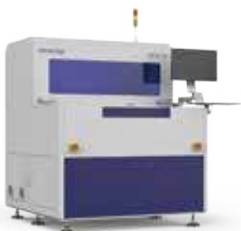


萨洛 芬兰 | 子公司

公司简介

珠海市申科谱工业科技有限公司是一家专注于高端标准工业设备设计和生产的国际化公司。总部位于珠海，在成都和太仓设有生产研发分部，在上海、北京设有办事处；在芬兰设立有研发中心和生产基地，同时在美国、德国、丹麦设有分公司，在匈牙利、法国和印度设有办事处。申科谱品牌已有40多年的发展历程，是全球领先的工业制程自动化解决方案提供商。申科谱工业拥有遍布全球的销售和售后服务网络，致力于快速响应客户需求和为客户提供快捷的现场服务。

四大核心技术



激光类设备
Laser



点胶类设备
Dispensing



视觉检测类设备
AOI



系统集成及自动化
SI & Automation

企业历史与规模



48⁺年
发展历史与经验积累



12个
国际/地区办公场所



36000⁺m²
办公生产区域



5000⁺台
设备服务于全球客户



400⁺位
专业研发团队



300⁺项
研发专利

光鉴科技专注软硬件结合的3D视觉感知技术，构建了覆盖“研发—生产—销售”的一体化产业生态。光鉴科技在光学传感、智能感知和高性能计算三大核心方向深耕，打造从底层硬件、感知算法到上层应用的全栈解决方案，并在全球布局超千项专利，依托自主研发与全国产化元器件生产，公司打破了国际垄断，成为中国科技创新的重要力量。



DEPTUM
光鉴科技

纳米光子芯片

NANO-PHOTONIC CHIP (WFP)



波前调制器 WFP(Wave-Front Processor)是由光鉴科技自主研发的量产消费级纳米光子芯片，通过在亚波长尺度中对光场的调制，突破了传统光学的物理限制，为3D感知提供了光场投射控制功能。纳米光子芯片技术将撬动巨大的民用市场，推动消费电子时代向消费光子时代跃迁。

- 自主研发的量产消费级纳米光子芯片

Independently developed mass-produced consumer-grade nano-photon chip

- 光场调制实现投射激光散斑

Light field modulation for projecting laser speckles

应用领域

APPLICATION & SOLUTION

- 生物识别 BIOMETRICS



光鉴科技刷掌验证方案采用掌纹+掌静脉双模态识别，实现非接触、高安全身份验证，赋能AI智能终端，实现无感支付、身份认证及个性化服务，成为人与AI公共服务设施的无缝对接入口。目前，该方案已广泛应用于交通出行、公共服务、智慧校园、零售餐饮、办公楼宇、健身运动等多个场景。

- 机器人 ROBOT



光鉴科技聚焦机器人智能空间感知，围绕 ToF、结构光、sToF、双目等多种技术路径，打造高性能3D深度视觉方案，赋予机器人出色的空间理解与环境感知能力，支持其自主建图、场景识别与智能响应，相关产品已落地于扫地机器人、商用机器人、水下机器人等领域，并在机械臂、具身智能等高潜力赛道完成技术布局。



ENABLING INTELLIGENCE

Berxel Photonics is a technology leader in high-performance semiconductor laser solutions powering AI data centers and next-generation optical networks. We specialize in the design and manufacturing of advanced VCSEL devices and arrays. Powered by breakthrough technologies like High-Contrast-Grating (HCG) VCSEL structures, our products deliver high bandwidth, low power consumption, and stability—essential performance metrics for 800G, 1.6T, and 3.2T optical transceivers. From GPU cluster interconnects to Co-Packaged Optics (CPO), Berxel combines chip design, wafer-level fabrication, and advanced packaging to deliver reliable, scalable optical engines built for hyperscale AI factories and cloud infrastructure.

Berxel Photonics continues to pioneer 3D sensing and imaging technologies. Highlighted by our internationally renowned 2024 R&D 100 Award-winning Polarization Structured Light 3D camera, our solutions combine in-house metasurface optics and advanced VCSEL technology to deliver high-precision depth imaging—even in complex, highly reflective environments. From robotics and AGVs to smart manufacturing and AIoT, Berxel empowers intelligent industrial upgrades with scalable, reliable 3D sensing solutions.



DataComm VCSEL



- 106 Gbps VCSEL, compliant with IEEE 802.3db standard
- Based on 6-inch wafer process, featuring high yield and excellent mass production capabilities

Applications:
400 and 800 Gbps Active Optical Cables (AOC)

AI Interconnect VCSEL



- High-performance, low-power VCSEL arrays
- Providing efficient optical interconnect solutions for AI computing and cloud data centers

Applications:
VCSEL NPO and CPO for AI computing and cloud data centers

3D Camera



- Pioneering polarization structured light to solve multipath and specular reflection challenges
- Outputs high-quality depth, color, and infrared images; supports synchronous output of depth and color images

Applications:
Service robots, logistic robots and AGV, smart manufacturing, and AIoT



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Inviting talents in optoelectronics and semiconductors



Shenzhen, Nanjing, Jiashan



info@berxel.com



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A Photonic & Quantum Sensing Expert
for Industry Applications



光纤光缆哑资源数智化

AI赋能光网络智能运维
让“哑资源”转化为数据价值



通感一体物联感知

通信 + 感知深度融合
构建泛在智能感知网络



光量子前沿技术

光子计数OTDR | 量子通信 | 光量子传感

应用领域



电信通信

Telecommunications



电力新能源

Power & New Energy



交通运输

Transportation



油气石化

Oil, Gas & Petrochemicals



清华团队
顶尖科研实力



20年+行业经验
光通信与AI专家团队



自主可控
核心技术领先



标准化产品
快速交付落地



全场景覆盖
多行业深度应用



国家高新技术企业



北京市“专精特新”企业



中关村瞪羚企业

歌尔光学科技有限公司

行业领先的XR光学解决方案提供商



歌尔光学成立于2012年,是全球XR光学零组件核心供应商之一,具备XR光学镜片、光学成像模组、微纳光学元件及激光模组等产品的设计研发、制造能力。

3700+

专利

70%+

发明专利



行业地位

- AR衍射光波导技术与产能全球领先
- AR光机模组出货量全球领先
- MR折叠光路模组出货量全球领先
- 国家制造业单项冠军

核心能力

- 一站式解决方案
- 光学设计
- 光学测量及测试
- 精密模具制造
- 自动化生产
- 光学工艺能力

歌尔光学科技有限公司

地址:中国(上海)自由贸易试验区临港新片区水芸路666号 邮编:201208

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