

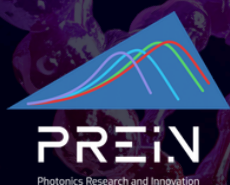


BOOK OF ABSTRACTS

— JOENSUU, FINLAND —

International Conference on
Nano-, Tera- and Bio-Photonics

— IN PARTNERSHIP WITH —



Federation of Finnish
Learned Societies

FLORIN



Funded by
the European Union

University of Eastern Finland
Center for Photonics Sciences

Book of abstracts

International Conference on Nano-, Tera- and Bio-Photonics

University of Eastern Finland, Joensuu, Finland

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Joensuu, Finland
2026

NTB-Photonics Schedule-at-a Glance

		August 17 (Monday)	August 18 (Tuesday)	August 19 (Wednesday)	August 20 (Thursday)	August 21 (Friday)		
9	00-15	Registration and coffee	Antonio Di Bartolomeo	FLORIN session	PREIN session	Shengyu Shan		
	15-30					Marijonas Tutkus		
	30-45		Matias Koivurova			Elias Sfeir	Antti J. Moilanen	Benedetta Bertoni
	45-00							
10	00-15	Opening	Janna Pennanen	Elena Filonenko	Jency Justus	Francesco Siconolfi		
	15-30	Patrice Genevet	Voitech Stankevici	Aurimas Kopustas	Reuben Amedalor	Jann Eike Kruse		
	30-45							
	45-00		Coffee break 10:30 - 11:00					
11	00-15	Marcin Bialek	THz-Skin session	Fedor Jelezko	Dmitry Golberg	Fiorenzo Vetrone		
	15-30							
	30-45	Yahong Chen		Irmantas Kasalynas	Filip Steiner	Shevchenko Andriy	Patrizia Lamberti	
	45-00							
12	00-15	Martti Hanhisalo						
	15-30	Najirul Islam	Aadya Menon	Ayda Nasiri	Fida Ali	Dmitry Semenov		
	30-45					Shuang Li		
	45-00					Closing		
13	00-15	Lunch 12:30 - 14:00				Lunch and departure		
	15-30							
	30-45							
	45-00							
14	00-15	EXTRASSENS session	HERMES session	Cultural activity 14:00 - 20:00	Junji Yumoto			
	15-30				Tadao Nagatsuma		Haruyuki Sakurai	
	30-45				Hiroshi Ito		Nikita Solonovich	
	45-00						Vytautas Janonis	
15	00-15				Nikita Belko		Andzej Urbanovic	Nima Rafsanjani
	15-30				Vsevolod Peshkov			Renata Karpicz
	30-45				Hanna Maltanova	Surya Revanth Ayyagari	Coffee break 16:00 - 16:30	
	45-00				Paulius Rindzevicius	Maxim Moscotin	Shotaro Kawano	
16	00-15	Coffee break 16:00 - 16:30			Roman Calpe			
	15-30							
	30-45	Alessandro Pitanti	Marek Tylutki					
	45-00							
17	00-15	Madona Mekhael	Poster session (17-20) + Side events: HERMES (18-19), FLORIN (19-20)					
	15-30							
	30-45							
	45-00							
18:00 - 21:00		Welcome reception		Conference Dinner				

Dear Friends, Welcome to Joensuu!

We are pleased to welcome each and every one of more than 80 participants of *International Conference on Nano-, Tera-, and Bio-Photonics*. Our conference brings together leading experts and young researchers who employ photonics as a research tool alongside scientists developing cutting-edge photonics-based techniques and methodologies.

The conference program spans a broad spectrum of disciplines – from condensed matter physics and electrodynamics to biophysics and biomedical sciences to quantum technologies – highlighting the unifying power of light-based technologies across diverse areas of modern research.

The conference is organized by the Department of Physics and Mathematics and the Center for Photonics Sciences of the University of Eastern Finland. It is supported by local funding bodies: Federation of Finnish Learned Societies, Joensuu University Foundation and City of Joensuu as well as research and international agencies: Research Council of Finland (Flagship Programme PREIN), QuantERA ERA-NET, Cofund program of the European Union under project EXTRASENS, Horizon Europe MSCA FLORIN and HERMES projects, Pathfinder Open THz-Skin project.

We hope you enjoy the conference as well as the beautiful landscapes of the Finnish Lakeland!

Polina Kuzhir

Matthieu Roussey

Harri Lipsanen

Georgy Fedorov

Sergei Malykhin

Aleksandr Saushin

<https://sites.uef.fi/anteb/>

Joensuu and the University of Eastern Finland

Joensuu, <https://www.joensuu.fi/>, the capital of North Karelia in eastern Finland, was founded in **1848** on the banks of the Pielisjoki River. Its location made it an important centre of trade, timber and forestry, with the river and waterways playing a major role in the development of the local economy. Today, Joensuu is known as the “**Forestry Capital of Europe**”, reflecting the region’s strong expertise in forestry, wood-based industries, and bioeconomy. The city has also developed into an important centre for technology, research, education, and innovation.

A central part of Joensuu’s identity is the **University of Eastern Finland (UEF)**, <https://www.uef.fi/en>. The Joensuu campus is located close to the city centre and is home to more than **9,000 degree students**. UEF is one of Finland’s largest and most multidisciplinary universities, with strong expertise in science, forestry, technology, environmental research, health sciences, and other fields. The university plays an important role in the region’s development by connecting **research, education, industry, and innovation**.

Today, Joensuu combines a strong **forestry and bioeconomy heritage** with modern research and technology-driven industries, making it a natural environment for emerging fields such as **photonics and advanced materials**.



Joensuu is surrounded by parks and natural attractions including the Koli National Park – one of the country's must-see places.

The Federation of Finnish Learned Societies

The Society was established in 1899 and is a national cooperative body for learning societies in Finland. It contributes to the cooperation between learned societies, supports and develops scholarly communication and publishing, and promotes awareness and usage of research results. It also supports and develops the role of its members in science policy discussion. The Federation has a membership of 301 societies and four academies from all branches of arts and sciences, in total 270,000 individual members. Every year these learned societies arrange hundreds of meetings and conferences, attended by the academic community and the general public. The societies and academies are among the foremost academic publishers in Finland: they issue more than 100 periodicals and some 250 new book titles each year. The Federation receives state subsidy for its activities from the Ministry of Education and Sciences. The Federation distributes state subsidies allocated by the Ministry of Education and Science for scholarly publishing and for organizing international conferences and national seminars.

Joensuu University Foundation

The purpose of the foundation is to support and raise awareness of the activities of the Joensuu Campus of the University of Eastern Finland. The foundation awards grants to units operating on the Joensuu Campus of the University of Eastern Finland, supports events relating to its scope of operations, and also otherwise promotes the activities and public awareness of the Joensuu Campus of the University of Eastern Finland.

The foundation can accept donations, bequeathed assets and other assets given to the foundation to carry out activities supporting its purpose. Furthermore, at the request of a donor, it is also possible to set up a specific fund.

Photonics Center and Photonics Finland

Photonics Center <https://www.photonicscenter.fi/> in Joensuu is a state-of-the-art hub for photonics research, innovation, and business, opened in 2022. It brings together researchers, companies, expertise, and advanced facilities under one roof, providing access to cleanrooms, laboratories, equipment, and office spaces.

As part of the Photonics Finland <https://www.photonics.fi/> ecosystem, the center supports collaboration between academia and industry, helps develop new photonics technologies and applications, and provides an environment for companies to grow and innovate.

PREIN – Flagship on Photonics Research and Innovation

PREIN <https://prein.fi/> is a Finnish Flagship bringing together leading universities and research groups to advance photonics research, innovation, and commercialization. Supported by the Research Council of Finland (2019 - 2026), PREIN develops new photonics technologies and applications addressing challenges in areas such as telecommunications, green technologies, agriculture, industry, energy, medicine, and healthcare. By combining the expertise and infrastructure of its partner universities, PREIN promotes high-quality research, new innovations, and collaboration with industry. It also raises awareness of photonics, its societal and economic impact, and career opportunities in the field. PREIN partners: Tampere University, University of Eastern Finland, Aalto University and VTT.

FLORIN - FLuorescent nanO-agents for super-Resolution Imaging and sensing

Horizon Europe MSCA staff exchange project (2022-2026), Grant agreement ID: 101086142, <https://cordis.europa.eu/project/id/101086142>
<https://sites.uef.fi/florin/>

FLORIN develops advanced **nanoparticle-based biosensing and bioimaging technologies** for real-time monitoring of living tissues. The project uses functional fluorescent and **frequency-upconverting quantum nanoparticles** as nanoscale probes to investigate their delivery, cellular targeting, and intracellular distribution.

By combining these nanoparticle probes with **super-resolution optical imaging**, including SOFISM and Q-ISM, FLORIN aims to achieve spatial resolution of **20–50 nm** and temporal resolution below **1 millisecond**. Highly sensitive optical thermal biosensing complements the imaging capabilities, enabling detection of subtle temperature changes with **20 mK accuracy**.

FLORIN has also created a strong foundation for new international collaborations and follow-up projects, including the **QuantERA projects EXTRASENS (2024-2027) and MultiQS (2026-2029)**, as well as the **EIC Pathfinder Open project THz-Skin (2026-2030)**. These initiatives extend the FLORIN research network into **quantum and Terahertz sensing, and novel biomedical applications**.

NTB-Photonics 2026 will be the final FLORIN conference, bringing together almost all FLORIN partners to present the project's achievements and discuss future collaborations. The conference will also feature a **plenary talk by Prof. Fiorenzo Ventrone**, a FLORIN associated partner from Canada, highlighting the project's international dimension.

EXTRASENS - Color centers in diamond nanoneedles for intra- and EXTRA-cellular quantum SENSing

QuantERA project (2024-2027)

<https://quantera.eu/extrasens/>

EXTRASENS is a research project developing new technologies for **ultra-sensitive sensing and imaging using diamond-based quantum sensors**. The project exploits the unique properties of **point-like defects in diamonds**, -- tiny imperfections in the crystal lattice that can act as highly sensitive quantum sensors.

These diamond sensors can detect extremely small changes in **magnetic fields, temperature, and other physical properties**, offering new possibilities for applications in areas such as **medicine, biotechnology, materials science, and advanced technologies**. The project brings together expertise in quantum technologies, photonics, materials science, and sensing to develop more precise and versatile tools for real-world applications.

THz-Skin - THz-FIR Colour Imaging of Skin Condition Based on Analysis of Its Thermal Emission

Horizon Europe Pathfinder Open EIC project (2026-2030), Grant agreement ID: 101257203

<https://cordis.europa.eu/project/id/101257203>

<https://www.thzskin.eu/about/>

THz-Skin is developing a new, accessible approach to **early skin cancer detection**. It combines advanced terahertz sensing with spectroscopic analysis to identify characteristic **molecular fingerprints of healthy and diseased skin**.

The project aims to create a **real-time, non-invasive, radiation-free and label-free** diagnostic platform that could make skin cancer screening faster, more affordable, and more widely available. The technology combines **miniaturised high-performance sensors** with an open-access database of spectral fingerprints from different skin conditions, supporting more accurate and accessible diagnosis.

HERMES - Towards a terahertz short-range wireless communication system based on graphene devices

Horizon Europe MSCA staff exchange project (2025-2029), Grant agreement ID: 101236439

<https://www.hermes-project.eu/>

HERMES is developing **ultra-fast wireless communication technologies** operating at room temperature and in the **terahertz frequency range**.

The project explores the use of **graphene and other two-dimensional nanomaterials** to create new THz emitters, detectors, and communication components. These technologies could enable faster and more compact short-range wireless systems, with potential applications extending beyond communications to **sensing, healthcare, security, and monitoring**. HERMES also strengthens collaboration and knowledge exchange between researchers and industry, supporting the development of future THz technologies.

Contents

Monday, August 17

10:15 – 11:00	Fundamentals and Design Principles of Metasurfaces Patrice Genevet, <i>Colorado School of Mines, Colorado, USA</i>	2
11:00 – 11:30	Strong and Deep Strong Light-Matter Coupling in Landau-Polaritons Dmitriy Yavorskiy ^{1,2} , David Hagenmuller ³ , Nouredine Charrouj ¹ , Yuriy Ivonyak ^{1,2} , Alexander Kazakov ⁴ , Yanko Todorov ⁵ , Jerzy Łusakowski ⁶ , Vladimir Y. Umansky ⁷ , Wojciech Knap ^{1,2} , Marcin Białek ¹ , ¹ <i>CENTERA Labs, Institute of High Pressure Physics, Polish Academy of Sciences, Warszawa, 01-142, Poland</i> , ² <i>CENTERA, CEZAMAT, Warsaw University of Technology, Warszawa, 02-822, Poland</i> , ³ <i>Institut de Physique et Chimie des Matériaux de Strasbourg, UMR 7504, Université de Strasbourg and CNRS, Strasbourg, 67000, France</i> , ⁴ <i>International Research Centre MagTop, Institute of Physics, Polish Academy of Sciences, Warszawa, 02-668, Poland</i> , ⁵ <i>Laboratoire de Physique et d'Étude des Matériaux, LPEM, UMR 8213, ESPCI Paris, Université PSL, Paris, F-75005, France</i> . ⁶ <i>Faculty of Physics, University of Warsaw, Warszawa, 02-093, Poland</i> , ⁷ <i>Weizman Institute of Science, Rehovot, Israel</i>	3
11:30 – 12:00	Classical entanglement in structured light Yahong Chen, <i>School of Physical Science and Technology, Soochow University, Suzhou 215006, China</i>	4
12:00 – 12:15	Coherence squeezing in optical two-slit interference Matti Hanhiala, Atri Halder, Tero Setälä, and Andreas Norrman, <i>Center for Photonics Sciences, University of Eastern Finland, P.O. Box 111, FI-80101 Joensuu, Finland</i>	5
12:15 – 12:30	Polarization squeezed light from two entangled two-level atoms Najirul Islam and Andreas Norrman, <i>Center for Photonics Sciences, University of Eastern Finland, P.O. Box 111, FI-80101 Joensuu, Finland</i>	6
14:00 – 14:30	Squeezing-enhanced interferometry with a single-mode readout Dmitri B. Horoshko and Fedor Jelezko, <i>Institute for Quantum Optics, Ulm University, Albert-Einstein-Allee 11, D-89081 Ulm, Germany</i>	7
14:30 – 15:00	Measurement of 3D polarization states of evanescent waves Zhen Dong ¹ , Kimmo Saastamoinen ¹ , Andreas Norrman ¹ , José J. Gil ² , Yahong Chen ³ , Ari T. Friberg ¹ and Tero Setälä ¹ , ¹ <i>Center for Photonics Sciences, University of Eastern Finland, Joensuu, Finland</i> , ² <i>Photonic Technologies Group, University of Zaragoza, Zaragoza, Spain</i> , ³ <i>School of Physical Science and Technology, Soochow University, Suzhou, China</i>	8

- 15:00 – 15:15 Effect of synthesis parameters on the physicochemical properties and cellular uptake of top-down carbon nitride quantum dots**
 Nikita Belko¹, Hanna Maltanova¹, Deborah Amos Adigun¹, Martynas Zalieckas², Konstantin Tamarov³, Renata Karpicz², Winnok H. De Vos⁴, Steffi Goffart⁵, Polina Kuzhir¹,
¹Department of Physics and Mathematics, University of Eastern Finland, Joensuu, Finland, ²Department of Molecular Compound Physics, Center for Physical Sciences and Technology, Vilnius, Lithuania, ³Department of Technical Physics, University of Eastern Finland, Kuopio, Finland, ⁴Laboratory of Cell Biology and Histology, Dept. Veterinary Sciences, University of Antwerp, Antwerp, Belgium, ⁵Department of Environmental and Biological Sciences, University of Eastern Finland, Joensuu, Finland 9
- 15:15 – 15:30 Optical Properties of N,O-Chelated Azine–Enol Boron Complexes: Effect of Aromatic Ring Fusion Pattern**
 Vsevolod Peshkov, Olga Pereshivko,
Center for Photonics Sciences, University of Eastern Finland, Joensuu 80100, Finland 10
- 15:30 – 15:45 The study of the ferroelectric transition in SbSI by spectroscopic and photoelectrochemical methods**
 Hanna Maltanova¹, Nikita Belko¹, Emmanuel Etebong Ibekwe¹, G. Krishnamurthy Grandhi², Paola Vivo², Polina Kuzhir¹,
¹Department of Physics and Mathematics, University of Eastern Finland, Joensuu, Finland, ²Hybrid Solar Cells, Faculty of Engineering and Natural Sciences, Tampere University, Tampere, Finland 11
- 15:45 – 16:00 Coherent anti-Stokes Raman scattering microscopy of diamond structures**
 Paulius Rindzevičius¹, Mariam Quarshie², Sergei Malykhin², Polina Kuzhir², Renata Karpicz¹,
¹Center for Physical Sciences and Technology, Lithuania, Saulėtekio av. 3, ²University of Eastern Finland, Joensuu, Yliopistokatu 2 12
- 16:30 – 17:00 Enhanced responsivity of thermomechanical detectors via Duffing nonlinearities**
 B. Bertoni^{1,2}, G. Di Carlo¹, A. Tredicucci¹, D. Giuressi^{2,3}, M. Cautero^{2,3}, G. Cautero^{2,3}, G. Fedorov⁴, P. Kuzhir⁴, A. Pitanti¹,
¹Dipartimento di Fisica, Università di Pisa, Largo B. Pontecorvo 3, 56127 Pisa, Italy, ²Elettra - Sincrotrone Trieste S.C.p.A., Strada Statale 14, km 163.5, 34149 Trieste, Italy, ³Department of Engineering and Architecture, Università degli Studi di Trieste, Via Alfonso Valerio 6/1, 34127 Trieste, Italy, ⁴Dep. of Physics and Mathematics, Center of Photonics Research, University of Eastern Finland, Ylio-pistokatu 7, FI-80101 Joensuu, Finland 13
- 17:00 – 17:15 Active control of phase matching in nonlinear metasurfaces using Pancharatnam–Berry phase**
 Madona Mekhael¹, Roman Calpe², Tommi K. Hakala², Robert Fickler¹, and Mikko J. Huttunen¹,
¹Photonics Laboratory, Physics Unit, Tampere University, Tampere, Finland,

² Center for Photonics Sciences, University of Eastern Finland, Joensuu, Finland	14
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Tuesday, August 18

9:00 – 9:30	Optoelectronic and Synaptic Functions in Two-Dimensional SnS₂, SnSe₂, and SnSSe Antonio Di Bartolomeoa, Sebastiano De Stefanoa, Andrea Sessaa, Ofelia Durantea, Aniello Pelellaa, Antonio Politanob, Gianluca D'Olimpiob, Tsotne Dadianib, Enver Faellab, Maurizio Passacantandob, Martino Aldrigoc, Catalin Parvulescuc, Adrian Dinescuc, Chia-Nung Kuod, Chin Shan Lued, ^a Department of Physics “E.R. Caianiello”, University of Salerno, Italy, ^b Department of Physical and Chemical Sciences, University of L'Aquila, Italy, ^c National Institute for Research and Development in Microtechnologies, IMT Bucharest, Romania, ^d Department of Physics, National Cheng Kung University, Taiwan.	16
9:30 – 10:00	Accelerating waves: connecting photonics, relativity, and time Matias Koivurova, Center for Photonics Sciences, University of Eastern Finland, P.O. Box 111, 80101 Joensuu, Finland	17
10:00 – 10:15	Phase winding without topological protection Janna Pennanen, Tero Setälä, Matias Koivurova, Center for Photonics Sciences, University of Eastern Finland, P.O. Box 111, FI-80100 Joensuu, Finland	18
10:15 – 10:30	High Pulsed Magnetic and Electric Field System for the Investigation of Nanostructured Manganite Films Voitech Stankevič ^{1,2} , Nerija Žurauskienė ^{1,2} , Darius Antonovič ¹ , Vilius Vertelis ^{1,2} , Skirmantas Keršulis ¹ , Valentina Plaušinitienė ^{1,3} , ¹ Department of Functional Materials and Electronics, Center for Physical Sciences and Technology, Saulėtekio Ave. 3, LT-10257 Vilnius, Lithuania, ² Faculty of Electronics, Vilnius Gediminas Technical University, Saulėtekio Ave. 11, LT-10223 Vilnius, Lithuania, ³ Department of Organic Chemistry, Center for Physical Sciences and Technology, Saulėtekio Ave. 3, LT-10257 Vilnius, Lithuania	19
11:00 – 11:45	Simulations of Linear and Nonlinear Optical Properties in low-dimensional materials Vasili Perebeinos, University at Buffalo, New York, United States	20
11:45 – 12:15	Room-Temperature Terahertz Photonics via Plasmons Excitation in Various Semiconductor Platforms Justinas Jorudas ¹ , Vytautas Janonis ¹ , Aadya Menon ² , Georgy Fedorov ² , Maxim Moscotin ¹ , Mikhail Shuba ¹ , Polina Kuzhir ² , Esko Kaupinen ³ , and Irmantas Kašalynas ¹ , ¹ Terahertz Photonics Laboratory, Center for Physical Sciences and	

Technology (FTMC), Sauletekio av. 3, 10257 Vilnius, Lithuania, ²Department of Physics and Mathematics, Center of Photonics Research, University of Eastern Finland, Yliopistokatu 7, 80101 Joensuu, Finland, ³Department of Applied Physics, Aalto University School of Science, Puumiehenkuja 2, Aalto, 00076 Espoo, Finland21

12:15 – 12:30 Black Nickel Coating: A Scalable Solution for Ultra-Broadband Absorption

Aadya Menon¹, Hanna Malanava¹, Nikita Belko¹, Maria Cojocari¹, Mikhail Gorbun¹, Aleksandr Saushin¹, Konstantin Tamarov², Jari T.T. Leskinen², Mikko Selenius², Sari Suvanto¹, Dmitry Semenov¹, Sergei Malykhin¹, Vesa-Pekka Lehto², Georgy Fedorov¹, and Polina Kuzhir¹,
¹University of Eastern Finland, Joensuu Campus, Yliopistokatu 7, Joensuu, 80101 Finland, ²University of Eastern Finland, Kuopio Campus, Yliopistonranta 8, 70210 Kuopio, Finland23

14:00 – 14:30 Photonics–Electronics Convergence for Terahertz Wireless: From Device Physics to Fully Integrated Systems

Tadao Nagatsuma,
 Graduate School of Science, The University of Tokyo, Japan24

14:30 – 15:00 THz-Wave Generation and Detection by Semiconductor Heterojunction Diodes

Hiroshi Ito,
 Institute for Photon Science and Technology, Graduate School of Science, The University of Tokyo25

15:00 – 15:30 Terahertz Spectroscopy for Advanced Material Characterization: Methods, Instrumentation and Applications

Andzej Urbanovic^{1,2},
¹Center for Physical Sciences and Technology (FTMC), Sauletekio av. 3, Vilnius 10257, Lithuania, ²UAB “TERAVIL”, Vilnius, Lithuania26

15:30 – 15:45 Planar Meta-Atom Photonic Sensor for Terahertz Detection of Organic Molecules

R.Ayyagari^{1,3}, S.Indrišiūnas², V.Janonis³, J.Macutkevič¹ and I.Kašalynas^{1,3},
¹Institute of Applied Electrodynamics and Telecommunications (IAET), Vilnius University, Sauletekio av. 9, Vilnius, LT-10222 Lithuania, ²Laser Microfabrication Laboratory, Center for Physical Sciences and Technology (FTMC), Savanoriu ave. 231, Vilnius, LT-02300 Lithuania, ³Terahertz Photonics Laboratory, Center for Physical Sciences and Technology (FTMC), Sauletekio av.3, Vilnius, LT-10257 Lithuania27

15:45 – 16:00 Investigation of AlGaIn/GaN modified edge field effect transistors for terahertz detection at cryogenic temperatures

Maxim Moscotin¹, Justinas Jorudas¹, Pawel Prystawko², Miroslav Saniuk¹, Vitalij Kovalevskij¹, and Irmantas Kašalynas¹,
¹Terahertz Photonics Laboratory, Center for Physical Sciences and Technology (FTMC), Lithuania, ²Institute of High Pressure Physics PAS (UNIPRESS), Poland28

16:30 – 17:00	Beyond Mean-Field Effects in Bose-Einstein Condensates: Supersolids, Droplets and Polarons Marek Tylutki, <i>Institute of Theoretical Physics, Wrocław University of Science and Technology, PL-50370 Wrocław, Poland</i>	30
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Poster session

P.1	Phototoxic Effects of Nanostructured Carbon Nitrides on HeLa Cells and Red Blood Cells Deborah Amos Adigun ¹ , Nikita Belko ¹ , Hanna Maltanova ¹ , Steffi Goffart ² , Polina Kuzhir ¹ , ¹ <i>Department of Physics and Mathematics, University of Eastern Finland,</i> ² <i>Department of Environmental and Biological Sciences, University of Eastern Finland</i>	32
P.2	THz-FIR library for skin cancer diagnostics Chivintar Amenty ¹ , Georgy Fedorov ¹ , Emanuele Nardone ¹ , Irmantas Kašalynas ² , Andzej Urbanovic ² , Justinas Jorudas ² , ¹ <i>Department of Physics and Mathematics, University of Eastern Finland,</i> ² <i>Terahertz Photonics Laboratory, Center for Physical Sciences and Technology (FTMC)</i>	33
P.3	Design of plasmonic superlattices Ali Banijamali, Tommi Hakala, and Antti J. Moilanen <i>Center for Photonics Sciences, University of Eastern Finland, Joensuu, Finland</i>	34
P.4	Optimizing MBE Growth of GaAsBi Quantum Wells for Biosensing Focused Laser Diodes Andrius Bičiūnas*, Aivaras Špokas, Andrea Zelioli ¹ , Mindaugas Kamarauskas, Bronislovas Čechavičius, Sandra Stanionytė, Evelina Dudutienė and Renata Butkutė, <i>Center for Physical Sciences and Technology, Saulėtekio av. 3, 10257 Vilnius, Lithuania</i>	35
P.5	Controlling morphology and optical properties of diamond needles Alex Bramwell, Nikita Solonovich, Sergei Malykhin, Elena Filonenko, Polina Kuzhir, <i>University of Eastern Finland, Joensuu, Finland</i>	36
P.6	Characterization of thermomechanical detectors in the 6-12 μm (25-50 THz) range G. Di Carlo ¹ , B. Bertoni ^{1,2} , A. Tredicucci ¹ , D. Giuressi ^{2,3} , M. Cautero ^{2,3} , G. Cautero ^{2,3} , G. Fedorov ⁴ , P. Kuzhir ⁴ , A. Pitanti ¹ ¹ <i>Dipartimento di Fisica, Università di Pisa, Largo B. Pontecorvo 3, 56127 Pisa, Italy,</i> ² <i>Elettra - Sincrotrone Trieste S.C.p.A., Strada Statale 14, km 163.5, 34149 Trieste, Italy,</i> ³ <i>Department of Engineering and Architecture, Università</i>	

- degli Studi di Trieste, Via Alfonso Valerio 6/1, 34127 Trieste, Italy, ⁴Dep. of Physics and Mathematics, Center of Photonics Research, University of Eastern Finland, Ylio-pistokatu 7, FI-80101 Joensuu, Finland 37*
- P.7 Design and characterization of chiral plasmonic lattices for circularly polarized lasing**
 Pathum Ranawalage Don, Roman Calpe, Laura Yrjänheikki, Tommi K Hakala, Antti J Moilanen,
Department of Physics and Mathematics, University of Eastern Finland, Yliopistokatu 7, FI-80100 Joensuu, Finland 38
- P.8 Coherence engineering of light beams carrying robust higher-order Poincaré polarization states**
 Zhen Dong¹, Yimeng Zhu², Yonglei Liu², Fei Wang², Yangjian Cai³, Tero Setälä^{1,3} and Yahong Chen²
¹Center for Photonics Sciences, University of Eastern Finland, Joensuu, Finland, ²School of Physical Science and Technology, Soochow University, Suzhou, China, ³School of Physics and Electronics, Shandong Normal University, Jinan, China 39
- P.9 Electric and magnetic 3D polarization of a random evanescent wave**
 Behnaz Fazlpour¹, Jose J. Gil², Ari T. Friberg¹, Tero Setälä¹, and Andreas Norrman¹,
¹Center for Photonics Sciences, University of Eastern Finland, Joensuu, Finland, ²Independent researcher, 29690 Casares Costa, Spain 40
- P.10 A FTIR spectroscopy and PLS-regression based prognostic model for human glioma age, gender and malignancy grading**
 O. Gnatyuk¹, Ie. Gubareni¹, A. Shmeleva², T.A. Malysheva², O.G. Chernenko², V. Kliuchka², G. Fedorov³, P. Kuzhir³, G. Dovbeshko¹,
¹Institute of Physics of National academy of sciences of Ukraine, 46 Nauky Prospekt, Kyiv, 03028, Ukraine, ²The State Institution Romodanov Neurosurgery Institute National Academy of Medical Sciences of Ukraine, 32 Platona Mayborody Str, Kyiv, 04050, Ukraine, ³Department of Physics and Mathematics, Center for Photonics Sciences, University of Eastern Finland, Yliopistokatu 7, Joensuu, FI 380101, Finland 41
- P.11 Biophysical characteristics of quantum sensing systems based on nanodiamonds and model lipid mimetics**
 O. Gnatyuk¹, M. Olenchuk¹, G. Monastyrskyi¹, G. Fedorov², P. Kuzhir², G. Dovbeshko¹,
¹Institute of Physics of National academy of sciences of Ukraine, 46 Nauky Prospekt, Kyiv, 03028, Ukraine, ²Department of Physics and Mathematics, Center for Photonics Sciences, University of Eastern Finland, Yliopistokatu 7, Joensuu, FI 380101, Finland 42
- P.12 Negative Optical Phase Accumulation in Ultrathin Conductive Films: Applications and Active Control**
 Mikhail Gorbun¹, Daniil Pashnev², Aleksandr Saushin¹, Xu Zhenyu³, Esko Kauppinen³, Vytautas Janonis², Andžej Urbanovič², Irmantas Kašalynas²,

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¹Center for Photonics Sciences, University of Eastern Finland, Joensuu, Finland, Department of Optoelectronics, ²Center for Physical Sciences and Technology (FTMC), Vilnius, Lithuania, ³Department of Applied Physics, Aalto University, Espoo, Finland43
- P.13 **Interferometric control of phase singularity splitting**
 Diya Govind¹, Jyrki Laatikainen², Andreas Norrman¹, Kimmo Saastamoinen¹, Tero Setälä¹ and Atri Halder¹,
¹Center for Photonics Sciences, University of Eastern Finland, P.O. Box 111, FI-80101 Joensuu, Finland, ²Department of Physics, University of Miami, Coral Gables, Florida 33146, USA 44
- P.14 **Steady-State and Time-Resolved Fluorescence study of meso-Tetraphenylporphyrin and Hexagonal Boron Nitride van der Waals Complex**
 Ivan Halimski^{1,2}, Renata Karpicz², Jevgenij Chmeliov^{1,3}, Erkki Lähderanta¹, Hanna Maltanova⁴, Nikita Belko⁴, Maksim Shundalau^{5,6},
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- P.15 **Local Laser Activation of Color Centers in Diamond Needles**
 Tanu Prava Mondal¹, Elena Filonenko¹, Mariam Quarshie¹, Yuki Hakamada², Haruyuki Sakurai², Kuniaki Konishi², Polina Kuzhir¹, Sergei Malykhin¹,
¹Department of Physics and Mathematics, Institute of Photonics, University of Eastern Finland, Joensuu, Finland, ²Institute for Photon Science and Technology, The University of Tokyo, Tokyo, Japan46
- P.16 **Systematic investigation of stripline width and contact metal effects on terahertz photoconductive antenna performance**
 I Nevinskas¹, M Kamarauskas¹, V Kovalevskij¹, D Vizbaras², K Ikamas^{1,2}, M E Daraei¹, A Bičiūnas¹ and V Pačebutas¹,
¹Center for Physical Sciences and Technology, Saulėtekio al. 3, Vilnius, 10257, Lithuania, ²Institute of Applied Electrodynamics and Telecommunications, Vilnius University, Saulėtekio al. 3, Vilnius, 10257, Lithuania47
- P.17 **Geometric phase of partially polarized classical light beams**
 Kaisa Rantaeskola¹, Kimmo Saastamoinen¹, Andreas Norrman¹, Yahong Chen², Ari T. Friberg¹, and Tero Setälä¹,
¹Center for Photonics Sciences, University of Eastern Finland, P.O. Box 111, FI-80101 Joensuu, Finland, ²School of Physical Science and Technology, Soochow University, Suzhou 215006, China 48

- P.18 **Ultrathin carbon metamaterial for control of THz polarization ellipticity**
 Aleksandr Saushin¹, Mizuho Matoba², Aadya Menon¹, Deborah Amos Adigun¹, Esko Kauppinen³, Kuniaki Konishi², Polina Kuzhir¹ and Georgy Fedorov¹,
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²University of Tokyo, 7-3-1 Hongo Bunkyo-ku, Tokyo, 113-0033 Japan,
³Aalto University, Otakaari 1 B, Espoo, 02150 Finland. 49
- P.19 **Master equation approach to twisted photons' propagation in the atmosphere**
 Tim Ehret, Vyacheslav Shatokhin, Andreas Buchleitner,
 Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str.3,D-79104 Freiburg, Germany 50
- P.20 **Cost-efficient black nickel substrates for surface-enhanced Raman spectroscopy**
 Arya Soltaneshagh¹, Hanna Maltanova¹, Nikita Belko¹, Roman Levin¹, Jari T. T. Leskinen², Sari Suvanto², Isaac Appiah Otoo¹, Sergei Malykhin¹, Aleksandr Saushin¹, and Polina Kuzhir¹,
¹Department of Physics and Mathematics, University of Eastern Finland, Joensuu, Finland, ²Department of Chemistry and Sustainable Technology, University of Eastern Finland, Joensuu, Finland 51
- P.21 **Characterization of Silicon-Vacancy Centers in Diamond Nanoneedles for Nanoscale Sensing**
 Rizwan Sultan, Mariam Quarshie, Nikita Solonovich, Alex Bramwell, Polina Kuzhir, Sergei Malykhin
 Department of Physics and Mathematics, University of Eastern Finland, Joensuu, Finland 52
- P.22 **LUCID and HandySPIM: A Simple and Cost-Effective Platform for Three-Dimensional Fluorescence Imaging**
 Hiroshi Onodera^{a,e}, Kenji Uehara^b, Takumi Murakami^c, Asami Tanaka^a, Yusuke Morishita^d and Junji Yumoto^{a,d},
^aThe University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan;
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- P.23 **Metal Ion Sensing Using Photoluminescent Carbon Nitride Quantum Dots**
 Martynas Zalieckas¹, Nikita Belko², Hanna Maltanova², Polina Kuzhir², Renata Karpicz¹,
¹Center for Physical Sciences and Technology, Saulėtekio Ave. 3, LT-10257 Vilnius, Lithuania, ²Department of Physics and Mathematics, University of Eastern Finland, FI-80100 Joensuu, Finland 54

Wednesday, August 19

- 9:00 – 9:30 **Single-molecule localisation microscopy augmented with tracking for live-cell carbonic anhydrase IX studies**
 A. Kvietkauskaitė¹, A. Kopūstas^{1,2}, M. N. Alsamsam^{1,2}, M. Žvirblis¹,
 J. Matulienė¹, D. Matulis¹, Š. Grincevičienė¹, M. Tutkus^{1,2}.
¹*Institute of Biotechnology, Life Sciences Center, Vilnius University, Vilnius LT-10257, Lithuania*, ²*Center for Physical Sciences and Technology, Vilnius LT-10257, Lithuania*56
- 9:30 – 10:00 **Diamond Color Centers for Quantum Technologies**
 Elias Sfeir, Ziad Abi akar, Roy Konnath Ancel, Surena Fatemi, Christophe Couteau
Laboratoire Lumière, Nanomatériaux et Nanotechnologies (L2n), Université de Technologie de Troyes, France 57
- 10:00 – 10:15 **pH-sensitive photoluminescence in diamond nanoneedles**
 Elena Filonenko¹, Sergei Malykhin¹, Radosław Łapkiewicz² and Polina Kuzhir¹
¹*Department of Physics and Mathematics, University of Eastern Finland, Joensuu, Finland*, ²*Division of Optics, Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland* 58
- 10:15 – 10:30 **Mechanistic insights into individual protein-DNA interactions of fundamentally different bacterial defense systems**
 Aurimas Kopūstas^{1,2}, Ugnė Bagdonaitė¹, Mohammad Nour Alsamsam^{1,2}, Ernesta Vitulskienė³, Tautvydas Karvelis¹, Mindaugas Zaremba¹, Marijonas Tutkus^{1,2}
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- 11:00 – 11:45 **Quantum sensing at nanoscale enabled by diamond spin qubits**
 Fedor Jelezko
Institute of Quantum Optics, Ulm University, Germany 60
- 11:45 – 12:15 **Surface engineering of nanodiamonds with NV centers for quantum sensing**
 Filip Steiner^{1,2}, Jakub Copak^{1,2}, Michal Gulka¹, Petr Cigler¹,
¹*Institute of Organic Chemistry and Biochemistry, Czech Academy of Sciences, Flemingovo nám. 2, Prague, Czechia*, ²*Department of Physical and Macromolecular Chemistry, Faculty of Science, Charles University, Albertov 6, Prague, Czechia* 61

- 12:15 – 12:30 **New Hybrid Photonic Platform for Directional Enhancement of Upconversion Luminescence in Single-Molecule Detection**
 Ayda Nasiri¹, Tian-Long Guo¹, Duc Le², Sanna Aikio², Jussi Hiltunen²,
 Matthieu Roussey¹
¹*Department of Physics and Mathematics, Center for Photonics Sciences, University of Eastern Finland, Joensuu, Finland,* ²*VTT Technical Research Centre of Finland, Oulu, Finland*62

Thursday, August 20

- 9:00 – 9:30 **High-dimensional optical communication in atmospheric turbulence**
 David Bachmann, Tim Ehret, Vyacheslav Shatokhin, Andreas Buchleitner
Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str.3, D-79104 Freiburg, Germany64
- 9:30 – 10:00 **Uncovering the Dynamics of Multimode Organic Polariton Lasing**
 Antti J. Moilanen^{1,2,3}, Darius Urbonas⁴, Kristin B. Arnardottir^{5,6,7}, Artem Strashko⁸, Ullrich Scherf⁹, Rainer F. Mahrt⁴, Jonathan Keeling⁵, Thilo Stöferle⁴, and Päivi Törmä¹
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- 10:00 – 10:15 **Two-level strip-loaded waveguides for controlled absorption**
 Jency Justus¹, Antonin Patricio-Gomes¹, Fangfang Li¹, Pradeep Ramanan², Petr Němec³, Laetitia Petit², and Matthieu Roussey¹
¹*Center for Photonics Sciences, University of Eastern Finland, P.O. Box 111, Joensuu, Finland,* ²*Photonics Laboratory, Tampere University, Korkeakoulunkatu 3, Tampere, 33720, Finland,* ³*Faculty of Chemical Technology, University of Pardubice, Studentska 573, 532 10 Pardubice, Czech Republic*66
- 10:15 – 10:30 **Spectroscopy with resolution beyond the encoder linewidth**
 Reuben Amedalor¹, Atsu L. Asilevi¹, Igor Reduto¹, Kimmo Saastamoinen¹, Santhosh Pandian², Tapio Niemi², and Matias Koivurova¹
¹*Center for Photonics Sciences, University of Eastern Finland, P.O. Box 111, 80101 Joensuu, Finland,* ²*Photonics Laboratory, Tampere University, 33720, Tampere, Finland*67
- 11:00 – 11:45 **State-of-the-art in situ TEM techniques for physical property studies of nanomaterials**
 Dmitri V. Golberg

	<i>Centre for Materials Science and School of Chemistry and Physics, Queensland University of Technology (QUT), 2 George str., Brisbane, QLD 4000, Australia</i>	68
11:45 – 12:15	Nanophotonic structures at higher-order resonances Andriy Shevchenko, Sagar Sehrawat, and Biao Chen <i>Department of Applied Physics, Aalto University, P. O. Box 13500, Aalto FI- 00076, Finland</i>	69
12:15 – 12:30	High-Sensitivity Optical Detectors for Ultra-Low-Light Detection and Imaging Fida Ali, Youqiang Huang, Fooqia Khalid, and Zhipei Sun <i>Department of Electronics and Nanoengineering, Aalto University, Aalto FI- 00076, Finland</i>	70
14:00 – 14:30	Low-Loss and Compact 300 GHz-Band Hollow Waveguide Components and Devices Fabricated by 3D Printing and Electroless Metal Plating Junji Yumoto <i>Institute for Photon Science and Technology, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan</i>	71
14:30 – 15:00	Quantification of fundamental laser-ablation phenomena for advancing laser processing technologies Haruyuki Sakurai <i>Institute for Photon Science and Technology</i>	72
15:00 – 15:15	Time to space ghost imaging with partially coherent light Nikita Solonovich ¹ , Polina P. Kuzhir ² and Dmitri B. Horoshko ³ ¹ University of Eastern Finland, Joensuu, Finland, ² Institute for Quantum Optics, Ulm University, Ulm, Germany	73
15:15 – 15:30	Coherent thermal radiation sources based on hybrid surface polaritons excitation in GaN Vytautas Janonis ¹ , Muhamad Umar ¹ , Pawel Prystawko ² , and Irmantas Kašalynas ¹ ¹ Terahertz Photonics Laboratory, Center for Physical Sciences and Technology (FTMC), Saulėtekio ave. 3, LT-10257, Vilnius, Lithuania, ² Laboratory of Semiconductor Characterization, Institute of High Pressure Physics PAS (UNIPRESS), ul. Sokolowska 29/37, 01-142, Warsaw, Poland.	74
15:30 – 15:45	Efficient TiO₂/Polymer Vertical Nano-Waveguide Edge Coupler Nima Rafsanjani ^{1,2} , Fangfang Li ² , Antonin Patricio Gomes ² , Guo ² , Emiliano Descrovi ¹ and Matthieu Roussey ² ¹ Politecnico di Torino, Department of Applied Science and Technology, Torino, Italy, ² University of Eastern Finland, Center for Photonics Sciences, Joensuu, Finland	75
15:45 – 16:00	Methodological Advances in CARS Microscopy for Chemical Imaging of Micro and Nanostructures Paulius Rindzevičius ¹ , Ivan Halimski ^{1,2} , Leonas Valkunas ¹ , Sergei Malykhin ³ ,	

Renata Karpicz¹

¹Department of Molecular Compound Physics, Center for Physical Sciences and Technology, Lithuania, ²Department of Physics, LUT University, Lappeenranta, Finland, ³Center for Photonics Sciences, University of Eastern Finland, Joensuu, Finland 76

16:30 – 17:00 Laser-induced periodic surface structures (LIPSS) on titanium thin films with femtosecond optical skyrmions

Shotaro Kawano¹, A. Srinivasa Rao^{2,3,4}, Haruyuki Sakurai¹, Kuniaki Konishi¹, and Takashige Omatsu^{3,5,6}

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17:00 – 17:15 Mode locking in plasmonic lattice lasers

Janne I. Heikkinen¹, Roman Calpe¹, Laura Yrjänheikki¹, Atri Halder¹, Antti J. Moilanen¹, Matias Koivurova¹, and Tommi K. Hakala¹

¹Center For Photonics Sciences, Department of Physics and Mathematics, University of Eastern Finland, Joensuu, Finland 78

Friday, August 21

9:00 – 9:30 Coherent light emission of WSe₂–WS₂ Interlayer Excitons in Photonic Crystal Cavities

Shengyu Shan¹, Antti J. Moilanen^{1,2}, Jonas D. Ziegler¹, Qia Lin¹, Guodong Xue³, Karolina Lempicka-Mirek¹, David R. Callegari⁴, Takashi Taniguchi⁵, Kenji Watanabe⁶, Kirsten Moselund⁴, Kaihui Liu³, Simone Iadanza⁴, Lukas Novotny¹,

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9:30 – 10:00 FPGA Readout of Thermomechanical Bolometers Arrays for THz Imaging

Benedetta Bertoni^{1,2}, Gaia Di Carlo¹, Alessandro Tredicucci¹, Matija Colja², Dario Giuresi², Giuseppe Cautero², Polina Kuzhir³, Georgy Fedorov³, Alessandro Pitanti¹

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	34149 Trieste, Italy, ³ Department of Physics and Mathematics, Center of Photonics Research, University of Eastern Finland, Ylio-pistokatu 7, FI-80101 Joensuu, Finland	81
10:00 – 10:15	Multifunctional Graphene Coatings for Advanced Electronic Packaging F. Siconolfi ^{1,2} , G. Cavaliere ^{2,3} , L. Tari ^{1,2} , M. Cojocari ⁴ , I. Appiah Otoo ⁴ , S. Sibilia ⁵ , G. Giovinco ^{2,6} , A. Maffucci ^{1,2} , ¹ Dept. of Electrical and Information Engineering, University of Cassino and Southern Lazio, Cassino (FR), Italy, ² EUT+ Institute of Nanomaterials and Nanotechnologies—EUTINN, European University of Technology, European Union, Cassino, Italy, ³ Dept. of Information Engineering, Electrical Engineering and Applied Mathematics, University of Salerno, Fisciano (SA), Italy, ⁴ Dept. of Civil and Mechanical Engineering, University of Cassino and Southern Lazio, Cassino (FR), Italy, ⁵ E-lectra srl, Cassino, Italy, ⁶ Dept. of Physics and Mathematics, University of Eastern Finland, Joensuu, Finland.	83
10:15 – 10:30	Evidence-Based Pathways from Research to Marketable Offers Jann E. Kruse CommonsLab SCE, 73 Ethnikis Antistaseos Ave., 71306 Heraklion, Greece.	84
11:00 – 11:45	From Photon Conversion to Biomedical Innovation: Rare Earth Nanoparticles at the Interface of Nano- and Bio-Photonics Fiorenzo Vetrone Centre Énergie Matériaux Télécommunications, Institut National de la Recherche Scientifique, Campus Laval, Université du Québec, 531 Boul. des Prairies, Laval (Montréal), Québec, H7V 1B7, Canada	85
11:45 – 12:15	Numerical investigation of cell electroporation in presence of nanoparticles Patrizia Lamberti ¹ , Elisabetta Sieni ² , Vincenzo Tucci ¹ ¹ Department of Information and Electrical Engineering and Applied Mathematics, University of Salerno, via Giovanni Paolo II 132, 84084 Fisciano (SA), ITALY, ² Department of Theoretical and Applied Science, Insubria University, Via O. Rossi 9, 21100 Varese, VA, Italy	86
12:15 – 12:30	Data-Driven Tissue Recognition: Revolutionizing Precision and Safety in Neurological Oncology Surgery Dmitry Semenov Scientific Liaison, Marginum Ltd / University of Eastern Finland Spectral Research	87
12:30 – 13:00	Optical Physical Reservoir Computing in an FGaT/WS₂ Valleytronic Heterostructure Shuang Li, Yue Fang, Rhodri Mansell, Youqiang Huang, Sebastiaan van Dijken, Zhipei Sun, Harri Lipsanen, Aalto University, Espoo 02150, Finland	88
	Author index	89

Monday, August 17



Fundamentals and Design Principles of Metasurfaces

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Phase control lies at the heart of modern photonics, enabling functionalities ranging from wavefront shaping and dispersion engineering to optical information processing. Historically, optical phase manipulation has relied on propagation effects, geometric phases, and resonant responses. In open photonic systems, however, resonant phase control can be understood within a broader framework governed by the complex analytic structure of the optical response. Because these systems exchange energy with their environment through radiation and absorption, they are naturally described by non-Hermitian operators whose spectra contain complex-frequency singularities, including poles and zeros. These singularities dictate the evolution of optical phase and, through analyticity and causality, fundamentally connect phase, amplitude, and dispersion.

In this talk, we will first briefly review established phase-engineering approaches based on propagation and Pancharatnam phases, before focusing on the physical mechanisms underlying resonant phase delay in open systems. We will discuss how complex singularities emerge and evolve in photonic platforms, and how their organization in parameter space is controlled by symmetry, material response, and structural design. This perspective provides a unified and systematic framework for resonant phase engineering across diverse photonic technologies, including integrated photonics and metasurfaces, and across multiple operational regimes. Finally, we will highlight how these concepts enable advanced functionalities in wavefront control, imaging, immersive displays, dispersion engineering, and optical signal and information processing.

Strong and Deep Strong Light-Matter Coupling in Landau-Polaritons

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Strong light-matter coupling [1] in the THz range enables the formation of hybrid light-matter states (polaritons) whose properties can be engineered through cavity design and electronic structure control. In this talk, I will present recent advances in THz cavity quantum electrodynamics in semiconductor systems, ranging from conventional high-mobility quantum wells to narrow-gap semiconductors hosting relativistic quasiparticles.

I will first discuss strong coupling of cyclotron resonance with cavity modes in high-mobility GaAs quantum wells [2]. Using phase-resolved THz time-domain spectroscopy, we directly observe the coherent build-up of Rabi oscillations following cyclotron excitation. The measurements reveal that the coupled light-matter state does not form instantaneously but develops progressively through repeated interactions between the cavity field and the electronic excitation, providing new insight into the dynamical formation of polaritons.

I will then turn to polaritons in thin film of $\text{Hg}_{0.85}\text{Cd}_{0.15}\text{Te}$ [3], a narrow-gap semiconductor hosting three-dimensional Kane fermions. The exceptionally small cyclotron mass and high electron density drives the system from the strong-coupling regime into the deep-strong-coupling regime, with normalized coupling strengths exceeding 1.6. The hybridized states remain well defined up to and beyond room temperature, demonstrating the potential of relativistic semiconductors for robust THz photonic devices.

Together, these studies illustrate how semiconductor cavity platforms provide access to both the dynamics and the extreme limits of light-matter interaction, opening new opportunities for coherent and tunable THz photonic technologies.

Acknowledgement

This work was partially supported by the Sonata Bis-13 2023/50/E/ST3/00584 grant of the National Science Centre of Poland.

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Classical entanglement in structured light

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1. Introduction

Light is an electromagnetic wave endowed with multiple degrees of freedom (d.o.f.s). The ability to tailor and manipulate these d.o.f.s has driven the rapid development of structured light and its diverse applications. While conventional approaches often treat different d.o.f.s independently, they can, in fact, be intrinsically coupled in a nonseparable manner, analogous to entanglement in quantum systems. Such classical entanglement in structured light has attracted considerable attention owing to its potential applications in optical communications, precision metrology, and classical analogs of quantum information processing. In this talk, I will present two recent advances in the study of classical entanglement.

2. Quantitative measurement of concurrence

The first advance concerns the quantitative characterization of classical entanglement in coherent vector beams. In such beams, the spatial and polarization d.o.f.s are intrinsically nonseparable. This nonseparability can be quantified by the optical concurrence, a quantity formally analogous to the quantum concurrence used to characterize entanglement in bipartite quantum systems. Conventional measurement techniques are typically based on Stokes polarimetry and require multiple polarization-resolved intensity measurements. Recently, we developed a new approach that maps the nonseparability of a vector beam onto the coherence properties of a partially coherent optical field [1]. As a result, the concurrence can be directly retrieved from either a single-shot measurement or a single-pixel detection scheme, significantly simplifying the characterization process.

3. Classical entanglement in phase space

The phase-space representation of optical fields naturally establishes correlations between real-space and momentum-space d.o.f.s, analogous to the position–momentum description in classical and quantum mechanics. We reveal a fundamental connection between the phase-space nonseparability of structured light and the optical beam shifts experienced by reflected wave packets [2]. Our results demonstrate that phase-space nonseparability can serve as a new degree of freedom for controlling and enhancing beam shifts at optical interfaces. This finding opens new opportunities for manipulating light–matter interactions and exploring novel applications of structured light in precision optical measurements.

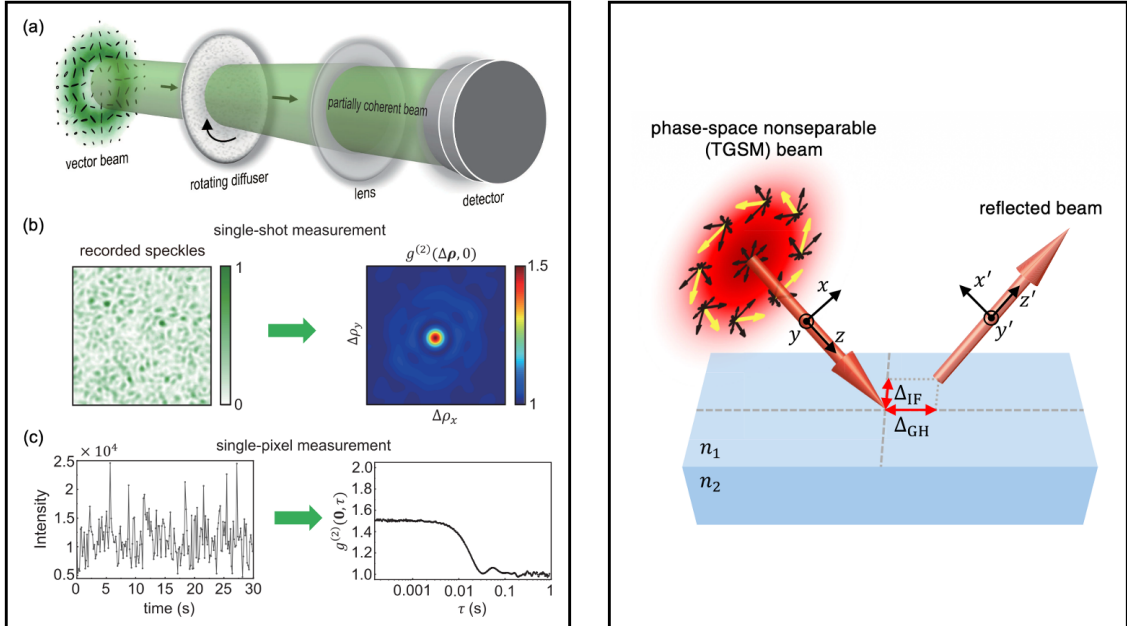


Figure 1. (left) Quantitative measurement of concurrence. (right) Phase-space nonseparable beam induces anomalous beam shifts.

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Coherence squeezing in optical two-slit interference

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1. Introduction

Interference is a fundamental phenomenon in classical and quantum physics, tightly intertwined with the concept of coherence. In optics, the two-slit experiment famously demonstrates how the coherence of light dictates the structure of interference fringes [1]. Analysis of interference fringes is vital for optical metrology and polarimetry. Ultimately, optical measurement precision is limited by the quantum fluctuations of light [2, 3]. By squeezing the uncertainty of amplitude, phase, and polarization of light, these quantum bounds have been pushed beyond classical limits [4]. However, squeezing of coherence has not yet been explored, despite its central role in optical physics and interference. Only recently was the concept of optical coherence uncertainty introduced [5], offering a foundation for the current investigation on coherence squeezing.

2. Coherence uncertainty and squeezing

We consider two quantized slit light fields, represented by annihilation operators $\hat{a}_1$ and $\hat{a}_2$. The first-order statistical properties of the fields can be characterized by four Hermitian operators [6]: $\hat{G}_0 = \hat{a}_1^\dagger \hat{a}_1 + \hat{a}_2^\dagger \hat{a}_2$, $\hat{G}_1 = \hat{a}_1^\dagger \hat{a}_1 - \hat{a}_2^\dagger \hat{a}_2$, $\hat{G}_2 = \hat{a}_1^\dagger \hat{a}_2 + \hat{a}_2^\dagger \hat{a}_1$, and $\hat{G}_3 = i(\hat{a}_2^\dagger \hat{a}_1 - \hat{a}_1^\dagger \hat{a}_2)$. The expectation value $G_0 = \langle \hat{G}_0 \rangle$ gives the total photon number, while G_1 describes the photon number difference between the slits. In particular, together, G_2 and G_3 quantify the mutual coherence of the fields. The latter three operators do not commute: $[\hat{G}_j, \hat{G}_k] = 2i\epsilon_{jkl}\hat{G}_l$, where ϵ_{jkl} with $j, k, l \in \{1, 2, 3\}$ is the Levi-Civita tensor. These commutators lead to three uncertainty relations, $\Delta G_1 \Delta G_2 \geq |G_3|$, $\Delta G_2 \Delta G_3 \geq |G_1|$, and $\Delta G_3 \Delta G_1 \geq |G_2|$, where $\Delta G_j = \left(\langle \hat{G}_j^2 \rangle - \langle \hat{G}_j \rangle^2 \right)^{1/2}$. These relations prohibit the exact simultaneous knowledge of G_1 , G_2 , and G_3 , i.e., the photon number difference and coherence.

We choose the two-mode coherent state $|\alpha\rangle_1 |\beta\rangle_2$ as a reference point for coherence squeezing. For it, $\Delta G_m = \sqrt{|\alpha|^2 + |\beta|^2} = \sqrt{\bar{n}}$, where $\bar{n}$ is the average total photon number and $m \in \{0, 1, 2, 3\}$. If the quantum fluctuations in the coherence parameter G_2 or G_3 fall below this level for a given light state, i.e. $\Delta G_2 < \sqrt{\bar{n}}$ or $\Delta G_3 < \sqrt{\bar{n}}$, we regard it as coherence squeezed [6]. Figure 1 depicts the isotropic uncertainty of a coherent state and the anisotropic uncertainty of a squeezed state via a three-dimensional representation spanned by G_1 , G_2 , and G_3 . For more details of the illustrated squeezed state, see [6]. We analyze the intensity fringe pattern through an interference law of the form $I = |K|^2 [\hat{G}_0 + \hat{G}_2 \cos(k\Delta r) - \hat{G}_3 \sin(k\Delta r)]$, where K is a constant, k is the wave number, and Δr is the path difference from the slits to the observation point. We especially show that coherence squeezing affects the quantum uncertainty of the magnitudes and positions of the intensity fringes.

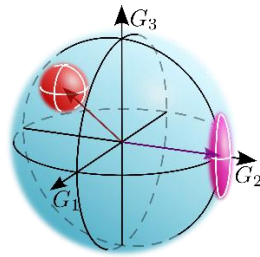


Fig. 1. Three-dimensional representation of the quantum fluctuations in the parameters G_1 , G_2 , and G_3 for a two-mode coherent state (red sphere) and a coherence-squeezed state (purple ellipsoid). For the latter, the fluctuations in G_1 and G_2 are reduced at the expense of increased fluctuations in G_3 .

3. Conclusions

We have explored the concept of optical coherence squeezing in two-slit interference by deriving coherence uncertainty relations and a corresponding squeezing criterion. Our work identifies coherence as a fundamental degree of freedom for squeezing that affects the quantum fluctuations in the interference fringes.

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Polarization squeezed light from two entangled two-level atoms

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We theoretically demonstrated polarization squeezed light of the far-field radiation from two entangled two-level atoms. The total far-field is transverse in nature as the observation direction is perpendicular to the total field. We construct the four standard Stokes operators of the total field projecting into two orthogonal polarization directions. We show that the far-field is polarization squeezed only when the transition dipole moments of the atoms are unequal. Within the single-excitation manifold, the dipoles become entangled and dipole asymmetry and geometry generate polarization-squeezed light. These results show that non-classical polarization states can arise from a minimal two-emitter system without any non-linear medium.

Squeezing-enhanced interferometry with a single-mode readout

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Optical interferometers are used in a wide variety of applications, including gravitational astronomy, high angular resolution astronomy, optical chemical sensors, optical coherence tomography, and many others. The idea of illuminating the unused input port of the Michelson interferometer with squeezed light [1] led to a significant increase in the sensitivity of modern gravitational wave detectors [2]. An extension of this idea led to the construction of nonlinear optical interferometers in which the squeezed light is generated internally [3,4]. Realization of such interferometers with the help of high-gain parametric down-conversion enabled Fourier-transform infrared spectroscopy [5] and low-coherence interferometry [6] in the mid-infrared spectral region. The ultimate limit of squeezing-enhanced interferometry, optimized over all possible measurements, is given by the quantum Fisher information (QFI) of the output light on the phase difference between the interferometer arms. It was found that in the case of two-mode readout, the QFI is given by $F_0 = |\alpha|^2 e^{2r} + \sinh^2 r$, where α is the amplitude of the input coherent state and r is the squeezing parameter of the input squeezed vacuum [7]. However, a two-mode readout is often difficult to realize in practice, and, for example, it is considered unfeasible in gravitational interferometry. In this work, we analyze a single-mode readout of a squeezing-enhanced Mach-Zehnder interferometer (see Fig. 1) and calculate the single-mode QFI on the difference phase [8].

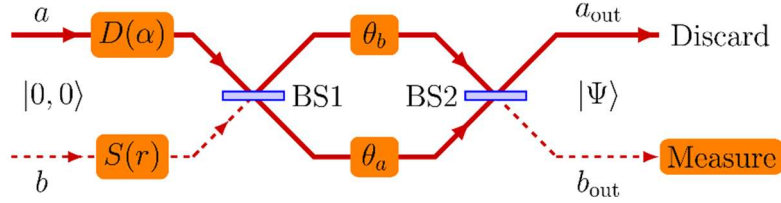


Fig.1. Mach-Zehnder interferometer created by beam splitters BS1 and BS2. The interferometer has a coherent (mode a) and a squeezed (mode b) fields in two inputs. Unknown phase shifts θ_a and θ_b are introduced inside the interferometer to modes a and b respectively. The task is to infer the difference phase $\theta = \theta_a - \theta_b$ from the measurement data of mode b_{out} .

Two modes a and b , initially in the vacuum state of both modes $|0,0\rangle$, pass through the laser (mode a) and the squeezer (mode b). The effect of laser generation is described by the displacement operator $D(\alpha) = e^{a\alpha^\dagger - \alpha^*a}$, where a is the photon annihilation operator for this mode. The squeezer is typically realized by a degenerate optical parametric amplifier, and its action is described by the squeezing operator $S(r) = \exp\left[\frac{r}{2}(b^2 - b^{+2})\right]$, where b is the photon annihilation operator for this mode. The ultimate limit of precision is given by the QFI matrix $\mathbf{Q}_\theta$ of mode b_{out} on parameters (Φ, θ) , where $\Phi = \theta_a + \theta_b$ is the sum phase.

The novelty of our approach consists in analyzing the mixed state of mode b_{out} , while all previous works were limited to pure states. We show that $Q_\theta^{\Phi\theta} = 0$ for all values of θ , which means that the precision limits for the parameters Φ and θ are given by $Q_\theta^{\Phi\Phi}$ and $Q_\theta^{\theta\theta}$, respectively. In the vicinity of the black fringe ($\theta = 0$), the QFI matrix element $Q_\theta^{\theta\theta}$ experiences a jump from the value $|\alpha|^2 e^{2r}$ to $F_0 = |\alpha|^2 e^{2r} + \sinh^2 r$. We see that this value of QFI is the same as that of the two-mode readout discussed above. Therefore, we conclude that the single-mode readout is optimal for estimating the difference phase. We also discuss the optimal measurement that realizes a projective measurement of mode b_{out} in the eigenbasis of the operator of symmetric logarithmic derivative, which we calculate for the mixed state of this mode [8].

This work was supported by QuantERA II Programme (project EXTRASENS). It was funded by Horizon 2020 Framework Programme (European Union) via grant 101017733 and Bundesministerium für Forschung, Technologie und Raumfahrt (Germany) via grant 13N16935.

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Measurement of 3D polarization states of evanescent waves

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Light in a genuine 3D polarization state exhibits electric field fluctuations in all three orthogonal spatial directions, regardless of the reference frame [1]. A polarization state can be visualized by an intensity ellipsoid as shown in Figs. 1(a)–(c), where the semi-axis lengths $a_1 \geq a_2 \geq a_3 \geq 0$ represent the intensities of the polarization state when rotated into its intrinsic coordinate frame. For a genuine 3D polarization state all three intensities are nonzero [Fig. 1(a)], while for a 2D state one intensity vanishes [Fig. 1(b)], and for a 1D state only one intensity is nonzero [Fig. 1(c)]. The polarimetric dimension is therefore reflected by the 3D intensity anisotropy of the polarization state [2]. In addition, genuine 3D polarization states can be categorized into regular and nonregular [3], with the latter exhibiting intriguing spin structures [4]. To analyze these properties, a state can be decomposed into three orthogonal pure states, forming the polarization matrix [1]

$$\mathbf{J} = \lambda_1 \hat{\mathbf{u}}_1 \hat{\mathbf{u}}_1^\dagger + \lambda_2 \hat{\mathbf{u}}_2 \hat{\mathbf{u}}_2^\dagger + \lambda_3 \hat{\mathbf{u}}_3 \hat{\mathbf{u}}_3^\dagger, \quad (1)$$

where $\lambda_1 \geq \lambda_2 \geq \lambda_3 \geq 0$ are the eigenvalues and $\hat{\mathbf{u}}_1, \hat{\mathbf{u}}_2, \hat{\mathbf{u}}_3$ are the corresponding unit eigenvectors of the matrix, with $\dagger$ denoting conjugate transpose. The eigenvectors represent orthogonal pure states, with their polarization ellipses typically lying in different planes [Fig. 1(d)]. For regular states, $\hat{\mathbf{u}}_1$ and $\hat{\mathbf{u}}_2$ lie in the same plane [Fig. 1(e)] and their associated spin density vectors satisfy $\hat{\mathbf{n}}_1 = -\hat{\mathbf{n}}_2$. Based on the condition $\hat{\mathbf{n}}_1 + \hat{\mathbf{n}}_2 + \hat{\mathbf{n}}_3 = 0$, the spin density vector $\hat{\mathbf{n}}_3$ corresponding to $\hat{\mathbf{u}}_3$ vanishes. However, for nonregular states, $\hat{\mathbf{u}}_1$ and $\hat{\mathbf{u}}_2$ lie in different planes [Fig. 1(f)], resulting in nonparallel $\hat{\mathbf{n}}_1$ and $\hat{\mathbf{n}}_2$ and therefore $\hat{\mathbf{n}}_3 \neq 0$. When $\hat{\mathbf{u}}_1$ is a circularly polarized state and $\hat{\mathbf{u}}_2$ is a mutually orthogonal linearly polarized state, as well as $\lambda_1 = \lambda_2, \lambda_3 = 0$ [Fig. 1(g)], the full state is a perfect nonregular state of maximal degree of nonregularity [3].

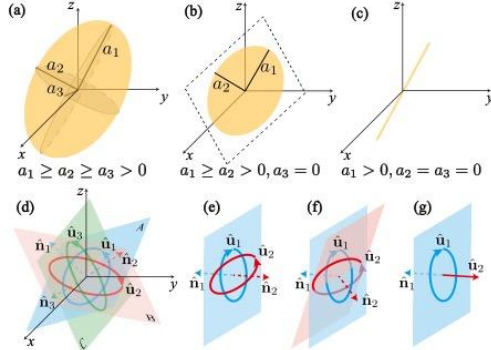


Fig. 1. Diagram for analyzing and illustrating 3D polarization properties [5].

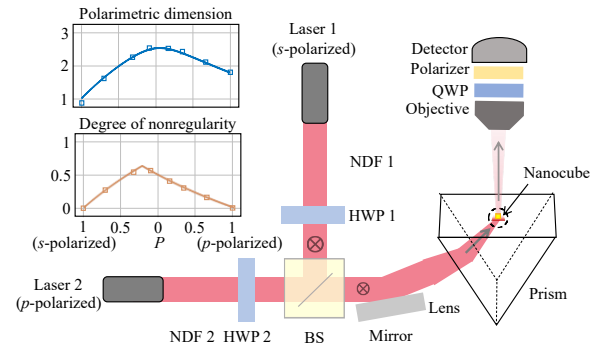


Fig. 2. Experimental setup for generating 3D evanescent waves and observing their polarization properties (after [5]).

The aim is to measure genuine 3D polarization states in evanescent waves generated by partially polarized beams undergoing total internal reflection at an interface between fused-silica and air. Employing a gold nanocube in the evanescent field and analyzing the scattered radiation (Stokes parameters) in the far zone, we may reconstruct the 3×3 polarization matrix of the evanescent wave and determine its dimensionality and nonregularity, when the degree of polarization P of the excitation beam is varied. The experimental setup is shown in Fig. 2 along with some results showing good agreement with expected behavior [5].

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Effect of synthesis parameters on the physicochemical properties and cellular uptake of top-down carbon nitride quantum dots

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Carbon nitride quantum dots (CNQDs) are promising nanomaterials for biosensing and bioimaging applications. They can be synthesized via relatively simple bottom-up and top-down approaches. The resulting nanostructures typically exhibit small size, aqueous dispersibility, tunable fluorescence, and favorable biocompatibility [1, 2]. In addition, CNQDs are capable of generating reactive intermediates upon photoactivation [3] while remaining non-toxic in the dark, which further expands their potential for theranostic applications.

Bottom-up CNQDs synthesis is based on hydrothermal treatment of organic precursors such as urea and citric acid [2]. This carries the risk of residual organic species remaining in the reaction mixture even after extensive purification [4], which may significantly contribute to the photophysical and photochemical behavior, and complicate distinction from the nanoparticle fraction. Top-down approaches offer a more reliable route, preserving the graphitic carbon nitride framework while reducing the presence of molecular by-products. Despite these advantages, systematic optimization of top-down synthesis conditions remains unexplored. Moreover, the impact of these parameters on the physicochemical and biological properties of the resulting CNQDs has not been addressed in the literature.

In this work, CNQDs are synthesized via top-down hydrothermal treatment of bulk graphitic carbon nitride in alkaline media. The synthesis parameters, including hydroxide type (LiOH, NaOH, or KOH), temperature, duration, and ultrasonic pretreatment, are systematically varied to evaluate their effect on the properties of the resulting nanomaterials.

The CNQDs are characterized by transmission electron microscopy, X-ray photoelectron spectroscopy, Fourier-transform infrared spectroscopy, and fluorescence spectroscopy. Their cellular uptake in HeLa cells is investigated using flow cytometry and confocal laser scanning microscopy. Cytotoxicity of the CNQDs towards HeLa cells is also assessed using MTT assay. The biological behavior is then correlated with the physicochemical characteristics of the samples, enabling the identification of synthesis conditions most suitable for biomedical applications.

All prepared samples contain CNQDs with sizes ranging from 2 to 50 nm. Samples synthesized in NaOH additionally exhibit nanofibers with a thickness of *ca.* 10 nm and lengths of several hundred nanometers. The presence of these nanofibers appears to promote strong aggregation of CNQDs, leading to the formation of micrometer-sized structures.

Most samples show time- and concentration-dependent cellular uptake, while the presence of proteins in the incubation medium has only a minor effect. Endocytosis is identified as the dominant uptake mechanism. No detectable cytotoxicity is observed for any of the samples. Short-term CNQD uptake experiments reveal no significant induction of canonical stress response pathways (lack of NF- κ B nuclear translocation) or DNA damage (absence of γ H2AX foci).

To summarize, this work addresses the influence of top-down synthesis parameters on the physicochemical and biological properties of CNQDs. The nanomaterials are prepared via alkaline hydrothermal treatment of bulk graphitic carbon nitride, and the effects of synthesis conditions are systematically evaluated. The results show that synthesis parameters affect particle morphology, aggregation behavior, and cellular uptake, while no cytotoxicity is observed. These findings provide guidance for controlling CNQD properties toward reliable biomedical applications.

This work was supported by EU Horizon Europe under the Marie Skłodowska-Curie COFUND grant No 101081327 YUFE4Postdocs and by the Research Council of Finland (Flagship Programme PREIN, decision 368653 and research project decision 35703)

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Optical Properties of N,O-Chelated Azine–Enol Boron Complexes: Effect of Aromatic Ring Fusion Pattern

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A series of N,O-chelated azine–enol boron complexes featuring four different fusion patterns between the benzene and pyridine rings of the azine fragment was synthesized and characterized (Fig. 1) [1]. Their optical properties were thoroughly investigated in dilute solution and in the solid state.



Fig. 1.

It was found that, for three of the complexes, the emission in dilute solution originates from a π – π^* transition that is typical of boron complexes of this type. In contrast, one complex exhibited distinctly different emissive behavior, with its fluorescence arising from an intramolecular charge transfer (ICT) transition. These findings demonstrate that seemingly minor structural variations can have a profound effect on the nature of the electronic transition, thereby governing the optical properties of these dyes in dilute solution.

In the solid state, however, crystal packing appears to play the dominant role in determining whether a dye exhibits strong fluorescence. Consequently, the influence of molecular structure on the optical properties of the solid state is less direct than in dilute solution. In particular, we identified a case in which two polymorphs of the same dye display completely different photophysical behavior: one exhibits strong crystallization-induced emission, whereas the other readily undergoes photochemical dimerization directly in the crystalline state.

For powder samples, the emissive characteristics strongly depend on the ratio of amorphous to crystalline phases. In many cases, this leads to mechanochromism, as mechanical treatment, such as grinding, alters the phase composition of the sample and, consequently, its optical properties.

Overall, our results demonstrate that the optical properties of N,O-chelated azine–enol boron complexes can be modulated and, potentially, fine-tuned through both molecular design and crystal-packing engineering. Furthermore, these findings may facilitate the development of new applications for this important class of organic photoluminescent materials.

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The study of the ferroelectric transition in SbSI by spectroscopic and photoelectrochemical methods

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SbSI is a narrow-bandgap ferroelectric semiconductor (*ca.* 2 eV) that undergoes a first-order ferroelectric phase transition near room temperature (19–22°C) [1]. Combining visible-light absorption, photoconductivity, and spontaneous polarization, SbSI serves as an ideal model platform to investigate the impact of ferroelectric order on carrier separation, recombination, and interfacial redox kinetics in photoelectrochemical (PEC) applications. Herein, we studied the spectroscopic, electrochemical (EC), and photoelectrochemical (PEC) performance of SbSI microrod-based film electrodes at different temperatures to determine the role of the intrinsic phase state in the physicochemical properties of SbSI.

Ferroelectric SbSI crystals were synthesized via vapor transport process from a mixture of Sb₂S₃ and 10 mol % excess SbI₃ in an evacuated ampoule at 450°C (5 h). Next, thin-film electrodes were fabricated by coating a suspension of SbSI in MeCN onto a transparent fluorine-doped tin oxide (FTO) films on glass or glassy carbon plates. The prepared materials were characterized by transmission electron microscopy (TEM), scanning electron microscopy (SEM), X-ray diffractometry (XRD), and diffuse reflectance spectroscopy (DRS). Finally, temperature-dependent photocurrent and Raman spectra were recorded to evaluate the general framework of SbSI for phase-transition-assisted EC and PEC functionality.

The electron microscopy and XRD results confirm that the synthesized material consists of well-crystalline SbSI microrods, which form porous films upon deposition on substrates. The SbSI microrods were optically characterized using DRS. The resulting spectrum exhibits typical semiconductor behavior, with strong absorption at wavelengths below 650 nm and negligible absorption at longer wavelengths. The indirect and direct band gaps were determined to be 1.88±0.08 eV and 2.00±0.08 eV, respectively. The electrochemical properties of SbSI film electrodes investigated via cyclic voltammetry revealed a gradual cathodic current increase below -0.3 V. Meanwhile, at potentials above 0.8 V, an autocatalytic anodic oxidation process occurred, causing a time-dependent current rise and film destruction. The prepared SbSI electrode exhibited pronounced PEC activity and behavior typical of nanostructured semiconductors, generating both anodic and cathodic photocurrents depending on the applied potential. The PEC response was tunable through film thickness and electrolyte pH: an optimal thickness of ~125 nm maximized photocurrent, while acidification enhanced cathodic photocurrent and shifted the transition potential from cathodic to anodic photocurrent. Oxygen concentration also played a key role: O₂-saturated electrolytes stabilized and increased the magnitude of cathodic photocurrent.

To observe this transition in SbSI microrods directly, we employed differential scanning calorimetry (DSC) and Raman spectroscopy. DSC exhibits an endothermic transition between 14 and 20°C, with a maximum at 17°C during heating, and the corresponding exothermic transition upon cooling. These peaks can be attributed to the reversible ferroelectric-to-paraelectric phase transition in the SbSI microrods. The peak is relatively broad, which is likely due to the size dispersion of the microrods. Raman spectra of the SbSI films revealed a clear signature of the phase transition, characterized by significant intensity variations, as well as pronounced shifts and broadening of the peaks at 209 and 247 cm⁻¹.

To explore the influence of this transition on the EC and PEC behavior of SbSI film electrodes, temperature-dependent measurements were performed. The temperature-dependent cathodic current was recorded under dark conditions and monochromatic illumination, with heating causing a pronounced increase in both dark and photocurrents. Above the phase transition temperature identified by DSC, a distinct inflection point appeared in the curves, after which the photocurrent increased more sharply. Spectral dependencies of photocurrent for SbSI electrodes pre-conditioned at 55°C show that while solution heating increased photocurrent across the entire spectrum, the quantum efficiency remained below 2–3% due to significant recombination losses at crystallite interfaces and high resistance of the microrods. Band gap values for SbSI films were extracted from photocurrent spectra using the combined Tauc and Butler–Gärtner methods, revealing both indirect (1.83–1.86 eV) and direct (2.02–2.04 eV) optical transitions with a 1–3% error. Notably, indirect band gap exhibits an inflection point near 25°C corresponding to the ferroelectric phase transition. The direct band gap exhibits a weak and non-monotonic dependence on temperature, varying between 2.02 and 2.04 eV. The band gap values for SbSI microrods determined from photocurrent spectra agree with those calculated from reflectance spectra, while the observed band gap change near the Curie temperature aligns well with reported data for SbSI single crystals.

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Coherent anti-Stokes Raman scattering microscopy of diamond structures

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Coherent anti-Stokes Raman scattering (CARS) is a third-order nonlinear process that can be used for vibrational imaging and spectroscopy of various samples [1]. CARS is useful for investigating crystal structures. Diamond is an important material in vibrational spectroscopy because of its intense and sharp Raman line at 1332 cm⁻¹. It was shown that polarization CARS can be employed to determine the crystallinity of diamond structures [2]. In this work, various diamond samples fabricated using chemical vapor deposition (CVD) method, including diamond structures decorated with metal nanostructures, were investigated using a home-made CARS microscope. It was observed that nanostructured Ti layer or Au nanoparticles on a diamond surface can enhance resonant diamond CARS signal. Experiments with Cu, Ag and Ni structures revealed thermal modification of the samples and did not provide any significant signal enhancement or even a resonant vibrational diamond response in some cases. The full description of the investigated samples, experimental setup and extended result analysis is presented in a publicly available preprint [3]. Moreover, further experiments show that polarization CARS can be employed not only for determining crystal orientations of diamond needles, but also other types of CVD diamond structures.

Acknowledgement

The authors are sincerely grateful to Dr. Andrej Dementjev for developing the methodology of CARS microscopy utilized in this study and for his comprehensive guidance throughout this work.

This work was supported by QuantERA project EXTRASENS through Lithuanian Research Council (No. S-QUANTERA-24-1) and Research Council of Finland (decision 361115), Horizon Europe MSCA FLORIN (No. 101086142) and Research Council of Finland (Flagship Programme PREIN, decision 368653; research project, decision 357033).

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Enhanced responsivity of thermomechanical detectors via Duffing nonlinearities

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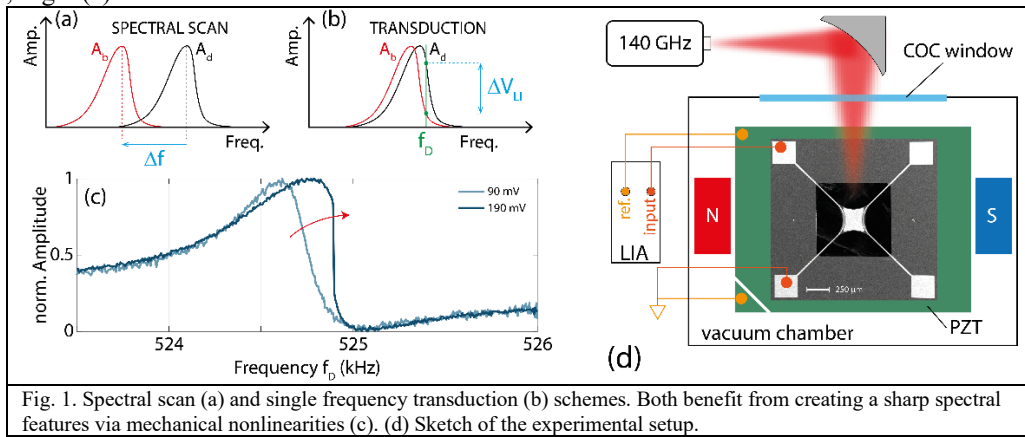
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1. Introduction

Uncooled far infrared detectors represent a highly promising technology for field deployment in the sub THz and THz spectral ranges. Within this class, thermomechanical bolometers (TMB) have recently attracted significant attention, demonstrating video rate operation together with noise equivalent power values on the order of hundreds of $\text{pW}/(\text{Hz})^{0.5}$ [1]. Although fully optical readout supports low noise performance, it is not particularly suitable for multi sensor architectures, such as focal plane arrays. Magnetomotive actuation and readout provide a practical alternative, and have already been used to realize a 16×16 matrix sensor with highly multiplexed control and detection [2]. In this work, we demonstrate enhanced detector responsivity by tailoring the mechanical lineshape. This strategy improves transduction without requiring substantial modifications to the device architecture, while also enabling external control of the dynamic range *times* responsivity product. These results further support the potential of fully electrical thermomechanical bolometers for field applications [3].

2. Methods and Results

We characterized TMBs built on $300 \times 300 \mu\text{m}$ Si_3N_4 membranes, further details on the sample design and fabrication can be found in [3]. Devices exploiting mechanical resonances can be operated either by comparing full spectral scans under illuminated and dark conditions, Fig. 1(a), or by monitoring variations in the transduced amplitude or phase at a fixed driving frequency, Fig. 1(b). Both readout techniques strongly benefit from sharp spectral features, which facilitate the extraction of spectral shifts in the former case and directly improve detection in the latter, since the transduced signal is proportional to the frequency derivative of the mechanical transfer function in the weak detecting power approximation. Our mechanical resonator exhibits a strong, drive dependent geometrical nonlinearity, Duffing nonlinearity, which can generate sharp spectral features without improving the Q factor, Fig. 1(c).



We characterized the devices with 140 GHz illumination employing the setup sketched in Fig. 1 (d). Testing different absorbing layer, namely simple gold or pyrolytic carbon, we found a drive-dependent noise equivalent power of $\sim 30 \text{ pW}/(\text{Hz})^{0.5}$ for the latter, which well compares with the state-of-the-art despite the all-electrical read-out and actuation.

Acknowledgement.

This work was supported by HORIZON-EIC-2025-PATHFINDEROPEN THz-Skin project # 101257203 and by ATTRACT, a European Union's Horizon 2020 research and innovation project (GA 101004462, h-cube)

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Active control of phase matching in nonlinear metasurfaces using Pancharatnam–Berry phase

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1. Introduction

Among available nonlinear phase-control mechanisms, the geometric—also known as Pancharatnam–Berry (PB)—phase is especially attractive since it depends only on meta-atom orientation, making it inherently broadband [1]. Yet implementations to date remain static once fabricated. Here, we introduce mechanical rotation as a new degree of freedom for dynamically tuning the second-harmonic generation (SHG) phase-matching condition. Extending our previous single-metasurface multipass-cell design [2] to a dual-metasurface configuration (Fig. 1(a)), rotating one metasurface relative to the other shifts the phase-matching peaks via the nonlinear PB phase of C_{3v} -symmetric plasmonic meta-atoms, completing a full 2π tuning cycle within 120° of physical rotation.

2. Experiments and discussion

The sample consists of three-bladed gold nanoparticles with arm length of 130 nm and arm width of 50 nm, as shown in Fig. 1 (b). The sample was fabricated using electron-beam lithography on a glass substrate and arranged randomly while keeping the same global orientation to suppress the collective lattice resonances. Under circularly polarized illumination, the C_{3v} symmetry dictates that the SHG carries a nonlinear PB phase $\Phi_{PB} = -3\sigma\theta$, where $\sigma = \pm 1$ is the helicity of the incident light and θ the nanoparticle rotation angle. Placing two identical metasurfaces inside the multipass cell allows the pump to interact with both on each pass, producing discrete SHG phase-matching peaks [2,3]. Rotating one metasurface by θ introduces this phase into the phase-matching condition, continuously shifting the peaks across the pump range. Fig. 1(c) shows the measured SHG spectra as one metasurface is rotated from 0° to 120° , demonstrating controlled spectral shifting across 900–970 nm, with the extracted geometric phase closely following the predicted dependence while the pump itself remains unaffected. Since this phase-control mechanism is independent of conversion efficiency, it can be combined with higher-efficiency dielectric metasurfaces or ultrathin nonlinear crystals, opening possibilities for compact, reconfigurable nonlinear sources such as pulse characterization and tunable frequency conversion.

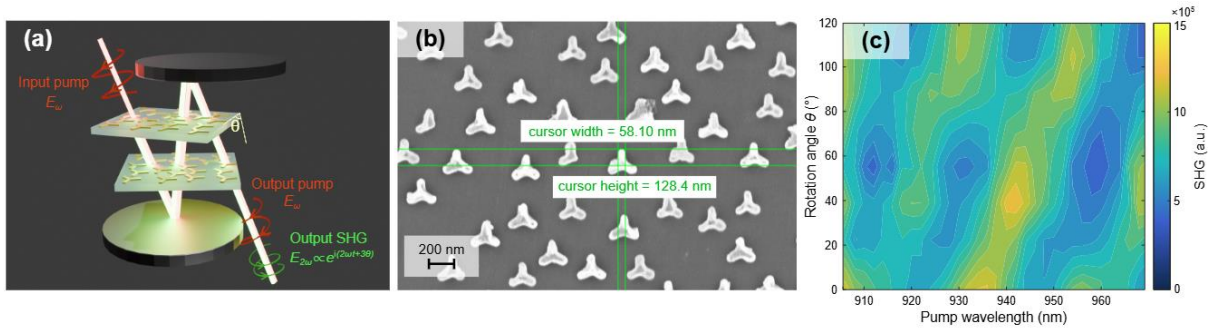


Fig. 1. (a) Schematic of the dual-metasurface multipass cell, where rotating one metasurface by θ imparts a nonlinear PB phase to the SHG output. (b) SEM image of the fabricated three-bladed gold nanoparticles (scale bar: 200 nm). (c) Measured SHG intensity as a function of pump wavelength and rotation angle, showing continuous tuning of the phase-matching peaks across 900–970 nm.

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Tuesday, August 18



Optoelectronic and Synaptic Functions in Two-Dimensional SnS₂, SnSe₂, and SnSSe

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1. Abstract

Two-dimensional tin-based chalcogenides have garnered significant attention for their potential to bridge conventional nanoelectronics and brain-inspired computing. This work presents a comparative analysis of SnS₂, SnSe₂, and the ternary SnSSe alloy, emphasizing how their distinct defect physics and interfacial properties enable diverse functionalities.

Tin disulfide (SnS₂), an n-type semiconductor with high on/off ratios reaching up to 10⁸, demonstrates exceptional performance in memory and high-gain photodetection. Notably, its memory window broadens with increasing temperatures up to 400 K, and it achieves a substantial synaptic weight change $\Delta W/W$ of approximately 3000, primarily driven by interface trap states and oxygen-mediated photogating under ambient conditions.

Tin diselenide (SnSe₂), while also n-type and trap-driven, typically exhibits higher carrier mobility, above 50 cm²/V·s. Its neuromorphic behavior is governed by gate-tunable persistent photocurrent, and unlike SnS₂, its mobility displays a "bell-shaped" temperature dependence peaking at 220 K. SnSe₂ effectively emulates synaptic functions such as Paired-Pulse Facilitation (PPF) with high reproducibility through reversible memory suppression.

The ternary SnSSe alloy integrates the strengths of its binary constituents. A notable distinction is the simultaneous presence of positive (PPC) and negative (NPC) photoconductivity; the positive response reflects trap-driven mechanisms similar to the binaries, while the broad-spectrum NPC spanning 780–1000 nm arises from a photogating effect.

Across all three materials, intrinsic and interfacial trap states, traditionally considered detrimental, form the functional basis for synaptic plasticity. Transitioning from binary to ternary compositions allows precise tuning between high-sensitivity visible-light detection and broadband, gate-tunable neuromorphic memory.

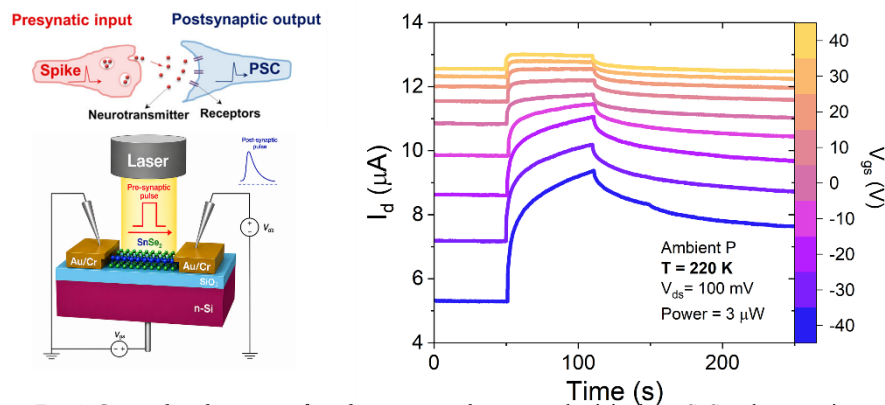


Fig. 1. Gate-induced transition from long-term to short-term plasticity in an SnSe₂ phototransistor operating as an optical synaptic device.

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Accelerating waves: connecting photonics, relativity, and time

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Recently, time-varying media has risen as a new paradigm in photonics [1]. This type of media implicitly allows waves to experience *longitudinal* acceleration. In fact, longitudinal acceleration occurs at any material interface where the refractive index changes. However, accelerating waves are **not** a solution to the standard wave equation. To study accelerating waves rigorously, we have derived the accelerating wave equation [2] in 1+1 dimensions,

$$\frac{\partial^2 f(x, t)}{\partial t^2} = c(t)^2 \frac{\partial^2 f(x, t)}{\partial x^2} - \dot{c}(t) \frac{\partial f(x, t)}{\partial x} \quad (1)$$

where $f(x, t)$ is the wave, $c(t)$ is the time dependent speed of the wave, and $\dot{c}(t)$ is the acceleration. If we choose c_0 as the (constant) vacuum speed of light, and write the speed variations as a modulation to the vacuum speed, such that $c(t) = c_0/n(t)$, we can find the plane wave solution to the accelerating wave equation as in

$$f(x, t) = A \exp(i\omega t' - ikx) + B \exp(i\omega t' + ikx) \quad (2)$$

Here, A and B are amplitude coefficients and $k = \omega/c_0$ is the wavenumber. Moreover, we have defined an intrinsic time for the electric field as $t' = \int n(t)^{-1} dt$, which is the time experienced by the wave. Intriguingly, this is fully equivalent to the definition of proper time in general relativity [3]. In other words, if we allow waves to accelerate, they exhibit properties that have natural parallels in the theory of relativity, such as time dilation and length contraction. To test this framework, we investigated simple refraction problems, as well as the more exotic disordered photonic time crystal [4]. Our results are entirely consistent with earlier studies, and our formulation can be used to model time-varying materials, as well as material interfaces without boundary conditions (i.e. our solutions are analytical and continuous over the whole domain) [2].

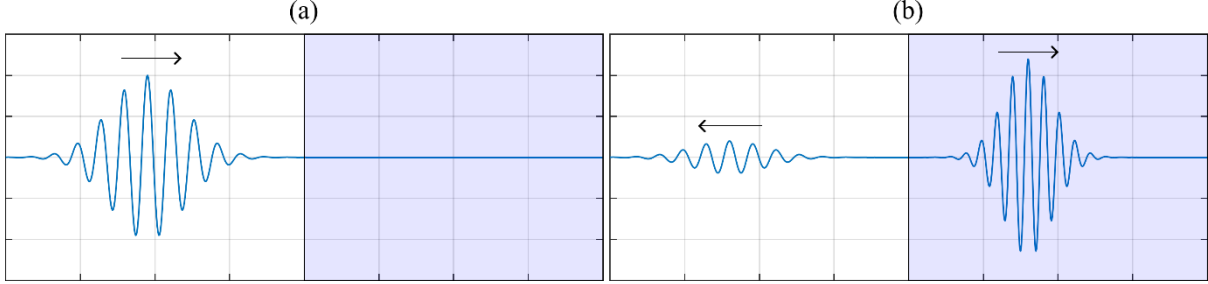


Fig. 1. Electric field at an interface, as seen in the laboratory frame. (a) Gaussian pulse incident on a dielectric, travelling from left to right (indicated by right pointing arrow), (b) the reflected pulse (left arrow) and the transmitted pulse (right arrow). This pulse was analytically simulated with continuous functions. The wavenumber of light does not change inside the dielectric, but rather, the pulse experiences length contraction.

Lastly, we have gained important new insight into two long-standing problems in physics [2]: the Abraham–Minkowski controversy and the arrow of time. To be more specific, by considering the effects of longitudinal acceleration, the Abraham–Minkowski controversy can be solved without dividing the overall momentum to wave and material portions. Moreover, the accelerating wave equation allows only solutions with a positive time, thus establishing a preferred temporal direction and shedding light on the microscopic arrow of time. Note that this is distinct from the thermodynamic (macroscopic) arrow of time.

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Phase winding without topological protection

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Keywords: structured light, singular optics, orbital angular momentum

Introduction

Structured optical fields carrying orbital angular momentum (OAM) are commonly described using Laguerre–Gaussian (LG) modes, in which the azimuthal mode index is directly associated with a well-defined topological charge and OAM per photon [1]. In realistic optical systems, however, beams frequently exhibit broken cylindrical symmetry, for example in the form of elliptically deformed LG profiles, where this direct correspondence is no longer present [2]. This raises the question of how the relevant properties – such as total OAM or topological charge – of beams without rotational symmetry should be defined.

Methods

In this work, we present an analytical treatment of the OAM content of an elliptic LG beam using Hermite Gaussian (HG) modal decomposition together with the canonical OAM operator [3]. The elliptic field is represented as a superposition of Hermite–Gaussian modes with different waists along x - and y -axes, which provides a natural description of beams lacking cylindrical symmetry. The OAM density is then evaluated from the operator expectation value, integrated over the transverse plane, and normalized by the total intensity to obtain the OAM per unit energy (per photon). Additionally, we use the same analysis for an elliptic HG beam. Numerical calculations are used to visualize the spatial distributions of the total OAM and its components, as well as intensity and phase at certain propagation distances. The latter two are shown in Fig.1.

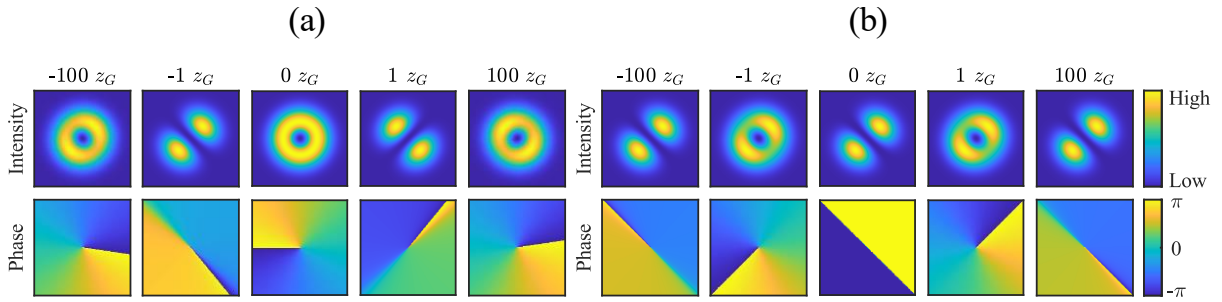


Fig. 1. The intensity (top row) and phase (bottom row) of (a) an elliptic LG beam and (b) an elliptic HG beam at different propagation distances. For both beams, the ratio between the waists along x - and y -axes is $w_{0x}/w_{0y} = 10$, and the scale of the axes is chosen to force a square aspect ratio at all propagation distances. The propagation distance is normalized with distance $z_G = \sqrt{z_x z_y}$, where z_x and z_y are the Rayleigh ranges in x - and y -directions.

Results

The analysis leads to three main findings [4]. First, an elliptic LG beam does carry a topological charge, although its vortex structure may become experimentally inaccessible upon propagation due to the geometry of the field. Second, the intrinsic OAM can be presented as a dynamical quantity and it depends on the overall field structure, so it is not carried only by phase singularities. Third, an elliptic HG beam can exhibit a “transient vortex”, a local phase singularity with no topological charge and zero net angular momentum. Therefore, an elliptic HG beam can be considered as a no-go example of a field exhibiting phase winding that is not associated with any conserved topological defect. This shows that phase winding alone is insufficient as a criterion for topological protection.

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High Pulsed Magnetic and Electric Field System for the Investigation of Nanostructured Manganite Films

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Abstract

Nanostructured manganites are intensively studied due to their colossal magnetoresistance (CMR) and electroresistance (ER) effects, which offer promising opportunities for the development of advanced electronic devices [1]. To optimize the functional properties of these materials, a detailed understanding of charge-carrier transport across grain boundaries (GBs) is required. In this work, we investigate the electrical conductivity of vertically aligned nanocolumnar films La–Sr(Ca)–Mn–O consisting of crystallites separated by structurally disordered grain boundaries. The films were subjected to synchronized nanosecond electric field pulses and pulsed magnetic fields up to 20 T over a broad temperature range. A pronounced magnetic field dependence of the electroresistance effect was observed, with the electroresistance either enhanced or suppressed depending on the temperature, electric field strength, and magnetic field magnitude. Analysis of the experimental results reveals that charge transport is governed by tunnelling processes across grain-boundary barriers. The observed behavior is attributed to the interplay between elastic spin-polarized tunneling and inelastic multistep tunnelling through disordered intergranular regions, together with the magnetic-field-induced redistribution of the electric potential between conductive nanocolumns and grain-boundary barriers [2]. In ferromagnetic state the magnetoresistance decreases with increasing of electric field, because of the increasing contribution of conductance caused by inelastic tunneling as well as the electroresistance magnitude decreases with the increase of magnetic field. In paramagnetic state the effect is much smaller. These results demonstrate that the transport properties and electroresistance of nanostructured manganite films can be effectively controlled by high magnetic fields through their influence on grain-boundary tunnelling mechanisms.

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Simulations of Linear and Nonlinear Optical Properties in low-dimensional materials

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Nonlinear optical phenomena in quantum materials offer a powerful platform for compact frequency conversion and integrated photonics. We present first-principles calculations of the second- and third-order nonlinear optical susceptibilities, χ^2 and χ^3 , in three classes of systems: rare-earth-doped i-MAX phases [1], carbon nanotubes (CNTs) [2], and defect-engineered hexagonal boron nitride (h-BN). For i-MAX materials, we use density functional theory (DFT) to investigate how rare-earth dopants modify the electronic structure, break inversion symmetry, and enhance the χ^2 response through dopant-induced hybridization. For CNTs, we apply the Bethe–Salpeter equation (BSE) formalism to accurately capture excitonic resonances and their effects on χ^2 and two-photon absorption, revealing substantial exciton-enhancement of nonlinearities. For h-BN, we examine the roles of point defects and substitutional dopants in creating mid-gap states and enabling otherwise-forbidden nonlinear resonant processes. Our results show that these three material platforms exhibit complementary tunability of nonlinear coefficients. We compare their performance with that of conventional nonlinear crystals and discuss their applications as promising candidates for next-generation integrated nonlinear photonic devices operating in the near- to mid-infrared frequency range.

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Room-Temperature Terahertz Photonics via Plasmons Excitation in Various Semiconductor Platforms

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Exciting collective charge density oscillations (two-dimensional (2D) plasmons) within the sub-micrometer channels of semiconductor devices provides a definitive path toward uncooled, room-temperature (RT) terahertz (THz) photonics [1]. While traditional electronics are bottlenecked by carrier transit times, 2D plasma waves propagate orders of magnitude faster, bypassing standard speed limits to achieve high-efficiency THz generation, modulation, and detection. The core challenge for room-temperature operation is meeting the Dyakonov–Shur resonance condition: ($\omega\tau > 1$), where ω is the angular frequency of electromagnetic wave and τ is the momentum relaxation (scattering) time of charge carriers [2]. At room temperature, intense electron-phonon scattering heavily dampens these plasma waves ($\omega\tau < 1$), shifting devices into a non-resonant regime. In addition, fundamental device physical parameters are required to sustain non-damped, collective free charge carrier density oscillations up to room temperature.

In this work we discuss physical mechanisms of plasmon coupling and excitation efficiency studying across distinct architectures, including AlGaIn/GaN high-electron-mobility transistor (HEMT) and carbon-based periodic grid structures. As for 2D plasmon excitation in AlGaIn/GaN HEMT structures: GaN boasts a high breakdown voltage and a massive 2DEG concentration ($\approx 10^{13} \text{ cm}^{-2}$) preserving decent electron mobility at room temperature. These devices use specialized grating-gate couplers to overcome the momentum mismatch between free-space light and highly confined 2D plasmons [3]. Integrating a metal grating over a continuous 2DEG channel spatially modulates the carrier profile resulting in plasmonic crystals approach [4]. This periodic configurations force the 2D plasmon dispersion relation to fold into the optical zone center ($k \approx 0$), enabling efficient coupling of 2D plasmons with incoming THz radiation. Altering the bias on the grating shifts the carrier profile from a weakly modulated state (high absorption) to a fully depleted state (high transmission), operating as an ultra-fast room-temperature THz modulator [5].

Graphene has emerged as a premier material for overcoming room-temperature damping. Because single-layer graphene natively experiences remarkably low intrinsic phonon scattering at ambient temperatures, it preserves high τ values, enabling resonant THz detection in single-layer graphene transistors [6]. One modification of graphene is single-walled carbon nanotube (SWNT): a hollow cylindrical nanostructure with diameter ranging from 0.8 to 3 nm and length extending up to several centimetres [7]. Exceptional electrical, mechanical, and optical properties of the SWNTs make them attractive for a wide range of applications, including flexible and transparent electrodes [7, 8]. In such context, substantial efforts have been directed toward reducing the sheet resistance of SWNT films while preserving their high optical transmittance [9]. Finally, we investigate the possibility of 2D plasmon excitation in the THz range using the carbon nanotube (CNT) grids. This specific configuration establishes that patterned CNT grids on a lossless silicon substrate can act as both the active plasmonic medium and the intrinsic diffraction coupler needed to capture and confine free-space THz radiation on a chip for future signal communication applications.

Acknowledgement

This work was supported by the European Union's Horizon Europe research and innovation programme under the Marie Skłodowska-Curie Actions through the project 101236439 “Towards a teraHERtz short-range wireless communication system based on graphene deviceS” (HERMES, 2025–2029) and by the Research Council of Lithuania (Lietuvos mokslo taryba) through bilateral Lithuania-Taiwan project S-LT-TW-24-10 “Study on Maskless Green Technologies of GaN and Ga2O3 Power Devices by Laser Micro-Processing (MasklessLMP, 2025-2026).

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Black Nickel Coating: A Scalable Solution for Ultra-Broadband Absorption

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Broadband electromagnetic absorbers capable of attenuating radiation across an ultrawide spectral continuum, spanning from the terahertz (THz) to the deep-ultraviolet (DUV) regimes, are critical components in advanced spectroscopy, high-resolution imaging, radiation shielding, and solar energy harvesting. However, conventional absorbing materials are frequently constrained by narrow operational bandwidths, environmental vulnerabilities, or a reliance on complex, high-cost lithographic nano structuring techniques. This published study [1] demonstrates a robust, cost-effective, and highly scalable black nickel (b-Ni) coating fabricated via electrodeposition onto copper substrates followed by controlled chemical etching.

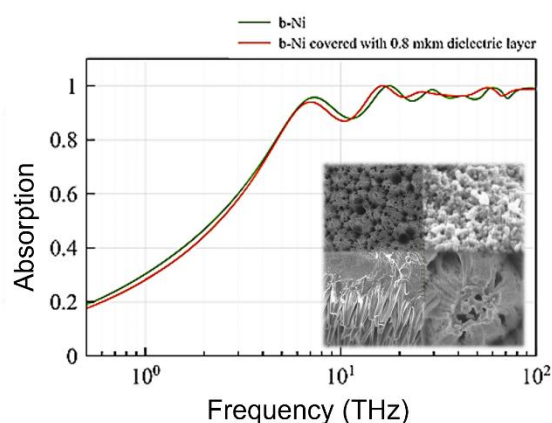


Fig. 1. Simulated Absorption spectrum of b-Ni. Inset: SEM images of b-Ni surface (Data curves and micrographs adapted from Menon et al., ACS Omega 2026)

The experimental framework involved the electrodeposition of a $45 \pm 5 \mu\text{m}$ thick nickel-phosphorus alloy layer onto copper foil, which was subsequently subjected to chemical etching in a nitric acid solution to generate a light-trapping surface morphology. Scanning electron microscopy (SEM) and X-ray photoelectron spectroscopy (XPS) confirmed the formation of a complex hierarchical architecture consisting of microscale, porous cone-like features covered in fine nanoscale surface textures. Optical evaluation utilizing custom Fourier-transform infrared spectroscopy (FTIR) and diffuse reflectance spectroscopy (DRS) demonstrated that this multi-scale topology yields exceptional ultrabroadband performance from 30 to 1500 THz, sustaining a continuous absorptivity exceeding 95% across the entire spectrum.

Full-wave COMSOL Multiphysics simulations verified that the coating's multi-scale geometry drives its broadband response, where the microscale cones govern lower-frequency THz attenuation and the surface nano roughness drives high-frequency DUV absorption. Combining high optical performance with mechanical durability, simple scalable processing, and high throughput, this chemically etched b-Ni coating offers a simple, scalable large-area alternative to delicate metamaterials or silicon moth-eye structures for industrial sensors, quantum device thermal management, and advanced scientific instrumentation.

This work was supported by the Research Council of Finland (Flagship Programme PREIN, decision 368653 and research project decision 357033) and the Horizon Europe MSCA HERMES Project 101236439. This research and Nikita Belko were supported by EU Horizon Europe under the Marie Skłodowska-Curie COFUND grant No 101081327 YUFE4Postdocs. The Pohjois-Savon Liitto DeepSurface projects (A78280 & A78303) support is acknowledged for XPS instrument acquisition and measurements.

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Photonics–Electronics Convergence for Terahertz Wireless: From Device Physics to Fully Integrated Systems

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Terahertz (THz) wireless technologies have advanced rapidly through progress in materials, device physics, and semiconductor integration [1-6]. While both photonics-assisted and all-electronic architectures have demonstrated beyond-100-Gbit/s performance in the D-band [2] and J-band [3-6], the transition from device-level demonstrations to scalable wireless systems remains a central challenge. Recent results indicate that photonics-enabled transmitters and receivers offer clear advantages in bandwidth scalability, frequency agility, and linearity, enabling record-class demonstrations such as 220 Gbit/s over 214 m [4] at 275 GHz, 120 Gbit/s over 850 m at 320 GHz [5] and 184 Gbit/s over 1.4 km using multi-channel photonic transceivers [6]. These trends highlight the growing importance of photonics-electronics convergence.

A system-level viewpoint is essential for future THz wireless. Heterogeneous integration—combining silicon photonics, III–V devices, SiGe/CMOS circuits, and advanced packaging—provides a pathway to overcome the limitations of purely electronic or purely photonic approaches. Co-design across digital (DSP/FEC), analog (THz RF), and photonic (CPO/SiPh) domains enables improved output power, sensitivity, and energy efficiency. Figure 1 illustrates this multi-domain integration, emphasizing dense I/O, chiplet-based architectures, and the need for roadmap-driven system optimization.

Looking ahead, we propose three directions for the THz community:

- (1) Unified photonic–electronic front-ends that merge optical frequency synthesis with THz up/down-conversion to achieve sub-THz/THz agility beyond current PLL-based limits.
- (2) System-aware device metrics, replacing traditional device-centric figures of merit with metrics tied to link budgets, DSP constraints, and energy-per-bit.
- (3) Application-driven THz architectures, including fixed wireless access, short-reach fiber alternatives, and hybrid sensing–communication platforms.

These perspectives suggest that photonic and electronic technologies are not competing alternatives, but complementary enablers of future THz wireless systems. System-level integration, packaging, and co-design will allow both to leverage their strengths. Ultimately, the convergence of optics, logic, and RF will be key to realizing fully integrated THz wireless systems for 6G and beyond.

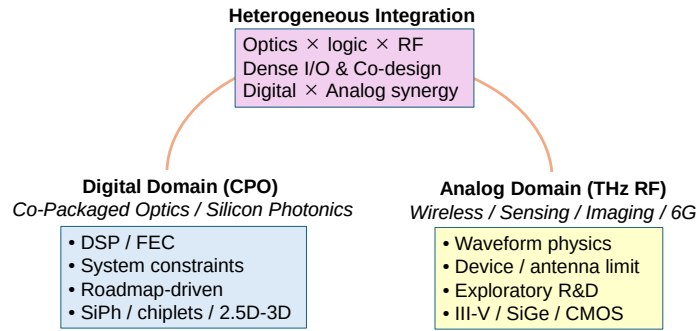


Fig. 1. Conceptual diagram of heterogeneous integration across optics, logic, and RF domains, highlighting co-design requirements for future THz wireless systems.

Acknowledgement.

Part of this work is supported by a Commissioned Research Project (JPJ012368C09801) from the National Institute of Information and Communications Technology (NICT), Research and Development for Expansion of Radio Resources (High-millimeter wave fixed wireless access as an alternative to optical fiber networks) from the Ministry of Internal Affairs and Communications (MIC), JSPS KAKENHI Grant Number JP 24K00887, and the RIKEN TRIP initiative.

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THz-Wave Generation and Detection by Semiconductor Heterojunction Diodes

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1. Devices for generation and detection of THz-waves

In this talk, two types of our original devices for the generation and detection of continuous THz-waves are presented. We use the photomixing for the THz-wave generation. This technique has several advantages, such as wide frequency tunability, narrow linewidth, good frequency stability, and capability of long-distance THz-wave signal transmission through low-loss optical fibers. For this purpose, we developed an InP/InGaAs photomixer called a uni-traveling-carrier photodiode (UTC-PD [1]) (Fig. 1). It has a unique mode of operation; namely only electrons are the active carriers that travel through the device. This feature provides several advantages over a conventional photodiode (pin-PD), such as higher operation speed, larger output saturation current, and lower operation voltage. As a THz-wave detector, we developed an InP/InGaAs hetero-barrier rectifier called a Fermi-level managed barrier (FMB) diode [2] (Fig. 2). It has stable, reproducible, and uniform characteristics compared with those for a conventional Schottky barrier diode (SBD). The low barrier height of the FMB diode (around 100 meV) enables both low differential resistance and high output current under zero-bias condition. These features are essential for simultaneously achieving broad-bandwidth and low noise-equivalent-power (NEP) detection.

2. New fabrication technology for improving performances of THz-wave devices

Recently, we applied the epi-layer transfer technique to fabricate the THz-wave devices explained above on heterogeneous substrates, such as SiC and Si, to further improve their performances. These substrates have better material characteristics than those of InP, and the epi-layer transfer enables the monolithic integration of these devices with passive RF components. By using this technique, we could successfully achieve an output power of more than 2 mW at 320 GHz from a UTC-PD fabricated on SiC substrate [3]. This output power is comparable to the maximum output power of an electrical amplifier in 300-GHz band. Thus, we can now fully utilize the advantages of photomixing without using external electrical amplifiers in practical systems. We also applied the epi-layer transfer technique to the FMB diode, and achieved a very low NEP of 3×10^{-19} W/Hz at around 300 GHz by a fundamental mixer fabricated on SiC substrate [4] and an extremely low NEP of 5×10^{-20} W/Hz at around 300 GHz by a balanced mixer fabricated on Si substrate [5].

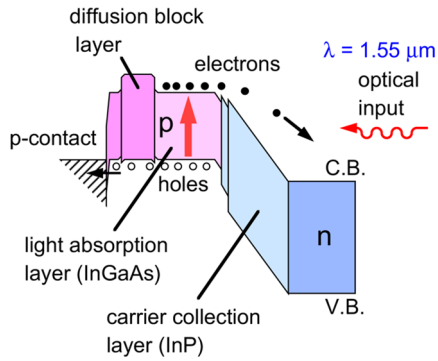


Fig. 1 Band diagram of UTC-PD.

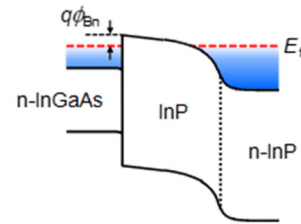


Fig. 2 Band diagram of FMB diode.

3. Acknowledgement.

This work was supported in part by the ACCEL Program (JPMJMI17F2) from the JST, the Beyond 5G R&D Promotion Program (JPJ012368C00901) from the NICT, the KAKENHI (23K03960) from the JSPS, and the RIKEN TRIP initiative.

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Terahertz Spectroscopy for Advanced Material Characterization: Methods, Instrumentation and Applications

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Terahertz (THz) photonics has become a powerful and versatile platform for non-destructive material characterization, enabling direct access to charge carrier dynamics, conductivity, dielectric properties, and structural features of a wide variety of materials. Located between the microwave and infrared spectral regions, THz radiation provides unique sensitivity to low-energy excitations that are often inaccessible by conventional optical techniques. Advances in ultrafast laser technology, photoconductive devices, and THz system engineering have substantially expanded the capabilities of THz spectroscopy, transforming it from a laboratory research tool into a mature technique for both scientific and industrial applications.

This invited presentation will provide an overview of modern THz measurement methodologies and their application to the characterization of semiconductors, nanomaterials, functional thin films, and emerging photonic materials. Particular attention will be devoted to experimental techniques for investigating ultrafast carrier dynamics and material transport properties.

Terahertz Excitation Spectroscopy (TES) will be introduced as a contactless technique for semiconductor characterization based on the analysis of THz radiation emitted following femtosecond optical excitation. By measuring the THz emission as a function of excitation photon energy, TES provides valuable information on band structure, carrier scattering mechanisms, hot-carrier dynamics, and ultrafast transport processes. The technique has proven particularly useful for investigating semiconductor heterostructures, nanostructured materials, and novel optoelectronic materials [1].

The Optical Pump–THz Probe (OPTP) methodology will be discussed as a versatile approach for measuring picosecond and sub-picosecond carrier lifetimes. Time-resolved THz probing allows direct observation of transient photoconductivity and recombination dynamics, providing insights into defect-assisted recombination, carrier trapping, and charge transport phenomena. Examples from semiconductor and nanostructured material studies will illustrate the capability of OPTP spectroscopy to evaluate material quality and device-relevant parameters

The presentation will further review Terahertz Time-Domain Spectroscopy (THz-TDS), one of the most widely used techniques for THz transmission and reflection measurements. THz-TDS simultaneously provides amplitude and phase information, enabling extraction of complex refractive index, absorption coefficient, dielectric function, and conductivity without requiring indirect analytical procedures. Practical aspects of measurement configuration, data analysis, and parameter retrieval will be addressed together with representative examples involving bulk materials, thin films, multilayer structures, and industrial samples.

In addition to methodological aspects, the talk will highlight recent developments in THz instrumentation and system engineering, emphasizing solutions that improve measurement sensitivity, spectral bandwidth, and applicability to real-world characterization challenges. The combination of advanced THz spectroscopy techniques with modern photonics continues to create new opportunities for the investigation of condensed matter systems, functional materials, and emerging technologies. As THz methods become increasingly accessible and robust, they are expected to play an expanding role in both scientific discovery and industrial innovation.

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Planar Meta-Atom Photonic Sensor for Terahertz Detection of Organic Molecules

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The terahertz (THz) spectrum is one of the most promising yet least exploited regions of the electromagnetic spectrum. It offers spectroscopically rich interactions with materials [1], and strong potential for sensing applications [2] due to its low photon energy, high penetration depth, and non-destructive inspection properties. However, the long wavelengths of THz radiation, typically ranging from millimeters to tens of micrometers (0.1–10 THz), fundamentally limit the sensitivity of conventional sensors for detecting small or subwavelength molecules. This limitation has hindered the development of highly sensitive and compact THz sensing devices. Therefore, understanding and controlling light–matter interaction at the subwavelength scale is therefore a key requirement for advancing THz sensing technologies. Meta-surfaces, are artificially engineered electromagnetic media that are composed of array of subwavelength structures, known as meta-atoms. Each individual meta-atom can strongly localize and confine electromagnetic (EM) fields within deeply subwavelength volumes, leading to substantial near-field enhancement and significantly increased light–matter interactions [3]. In this work, we demonstrate a THz photonic sensing platform based on a single planar meta-atom composed of concentric disk- and ring-shaped elements patterned on a freestanding metal film. The proposed structure is designed to support strongly confined resonant modes that enhance its sensitivity to the presence of organic molecules at THz region. To evaluate its sensing performance, the meta-atom was coupled to a layer of α -lactose monohydrate. The presence of the lactose layer resulted in enhancement of resonance amplitudes and induced significant redshifts of the resonance frequencies, from 0.35 THz and 0.80 THz to 0.26 THz and 0.53 THz, respectively. Furthermore, the characteristic absorption feature of lactose at 0.53 THz [4] produced a pronounced transmission dip at the second resonance, providing direct evidence of molecule-specific detection.

These results demonstrate that the planar meta-atom can serve as a compact and highly sensitive THz sensor, offering a approach for the identification of small volumes of organic and biomolecules promising for future miniaturized THz spectroscopy applications.

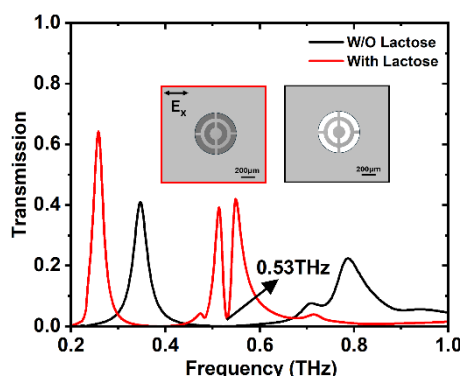


Fig. 1. Transmission spectra of a single planar meta-atom with (red) and without (black) a 60 μm α -lactose monohydrate layer using FDTD simulations. Inset: schematics of the corresponding structures

Acknowledgement

This work is supported by Lietuvos Mokslo Taryba (LMT) Postdoctoral project under the GA no. SPD-25-44 and THz-Skin project, GA no. 101257203.

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Investigation of AlGaIn/GaN modified edge field effect transistors for terahertz detection at cryogenic temperatures

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Abstract

We investigate AlGaIn/GaN modified edge field-effect transistors (m-EdgeFETs) as broadband terahertz detectors operating from room temperature down to liquid-nitrogen temperature. The devices employ laterally placed gate electrodes interconnected by a narrow bridge across the channel, providing strong electrostatic control while preserving lateral-field asymmetry beneficial for rectification. The response characteristics of m-EdgeFETs measured at 300 GHz in source-drain polarization demonstrated a pronounced enhancement at cryogenic temperature. For a 13.5 μm -channel m-EdgeFET device, the peak responsivity increases from 0.08 V/W at 300 K to 2.25 V/W at 77 K.

Introduction

Terahertz (THz) radiation has attracted considerable interest due to its applications in spectroscopy, imaging, security screening, and astronomy [1,2]. The development of compact, fast, and sensitive THz detectors remains an active research area. Field-effect transistor (FET)-based detectors offer a promising approach, enabling broadband THz detection by rectifying high-frequency radiation in the transistor channel [3,4].

The AlGaIn/GaN high-electron-mobility transistors (HEMTs) are especially well suited for THz detection owing to their high two-dimensional electron gas (2DEG) density and robustness under high electric fields due to the high breakdown field of the material [5]. Previous studies have shown that introducing structural or electrical asymmetry in FETs can substantially enhance THz rectification [6]. In edge-gated FETs, laterally placed gates provide tunable channel-width control and can reduce plasma-wave damping by confining high-frequency excitation to a narrower effective conduction region [7,8]. A further refinement of this concept is the modified edge field-effect transistor (m-EdgeFET), where laterally placed gate electrodes are interconnected by a narrow bridge crossing the channel. This geometry improves electrostatic control of the channel while preserving lateral field components, potentially combining the advantages of conventional top-gated and edge-gated designs [7,8].

While GaN-based FET THz detectors extensively investigated at room temperature [7,8], the experimental studies of edge-gated and modified edge-gated architectures under cryogenic conditions remain limited. In this work, we investigate m-EdgeFETs developed from AlGaIn/GaN HEMT structures as the THz detectors in the range from room temperature down to cryogenic temperatures.

Experimental Details

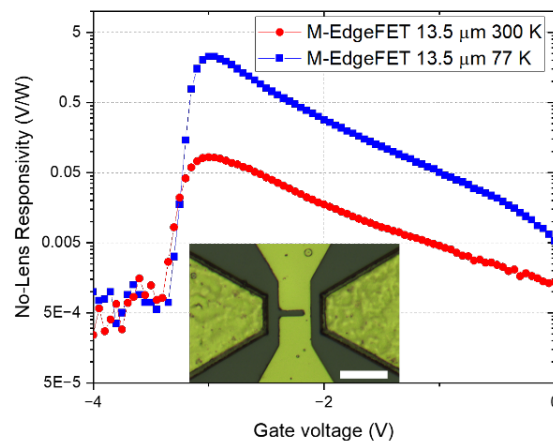


Figure 1. Gate-voltage dependence of the THz responsivity of an AlGaIn/GaN modified edge field-effect transistor (m-EdgeFET) with a channel length of 13.5 μm measured at 300 K and 77 K. The inset shows an optical photo of the active region of the m-EdgeFET (scale bar: 20 μm).

The m-EdgeFET detectors were fabricated from an AlGaIn/GaN HEMT structure using a standard sequence of lithography, metal deposition, and lift-off processes. Device regions were electrically isolated by patterned ion

implantation. Source and drain contacts were formed by depositing a Ti/Al/Ni/Au metal stack and performing a short high-temperature anneal in nitrogen. Finally, the gate metallization (Ni/Au) was patterned to realize the modified edge-gate layout, where two side gates are connected by a narrow bridge crossing the channel. A microscope picture of the fabricated sample is shown in the inset of Fig. 1.

For THz coupling, every transistor sample was integrated with a pair of planar bow-tie antennas, with the source–drain and gate terminals connected to the antennas to couple the incident electric field in the active region efficiently. The THz photoresponse was measured at 300 GHz using lock-in detection under 1 kHz modulation, in source–drain (SD) mode, when the linearly polarized incoming radiation is aligned with the source–drain antenna. Measurements were performed at 300 K and 77 K temperatures provided by a liquid-nitrogen cryostat while sweeping the gate voltage to tune the channel conductivity.

Results and Discussion

Figure 1 shows the responsivity versus gate-voltage dependence of a 13.5 μm AlGaIn/GaN m-EdgeFET sample at 300 K and 77 K temperatures. The responsivity exhibits a pronounced peak located close to the onset of channel depletion. Such a bias dependence is typical for overdamped plasma-wave (resistive self-mixing) rectification, where the dc signal is governed by the nonlinearity of carrier transport and is maximized in the gate-voltage range where the channel conductivity varies most rapidly. In this regime, the response therefore closely follows the evolution of the channel transconductance with the gate voltage sweep.

Cooling from 300 K to 77 K produces a strong enhancement of the photoresponse: the maximum responsivity increases from 0.08 V/W at room temperature to 2.25 V/W at 77 K ($\approx 30\times$). This improvement can be attributed primarily to reduced carrier scattering at low temperature. Suppression of phonon scattering increases the electron mobility μ and, correspondingly, the momentum relaxation time τ ($\mu = e\tau/m^*$). A larger τ reduces plasma-wave damping and increases the characteristic decay length of the ac excitation in the channel, $l = s\sqrt{2\tau/\omega}$, so that a larger fraction of the channel effectively participates in rectification at 300 GHz. In parallel, the transfer characteristics typically become steeper at 77 K (higher g_m and $d\sigma/dV_g$ near threshold), which amplifies the self-mixing nonlinearity precisely in the bias range where the responsivity peak is observed. Together, reduced high-frequency dissipation (larger effective l , higher $\omega\tau$) and enhanced conductivity nonlinearity near depletion provide a consistent explanation for the markedly higher 300 GHz responsivity at 77 K while preserving the same “near-threshold” peak position characteristic of overdamped plasma-wave detection. It is worth noting that the optical for Si-based Tera-FETs developed based on CMOS technology demonstrated the THz response at 0.6 THz, which corresponds to an increase by a factor of 4 compared to room temperature [9].

Conclusions

To summarize, the AlGaIn/GaN terahertz detectors based on a modified edge field-effect transistor coupled to a bow-tie antenna design were investigated at 300 GHz frequency, at 77 K and 300 K temperatures. A pronounced enhancement of the THz photoresponse was observed upon cooling the detector from room temperature to 77 K, with the maximum responsivity reaching values up to 2.25 V/W without Si lenses. The modified edge-gated transistor design was shown to provide effective electrostatic control while maintaining lateral field asymmetry. It is worth noting that state-of-the-art Si-based TeraFET detectors developed in CMOS technology demonstrated an increase in THz response at 77 K in comparison to room temperature by a factor of 4, only. Our results demonstrate the high potential of m-EdgeFET architectures for sensitive THz detection at cryogenic temperatures and motivate further optimization for low-noise and high-frequency applications.

Acknowledgement

This work was supported by the Research Council of Lithuania (Lietuvos mokslo taryba) under the “MasklessLMP” project grant No. S-LT-TW-24-10; by the EC under Horizon-MSCA-2024-SE project “Towards a terahertz short-range wireless communication system based on graphene devices (HERMES)” Grant No: 101236439.

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Beyond Mean-Field Effects in Bose-Einstein Condensates: Supersolids, Droplets and Polarons

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The progress in cooling and control of ultracold quantum gases and their mixtures allowed for the engineering of new states of matter. Ultradilute quantum liquid of a binary mixture of Bose-Einstein condensates (BECs) at the border of stability is one example. It allows for formation of finite-size, self-bound quantum droplets. Another possible mechanism of droplet formation is through long-range dipolar interactions. In this talk I will present an overview of these phenomena, and discuss one-dimensional ultradilute quantum liquids in binary BECs in the context of their collective excitations and Josephson dynamics. I will also consider a mobile impurity and its out-of-equilibrium properties, such as the stationary momentum at long times, which is nonzero due to the superfluid nature of the medium, the effective mass and the oscillatory dynamics of the momentum transfer between the impurity and the condensate.

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Poster session



Phototoxic Effects of Nanostructured Carbon Nitrides on HeLa Cells and Red Blood Cells

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Nanostructured carbon nitrides (n-CN) have emerged as promising nanomaterials for biomedical applications [1], owing to their tunable optical properties, low toxicity, and photosensitizing capability. Bulk graphitic carbon nitride (g-C₃N₄) is a versatile material that can be transformed into a range of nanostructures, including quantum dots (CNQDs) and nanowires (CNNWs), with applications in photocatalysis, energy conversion, environmental remediation, and biomedicine. Transitioning to the nanostructured carbon nitrides (n-CN) enhances the material's biocompatibility and surface area, making it highly attractive for cellular interactions. Despite their promising properties, systematic studies of cellular responses to CNQDs and CNNWs, particularly those triggered by light exposure, are still lacking.

In this work, we investigate the photo-induced biological effects of two nanostructured carbon nitrides (n-CN) samples synthesized via hydrothermal alkaline etching using LiOH and NaOH [2]. These samples are referred to as n-CN(Li) and n-CN(Na), respectively. CNQDs with sizes ranging from 5 to 50 nm were observed in both samples. In addition to CNQDs, n-CN(Li) formed extended CNNW networks containing numerous embedded CNQDs. In contrast, n-CN(Na) exhibited CNNW networks of variable density and only rarely contained entangled nanoparticles. Overall, n-CN(Na) contained a greater fraction of larger, micron-sized flakes and showed a stronger tendency to aggregate in aqueous media.

For these two samples with different amounts of smaller and larger structures, reactive oxygen species generation was first characterized in solution to establish the intrinsic photosensitizing activity of both variants. Efficient generation of superoxide anion radical and hydroxyl radical were observed under light activation at 385 nm for both samples.

Both n-CN samples demonstrated time- and concentration-dependent cellular uptake in (cervical cancer) HeLa cells. While virtually no toxicity was observed under dark conditions, light activation at 385 nm of the internalized n-CN caused oxidative stress induction and subsequent cell death.

For red blood cells (RBCs), n-CN were incubated for 24 hours followed by irradiation, and cell viability was evaluated through hemoglobin release assay. Both n-CN samples exhibited good hemocompatibility, with no statistically significant hemolysis detected under either dark or light conditions.

The distinct responses of HeLa cells and RBCs are likely attributable to differences in their cellular biology. HeLa cells can internalize nanoparticles through endocytic pathways, enabling intracellular ROS generation upon light activation of n-CN, whereas RBCs lack endocytic activity and therefore remain exposed primarily to extracellular particles.

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THz-FIR library for skin cancer diagnostics

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We present early progress on the Horizon Europe Pathfinder project THz-Skin on the design and population of a unified, public, online spectral library combining experimental and simulated THz-FIR data for healthy and cancerous skin tissue, focusing on the range 3–25 THz; a range largely unexplored in current biomedical THz literature. We outline the methodology developed for THz time-domain spectroscopy data processing and discuss the proposed metadata schema and controlled vocabulary underpinning the library's structure, intended to consistent, richly annotated, and machine-readable entries across consortium contributions while remaining intuitive for the other, relevant research communities. Preliminary results from the processing pipeline are presented, illustrating the workflow from raw spectroscopic data to standardized datasets or spectral cubes ready for library integration.

Acknowledgement.

This work was supported by the THz-Skin project, which has received funding from the European Union (grant no. 11166388).

Design of plasmonic superlattices

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We investigate surface lattice resonances (SLRs) in plasmonic superlattices with various configurations [1]. By analyzing angle-resolved transmission spectra and induced dipole moments, we show that selective illumination reveals strong radiative coupling between lattices, persisting over macroscopic distances. Furthermore, checkerboard superlattices with alternating periods support multiple tightly spaced SLR modes, offering a promising platform for mode-locked multimode lasing [2].

Here, the coupled dipole approximation (CDA) is utilized [3,4]. Results for a 2×1 superlattice are shown in Fig. 1 (patches: $p_0=520$ nm, $p_1=570$ nm, 31×11 nanoparticles per patch). In Fig. 1a-b, dipole moments of patch 1 and patch 2 peak at the respective SLR mode band edges (Fig. 1c). Fig. 1d-e show the same superlattice under selective illumination (only patch 1 illuminated). Due to strong inter-patch radiative coupling, the dipole moment in patch 2 maximizes at the band-edge wavelength of patch 1. Notably, this induced dipole moment remains comparably strong even when patch separation extends from tens to hundreds of micrometers. As shown in Fig. 1f, the maximum dipole-moment magnitude in patch 2 follows a clear linear trend with the macroscopic period on a logarithmic scale, corresponding to an inverse power-law decay. To demonstrate superlattice engineering, Fig. 2 presents the transmission spectrum of a 4×2 checkerboard superlattice with alternating periods, where multiple SLR-mode band edges emerge near normal incidence. Such closely spaced resonant modes can be leveraged for mode-locked multimode lasers.

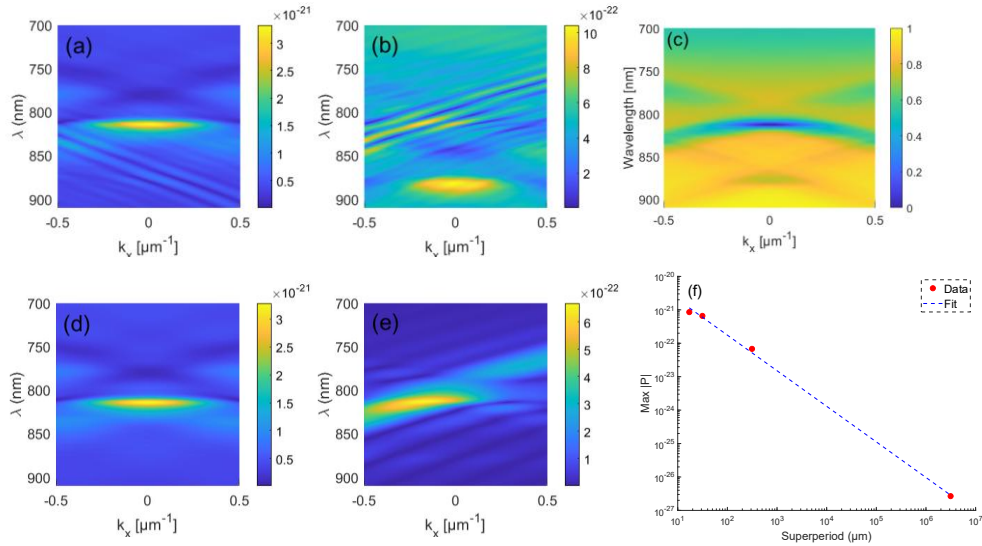


Figure 1. (a)-(b) Absolute dipole moment of the center particle in patches 1 and 2, and (c) transmission spectrum of a 2×1 superlattice with both patches illuminated ($p_0 = 520$ nm, $p_1 = 570$ nm, superperiod= $55p_1$). (d)-(f) The same superlattice under selective illumination (only patch 1 is illuminated). (d)-(e) Dipole moments of patch 1 and patch 2, and (f) maximum dipole moment in patch 2 as a function of the macroscopic period.

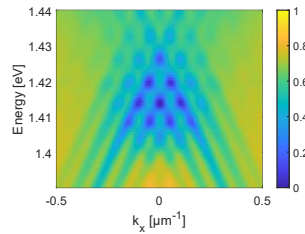


Figure 2. Transmission spectrum of a 4×2 checkerboard superlattice with alternating periods $p_0 = 520$ nm and $p_1 = 570$ nm, and a superperiod of $55p_1$. Multiple SLR mode band edges emerge near the $k_x = 0$.

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Optimizing MBE Growth of GaAsBi Quantum Wells for Biosensing Focused Laser Diodes

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Currently the near-infrared (NIR) spectral region has been gaining even more importance, due to its uses in the expansion of the integrated sensors for smart devices, LiDAR systems for autonomous driving vehicles, as well as the increased demand for optical interconnects in data centers driven by the advances of artificial intelligence. The growing demand also drives the investigations into novel material engineering approaches, focused at more efficient, flexible, and versatile solutions for NIR lasers. One of the most prominent efficiency loss mechanisms in narrow-bandgap semiconductors used for this spectral region is Auger recombination. This motivates the exploration of alternative NIR optoelectronic materials such as GaAsBi. It has been showcased that substituting As by Bi in the GaAs lattice results in a large increase of spin-orbit split-off energy, while rapidly decreasing the bandgap (up to 88 meV/%Bi) [1]. The combination of these effects results in suppression of one of the Auger recombination paths as the bandgap energy becomes smaller than the split-off energy at 10.5% of Bi concentration [2]. Furthermore, GaAsBi is attractive in NIR applications due to its room-temperature operation and low wavelength dependence on temperature, making cooling less crucial, adding to the possible improvements in wall-plug-efficiency [3]. Finally, the rapid bandgap reduction allows to grow emitters on GaAs substrates in the wavelength region longer than 1100 nm, with manageable stress. Despite these advantages, the practical implementation of GaAsBi for NIR emitters remains challenging. The growth of GaAsBi requires low growth temperatures and highly precise flux control, which degrades the crystal quality and promotes additional non-radiative recombination defect centers. This ultimately limits the wider applications as most of the semiconductor Fabry-Perot laser diodes (LDs) operate only under pulsed electrical injection, with very few reports on lasing by continuous wave (CW) pumping at very high current thresholds (I_{th}) in the order of kA/cm² [4,5]. In this work we present development of GaAsBi quantum well growth technology catered at the classic electrically pumped FP-type edge emitting LDs, with utilization of parabolic barrier design and substrate thinning to reduce the I_{th} .

The structures overviewed in this work were grown using a solid-source Veeco GenXplor R&D molecular beam epitaxy system. 350 μ m thick, n-type, 2-inch diameter GaAs (100) substrates were used. Two material systems were chosen, a well-studied InGaAs and a rather exotic GaAsBi alloy. To calibrate and optimize the emission of the gain region, 3 QW structures were grown.

The fabricated LDs emitting in the range of 1025 nm to 1106 nm had three major design differences. The first architecture utilized a classical GaAsBi/GaAs three rectangular QW design, while the second one had the same amount of QWs inserted in a parabolically graded profile. Additionally, some LDs were fabricated after thinning the n-type substrate. The laser bars were formed of the same dimensions making their characteristics comparable, a detailed growth and processing protocol is explained in our earlier work [6]. Both factors, the parabolic profile and structure thinning had a positive impact on the laser performance. where the use of parabolic profile decreased, while the thinning showed further improvement with 10 times smaller I_{th} and more than 10 higher power compared to the classical rectangular design.

Acknowledgement

This project has received funding from the Research Council of Lithuania (LMTLT), agreement No. S-MIP-24-99.

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Controlling morphology and optical properties of diamond needles

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The focus of this research project is to fabricate diamond-hosting colour centres in a pyramidal shape, known as diamond nanoneedles. Colour centres are atomic defects, such as a carbon atom replaced with nitrogen, next to a missing carbon atom, known as a nitrogen-vacancy (NV) centre [1]. Another similar example is a silicon-vacancy centre (SiV). Colour centres can effectively sense thermal gradients, pressure, strain, electric and magnetic fields [2], and through their charge state (NV^- , NV^0 and NV^+), different sets of spin states exist. The NV^- state is valuable because it holds the electron spin used in quantum computing [3]. Diamond is an excellent host for applications because of its unique properties including biocompatibility, high hardness and thermal conductivity, and wide 5.5 eV bandgap providing transparency in a wide spectral range [4].

An NV centre can be made by adding in-situ dopant gases of nitrogen during chemical vapour deposition (CVD). The goal of a CVD chamber is to manage gas dynamics, vacuum conditions, high-temperature, plasma control, and to ensure a diamond growth environment is created and maintained. The main stages of obtaining process of individual diamond needles are presented in Fig. 1. They include CVD synthesis of a carbon film consisting of diamond needles fixed inside the matrix of other carbon materials, selective oxidation of the synthesized film to eliminate the matrix and transfer of the needles to isolate them.

In this work, we discuss the influence of various CVD synthesis parameters on the morphology and optical properties of diamond needles and experimentally demonstrate the effective integration of previously developed techniques for the precise engineering of diamond micro- and nanoneedles.

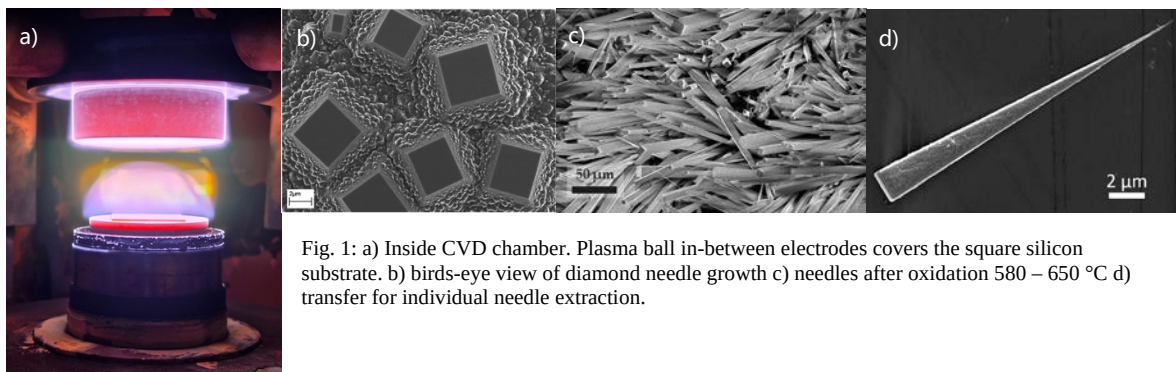


Fig. 1: a) Inside CVD chamber. Plasma ball in-between electrodes covers the square silicon substrate. b) birds-eye view of diamond needle growth c) needles after oxidation 580 – 650 °C d) transfer for individual needle extraction.

Acknowledgements

This work was supported by the Research Council of Finland through PREIN (decision 368653), EXTRASENS (decision 361115), CHARACTER (decision 357033), and by the Horizon Europe MSCA FLORIN project (101086142). The research project is a part of summer internship within the Erasmus Mundus Joint Masters for intelligent Photonics for Security, Reliability, Sustainability and Safety (iPSRS).

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Characterization of thermomechanical detectors in the 6-12 μm (25-50 THz) range

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1. Introduction

The infrared (IR) spectral range offers valuable features for imaging applications. Materials such as paper, plastic, and fabrics have transparent windows in this range; moreover, photons are non-ionizing, so biological tissues are not damaged upon exposure. Finally, water and several organic compounds present characteristic spectral fingerprints in this range, enabling chemical identification alongside spatial imaging, which is of extreme interest for health diagnostic applications. However, sources face significant limitations especially towards the long wavelength limit. Most notably, quantum cascade lasers, one of the most widely used coherent sources in the IR, require cryogenic cooling when operating in the THz range. In the mid-IR, even though cryogenic cooling is not required, sources remain bulky, expensive and lack a wide tunability necessary for spectroscopic characterization. On the detector side, thermomechanical bolometers (TMBs) based on silicon nitride membranes [1], offer room-temperature operation, video-rate acquisition speed, and a noise-equivalent power (NEP) of hundreds of $\text{pW}/\sqrt{\text{Hz}}$. TMBs are characterized by a mechanical resonance frequency that undergoes a red-shift when the membrane is heated, for instance when radiation is absorbed. An approach to overcome the need for an active source is to exploit blackbody radiation. A body at room temperature emits a broadband spectrum peaking at approximately 20 THz, with a tail extending into the THz and sub-THz range. While TMBs have already been characterized in the visible and sub-THz range, here we demonstrate operation in the MIR, which is relevant for their use in source-free architecture exploiting black-body emission. Implementing a phase-locked loop in a full electrical readout, TMB can be probed in real time, enabling scan-less imaging, improved detection sensitivity, and passive detection of blackbody radiation without any external illumination source.

2. Methods

A TMB based on a 300 nm thick silicon nitride trampoline membrane coated with a 20 nm thin pyrolyzed-carbon (PyC) film [2], Fig. 1(a), is used for these measurements. The presence of this absorbing layer allows to achieve approximately 40% broadband absorption from 0.5 to 50 THz. To validate the TMB response in the mid-IR range, a tunable laser source is employed. This source relies on an external-cavity quantum cascade laser configuration, which allows single-mode excitation selectable over a span from 25 to 50 THz. By mounting the sample on two motorized translation stages, it is possible to acquire a spatial map in which, at each position, a frequency sweep is performed and the resonance shift is recorded. This allows one to identify the positions at which the membrane is illuminated by the radiation beam, reconstructing a spatial image of the source. Maps have been acquired at different excitation wavelengths; a representative map recorded at 9 μm is reported in Fig. 1(b).

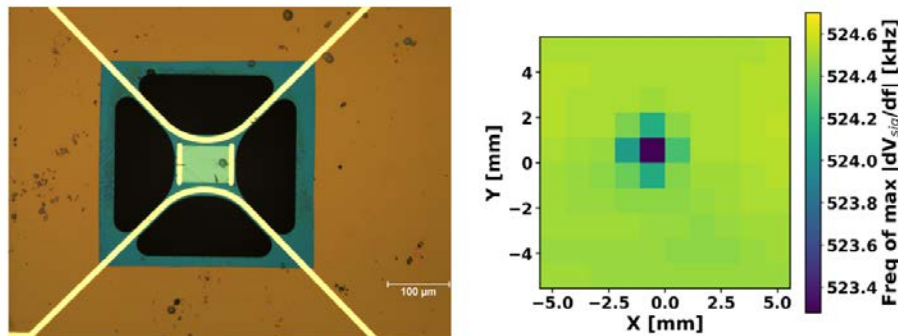


Fig. 1. (a) SEM of the TMB with the PyC film. (b) Colour plot of the spatial distribution of the resonance frequency shift, recorded by performing a frequency sweep at each position. The excitation wavelength is set to 9 μm .

Acknowledgement

This work was supported by HORIZON-EIC-2025-PATHFINDEROPEN THz-Skin project # 101257203 and by ATTRACT, a European Union's Horizon 2020 research and innovation project (GA 101004462, h-cube).

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DESIGN AND CHARACTERIZATION OF CHIRAL PLASMONIC LATTICES FOR CIRCULARLY POLARIZED LASING

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Abstract

Circularly polarized nanolasers play a crucial role in advancing next-generation photonic technologies, where precise control of polarization at the nanoscale is essential for applications such as optical communication, sensing, and information processing. To achieve nanoscale miniaturization, plasmonic structures play a significant role, as they enable light confinement beyond the diffraction limit. In addition, chiral plasmonic structures provide an effective mechanism for distinguishing between different polarization states. This study focuses on investigating the degree of circular polarization (DCP) of emission in L-shaped gold nanoparticle arrays combined with IR-792 dye as the gain medium under different input pump polarization states. The work aims to achieve a strong chiral response with high DCP in plasmonic nanolasers while examining the influence of input polarization on the emitted chiral light. The numerically optimized L-shaped nanoparticle arrays were fabricated using electron beam lithography (EBL) and a lift-off process. The structures were optically pumped and characterized through transmission, threshold, and k-space and real-space measurements under linearly polarized, left-circularly polarized (LCP), and right-circularly polarized (RCP) excitation conditions.

Lasing from the L-shaped nanoparticle arrays was confirmed through analysis of threshold behavior, spectral linewidth narrowing, and measurements of spatial coherence in both k-space and real-space, together with temporal coherence analysis. In this study, near-unity circular output polarization was recorded for linear input polarization. Although LCP and RCP inputs produce opposite DCP signs, indicating polarization dependence, linear excitation yields the highest DCP values, suggesting that the chiral response is more strongly influenced by the nanoparticle geometry than by the input polarization state. This study establishes chiral nanoparticle arrays as a promising platform for circularly polarized nanolasers and chiral nanophotonic applications.

Coherence engineering of light beams carrying robust higher-order Poincaré polarization states

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Optical vector beams with complex polarization-state distributions have attracted considerable interest due to their extraordinary properties and potential applications [1]. A specific class of such beams can be represented by points on the higher-order Poincaré (HOP) spheres [2]. Recently, a coherence engineering method based on the generalized van Cittert-Zernike theorem was presented for encoding the HOP polarization states into the spatial coherence structure of a light beam [3]. It was demonstrated that such beams can be highly robust against strong disturbances in the propagation path and the HOP polarization state can be well reconstructed in the far field. In this work, we introduce a novel encoding protocol based on the complex-random-mode representation, which is more compact and intensity efficient than the previous method [4].

A fully polarized random beam whose polarization state is specified by the angles $\Theta \in [0, \pi]$ and $\Phi \in [0, 2\pi]$ of the HOP sphere is represented by the polarization matrix $\Phi = \mathbf{E}^*(\mathbf{v}) \mathbf{E}^T(\mathbf{v})$ with

$$\mathbf{E}(\mathbf{v}) = \cos(\Theta/2)\exp(-i\Phi/2)\mathbf{E}_N(\mathbf{v}) + \sin(\Theta/2)\exp(i\Phi/2)\mathbf{E}_S(\mathbf{v}), \quad (1)$$

where $\mathbf{E}_N(\mathbf{v}) = E_0 \mathcal{L}_{0,l}(\mathbf{v}) \hat{\mathbf{e}}_R$ and $\mathbf{E}_S(\mathbf{v}) = E_0 \mathcal{L}_{0,-l}(\mathbf{v}) \hat{\mathbf{e}}_L$ refer to the north and south pole states. Further, E_0 is the (real) amplitude, $\hat{\mathbf{e}}_R$, $\hat{\mathbf{e}}_L$ are the unit vectors of circular polarizations, and $\mathcal{L}_{0,\pm l}(\mathbf{v})$ is the Laguerre-Gaussian mode function. In the random-mode method the cross-spectral density matrix (CSDM) is given by the mode superposition $\mathbf{W}(\mathbf{r}_1, \mathbf{r}_2) = \sum_{m=1}^M \mathbf{E}_m^*(\mathbf{r}_1) \mathbf{E}_m^T(\mathbf{r}_2)$, where $\mathbf{E}_m(\mathbf{r})$ is constructed as a suitably scaled and filtered Fourier transform of $\mathbf{E}(\mathbf{v})$ which is modulated by a complex random-variable distribution [4].

The modes $\mathbf{E}_m(\mathbf{r})$ are synthesized by using multiplexed computer generated holograms (CGHs) containing information on the HOP polarization state and the desired spatial coherence width. The data for the x and y components is loaded into a spatial light modulator (SLM) in the form of two phase gratings whose +1 diffraction orders are extracted and combined. Averaging the output over the varying CGHs yields the source CSDM into which a HOP polarization state is encoded. Figure 1 shows the intensity and the polarization state for the HOP state $\Theta = \pi/2$, $\Phi = 0$, $l = 2$ at various planes after the source up to the focal plane ($z = f$) of a lens inserted behind the source. The source ($z = 0$) is unpolarized and with increasing z the encoded HOP state with annular intensity distribution appears.

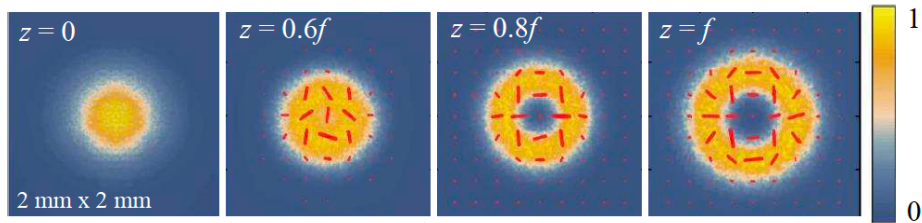


Fig. 1. Distributions of the intensity and polarization state at different distances from the source at $z = 0$.

If the coherence width of the source is adjusted to be sufficiently short, the beam can be highly robust against strong disturbances in the propagation path. For example, the desired HOP polarization state can be faithfully reconstructed in the far field despite partial blockage at the source plane [3,4]. After a Fourier transformation, the beam can also be used as the incident beam of defective $4f$ imaging systems to achieve robust polarization imaging [5].

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Electric and magnetic 3D polarization of a random evanescent wave

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1. Introduction

Polarimetric considerations often focus on the electric field because it dominates light-matter interactions in natural media. Nevertheless, the polarization properties of the magnetic field component become increasingly significant particularly in nano optics and subwavelength photonics involving metamaterials [1]. Specifically, such near-field scenarios typically involve evanescent waves, which can possess three-dimensional (3D) polarization properties that are fundamentally different from those of propagating waves [2]. Their vectorial electromagnetic structure gives rise to spin, momentum, and polarization effects that may be strongly affected by the interaction between electric and magnetic field components. Furthermore, understanding how partial polarization appears in evanescent fields is crucial for near-field optics and nanophotonics, where the randomness of light often occurs. Therefore, a systematic comparison of the polarimetric properties of the electric and magnetic fields of random evanescent waves offers deeper insight into the fundamental symmetry and asymmetry of electromagnetic near fields.

2. 3D Polarization properties

We investigate the 3D polarimetric spectral behavior of both the electric and magnetic fields within an evanescent wave generated by a random, stationary light beam under total internal reflection, as shown in Fig. 1 [3].

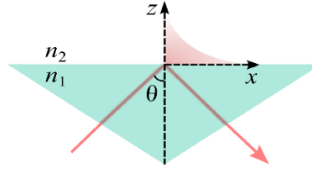


Fig. 1. Schematic of the geometry for generating an evanescent wave.

The electric/magnetic polarization characteristics of the random evanescent wave are fully described by the 3×3 spectral electric/magnetic polarization matrices [4]

$$\Phi^{(E)}(\mathbf{r}, \omega) = \langle \mathbf{E}^*(\mathbf{r}, \omega) \mathbf{E}^T(\mathbf{r}, \omega) \rangle, \quad \Phi^{(H)}(\mathbf{r}, \omega) = \langle \mathbf{H}^*(\mathbf{r}, \omega) \mathbf{H}^T(\mathbf{r}, \omega) \rangle. \quad (1)$$

Above, the generally three-component column vectors $\mathbf{E}(\mathbf{r}, \omega)$ and $\mathbf{H}(\mathbf{r}, \omega)$ are realizations representing the electric ($\mathbf{E}$) and magnetic ($\mathbf{H}$) fields at a point $\mathbf{r}$ and angular frequency ω . Furthermore, $\langle \rangle$, $*$, and T denote the ensemble average, complex conjugate, and transpose, respectively. Based on Eq. (1), we investigate the degrees of polarimetric purity [5], polarimetric dimensions [6], nonregularity properties [7], and spin density vectors [8] of the electric and magnetic fields, and further assess the total spin angular momentum density [9]. We show that some properties depend only on geometry, and that both fields can exhibit true 3D nonregular polarization states. The electric and magnetic spin density vectors generally contain transverse and longitudinal components. They also possess a specific polarimetric structure for nonregular states.

3. Acknowledgment

This work was supported by the Research Council of Finland (Grants No. 354918, No. 349396, and No. PREIN 346518). B.F. acknowledges financial support from the Finnish Ministry of Education and Culture through the Quantum Doctoral Education Pilot Program (QDOC VN/3137/2024-OKM-4).

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A FTIR spectroscopy and PLS-regression based prognostic model for human glioma age, gender and malignancy grading

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The study aimed to establish structural and molecular features of gliomas with different degrees of anaplasia and to identify possible correlations with the stage of the disease, age and gender of the patient. Biopsy material from patients aged 22 to 70 years, at different stages of the disease, was examined. 2–6 infrared absorption spectra were recorded for each sample to minimize the influence of tissue heterogeneity and sample preparation. Partial least squares (PLS) methods implemented in OPUS Quant 2 software (Bruker) were used to build prognostic models for age, gender and tumor stage. Model performance was assessed using the correlation coefficient between experimental and predicted values (R), prediction plots, principal component analysis (PCA), regression coefficients and principal component loadings.

The best results were obtained for tumor stage prediction with a correlation of 75%. Changes in proteins and nucleic acids during tumor progression allowed the development of a reliable prognostic model. The resulting model demonstrated a strong correlation between predicted and actual values ($r = 0.92$), indicating a high level of accuracy in describing the relationship between spectral characteristics and tumor stage. The root mean square error of cross-validation (RMSECV = 0.5222) confirmed the satisfactory prognostic performance of the model.

For predicting the age of patients, the model showed moderate performance with a correlation of 60%. The results indicate that age-related changes in the biochemical composition of brain tissue persist even in the presence of pathological processes and can be detected using IR spectroscopy. Fourier transform IR spectroscopy combined with PLS regression may provide a useful approach for assessing the biological age of patients regardless of gender or tumor status. However, significant inter-individual variability reduced the prediction accuracy. However, the model was ineffective for gender classification based on brain tumor spectra, showing a correlation of only 25%. This low predictive performance is likely due to both interindividual variability and the lack of stable gender-specific biochemical signatures in the tissue analyzed.

Acknowledgement.

PT/2026.3 Physicochemical properties of hybrids based on carbon particles and other combustion products and physical properties of carbon nanotubes and DNA as possible power elements.

1.4. B/218 Physical effects and molecular mechanisms of interaction of biological molecules and biological systems of different levels of structural organization with small molecules, nanoscale and supramolecular complexes.

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Biophysical characteristics of quantum sensing systems based on nanodiamonds and model lipid mimetics

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Among the wide range of nanomaterials, nanodiamonds have attracted considerable research interest. They are considered a promising platform for biomedical applications due to their unique combination of physicochemical and biological properties. Despite significant progress, there are still limitations in the use of nanodiamonds in vitro, let alone their clinical implementation. Although nanodiamonds are ideal quantum sensors under controlled conditions, their performance in living cells is limited by background autofluorescence, light scattering, and a highly dynamic intracellular environment, which reduces their quantum sensitivity and complicates signal interpretation. Therefore, current research is focused on developing systems that preserve the luminescent properties of nanodiamonds while protecting them from environmental influences. One promising approach is to incorporate nanodiamonds into liposomes.

This paper presents data on the obtaining the sensing system based on nanodiamonds with DOPC liposomes. A unique author's method for preparing liposome-nanodiamond systems with particles localized both inside and outside liposomes is presented. Changes in the absorption region of phosphate groups, as well as the redistribution of contributions in the hydrogen bond region, indicate the interaction between nanodiamonds and lipid molecules and suggest possible locations for particle localization. Spectroscopic and microscopic data indicate the incorporation of nanodiamonds into liposomes, which will be further investigated in cellular experiments using luminescent markers for both liposomes and nanodiamonds. In addition, nanodiamonds encapsulated in DOPC liposomes were successfully visualized using scanning electron microscopy, demonstrating the possibility of creating such hybrid systems.

Acknowledgement.

1. PT/2026.3 Physicochemical properties of hybrids based on carbon particles and other combustion products and physical properties of carbon nanotubes and DNA as possible power elements.
2. 1.4. B/218 Physical effects and molecular mechanisms of interaction of biological molecules and biological systems of different levels of structural organization with small molecules, nanoscale and supramolecular complexes.

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Negative Optical Phase Accumulation in Ultrathin Conductive Films: Applications and Active Control

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We report the direct observation of negative optical phase accumulation in an ultrathin free-standing carbon-nanotube (CNT) film in the terahertz range. The studied sample was a CNT film with a thickness of approximately 100 nm and a sheet resistance of about $100 \Omega/\square$, suspended over a 4 mm circular aperture. Its transmission response was measured by terahertz time-domain (THz-TDS) spectroscopy, providing both amplitude and phase information.

The pulse transmitted through the CNT film reaches the detector earlier than the reference pulse passing through the empty aperture. The maximum of the transmitted pulse is advanced by approximately 40 fs, while the amplitude is reduced only moderately, by a factor of about 2.5. The spectral phase difference is negative throughout a broad terahertz range. Both the transmission and phase spectra, as well as the reshaping of the transmitted waveform in the time domain, are quantitatively reproduced by a Drude model. This agreement indicates that the observed effect originates from the carrier dynamics in the conductive layer rather than from a resonance-specific mechanism.

The effect is not limited to CNT films and should occur in other ultrathin conductive layers with suitable conductivity and scattering parameters. Such films therefore provide a simple platform for broadband phase engineering without requiring thick dielectric stacks or resonant metasurface geometries.

We additionally investigate optical control of the THz response by illuminating the CNT film with an 808 nm laser beam. Photoexcitation reduces the magnitude of the negative phase shift, demonstrating the possibility of active tuning. Patterning the CNT film into parallel stripes could further introduce strong anisotropy: the effective conductivity along the stripes remains comparatively high, whereas the transverse conductivity is strongly suppressed. Combining this anisotropy with negative phase accumulation and optical tuning may enable tunable THz polarisers and conversion of linearly polarised radiation into elliptically polarised light.

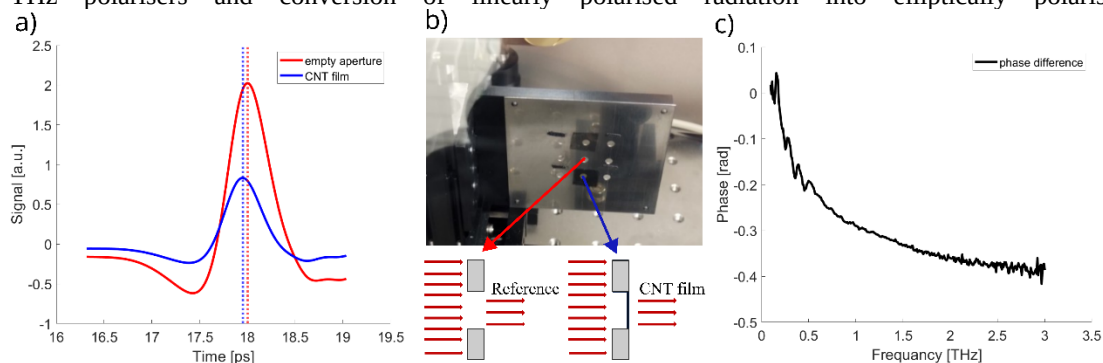


Fig. 1 a) Timetraces of THz pulses passing through empty aperture and CNT film; b) Photo of the sample and the reference aperture; c) Phase difference spectrum

4Acknowledgement.

This work was supported by the Research Council of Finland PREIN project, decision no. 368653 and research project decision no. 343393, EU Horizon 2020 MSCA project 01007896 (CHARTIST) and EU Horizon 2024 MSCA project 101236439 (HERMES). We acknowledge the financial support of the Finnish Ministry of Education and Culture through the PREIN/I-DEEP doctoral pilot (VN/3137/2024-OKM-4)

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Interferometric control of phase singularity splitting

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Phase singularities and orbital angular momentum (OAM) are defining features of structured light beams and lie at the heart of singular optics [1]. Owing to their unique properties, OAM-carrying beams have found wide use in imaging, optical communications, quantum information processing, and light-matter interactions [2]. Although phase singularities can split naturally when vortex beams interfere with coherent reference fields [3,4], a method for deliberately controlling this process has so far been lacking.

We introduce a Mach–Zehnder (MZ) interferometric approach that enables precise splitting and repositioning of phase singularities while keeping the total OAM conserved [5]. We employ a flat-top vortex beam of topological charge ℓ in arm 1 of the interferometer, and a Gaussian (or annular beam) with uniform phase in arm 2. Analytical treatment of the output intensity zeros reveals that a charge ℓ singularity can be decomposed into $|\ell|$ unit-charge singularities on a single ring (Gaussian case) or $2|\ell|$ singularities distributed across two rings (annular case). The ring radius is tunable via the beam intensity ratio, and the angular positions of the singularities can be rotated continuously by adjusting the relative optical path length Δl , as shown in Fig. 1.

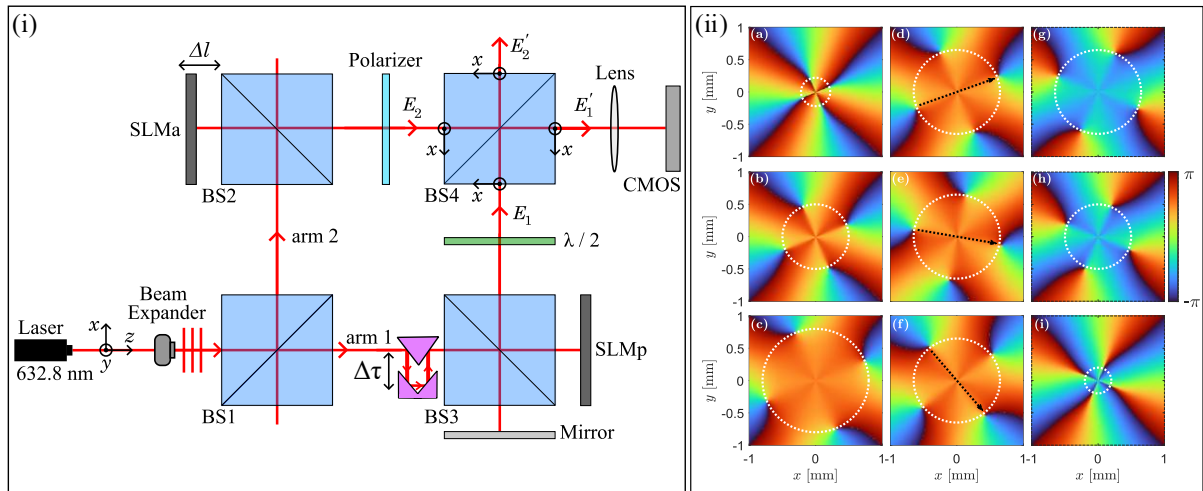


Fig. 1: (i) Schematic of the experimental setup. (ii) Simulated phase distributions of an output beam showing controlled singularity splitting with Gaussian beam in arm 2. In (a-c), the singularities move radially outward as intensity ratio $I_2/I_1 = 1.51, 2.78$, and 5.73 , with $\Delta\tau = 0$ and Δl fixed. In (d-f), the cluster rotates azimuthally as $\arg(E_2) = -0.58, -1.55$ and -3.67 , with $\Delta\tau = 0$ and I_2/I_1 fixed [5]. In (g-i), the singularities shift radially inward as $|\mu| = 0.9, 0.5$, and 0.2 , with I_2/I_1 and Δl fixed. Although here we illustrate cases for $\ell = 4$, we see similar effects for other values of ℓ .

Experiments using a HeNe laser confirm the theoretical predictions [5]. A phase-only SLM generates the flat-top vortex beam with intensity I_1 in arm 1, while an amplitude-only SLM produces the Gaussian (or annular beam) with intensity I_2 in arm 2. The recorded intensity and phase distribution match with theoretical predictions throughout: an increasing I_2 moves the singularities radially outward and varying the relative phase $\arg(E_2)$ rotates the entire cluster. Such independent control over the radial and azimuthal singularity locations opens pathways for structured-light engineering, OAM multiplexing, and multi-particle optical trapping.

We further extend the scheme to mutually partially coherent beams by introducing a controllable time delay $\Delta\tau$ in arm 1 to adjust the complex degree of coherence (DoC) μ . The phase singularities are then observed in the mutual coherence function with a reference test beam. As the magnitude of DoC $|\mu|$ decreases, the split singularities shift radially inward. This shows that inter-beam correlation can also affect the singularity splitting dynamics and thus provide a framework for singularity control of partially coherent beam superposition.

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Steady-State and Time-Resolved Fluorescence study of *meso*-Tetraphenylporphyrin and Hexagonal Boron Nitride van der Waals Complex

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Van der Waals (vdW) functionalization method is a promising technique, since it allows modifying a material's properties without violation of its structure. The manifestation of vdW interaction can be observed in THz, infra-red and visible regions of the spectra. However, precise understanding of the molecular events occurring due to vdW interaction between compounds remains unclear.

In this study we applied steady-state and ultra-fast streak-camera based time-resolved fluorescence (TRFL; Fig. 1) techniques to characterize electronic processes at drop-cast film of *meso*-tetraphenylporphyrin (TPP) and hexagonal boron nitride (hBN) van der Waals (vdW) complex. The studied system is a good model system of such complexes, since TPP is a polar (0.5 D) organic molecule, whereas hBN is a non-polar one, therefore it is possible to observe both pure manifestation of vdW interaction and adsorption-related changes in TPP spectroscopic behavior.

It was observed that vdW interaction between TPP and hBN reduces FL quenching of TPP and enhances FL quantum yield from the TPP Soret states (higher excited states) almost 6 times, making such complexes promising for bio-sensing and -imaging as well as optoelectronics and artificial photosynthesis.

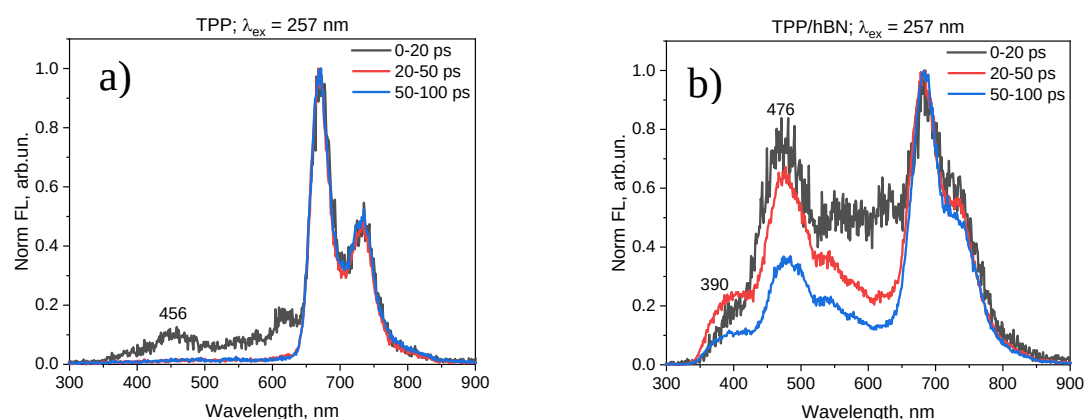


Fig.1. Time slices of TRFL of TPP a) and TPP/hBN b) excited at 257 nm.

Local Laser Activation of Color Centers in Diamond Needles

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1. Introduction

Color centers in diamond (NV^0 , NV^- , SiV^-) are leading candidates for quantum photonics and nanoscale sensing due to stable room-temperature fluorescence [1,2]. While planar plates serve for baseline tests, single-crystal diamond needles (SCDNs) offer a one-dimensional (1D) geometry that enhances directional photon extraction and localized probing [2]. Femtosecond (fs) laser irradiation enables direct-write defect engineering [1], yet 1D structures exhibit distinct laser-matter interactions compared to bulk diamond due to geometrical field enhancement and reduced thermal dissipation [2]. Here, we investigate localized color center activation in CVD-grown diamond needles under focused fs-laser irradiation and compare their response to bulk diamond plates.

2. Experiment and Results

SCDNs were grown via CVD in methane-hydrogen plasma followed by selective oxidation to yield free-standing 1D needles [2]. Needles on silicon substrates and bulk reference plates were irradiated with a 750 nm fs-laser (170 fs, 6 kHz, 50–550 μW , 10 ms–300 s). Confocal photoluminescence (PL) and Raman mapping under 532 nm excitation tracked Diamond Raman (573 nm), NV^0 (575 nm), NV^- (637 nm), and SiV^- (738 nm) zero-phonon lines (ZPLs).

Comparative analysis reveals distinct sensitivity regimes between 1D needles and planar bulk plates (Fig. 1). On bulk plates, moderate powers (60–200 μW) enhance NV^0 emission non-destructively, whereas high powers (600 μW) cause surface ablation. In contrast, SCDNs exhibit higher sensitivity: intermediate powers induce NV quenching and SiV amplification, while extended exposures produce bright luminescent halos around the focal spot via vacancy migration (Fig. 1a). Spatially resolved spectra confirm strong NV^- and SiV^- ZPL enhancement in the outer halo relative to the central quenched core (Fig. 1b,c). Depth-resolved z-plane profiling further verifies that the laser modification is tightly confined to the needle surface plane.

These comparative findings provide essential insights into ultrafast laser-matter interactions in 1D diamond nanostructures, establishing a reliable route for targeted color center engineering in tailored quantum micro-devices [2].

3. Acknowledgements

This work was supported by the Research Council of Finland through PREIN (decision 368653), EXTRASENS (decision 361115), CHARACTER (decision 357033), Horizon Europe MSCA FLORIN (101086142), and Scandinavia-Japan Sasakawa Foundation (GA24-FIN-0158). We thank Prof. Konishi and his group at The University of Tokyo for collaboration.

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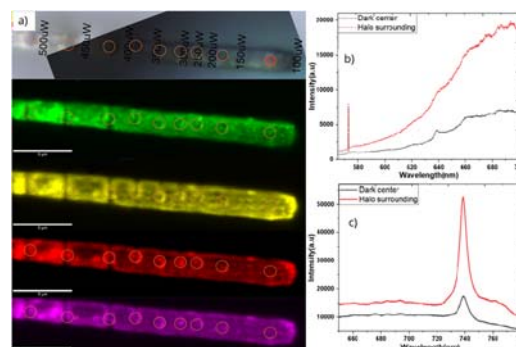


Figure 1. (a) PL maps of an SCDN showing localized activation halos (orange circles). (b, c) PL spectra comparing dark quenching cores against bright luminescent halos for NV^- and SiV^- centers, respectively, under 532 nm excitation.

Systematic investigation of stripline width and contact metal effects on terahertz photoconductive antenna performance

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Terahertz photoconductive antennas are commonly treated as devices whose performance is mainly determined by the semiconductor carrier lifetime and antenna geometry. In this work, we show that contact metallization also plays a critical role, especially when the antenna dimensions are reduced to shift the emission toward higher frequencies. GaAs-based coplanar-stripline photoconductive antennas with strip widths from 20 to 100 μm were fabricated using two metallization schemes: conventional AuGe/Ni/Au ohmic contacts and standalone Ti contacts. The devices were characterized by emitted terahertz power measurements and terahertz time-domain spectroscopy under femtosecond excitation at 780 nm.

The emitted power depends strongly on both bias voltage and contact metal. AuGe/Ni/Au antennas emit more efficiently at low bias, indicating better carrier injection and a stronger effective field in the photoconductive gap. Ti-based antennas are initially limited by the Schottky barrier, but their output increases rapidly at higher bias, becoming comparable to AuGe/Ni/Au devices. For AuGe/Ni/Au contacts, the emitted power reaches an optimum for strip widths around 50–60 μm , suggesting improved impedance matching between the photocarrier source and antenna load.

Spectral measurements show that reducing the stripline width shifts the terahertz spectral maximum toward higher frequencies and broadens the response. Wider striplines follow the trend expected from classical half-wave dipole theory, while narrower striplines deviate from this model, indicating a transition to a bandwidth-limited regime governed by the combined response of the photoconductive gap, feed region, antenna arms, and metallic contacts. In this regime, Ti-metallized antennas exhibit higher peak frequencies and broader spectra than AuGe/Ni/Au devices, consistent with stronger resistive damping and faster decay of antenna currents.

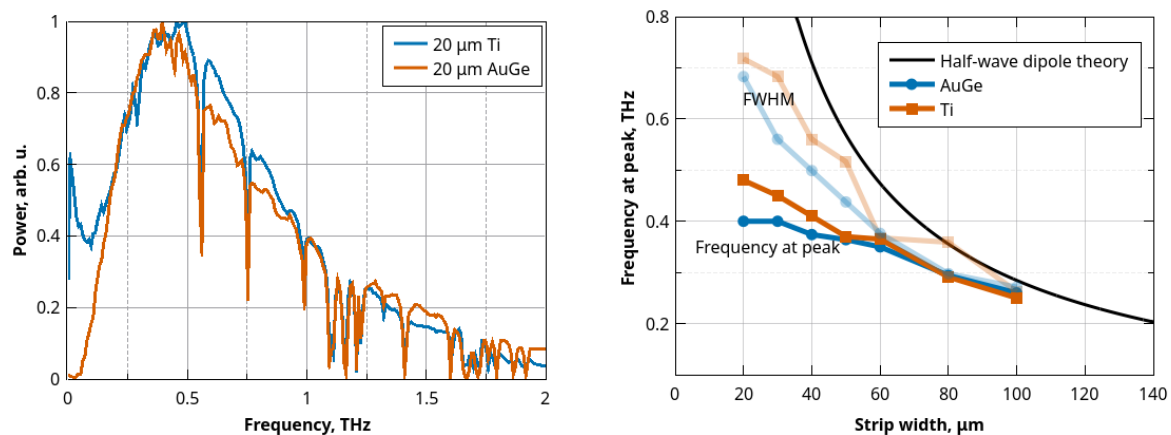


Fig. 1. On the left is the frequency comparison of two identical antennas differing only by metallization, and on the right are the extracted spectra peaks for all investigated antennas.

These results demonstrate that high-frequency photoconductive antenna performance is limited not only by carrier dynamics and geometry, but also by the finite, frequency-dependent impedance of the contacts. Therefore, future terahertz photoconductive antennas should be optimized through simultaneous engineering of stripline geometry, contact material, and feed-region impedance.

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Geometric phase of partially polarized classical light beams

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1. Introduction

According to Pancharatnam's definition, two classical monochromatic light beams with generally different polarization states are in phase when their superposed field attains maximum intensity [1]. As the polarization state changes, Pancharatnam's connection requires a phase adjustment that keeps neighboring states in phase. If the polarization state undergoes a cyclic evolution under this in-phase condition, an additional phase factor known as the Pancharatnam–Berry geometric phase emerges. This phase corresponds to the accumulation of phase adjustments on the path and is purely geometric with no dynamical contribution. Its magnitude is equal to half the solid angle subtended by the related trajectory on the Poincaré sphere.

2. Theory

We employ Pancharatnam's approach to introduce the phase difference $\varphi = \arg\langle \mathbf{E}_2^T \mathbf{E}_1^* \rangle$ between two random electromagnetic beams $\mathbf{E}_1$ and $\mathbf{E}_2$ [2], where $\arg$, $\langle \rangle$, T , and $*$ denote the argument, time average, transpose, and complex conjugate, respectively. When φ is zero, the beams are in phase and Pancharatnam's connection for random partially polarized light beams is satisfied.

Cyclic unitary evolution of the state of partial polarization can be visualized within the unit Poincaré sphere (Fig. 1). Two antiparallel Poincaré vectors, $\hat{\mathbf{s}}_{\pm}$, corresponding to orthogonal eigenvectors of the polarization matrix, trace similar trajectories but in opposite directions on the surface. The evolution of the total state is described by a Poincaré vector $\hat{\mathbf{s}} = P\hat{\mathbf{s}}_{+}$, where P is the degree of polarization which remains intact under unitary evolution. The trajectory of $\hat{\mathbf{s}}$ is on a ball of radius P and subtends the same solid angle Ω as $\hat{\mathbf{s}}_{\pm}$. Applying the spectral decomposition of the beam-field polarization matrix, we can derive the following expression for the geometric phase [2]

$$\varphi_g = \pm \arctan \left[P \tan \left(\frac{\Omega}{2} \right) \right], \quad (1)$$

where the upper (lower) sign corresponds to the counter clockwise (clockwise) evolution of the Poincaré vector $\hat{\mathbf{s}}$. We see that for a fully polarized field with $P = 1$ the phase becomes $\varphi_g = \pm\Omega/2$, in agreement with earlier results on monochromatic fields [1].

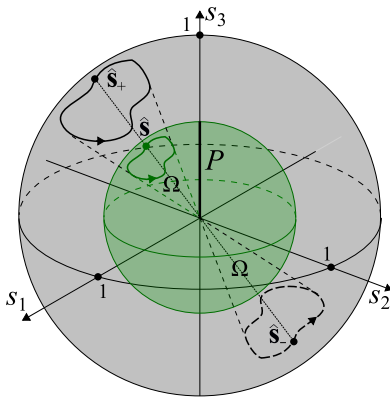


Fig. 1. Illustration of the Poincaré vectors $\hat{\mathbf{s}}$, $\hat{\mathbf{s}}_{+}$, and $\hat{\mathbf{s}}_{-}$ in a cyclic, unitary polarization-state evolution within the unit Poincaré sphere in the Stokes parameter (s_1, s_2, s_3) space. The tip of $\hat{\mathbf{s}}$ is on the inner ball whose radius is P , whereas $\hat{\mathbf{s}}_{\pm}$ are on the surface of the sphere. The solid angle of the paths traversed by the three vectors is Ω .

In the present work, we have shown that the degree of polarization affects the geometric phase. Besides polarization, our recent results show that variations in spatial two-point coherence can induce a geometric phase [3].

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Ultrathin carbon metamaterial for control of THz polarization ellipticity

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Natural materials provide significant opportunities for controlling electromagnetic radiation; however, the desired properties are not always achievable. This limitation can be overcome by using metamaterials, which allow electromagnetic properties to be tailored over a wide range. A typical metamaterial consists of two- or three-dimensional arrays of microstructures with a subwavelength period, which act as artificial atoms (meta-atoms). Science and industry are interested in manipulating of THz waves state to obtain new information from THz measurements [1]. And since THz radiation has longer wavelength in comparison with optical radiation, metamaterials for THz range can be easily fabricated with photolithography, laser processing or 3D-printing. However, because of wavelength they should be thick enough to provide significant influence on the radiation. Thickness can reach of hundreds of micrometers, which is problem for developing of microscale devices to control parameters THz radiation.

Ultrathin metamaterials can become a solution to control state of THz wave in limited space because nanometer-thickness layers of metamaterial can be easily inbuilt in microscale THz devices. One of the basements for such metamaterial is carbon nanotubes (CNT). They possess small thickness and tunable conductivity, which is important for THz application.

In this work we demonstrate ultrathin metamaterial to control polarization ellipticity of THz radiation. To observe polarization conversion, we prepared stripes made of CNT film applied on silicon substrate. In experiments we directed linearly polarized THz radiation to vertically aligned CNT stripes samples at different angles φ between plane of polarization and CNT stripes; and simultaneously measured vertical and horizontal components of electric field using the time domain principle [2].

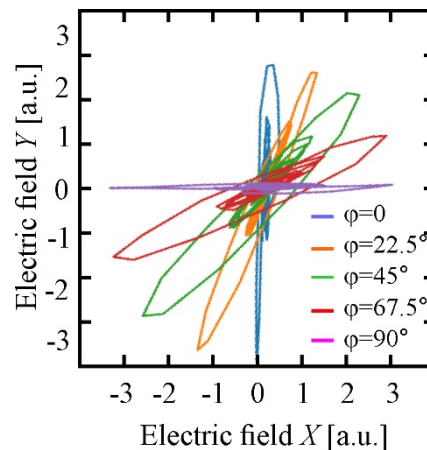


Fig. 1 Polarization state evolution of the radiation passed through a sample.

Analyzing the interferograms obtained we found that at $\varphi = 0$ and 90° the THz radiation stays linearly polarized, while at $\varphi \neq 0$ or 90° it becomes elliptical and has maximum at $\varphi = 45^\circ$ (see Fig. 1, where the polarization state evolution of the radiation passed through a sample is shown). Using Fourier transform we calculated spectra of azimuth, ellipticity and degree of polarization of passed THz radiation. The results open way for developing of ultrathin THz devices for polarization control in THz spectrometry and THz imaging.

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Master equation approach to twisted photons' propagation in the atmosphere

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The propagation of photonic spatial modes carrying orbital angular momentum (OAM) through a turbulent atmosphere is an active research area that is important from the fundamental point of view, as well as for applications. A standard approach to account for atmospheric effects on spatial modes is based on the stochastic parabolic equation [1] and the numerical multiple phase screens method derived therefrom. Notwithstanding the success of these approaches, a fully quantum treatment of the propagation of twisted photons through turbulence taking full advantage of the open quantum system toolbox may pave the way for a much more efficient treatment of the problem. However, until recently this programme has remained unaccomplished.

In the present contribution, we derive a Lindblad quantum master equation for the disorder-averaged density matrix of single photons populating Laguerre-Gaussian (LG) modes that are phase distorted by turbulence. This equation relies on a mapping between open and disordered quantum systems [2] which we here generalize to twisted photons in Kolmogorov turbulence --- in order to analyse OAM crosstalk in the atmosphere. We establish the formal equivalence of our equation to that postulated by F. S. Roux [3], and present some numerical results which reproduce established features of the crosstalk matrix of LG photons (see Fig. 1). Furthermore, we derive an entanglement decay law of a maximally entangled photon pair, which agrees with known results [4]. Finally, we summarize advantages and limitations of our master equation, and discuss prospective future problems to which it can be applied.

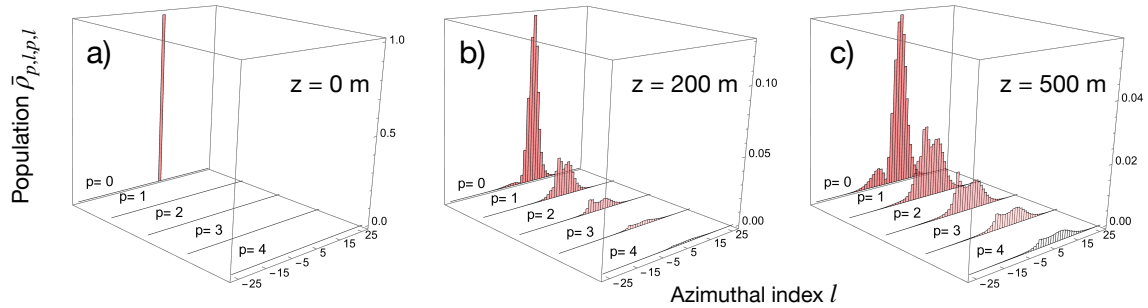


Fig.1. The evolution of crosstalk in Kolmogorov turbulence for an initially injected $LG_{0,5}$ mode, with radial and azimuthal indices $p=0$ and $l=5$, respectively, with increasing propagation distances a) $z=0$ m, b) $z=200$ m, c) $z=500$ m. The different slices correspond to projections onto $p=0, \dots, 4$ subspaces.

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Cost-efficient black nickel substrates for surface-enhanced Raman spectroscopy

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Porous black nickel (b-Ni) can be used as a cost-efficient substrate for noble-metal surface-enhanced Raman spectroscopy (SERS). Because point spectra do not reveal the underlying spatial heterogeneity, this study evaluates whether the characteristic 4-mercaptobenzoic acid (4-MBA) bands near 1075 and 1585 cm⁻¹ [1] are spatially correlated at paired positions across Ag- and Au-coated b-Ni maps.

The b-Ni substrates were prepared through electrodeposition followed by acidic etching, as described previously[2], and coated with nominal 5, 20, or 50 nm Ag or Au. Substrates were kept in 1 mM solution of 4-MBA in ethanol for 18 h, rinsed with ethanol, and dried under ambient conditions. SEM and qualitative EDS mapping were performed using an SU3900SE microscope and an Oxford Instruments Ultim Max Infinity detector at 15 kV. Raman mapping used a WITec alpha300 RAS, 785 nm excitation (study-wide 0.5-5.0 mW), and a Zeiss 10× objective. One 30 × 30 map (900 spectra) covered 1.5 × 1.5 mm². At each pixel i , we compute $A_{1075,i}$, $A_{1585,i}$, x_i , y_i , C_i where A is the area under signed bands and C_i represents the spectral background.

We convert areas into ranks in order to deduce Spearman correlation and the analysis is controlled for possible nuisance effects. Hence, we removed the effects of map coordinates, second-order spatial terms, and spectral continuum, and the remaining residuals were then correlated using $\rho_{adjusted} = corr(\varepsilon_{1075}, \varepsilon_{1585})$. The two band maps were circularly transformed relative to each other in all 899 non-zero shifts, which provided a reference distribution of correlations expected when the true pixel-to-pixel alignment was disrupted.

SEM/EDS analysis indicated that Ag and Au were distributed over the porous b-Ni morphology. Both 4-MBA bands were distinctly resolved in the Ag-coated fields. The raw paired-pixel Spearman coefficients were 0.965-0.991 and remained 0.889-0.937 after background and scan adjustment. In contrast, Au fields exhibited more variable adjusted correlations (0.106-0.566) under the recorded conditions (Fig. 1). Across all six coated fields, the zero-shift correlation exceeded the 95th percentile of the 899 nonzero shifts; zero shift represented the global maximum in five fields, with Au 5 nm as the exception. In the Ag fields, the top 10% of highest-response pixels accounted for 18-26% of positive band area, while guarded median A_{1585}/A_{1075} ratios were 0.69, 0.79, and 0.69. Adjusting the baseline windows altered the coated-field median areas by no more than 7.7% and the adjusted correlations by no more than 0.038.

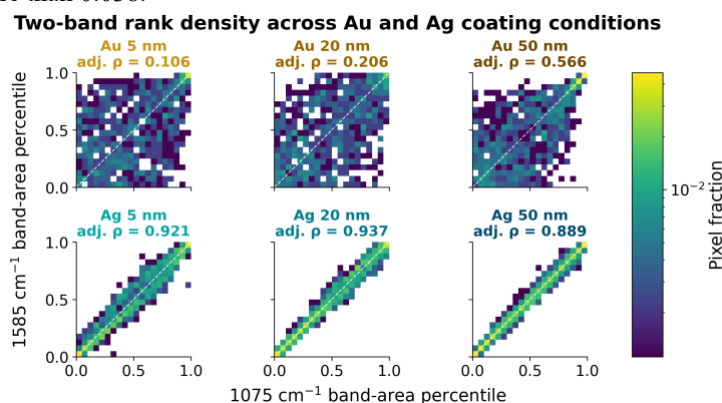


Fig. 1. Paired-pixel two-band rank densities are presented for signed 1075 and 1585 cm⁻¹ regions across all six Au- and Ag-coated fields.

Each panel displays raw within-map percentiles using a single logarithmic color scale, and annotations indicate background- and scan-adjusted Spearman ρ values. These values represent descriptive within-field correlations rather than independent-pixel significance tests or raw-intensity performance rankings.

With the present measurement conditions, the Ag-coated b-Ni showed spatially heterogeneous SERS intensity while still exhibiting a highly consistent molecular response. More specifically, those areas showing a stronger 1075 cm⁻¹ band tended also to show a stronger 1585 cm⁻¹ band. This correlation stayed strong even after accounting for smooth spatial gradients and broad variations in the spectral continuum, and it was most evident when the true pixel alignment was considered. The results thus show a genuine co-variation that is specific to position rather than one that is caused by the scanning process. Together, these findings underline the potential of Ag-coated b-Ni as a promising and cost-effective SERS platform and confirm matched-pixel two-band analysis as a rigorous approach for assessing spatial consistency in heterogeneous SERS substrates.

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Characterization of Silicon-Vacancy Centers in Diamond Nanoneedles for Nanoscale Sensing

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1. Introduction

Silicon-vacancy (SiV) color centers in diamond have emerged as promising quantum emitters for applications in nanophotonics, quantum information processing, and nanoscale sensing due to their narrow zero phonon line (ZPL), high spectral stability, and thermal sensitivity [1,2]. Integrating SiV centers into isolated diamond nanostructures can enhance photon collection efficiency while providing a versatile platform for multifunctional sensing applications, including high resolution optical thermometry [2,3]. Despite these advantages, measuring the number of SiV centers in individual nanostructures and studying how their optical properties vary between nanostructures are still major challenges for developing reliable diamond-based quantum sensing devices.

In this work, isolated diamond nanoneedles containing SiV centers were investigated using scanning electron microscopy (SEM) and confocal photoluminescence (PL) microscopy. The primary objective was to estimate the content of SiV centers in individual nanoneedles by comparing their fluorescence response with that of a single SiV emitter. In addition, the prospects of individual nanoneedles for optical thermometry were evaluated.

2. Experiment and Results

Candidate nanoneedles were initially identified using SEM and subsequently correlated with confocal PL mapping to confirm SiV emission from isolated nanoparticles. The spectral position and line shape of the SiV ZPL were analyzed for multiple nanoneedles to evaluate variations between individual nanoneedles and to assess the feasibility of ensemble-based temperature sensing without requiring calibration of each nanoneedle.

Current analysis focuses on quantifying the number of SiV centers in individual nanoneedles, investigating spectral variations among different nanoneedles, and evaluating laser induced local heating to enable quantitative nanoscale thermometry.

The presented methodology provides an important step toward the quantitative characterization of SiV containing diamond nanostructures and supports the development of multifunctional diamond sensing chips for future quantum photonic, biosensing, and nanoscale temperature sensing applications.

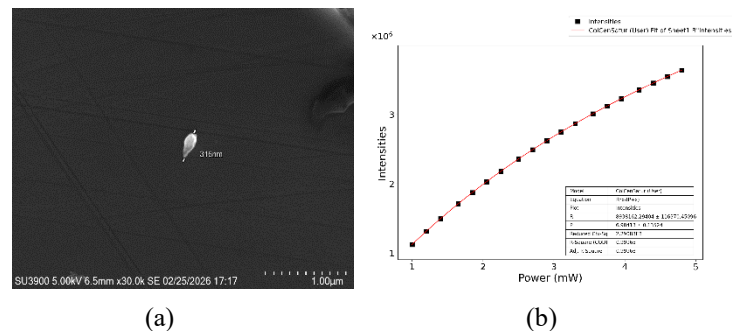


Figure 1. (a) SEM image of an isolated diamond nanoneedle. **(b)** Power-dependent photoluminescence (PL) saturation curve of the corresponding nanoneedle.

3. Acknowledgements

This work was supported by the Research Council of Finland through PREIN (368653), EXTRASENS (361115), CHARACTER (357033) and by the Horizon Europe MSCA FLORIN project (101086142).

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LUCID and HandySPIM: A Simple and Cost-Effective Platform for Three-Dimensional Fluorescence Imaging

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Three-dimensional fluorescence imaging has become an essential technique for understanding the complex architecture of biological tissues and organs. Recent advances in tissue-clearing technologies and light-sheet microscopy have enabled high-resolution volumetric imaging; however, these methods often require specialized instrumentation, expensive laser systems, and complicated optical alignment. In addition, many tissue-clearing reagents require lengthy processing, are toxic, or are unsuitable for long-term specimen preservation. These limitations continue to hinder the widespread adoption of three-dimensional imaging in routine biological research and clinical pathology. To address these challenges, we have been developing two complementary technologies: LUCID, a tissue-clearing reagent, and HandySPIM, a compact lens-free LED light-sheet illumination module. Together, these technologies provide a simple, inexpensive, and practical platform for three-dimensional fluorescence imaging using conventional laboratory microscopes [1, 2].

LUCID provides excellent optical transparency while preserving tissue morphology and fluorescence. Unlike many existing clearing reagents, LUCID is non-toxic and allows cleared specimens to be stored for more than ten years without detectable degradation. Furthermore, it is compatible with a broad range of labeling techniques, including immunostaining, nuclear staining, fluorescent proteins, and multiplex fluorescence imaging. An important advantage of LUCID is its reversible clearing capability: specimens can be returned to their original opaque state simply by immersion in water, allowing conventional histological analyses, including hematoxylin-eosin (HE) staining, to be performed using the same specimen. This feature enables complementary structural and molecular analyses of valuable biological and clinical specimens.

The second key technology, HandySPIM, is a lightweight light-sheet module that can be mounted directly onto the stage of a standard optical microscope. Instead of employing lasers and complex optical components, HandySPIM uses LEDs and a lens-free optical configuration to generate a thin light sheet, resulting in a highly robust and low-cost system with minimal optical alignment. Recent improvements include selectable excitation wavelengths of 405, 450, 470, and 590 nm together with automated Z-axis scanning for volumetric image acquisition. These enhancements broaden fluorescence imaging capabilities and enable efficient three-dimensional imaging of cleared tissues.

The combination of LUCID and HandySPIM enables high-quality volumetric fluorescence imaging using existing microscopes without requiring dedicated light-sheet microscopy systems. Representative examples, including fluorescence imaging of mouse tissues stained with fluorescent dyes, immunofluorescence labels, and fluorescent proteins, demonstrate the versatility of the platform and its applicability to diverse biological specimens. The integrated system significantly lowers the technical and financial barriers to three-dimensional imaging, making it suitable not only for advanced research laboratories but also for educational institutions and smaller biomedical facilities.

In this presentation, we will introduce the principles of LUCID and HandySPIM, summarize recent technical developments, and discuss future applications in biological research, regenerative medicine, and digital three-dimensional pathology. As pathology increasingly shifts from conventional two-dimensional observation toward volumetric tissue analysis, the combination of long-term specimen preservation, broad staining compatibility, and affordable three-dimensional imaging is expected to provide an attractive foundation for next-generation pathological diagnosis and biomedical research.

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Metal Ion Sensing Using Photoluminescent Carbon Nitride Quantum Dots

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The development of simple fluorescent probes for metal ion detection is important for environmental monitoring, analytical chemistry, and bio-related applications. Carbon nitride quantum dots (CNQDs) are promising candidates for this purpose due to their visible photoluminescence, chemical stability, low toxicity, and sensitivity to changes in the surrounding chemical environment.(1). Carbon nitride quantum dots were used as electrochemical and fluorescence probes for the detection of metal ions, biomarkers and other environmental or food impurities due to their unique advantageous optical and electronic properties. Leveraging the specific fluorescence quenching effect of metal ions on g-C₃N₄ QDs enables highly sensitive detection (2,3).

In this work, photoluminescent carbon nitride quantum dots were synthesized from graphitic carbon nitride using an alkali-assisted exfoliation approach followed by mild thermal treatment. The optical properties of the obtained nanomaterials were first evaluated by UV-Vis absorption and photoluminescence spectroscopy. The quantum dots showed a characteristic absorption feature in the ultraviolet region and broad visible emission. Excitation-emission mapping confirmed that the emission originates from multiple emissive states which is beneficial for environment-sensitive fluorescence response.

The sensing potential of the carbon nitride quantum dots was investigated by monitoring their photoluminescence in the presence of iron ions and under different solution conditions. The addition of Fe³⁺ ions resulted in a gradual decrease of fluorescence intensity, indicating concentration-dependent quenching of the emission. This behavior suggests that the prepared quantum dots can act as potential optical probes toward Fe³⁺ ion sensing. At the same time, pH-dependent measurements showed that the fluorescence intensity is strongly influenced by the chemical environment, suggesting that surface functional groups play an important role in the observed sensing response.

The results indicate that carbon nitride quantum dots are promising photoluminescent material for metal ion sensing, particularly toward Fe³⁺ detection in aqueous media. However, the observed response is likely influenced by both direct metal-nanomaterial interactions and pH-related changes caused by iron ion hydrolysis. Therefore, future work will focus on improving selectivity, separating pH effect from metal ion quenching and evaluating the analytical performance of the system.

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Wednesday, August 19



Single-molecule localisation microscopy augmented with tracking for live-cell carbonic anhydrase IX studies

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The plasma membrane (PM) of a mammalian cell serves for material exchange, signal transduction, and metabolic regulation. Integral membrane proteins (IMPs) are the true orchestrators of membrane function. Recent single-molecule (SM) *in vitro* studies revealed that IMPs are not static molecular fixtures.^{1,2} They are undergoing conformational changes, shifting between oligomeric states, and forming transient interactions.^{3–6} For instance IMPs can organize into multi-IMP assemblies known as transport metabolons. In these complexes, an enzyme is physically (transiently) coupled to membrane transporters, accelerating metabolite flux by bypassing free diffusion limitations.⁷ The bicarbonate metabolon is essential for pH regulation:

- Carbonic Anhydrase IX (CAIX): catalyzes the reversible hydration of CO₂ to HCO₃[−] and H⁺. Exists as a dimer, featuring a ~9 nm extracellular (catalytic (CA) and proteoglycan-like (PG) domains) and a ~4 nm cytoplasmic (intracellular (IC) domain) extensions.
- Na-Bicarbonate Cotransporters: use the Na⁺ gradient to import HCO₃[−] across the PM, achieving maximal efficiency only when HCO₃[−] is generated directly adjacent to them by CAIX.
- Anion Exchanger 2: exchanges intracellular HCO₃[−] for extracellular Cl[−], providing an alternative pathway to fine-tune intracellular pH.

The real-time, live-cell regulatory logic of the bicarbonate metabolon remains hidden because of ensemble averaging of conventional methods and methodological blind spots. While theoretically ideal, conventional single-molecule tracking (SMT) fails for these studies too.⁸ Rapid photobleaching limits tracking to just a few sec, completely missing metabolon assembly events that likely take >100 s.⁹ Furthermore, typical bivalent antibody probes artificially cross-link target IMPs. CAIX's location at the basal membrane⁹ limits access of probes to CAIX, compounded by background noise from non-specific probe adsorption on glass.

Here we will present our research results that leverages advanced SM localization microscopy (SMLM) approach with SMT to unravel the dynamic behavior of CAIX in live cell membranes using our developed multi-purpose suite of CAIX-targeting probes:

- (1) Small-molecule ligands with tunable affinity and sulforhodamine B labeling¹¹,
- (2) Fab antibody fragments labeled with ATTO647N/abberiorCAGE635 targeting the CAIX PG domain¹²,
- (3) Nanodiamonds with nitrogen-vacancy centers functionalized with CAIX ligands¹³.

Live-cell SMT experiments were performed in wild-type and CAIX knock-out HeLa cells using low nM probes. Using our open-source miEye microscopy platform,¹⁰ we quantified CAIX localization densities, diffusion coefficients, and track lengths revealing cell-to-cell heterogeneity in CAIX expression and mobility.

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Diamond Color Centers for Quantum Technologies

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Single-photon emitters are among the fundamental building blocks of emerging quantum technologies, enabling applications in quantum communication, quantum computing, and quantum metrology [1–3]. Among the different solid-state quantum emitters, diamond color centers have attracted considerable interest thanks to their remarkable optical stability, long spin coherence times, and ability to operate under ambient conditions [4–6].

This presentation provides an overview of diamond color centers and their role in modern quantum photonics. After introducing the importance of single-photon emitters for quantum technologies, several families of diamond defects will be briefly reviewed, with particular emphasis on Group-IV color centers and the nitrogen-vacancy (NV) center. Owing to its unique combination of optical and spin properties, the NV center enables optical spin initialization, coherent microwave manipulation, and spin-state readout through spin-dependent fluorescence, making it one of the most versatile solid-state quantum systems [5,6].

These remarkable properties have established NV centers as powerful quantum sensors capable of measuring magnetic field with high sensitivity and nanoscale spatial resolution using optically detected magnetic resonance (ODMR) [5-7]. Representative examples of magnetic sensing applications will be presented to illustrate the versatility of this platform [8].

Finally, we discuss how the same physical mechanisms can be exploited beyond quantum sensing for communication processing. Using ensembles of NV centers, we investigate optical information encoding and decoding based on spin-dependent fluorescence. Communication performance is evaluated through metrics such as transmission rate and bit-error rate, highlighting the potential of diamond color centers as multifunctional platforms combining quantum photonics, sensing, and optical communication.

The presented work illustrates the versatility of diamond color centers and their growing role in next-generation quantum technologies, bridging single-photon science, quantum sensing, and photonic information processing.

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pH-sensitive photoluminescence in diamond nanoneedles

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1. Introduction

Diamond-based optical probes attract interest in biological sensing due to their biocompatibility, chemical stability, and unique sensing capabilities of optically active defects known as color centers [1,2]. Although NV centers in bulk diamond are generally considered highly photostable, color centers in nanodiamonds or close to the surface in bulk diamond can demonstrate significant photoluminescence (PL) intermittency [3]. This behavior has been associated with $NV^- \leftrightarrow NV^0$ charge-state switching and interactions of near-surface defects with surface-related trap states [3,4].

For diamond nanoneedles, this behavior has not yet been investigated, while the contribution of surface-related processes is expected to be strong. Since pH can modify the local charge environment, our motivation was to understand whether changes in pH affect the PL behavior of color centers in diamond nanoneedles and whether PL fluctuations could be used as a sensing channel.

2. Experiment

pH-dependent PL fluctuations were studied for ~200 nm single-crystal diamond nanoneedles using wide-field fluorescence microscopy. Different pH conditions were introduced through a bottomless multi-channel slide mounted on the coverslip with the deposited nanoneedles, enabling buffer delivery to the investigated area. Different pH conditions, ranging from strongly acidic to strongly alkaline environments, were tested. PL image stacks of 10,000 frames (Fig.1) were recorded under laser excitation with different optical filters. An exposure time of 100 ms was selected for resolving PL fluctuations. Second-order SOFI was used to visualize emitters with correlated PL fluctuations and to select regions of interest (ROI) for temporal-trace analysis.

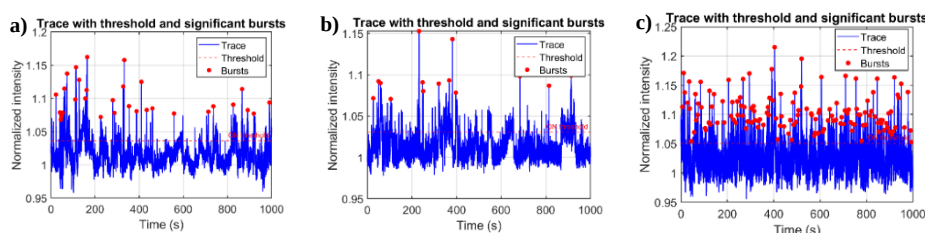


Fig. 1. ROI's temporal normalized PL intensity traces with the applied ON-state threshold and detected burst-like events for different environmental conditions: (a) no liquid addition, (b) strong alkaline environment, and (c) strong acidic environment.

3. Results

The measurements under green excitation showed the most pronounced PL fluctuation behavior when using the F600/37 filter, which suggests that the observed dynamics are related to the NV^0 PL band. Compared with the reference state, the acidic environment increased the mean SOFI intensity, transition rate, and number of burst-like events, indicating enhanced fluctuation activity. In contrast, the alkaline environment led to lower SOFI intensity and fewer bursts. Similar behavior was observed for selected localized emitters, suggesting that NV^0 -related PL fluctuations in diamond nanoneedles are sensitive to pH-induced changes in the local environment.

4. Acknowledgement

The authors acknowledge the University of Warsaw Quantum Imaging Laboratory staff for technical assistance and valuable advice, and Dr. Nikita Belko and Nikita Solonovich from the University of Eastern Finland for assistance with experimental equipment.

This work was supported by the Research Council of Finland through PREIN (368653), EXTRASENS (361115), and by the Horizon Europe MSCA FLORIN project (101086142).

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Mechanistic insights into individual protein-DNA interactions of fundamentally different bacterial defense systems

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Bacteria are constantly facing various outside threats, such as bacteriophages and parasitic plasmids. Due to the rapid advance of bioinformatic tools, more than hundred different bacterial defense system candidates have been proposed to date. The canonical bacterial defense systems – restriction-modification, CRISPR-Cas and prokaryotic Argonaute protein-based – were extensively studied using bulk biochemical assays and diverse structural techniques. However, single-molecule characterization of these systems' effectors is still lacking, which could aid in elucidating their complete molecular mechanisms. Here, we investigated the DNA-interaction dynamics of three fundamentally different bacterial defense system effector proteins at the single-molecule level. We used single-molecule FRET to detect and monitor *in cis* and *in trans* interactions between DNA and BfiI restriction endonuclease from *Bacillus firmus*. Next, by combining single-molecule fluorescence microscopy with DNA flow-stretch assay, we revealed filamentation-based mechanism of action of the novel anti-plasmid defense system SPARDA from *Xanthobacter autotrophicus* strain Py2. Finally, we performed dSTORM-based single-molecule tracking of *Streptococcus pyogenes* Cas9 diffusion to probe its target search in living *Escherichia coli* cells. Our findings should expand the mechanistic understanding about these key effector proteins and pave the way for effectively applying them as optimized or novel molecular tools in genome engineering, biotechnology and biomedicine.

Quantum sensing at nanoscale enabled by diamond spin qubits

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Synthetic diamond has recently emerged as a candidate material for a number of quantum applications, including quantum information processing and quantum sensing. Nitrogen-vacancy (NV) centres in diamond combine unique electronic and spin properties, enabling their spins to be initialised and read out optically. In this talk, we will show how single NV colour centres can be created near the diamond surface and used as nanoscale sensors of electric and magnetic fields. We will also demonstrate novel dynamical decoupling techniques allowing to improve the sensitivity of diamond quantum sensors and discuss applications of small-scale quantum registers for nanoscale NMR. Temperature sensing at the nanoscale using NV centres will be demonstrated. The application of quantum sensing to detect biomolecules, including RNA, will be shown. Applications of NV centres for hyperpolarisation of nuclear spins and application of optical spin polarisation in MRI will be presented.

Surface engineering of nanodiamonds with NV centers for quantum sensing

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Nanodiamonds (NDs) hosting nitrogen-vacancy (NV) centers offer a unique platform for non-perturbing sensing in biological systems. [1] Their optically readable spin states enable quantum-based probes that can report on local magnetic and spin-related processes. [2,3] However, the broader biological application of NV relaxometry remains limited by short relaxation times, suboptimal NV⁻/NV⁰ charge-state ratios, and insufficient colloidal stability under complex biological conditions.

I'll present an integrated strategy to overcome these limitations through controlled ND synthesis and rational surface engineering. First, we enhance the intrinsic spin properties of NDs using a single-step manufacturing approach that exploits plastic deformation of the diamond lattice to improve NV-center performance. [4] Second, we tune the near-surface electronic environment through fluorination, azidation, [5] and amination protocols, together with shape control of NDs, [6] providing atomic-level control over surface termination and charge-state stabilization. Finally, we demonstrate that dense functionalization with DNA oligonucleotides [5,7] enables stable, sequence-selective biointerfaces, opening a route toward ND-based quantum probes for nucleic acid sensing.

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New Hybrid Photonic Platform for Directional Enhancement of Upconversion Luminescence in Single-Molecule Detection

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1. Abstract

Upconversion luminescence (UCL) provides deep penetration, low-background optical signals through nonlinear process converting NIR excitation into visible emission, which is valuable for bio-imaging and bio-sensing, yet it suffers from intrinsically low quantum efficiency [1]. Prior enhancement approaches have included plasmonic (metallic) nanostructures such as nanoholes, cross-shaped cavities, and nanoantennas yielding tens- to hundreds-fold improvements [2,3]. Photonic crystal (PhC) and all dielectric resonators achieve strong field and emission improvement [4]. By combining the two approaches [5], this work sets the design and evaluates a new hybrid plasmonic-photonic crystal nanostructure. Le *et al.* proposed a surface plasmon polariton-enhanced design for excitation enhancement at low power [6]. Followingly, we propose an alternative nanostructure integrating gold gratings onto a one-dimensional PhC or multilayer (ML) substrate comprising bilayers of TiO₂ and SiO₂, forming a photonic bandgap. The structure enhances excitation and improves emission directionality of UCL from lanthanide-doped upconversion nanoparticles (UCNPs).

The optical response of the system was investigated through numerical analyses using finite element and transfer matrix methods. The simulations for ML-based structure reveal an increase in the excitation enhancement from analysing the surface plasmon polariton (SPP) coupling efficiencies at $\lambda = 980$ nm, as well as directional emitted radiation pattern from a dipole within the Bragg wavelength at $\lambda = 540$ nm. The proposed platform was fabricated and experimentally characterized to validate the enhancement mechanism. Comparative measurements were performed on two samples with gold gratings fabricated on ML and silica substrates. The results demonstrate a maximum total enhancement of approximately threefold in the detected upconversion luminescence for the ML-based hybrid nanostructure, compared to the reference (silica substrate). This enhancement arises from the combined effect of SPP-enhanced excitation and PhC's directional emission enhancement.

Although metal-induced quenching remains present, the ML substrate significantly improves emission collection efficiency by increasing vertical directionality, leading to superior emission performance compared to plasmonic structure. The presented hybrid structure provides an effective strategy to overcome the weak emission inherent to upconversion processes and opens pathways toward highly resolved images in single-molecule detection.

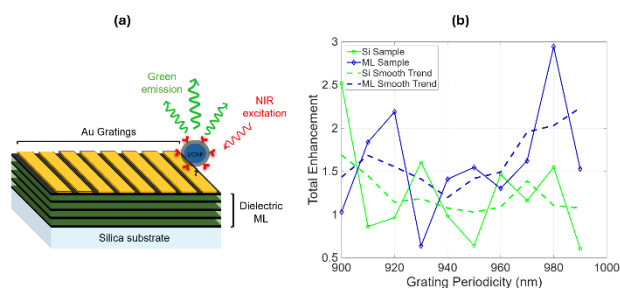


Fig. 1. (a) Schematic of the emitter (UCNP) on the hybrid platform. (b) Experimental results of the total enhancements for two samples; with multilayer and silica substrates to their references without gratings, for varying grating periodicity. Labeling: silica (Si) and multilayer (ML).

2. Acknowledgement.

Research Council of Finland through the Flagship PREIN (346518) and the research project DiSiMo (Decision 363445).

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Thursday, August 20



High-dimensional optical communication in atmospheric turbulence

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Photonic spatial degrees of freedom allow for high-dimensional encoding in free-space communication, and promise increased channel capacity and enhanced security of quantum key distribution. A standard way of spatial encoding employs the familiar Laguerre-Gaussian (LG) modes carrying an orbital angular momentum (OAM), and other complete, orthonormal, and unbounded modal bases. However, the spatial structure of predefined modes is fragile with respect to atmospheric turbulence, which introduces disturbances to the beams' transverse spatial profiles, resulting in intermodal crosstalk [1,2]. The latter effect is the main obstacle to achieving free-space high-dimensional information transfer using photonic spatial modes.

In the present contribution, we will first outline our theoretical approaches to a description of turbulence-induced crosstalk among LG modes, in particular, a master equation approach, and present some techniques such as adaptive optics that can partially mitigate atmospheric effects on structured light beams [1]. Thereafter, we will focus on information encoding into spatial eigenmodes of light, for a given realization of turbulence ("frozen" atmosphere) [3]. By construction, such modes are mutually orthogonal and therefore exhibit no crosstalk. Moreover, those eigenmodes associated with large eigenvalues propagate through the atmosphere with little loss. Even in strong turbulence, it is possible to identify several highly transmitting eigenmodes (communications modes), whose spatial distribution is typically characterized by pronounced transverse localization (see Fig.1). Finally, we will demonstrate the stability of the spatial eigenmodes in dynamic turbulence, and discuss their experimental feasibility using state of the art photonic devices.

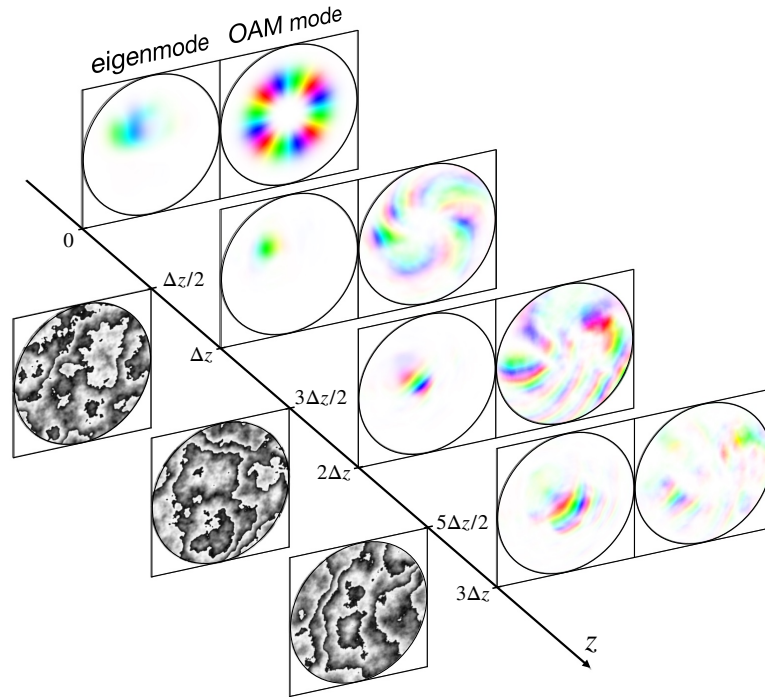


Fig.1. A complex, localized spatial distribution at $z=0$ corresponds to a highly transmitting eigenmode of the transfer matrix of a given turbulent channel (here presented by three grayscale random phase-front disturbances on the left of the figure). As a result, this mode remains well localized, such that it propagates with negligible loss (see the snapshots of the amplitude and phase distributions of the eigenmode at Δz , $2\Delta z$, $3\Delta z$). In contrast, an OAM-carrying mode (a symmetric multicolor ring at $z=0$) gets rapidly distorted and spreads out in the transverse plane as it propagates, which results in severe power loss..

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Uncovering the Dynamics of Multimode Organic Polariton Lasing

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Multimode exciton-polariton dynamics play a central role in various nonlinear optical phenomena, yet the mechanisms underlying multimode polariton lasing remain only partially understood. In typical experiments, time-integrated photoluminescence spectra can display several distinct lasing peaks, often interpreted as signatures of simultaneous multimode lasing. However, our theoretical analysis using the second-order cumulant model we developed shows that these apparent multimode features usually arise from rapid temporal switching rather than concurrent occupation of multiple states (Figure 1). According to our simulations, true bimodal lasing occurs only within a narrow parameter window, whereas temporal switching dominates across a much broader regime [1, 2].

Guided by these predictions, we have experimentally investigated multimode polariton lasing in Gaussian-defect microcavities incorporating the polymer active material MeLPPP. Time-resolved interferometric measurements reveal picosecond-scale modulation between polariton modes, providing direct evidence of the predicted mode-switching dynamics [3]. Together, theory and experiment establish temporal mode switching as a plausible origin of multimode signatures in polariton systems and highlight the importance of time-resolved population dynamics for interpreting multimode polariton lasing behavior.

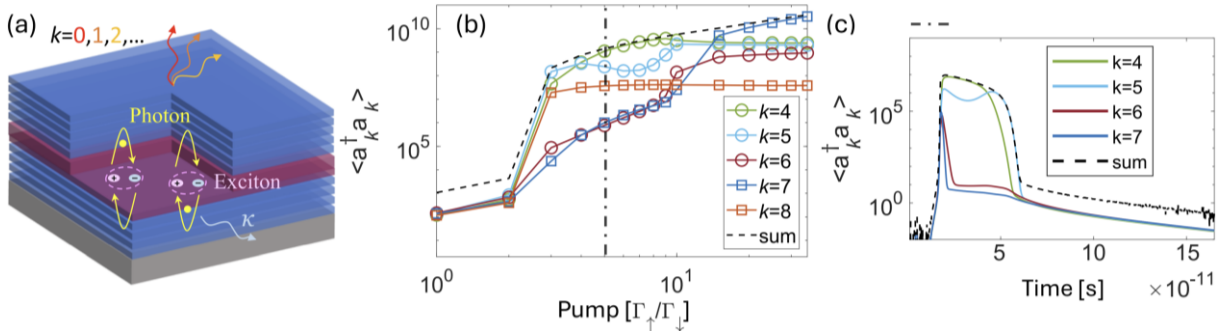


Figure 1. (a) A schematic of the microcavity exciton-polariton system. (b) Computed time-integrated mode occupations as a function of pump strength. (c) Computed mode occupations as a function of time, at a pump level marked by the dash-dot line in b, showing switching between the $k=4$ and $k=5$ modes.

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Two-level strip-loaded waveguides for controlled absorption

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1. Abstract

This work deals with the experimental investigation of two-level strip-loaded waveguides. This platform offers an elegant way to control vertically the position of the optical mode and therefore to choose in which film light is guided. A strip-loaded waveguide is composed of a guiding film of high refractive index on a low refractive index substrate. It ensures the vertical confinement of light. The channelling, i.e., the lateral confinement, is performed by a resist loading strip. Our proposal is here to use two materials for the guiding film. A first layer is a tellurium-bismuth glass doped with erbium ions. The second one is a titanium dioxide film.

The TiO₂ film is very low loss. The glass film is highly doped, 2.5% concentration, to increase the absorption in the C-band. The refractive index of the glass is $n_{\text{glass}} = 1.95$ at $\lambda = 1550$ nm, while the refractive index of the titania is slightly higher $n_{\text{TiO}_2} = 2.23$. The titania layer is partly etched away for some length L along the propagation direction. 45 straight waveguides are patterned per chip, corresponding to different lengths without titania. Light tends to propagate in the highest refractive index material, therefore when the two layers exist, light is guided in the titania, otherwise in the glass film. The modal distribution showing the light confinement are presented in Fig.1. (a) and (b). SEM images of the cross sections of the fabricated waveguides are shown in Fig.1 (c) and (d). Measuring the loss through waveguides with different opening length, gives a direct reading of the absorption, for this type of waveguides, since the length and overall geometry remains unchanged except the opening length. It proves also that the concept of two-level waveguide is properly operating.

Using a four-direction cutback method across 45 waveguides in nine lengths (0–2.00 mm), three data-processing strategies were compared. Individual outlier removal introduced anomalous slope increases, while length group removal applied to the raw data gave the most reliable results, with a good correlation coefficient $R^2 = 0.944$ – 0.996 . We obtained a value $\alpha = 4.41 \pm 0.41$ dB/cm in a compact device that can be easily integrated with more functional systems.

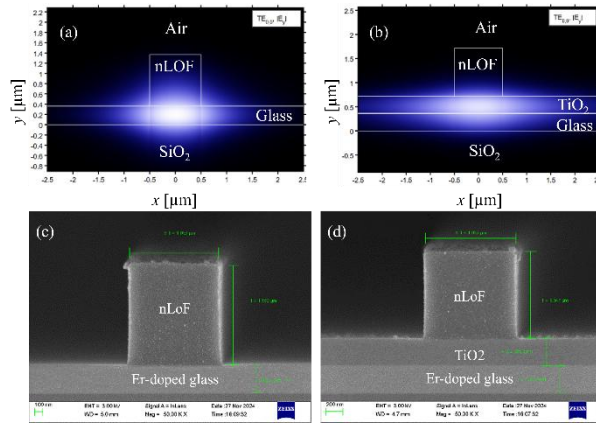


Fig. 1. Calculated modal distribution for (a) a strip-loaded waveguide with glass as guiding film and (b) a strip-loaded waveguide on a TiO₂-glass stack. (c) and (d) are the corresponding SEM images of the fabricated structures.

2. Acknowledgements

The work has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101092723/IBAIA. UK participants in Horizon Europe Project IBAIA are supported by UKRI grant number 10062902 (MODUS). The work is also supported by the Flagship on Photonics Research and Innovation (PREIN) funded by the Research Council of Finland, decision 368653 (UEF) and 368650 (TAU).

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Spectroscopy with resolution beyond the encoder linewidth

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In conventional spectrometers, there is trade-off between device size, complexity, and resolution. Reconstructive spectrometers partially relax these constraints by inferring spectra from encoded measurements. However, existing implementations typically rely on random scattering media, filter arrays, or statistical reconstruction, which demand extensive calibration and still remain bounded by encoder linewidths [1-3].

We introduce deterministic single-encoder reconstructive (DSR) spectrometers as a distinct metrological category. Instead of isolating wavelengths, the device deterministically mixes spectral components through angle-wavelength mapping. Importantly, the device does not function as an angular-scanning monochromator; each measurement corresponds to a weighted mixture of the entire spectrum, and recovery is achieved through physics-aware deconvolution. As a result, the resolution is not directly limited by the encoder linewidth but instead by the information preserved in the encoding.

The system consists of two main components: a rotating metasurface and a detector, as illustrated in Fig. 1(a). Rotation of the metasurface maps spectral information onto an angle-dependent intensity distribution that is detected with a single-pixel photodiode. The DSR spectrometer was used to measure the spectrum of a multimode laser diode emitting near 800 nm. The effective PSF was obtained via a novel and self-contained multipass monochromatization method, which was compared to a PSF obtained by direct deconvolution of the measured intensity with a high-resolution reference spectrum. Figure 1(b) shows the PSF measured with both methods. The reconstructed spectrum was benchmarked against a laboratory-grade double-pass spectrometer, with a resolution of 20 pm, with the result presented in Fig. 1(c). Deconvolution of the reconstructed spectrum with the reference spectrum yields the instrument line shape for the DSR spectrometer, from where we estimate the effective spectral resolution as the full-width at half-maximum of the central peak. The resolution estimate with this method is 37.4 pm, which is a factor of 40 narrower than the encoder linewidth.

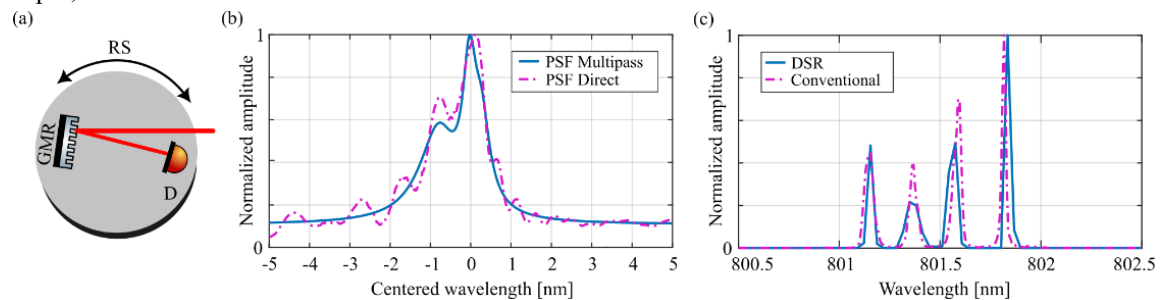


Fig. 1. (a) Schematic of the setup, GMR is a guided-mode resonance grating, used as an angle-wavelength encoder, D is detector, and RS is the rotation stage. (b) PSF of the device measured with two different methods, a novel multipass method (blue solid) and a direct deconvolution with a high-resolution reference spectrum (magenta dash dotted). (c) Spectrum of a multimode laser diode as measured with the DSR spectrometer (blue solid) and the conventional high-resolution spectrometer (magenta dash dotted).

Our results demonstrate that deterministic spectral mixing can effectively decouple resolution and bandwidth from device size and complexity. In particular, the DSR approach avoids random encoding, large channel counts, and data-driven reconstruction. Although demonstrated using mechanical angular scan, the encoding principle is not inherently tied to this mechanism and may be extended to alternative deterministic modulation schemes. More generally, deterministic single-encoder reconstruction offers a versatile framework for compact spectroscopy in measurement-critical applications.

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State-of-the-art *in situ* TEM techniques for physical property studies of nanomaterials

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Knowledge of optoelectronic, optomechanical, electromechanical and electrochemical properties of a nanomaterial is of prime importance as far as its smart integration into modern and future technologies is envisioned. However, typically, such properties have been measured using instruments having no direct access to the nanomaterial atomic structure, its defects, crystallography and spatially resolved chemistry.

In this Project, diverse 1D and 2D nanomaterials' optoelectronic, electromechanical and nanomechanical signatures were analyzed by using laser compatible *in situ* high-resolution transmission electron microscopy (TEM) utilizing optical-fiber embedded TEM holders and in-column laser beam lines allowing for the simultaneous electron irradiation, mechanical deformation, electrical probing and light illumination of a sample [1]. Various modes of deformations: (i) bending of a nanomaterial perpendicular to its basal atomic plane; (ii) edge deformation parallel to the basal atomic planes; and (iii) stretching of a nanomaterial along its growth axis led to distinctly different performances and physical properties' modifications.

The materials/devices of interest include carbon and boron nitride nanotubes, cadmium sulfide nanowires, molybdenum, indium sulfide/selenide nanosheets, phosphorene and MXene nanosheets, secondary ion battery electrodes etc. The experimental results were verified by *ab initio* calculations using density functional theory (DFT) [2]. The results provide useful pathways for nanomaterial property/structure engineering *via* tuning the material synthetic conditions, its deformation modes and electron/light irradiations [3,4].

The author is grateful to Dr. Chao Zhang, Dr. Joseph Fernando, Dasun Guruge, Zhenhuan Chen and Dr. Konstantin Firestein for their key contributions to the *in-situ* TEM experiments over the years and to Prof. Dmitri Kvashnin of Russian Academy of Science, for supporting the regarded projects with Density Functional Theory (DFT) calculations. *In situ* TEM projects at QUT were funded through the Australian Research Council (ARC) in the frame of the Laureate Fellowship Program (D.G.) FL160100089.

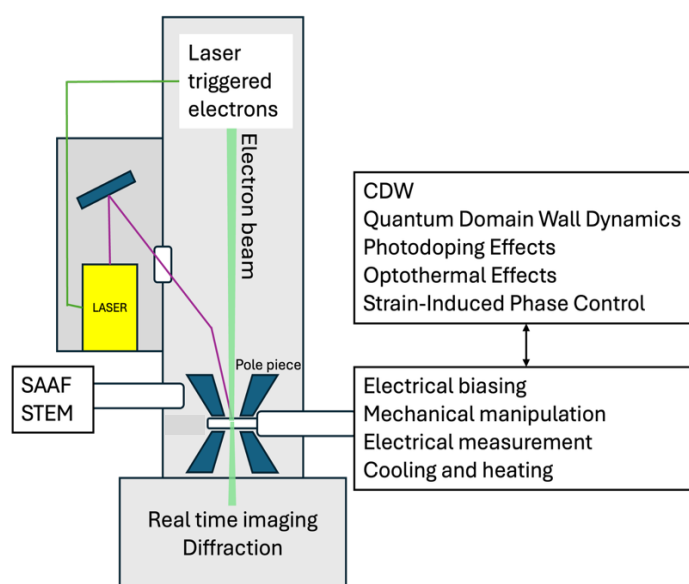


Fig. 1. Schematics of the experimental setup with associated framework.

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Nanophotonic structures at higher-order resonances

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1. Introduction

Nanophotonic structures are increasingly used in science and technology, enabling more compact and highly efficient optical devices. These architectures encompass both isolated elements, such as plasmonic nanoparticles, and periodic arrangements, including photonic crystals, metamaterials, and metasurfaces. If the building blocks of the structure are small compared to the wavelength, their optical response is primarily of the electric dipole nature. Higher-order multipole moments contribute only weakly to light scattering, and the incident light does not excite higher-order propagating modes. In this work, we go beyond the lowest-order excitation condition and design individual and arrayed nanostructures, in which higher-order multipole resonances and higher-order guided modes play a crucial role. This extends the capabilities of the structures, allowing for higher near-field enhancement and more efficient control of the spatial and spectral properties of light.

2. Higher-order resonances in photonic structures

Classical multipole expansion describes the fields scattered or radiated by small particles, making use of the orthogonality of the vector spherical harmonics. However, the expansion does not distinguish between the conventional and toroidal multipoles, because they radiate indistinguishable fields, and it misses non-radiating electric charge excitations called anapoles. To include all electromagnetic excitations in the scatterer, we use an alternative, scattering-current multipole expansion introduced in [1] and extended in [2] to describe particles of arbitrary sizes and shapes. Using the expansion, we find that higher-order multipole resonances in plasmonic particles can result in an exceptionally high near-field enhancement. As an example, Fig. 1(a) shows the spectrum of the electric-field enhancement in the gap between two closely spaced silver nanospheres. The sharp peak at $\lambda \approx 440$ nm originates from the octupole resonance in the dimer [3].

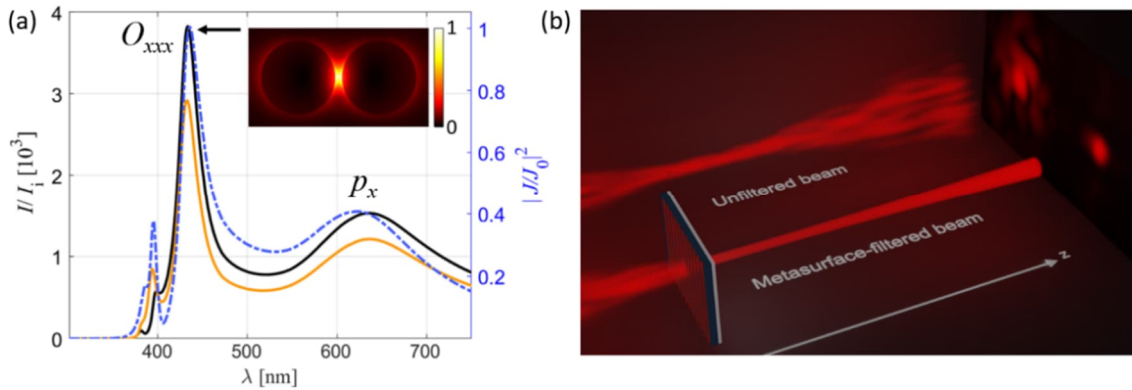


Fig. 1. (a) Near-field intensity enhancement spectrum (black line) and effective current density (blue dash-dotted line) of a silver dimer. The enhancement factor averaged over the effective volume of the gap is shown by the yellow line. The two peaks originate from the octupole (O_{xxx}) and dipole (p_x) resonances [3]. (b) Spatial filtering with a nonlocal metasurface [4].

We also find that, in periodic structures supporting higher-order guided-mode resonances, light can be trapped, resulting in narrowband quasi-bound states in the continuum, or coupled to in-plane propagating modes providing efficient spatial filtering of the field [4] (see Fig. 1b). We also show that an optical metasurface made of plasmonic particles can be made free of absorption and scattering losses [5]. Our results offer broad applications across nano-optics, and the scattering-current multipole expansion theory we propose paves the way for discovering new phenomena based on higher-order multipole resonances and designing nanostructures with new functionalities.

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High-Sensitivity Optical Detectors for Ultra-Low-Light Detection and Imaging

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Ultra-sensitive optical detectors are essential for capturing extremely weak optical signals and imaging, which are crucial for applications in quantum communication, low-light imaging, biomedical diagnostics, environmental monitoring, and security. As these fields evolve, detectors must combine extreme sensitivity and precision with compact, low-power, and wearable form factors. Two-dimensional (2D) materials are promising for this purpose due to their strong light-matter interactions and tunable optoelectronic properties^[1]. Here, we report a 2D p-type InSe phototransistor with pre-deposited van der Waals contacts, designed to preserve intrinsic channel properties and achieve a low subthreshold swing ^[2]. This device architecture enables efficient carrier injection with minimized dark current, allowing highly sensitive operation in the subthreshold regime. The device achieves femtowatt-level optical sensitivity with high responsivity and detectivity and maintains performance across a wide temperature and wavelength range. We further demonstrate a proof of concept for low-light imaging of astronomical targets and object identification from vehicle number plates, underscoring its potential for ultra-weak-light imaging.

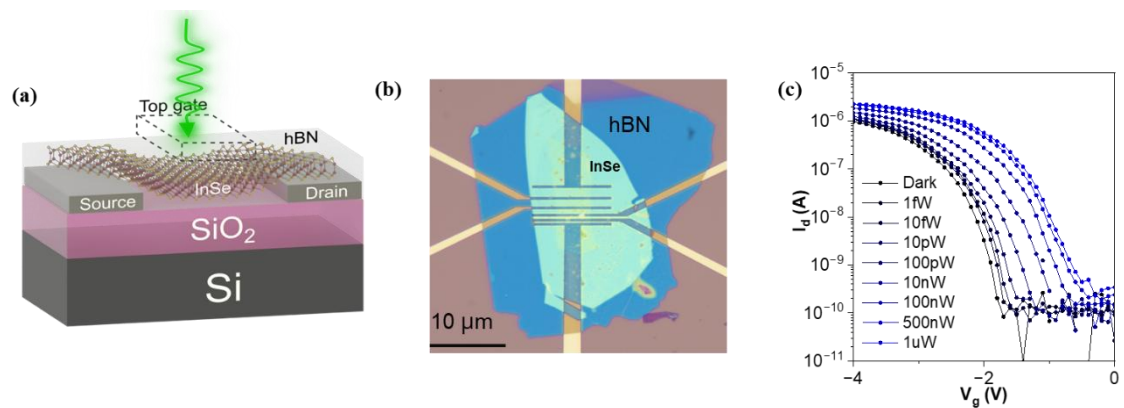


Figure: (a) Schematic of the device, (b) optical imaging of the device, (c) photocurrent measured in the dark and under a 532 nm laser.

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Low-Loss and Compact 300 GHz-Band Hollow Waveguide Components and Devices Fabricated by 3D Printing and Electroless Metal Plating

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Terahertz (THz) communication and sensing systems demand low-loss, compact, and highly integrated components to replace conventional, bulky free-space optical architectures. While hollow waveguides (WGs) are ideal for the 300 GHz band, standard rectangular waveguides for the 300 GHz band have a cross-section of $0.86 \times 0.43 \text{ mm}^2$ and are typically fabricated in lengths exceeding 25.4 mm (1 inch). The fabrication of sub-millimeter-scale metallic hollow structures with high aspect ratios remains a significant challenge using conventional machining techniques. To overcome this challenge, we developed a fabrication technology for THz-band hollow waveguide devices using our in-house UV-curable-resin-type 3D printer, RECILS, followed by electroless metal plating on the inner surfaces of resin-based hollow structures [1]. The resulting waveguides exhibit a propagation loss of less than 0.4 dB/inch, comparable to that of commercially available precision-machined metallic WGs. This technology enables the fabrication of free-form 3D hollow waveguide structures with sub-millimeter cross sections, allowing the realization of various functional devices, including bandpass filters (BPFs), Y-branches, and directional couplers (DCs) [2].

For the BPFs, an extinction ratio of about 90 dB between the passband and the stopband was achieved. The Y-branches exhibit both low insertion loss and low reflection by employing a mode converter between the TE_{10} and TE_{20} modes [3]. The DCs provide 3-dB coupling with a 90° phase difference between two output ports, enabling a wide variety of signal-processing and sensing functions.

By integrating these elements, both balanced and unbalanced Mach-Zehnder interferometers (MZIs) were realized using a Y-branch and a DC. The fabricated MZIs exhibit free spectral ranges of 10–20 GHz with an insertion loss of approximately 2 dB and an extinction ratio of about 20 dB [4]. These MZIs were further applied as frequency-selective filters in a 300 GHz OFDM wireless system [5]. In addition, 300-GHz waveguide phase modulators incorporating a metamaterial semiconductor chip are demonstrated. A full 2π phase shift was achieved by applying a voltage of about 1.5 V across the metamaterial chip [6].

These results demonstrate that RECILS-based 3D printing combined with electroless metal plating provides a versatile platform for realizing highly integrated THz waveguide devices. This waveguide platform is expected to pave the way toward compact, robust, and highly integrated THz communication and sensing systems, providing an attractive alternative to conventional free-space optical architectures.

Acknowledgement.

This work was supported by the Center of Innovation Program, JST (JPMJCE1313). This research was also partially supported by JSPS KAKENHI Grant No. 21H01320, NEDO under the New Energy Program (NEP) (2021 New Energy Innovation No. 0420005), the Beyond 5G R&D Promotion Program (JPJ012368C-00901) from the National Institute of Information and Communications Technology (NICT), Japan, MEXT Quantum Leap Flagship Program (MEXT Q-LEAP) under Grants No. JPMXS0118067246, JST CRONOS Japan Grant Number JPMJCS24N7, and the RIKEN TRIP Initiative.

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Quantification of fundamental laser-ablation phenomena for advancing laser processing technologies

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Ultrashort pulsed-laser processing has matured in recent years beyond being a simple research topic in the scientific community to a practical technique relied on to support key processes in critical industrial applications, for example, the cutting and drilling of precise holes for electronic and medical devices. Especially regarding the processing of hard, transparent materials, ultrashort laser processing has emerged as a promising and unique tool for precise microfabrication [1]. However, there remain key problems and bottlenecks that have hindered its adoption across a wider range of applications. While the specifics of these bottlenecks vary by application, a common theme often observed is a lack of designability, where recipes and methods must largely be refined through trial-and-error approaches.

Such needs for more robust optimization methods have driven decades of research into understanding the processes governing the laser ablation phenomenon. This has led to the creation of countless models to better understand the phenomenon, relying on concepts from nonlinear optics and non-perturbative light-matter interactions to predict the resulting dynamics of highly excited and unstable materials [2]. On the other hand, recent trends have also sought to leverage data-driven paradigms to overcome difficulties arising from theoretical approaches. Deep learning and related methods have enabled the establishment of ad hoc understandings of the relationship between input parameters and output results without necessarily fully understanding the system itself [3]. However, in either case, the most important factor remains the acquisition of a systematic and high-quality dataset from which to build such models.

To address these issues, we have been working in recent years to develop systems and methods to reliably and systematically control and measure laser ablation phenomena and outcomes. The key question then becomes: how can we reliably reduce systematic errors arising from high-power laser systems? The first effects we focused on involved removing uncertainties in beam profile characterization, which resulted in improved accuracy in metrology results while enabling order-of-magnitude increases in data utilization efficiency [4]. We expanded these discussions to nonlinear propagation regimes as well, identifying robust signatures of air-propagation-induced distortions in processing results [5]. In this talk, I introduce our latest efforts to extend such quantification to two additional frontiers: wavelength and pulse duration. First, we detail the construction and deployment of fully automated systems (Fig. 1) to control and characterize the output light from optical parametric amplifiers, enabling the identification of intricate wavelength dependencies in ablation characteristics predicted decades ago yet previously beyond common system sensitivities. Next, we present recent work revisiting short pulse duration processing near 10 fs, as a modern re-examination of long-standing observations of qualitative changes in processing results using contemporary light sources and control methods.

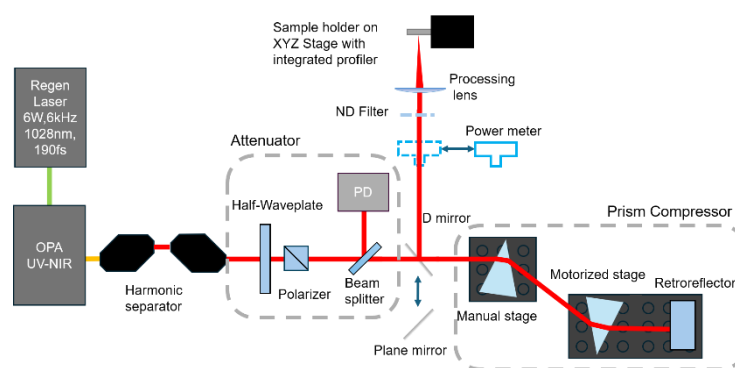


Fig. 1. Wavelength dependent ablation characterization system

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Time to space ghost imaging with partially coherent light

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Ghost imaging is a technique for creating an image of a spatial [1], temporal [2] or spectral object using two beams of light correlated in relevant degrees of freedom. The spatial-temporal approach for ghost imaging with quantum light was introduced by Dmitri Horoshko [3] and it is combining spatial and temporal approaches. That technique allows one to obtain spatial image of the temporal object by using spatio-temporal light correlations. In that work we have considered spatio-temporal ghost imaging scheme with classical partially coherent light.

We introduced the spatio-temporal Gaussian Schell model (STGSM) for partially coherent pulsed light, which is a generalization of the spatial Gaussian Schell model to the case of spatio-temporal correlations. Although the generalization is straightforward, we are unaware of a similar work. In addition, we have described a method for creating an STGSM source in the limit of infinite temporal coherence by passing a short pulse of coherent laser light through a combination of a diffraction grating and an SLM. Using this model for the source of partially coherent light, we have shown that a time-to-space ghost imaging scheme can be built on its basis, that allows one to create a spatial ghost image of a temporal object. The key advantage of this technique is very short resolution time, on the order of 100 fs, two orders of magnitude below that of the conventional temporal ghost imaging limited by the response time of the photodetectors [2].

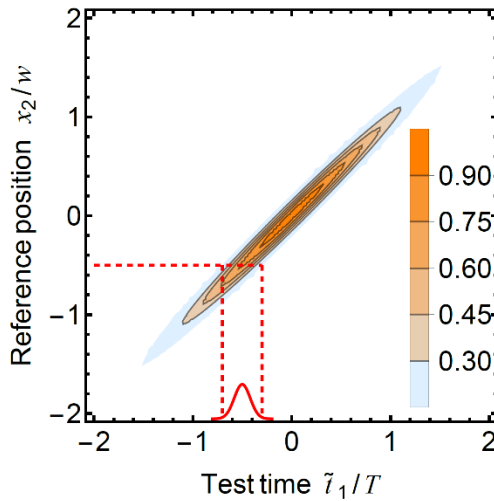


Figure 1. Normalized point spread function of the time-to-space ghost imaging system. Each position point corresponds to a temporal interval which is characterized by Gaussian distribution over time with the standard deviation constituting the temporal.

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Coherent thermal radiation sources based on hybrid surface polaritons excitation in GaN

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Tailoring thermal emission through engineered surface polariton modes is relevant for sensing, spectroscopy, radiative heat management, and midinfrared photonics [1,2]. While surface plasmon polaritons (SPPs) and surface phonon polaritons (SPhPs) have been widely used for this purpose, the research into hybridised states of surface plasmon–phonon polaritons (SPPhPs) in doped polar semiconductors is ongoing and showing great promise in development of novel polaritonic optical components [3]. GaN is particularly suitable due to its high crystalline quality, mechanical robustness, and strong plasmon–phonon coupling in heavily doped semiconductors in the Reststrahlen band region [4]. Surface-relief-grating (SRG) was developed on n-GaN to excite polaritons coupling out thermal radiation directionally in a narrow spectrum range (coherently).

In this work we experimentally and theoretically investigate the dependance of amplitude, peak position and linewidth of the polaritonic resonance on the doping level of n-GaN and the period and filling factor of SRG. The SRG samples with both radial and linear grating geometries possessing the periodicity from 15.5 to 18 μm and the Filling Factor ($FF=W/P$, where W is the ridge width and P is the grating period) of 25%, 50% and 75% were fabricated on n-GaN semiconductors with free-carrier concentration ranging from $5 \times 10^{17} \text{ cm}^{-3}$ to $1.5 \times 10^{19} \text{ cm}^{-3}$. The samples were fabricated using UV lithography and Cl-based reactive ion etching, following procedures established in earlier work [3,4] Thermal radiation spectra and emission angular profiles were measured by Fourier-transform infrared (FTIR) spectrometer in the far-field region. Rigorous-coupled-wave analysis (RCWA) method was employed to analyze the experimental trends aiming to optimize directional (in a normal direction) emission efficiency of hybrid SPPhP resonant features in various geometry and doping levels of n-GaN gratings.

Measured thermal radiation spectra of the samples demonstrated narrowband and directive thermal emission features indicating high temporal and spatial coherence. The sample with a grating period of 17.5 μm and FF of 25% demonstrated highest quality polariton emission features possessing the directivity of about 1. degree and the linewidth of about 6 cm^{-1} in experiment and 1 cm^{-1} in theory at the frequency of 570 cm^{-1} . Such discrepancy between theory and experiment was explained by the usage of limited resolution and finite angular aperture in the FTIR measurements. Change in the SRG filling factor allowed us to observe excitation of only +1, -1, and both ± 1 polariton modes in the samples with FF of 25%, 75% and 50% respectively, demonstrating the ability to select for excitation different modes with different dispersion characteristics. Periodicity change from 17.5 to 15.5 μm caused the resonant frequency blueshift to around 630 cm^{-1} and widening of the linewidth up to 10 cm^{-1} . On other hand, the change in doping level caused small changes in the resonant SPPhP emission features while provided control over the spectrum range for the SPPhP excitation. All these results demonstrate that n-GaN based platform is promising for surface plasmon-phonon polaritons excitation and usage for development of coherent thermal radiation emitters possessing high temporal coherency and special directivity characteristics.

4. Acknowledgement.

This work was supported by the European Union's Horizon Europe research and innovation programme under the Marie Skłodowska-Curie Actions through the project 101236439 “Towards a teraHERtz short-range wireless communication system based on graphene deviceS” (HERMES, 2025–2029).

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Efficient TiO₂/Polymer Vertical Nano-Waveguide Edge Coupler

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1. Introduction

Optical interconnects are a key solution to overcome bandwidth and power limits of conventional data links, with photonic integrated circuits (PICs) playing a central role [1]. However, coupling a wide input beam (2–3 μm) into a narrow vertical nano-waveguide (~ 200 nm) leads to high losses due to mode mismatch. Typical approaches use tapers or external lenses [2], but lenses are alignment-sensitive [3], and conventional tapers do not suit our structure due to fabrication constraints. Here, we propose a branch-based edge coupler design that enables efficient coupling while remaining compatible with fabrication requirements.

2. Device Design and Constraints

The vertical nano-waveguide consists of two negative tone photoresist ma-N 2400 walls with a TiO₂-filled gap (Fig. 1) [4], where the TiO₂ layer is deposited by atomic layer deposition (ALD). To ensure single-mode operation at telecom wavelengths, the titania width is fixed at 200 nm. Due to the conformal nature of ALD, the film thickness is limited to 100 nm, which restricts widening the waveguide at the input to improve mode overlap.



Fig.1. Cross-sectional schematic of the vertical nanowaveguide. Light is confined in the TiO₂ region between two ma-N 2400 walls.

3. Branch-Based Mode Engineering

To overcome this limitation, the input is split into closely spaced branches (Fig. 2a) with gaps below ~ 200 nm, fully filled with TiO₂. These branches form an effective wide mode and enable tuning of the input profile (uniform, Gaussian, or intermediate) to improve mode overlap. The wider input also increases tolerance to lateral misalignment. The proposed geometry and corresponding ANSYS Lumerical simulation results are shown in Fig. 2. The branches gradually redistribute the optical field toward the central branch, forming confined modes that concentrate the beam into a single guided mode through evanescent coupling between branches. Fig. 2d shows an SEM cross-section of the fabricated coupler. Initial characterization demonstrates strong performance despite variations in groove depth, highlighting the robustness and tolerance of the design.

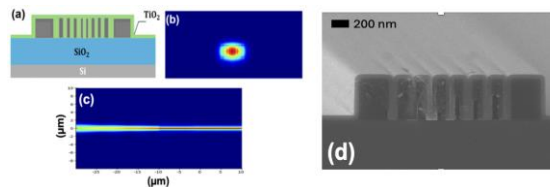


Fig.2. Simulation and fabrication of the proposed structure. a) Cross-sectional schematic of the input region showing the branch configuration. b) Input optical mode. c) Optical power distribution illustrating the mode evolution along the propagation direction. d) Scanning electron microscope (SEM) picture of the cross-section view of the branch-based edge coupler

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Methodological Advances in CARS Microscopy for Chemical Imaging of Micro and Nanostructures

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Coherent anti-Stokes Raman scattering (CARS) is a nonlinear optical technique in which coherently scattered light from individual molecules interferes constructively, resulting in a strong enhancement of the vibrational signal. The highest signal amplification is typically observed in highly ordered systems, such as bulk crystalline materials. This intrinsic advantage makes CARS a powerful tool for chemical imaging of crystalline materials, enabling visualization of crystallinity, orientation of crystal axes, and other structural features that are often inaccessible by conventional Raman microscopy.

In this work, we demonstrate the application of CARS microscopy for probing the monocrystallinity of micro and nanocrystals, including diamond microneedles. Furthermore, we show how CARS imaging can be used to study material separation, phase purity, and aggregate formation in systems composed of *trans*-stilbene and *cis*-stilbene, as well as *trans*-stilbene combined with hexagonal boron nitride nanoparticles. These examples highlight the capability of CARS to resolve subtle structural and chemical differences in organic and inorganic micro and nanoscale materials, underscoring its potential as a versatile tool for advanced materials characterization.

Acknowledgement

We would like to express our sincere gratitude to Dr. Andrej Dementjev for developing the methodology of CARS microscopy utilized in this study and for his comprehensive guidance throughout this work. This work was supported by the Horizon Europe FLORIN project (No. 101086142), QuantERA project EXTRASENS, supported by the Research Council of Lithuania, Project No. S-QUANTERA-24-1.

Laser-induced periodic surface structures (LIPSS) on titanium thin films with femtosecond optical skyrmions

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Optical skyrmions are topological quasiparticles of light, possessing spatially winding polarization textures across a beam cross-section [1]. Such vectorial light fields are finding utility for free space communication under turbulence (polarization textures are topologically protected under spatial propagation through turbid media) and advanced light-matter interactions. To date, direct imprint of polarization textures of optical skyrmions has been demonstrated in cold atoms and azobenzene polymers [2,3]; however, there are no reports detailing transcription onto hard materials such as semiconductors and metals, and thus materials fabrication with optical skyrmions is still in its fancy.

Here, we demonstrate the fabrication of laser-induced periodic surface structures (LIPSS) [4] on a titanium thin film using femtosecond optical skyrmions. Femtosecond optical skyrmion was generated by employing a partial spin-orbit conversion approach with a commercial q-plate [5]. A circularly polarized 1030-nm femtosecond laser (pulse width: 190-fs, PRF: 1-kHz, spatial form: Gaussian mode) was directed to a q-plate designed for 780 nm, thus allowing the generation of optical skyrmion formed by the coherent superposition of Gaussian and first-order vortex modes with orthogonally circular polarizations (Fig. 1(a)). The generated skyrmion beam was focused on a titanium thin film deposited on a borosilicate glass substrate, and its polarization texture was directly characterized at a focal-plane by a home-made micro-beam profiler [6].

The optical skyrmion exhibited a lemon (Néel) or a star (anti) shaped polarization texture with a central C-point defect, and its skyrmion number was measured to be ~ 0.9 , as shown in Fig. 1(b). Figure 1(c) demonstrates SEM images of LIPSS formed on a titanium thin film by the irradiation of Néel skyrmion and anti skyrmion beams. Note that the average laser power of optical skyrmion was then fixed to be 1.8 mW. After 100 pulses were overlaid, subwavelength ripple-like structures were formed around the C-point defect, and their orientations were approximately perpendicular to the local polarization of irradiated optical skyrmions. It is worth mentioning that no periodic structure was seen at the C-point defect with moderate optical intensity. This phenomenon was still observed even when the pulse number was increased to 500. Near the C-point, the magnitude of the circular-polarization component is large, and the in-plane linear-polarization component that defines the polarization azimuth is weak. The absence of a strong polarization anisotropy is therefore likely to suppress the formation of orientation-selective LIPSS in this region. These results manifest that topologically protected polarization textures of femtosecond optical skyrmions are imprinted on titanium thin films as LIPSS.

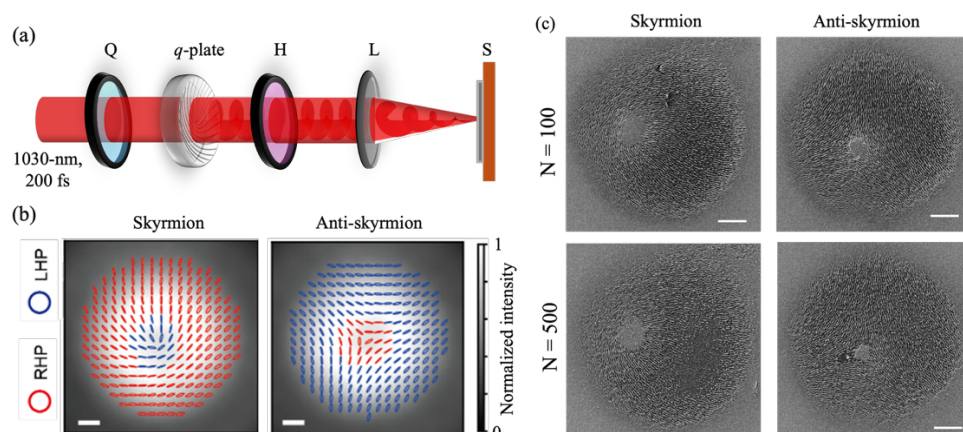


Fig. 1. LIPSS formation on titanium thin films using femtosecond optical skyrmions. (a) Experimental setup. Q, quarter-wave plate; H, half-wave plate; L, plano-convex lens; S, sample. (b) Polarization distributions of the generated skyrmion and anti-skyrmion beams. (c) SEM images of LIPSS formed by skyrmion and anti-skyrmion irradiation with $N = 100$ and 500 pulses. Scale bars, 10 μm .

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Mode locking in plasmonic lattice lasers

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We experimentally demonstrate the generation of phase-locked ultrafast laser pulses in metallic nanoparticle lattices coupled to optically pumped organic fluorescent molecules. Cross-correlated frequency-resolved optical gating measurements show that the emitted pulses exhibit picosecond scale durations with sub-picosecond temporal modulation. Complementary finite-difference time-domain simulations incorporating a four-level gain medium indicate that the modes of the lattice become phase-locked due to shared excited state populations near the nanoparticles.

Ultrafast optical pulses are important tools for investigating fast events occurring in nature [1,2]. Conventional mode-locked ultrafast lasers tend to be bulky, as their cavity dimensions cannot be reduced arbitrarily and the mode-locking mechanisms typically require additional components. Here, we demonstrate phase-locked multimode lasing in a plasmonic superlattice structure overlaid with optically pumped organic dye molecules. Plasmonic superlattices support multiple surface-lattice resonances (SLRs) with tunable energies and emission angles [3]. Using cross-correlated frequency-resolved optical gating (XFROG) measurements, we show that the different lasing modes coexist simultaneously in the lattice and exhibit a well-defined relative phase [4]. Finite-difference time-domain (FDTD) simulations incorporating a four-level gain model further reveal that the plasmonic hotspots associated with these modes overlap spatially, providing the correlations necessary for the phase locking to emerge [4]. This platform offers a promising route toward compact, chip scale ultrafast light sources.

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Friday, August 21



Coherent light emission of WSe₂–WS₂ Interlayer Excitons in Photonic Crystal Cavities

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Coherent on-chip light sources are essential for integrated photonics, enabling interference-based logic, high-fidelity signal routing, and precision sensing. However, achieving efficient coherent light emission on a silicon platform is fundamentally hindered by its indirect bandgap and the lattice mismatch constraints of conventional semiconductors [1]. Two-dimensional (2D) transition metal dichalcogenides (TMD) circumvent these limitations leveraging their atomically thin nature and van der Waals bonding for integration onto arbitrary substrates.

In their monolayer form, TMDs are direct bandgap semiconductors and they have been utilized a gain medium for coherent light emission [2]. Moving beyond monolayers, TMD heterobilayers offer distinct advantages for cavity-enhanced optoelectronics due to their characteristic type-II band alignment. By hosting interlayer excitons with emission energies below the monolithic bandgaps, these heterobilayers experience negligible optical absorption, allowing overlapping cavity resonances to maintain exceptionally high quality (Q) factors. While interlayer exciton coherent light emission has recently been demonstrated in systems like WSe₂–MoSe₂ [3,4] and WSe₂–MoS₂ [5,6], the specific combination of WS₂–WSe₂ has not yet been investigated. Nevertheless, WSe₂–WS₂ heterobilayer stands out as an ideal candidate. Its ~4% geometric lattice mismatch suppresses mesoscopic atomic reconstruction to yield uniform, spectrally homogeneous emission [7,8], while its nanosecond-scale exciton lifetimes facilitate high-density accumulation under continuous-wave excitation.

In this work, we report on the emergence of coherent light emission from WS₂–WSe₂ interlayer excitons coupled to a photonic crystal cavity. Building on hybrid hexagonal boron nitride (hBN) and silicon nitride (Si₃N₄) cavity platform [3,9] that offers excellent optical confinement and compatibility with on-chip 2D-material integration, we developed a high-Q 2D photonic crystal cavity. Within this architecture, the hBN layer serves three critical functions: first, it provides an atomically smooth substrate that preserves the pristine properties of the active gain material; second, the closely matched refractive indices of hBN and Si₃N₄ (both around 2) enable the optical co-design of the cavity; and third, it allows the WS₂–WSe₂ heterobilayer to be placed close to the cavity centre, ensuring good spatial mode overlap. As the optical pump power increases, the emission becomes increasingly coherent, with coherence lengths surpassing 5 μm. This is the first demonstration of coherent light emission from interlayer excitons in a WS₂–WSe₂ heterobilayer coupled to a nanocavity.

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FPGA Readout of Thermomechanical Bolometers Arrays for THz Imaging

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Terahertz (THz) imaging is a promising non-invasive technology that requires fast, uncooled detectors compatible with focal plane array (FPA) integration. MEMS-based thermomechanical bolometers (TMBs) are attractive candidates due to their high sensitivity, scalability, and room-temperature operation. Silicon nitride trampoline-shaped TMBs have demonstrated excellent sub-THz performance [1], achieving a noise-equivalent power as low as 30 pW/ $\sqrt{\text{Hz}}$ [2] and video-rate operation. In the developed prototypes, mechanical vibrations are actuated by a piezoelectric element, while gold electrodes along the membrane edges enable an all-electrical magneto-inductive readout. This architecture is well suited for large-scale parallelization: resonators with distinct eigenfrequencies are arranged in a 16x16 matrix, with a single electrode connecting each row (Fig. 1(a), 1(b)). Frequency-division multiplexing allows simultaneous addressing of multiple devices, encoding both spatial and bolometric information within a single communication channel and simplifying the readout electronics. The readout is implemented on a field-programmable gate array (FPGA) [3,4], supporting both open-loop and closed-loop operation. In open-loop mode, resonance shifts are measured by comparing frequency sweeps acquired under dark and illuminated conditions, with acquisition times reduced by subdividing the sweep range into narrower ones around each resonance. In closed-loop mode, a phase-locked loop (PLL) continuously tracks the resonance frequency, enabling faster scan-less imaging and improved resolution. The efficient multiplexed readout, combined with the possibility of resonator functionalization, opens the way to THz hyperspectral imaging. Within this context, the THz-Skin project aims to develop a passive hyperspectral THz imaging platform for early skin cancer detection by exploiting spectral differences between healthy and malignant tissues in the 3–25 THz range. The project goal is also the creation of a comprehensive spectral library of skin cancers to support rapid identification and classification. Here, we present a first prototype hyperspectral chip based on silicon nitride trampoline-shaped TMBs functionalized with split-ring metasurface filters (Fig. 1(c)). The chip comprises one broadband absorbing pixel and three spectrally selective pixels centered at 0.5 THz, 1.2 THz, and 2 THz, effectively mimicking an RGB imaging system in the THz domain. Initial characterization was performed using THz time-domain spectroscopy on identical metasurface arrays fabricated on unpatterned membranes. Current work focuses on optimizing the spectral filters, TMB responsivity, and PLL noise rejection to enable detection of blackbody radiation emitted by the human body. This represents a key step toward distinguishing healthy and cancerous skin tissues through their THz spectral signatures.

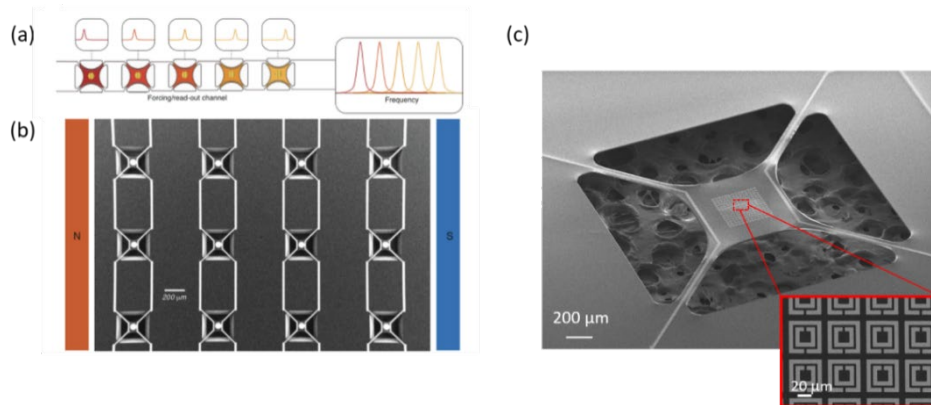


Fig. 1. (a) Schematic of frequency-division multiplexing, where multiple devices with distinct resonance frequencies are simultaneously addressed through a single readout or actuation channel. (b) SEM image of a portion of the TMBs array placed in a static magnetic field. (c) SEM image of a trampoline TMB functionalized with a split-ring metasurface.

Acknowledgement

This work was supported by HORIZON-EIC-2025-PATHFINDEROPEN THz-Skin project # 101257203 and by ATTRACT, a European Union's Horizon 2020 research and innovation project (GA 101004462, h-cube)

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Multifunctional Graphene Coatings for Advanced Electronic Packaging

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1. Summary

The increasing complexity of heterogeneous electronic systems requires packaging solutions capable of simultaneously addressing electromagnetic compatibility, thermal management, and structural integration [1]. In this work, an industrial-grade graphene nanoplatelet (GNP)-based material is investigated as a multifunctional coating for advanced electronic packaging applications. Unlike conventional solutions, where shielding, sensing, and heat spreading are achieved through separate components, the proposed graphene coating integrates all these functionalities within a single lightweight material platform. The investigated material, commercially available as G-Preg 50/50 from the company Nanasa [2], consists of graphene nanoplatelets dispersed in an epoxy matrix with a graphene content exceeding 50 wt.%.

A comprehensive experimental characterization was carried out to evaluate its electrical, thermal, and electromagnetic properties. Electrical measurements performed between $-40\text{ }^{\circ}\text{C}$ and $+60\text{ }^{\circ}\text{C}$ revealed a highly repeatable linear dependence of resistance on temperature, enabling the use of the coating as a distributed temperature sensor [3]. Thermal characterization demonstrated an in-plane thermal conductivity of approximately $330\text{ W m}^{-1}\text{ K}^{-1}$, highlighting the material's capability to efficiently spread heat [4]. Electromagnetic measurements in the 1–6 GHz frequency range showed shielding effectiveness values between 18 dB and 46 dB for a coating thickness of only 60 μm .

To demonstrate the practical impact of this multifunctionality, the material was applied as a coating on lightweight polymeric enclosures for automotive and aeronautical electronics. Experimental radiated-emission tests showed effective suppression of emissions generated by integrated wireless devices operating at 2.5 GHz and 5.5 GHz, ensuring compliance with stringent electromagnetic compatibility requirements (Fig. 1a). In parallel, the coating was successfully employed as a distributed temperature sensor with a maximum prediction error below $\pm 2\text{ }^{\circ}\text{C}$, Fig. 1b. Numerical thermal simulations further demonstrated heat-spreading performances comparable to those obtained using copper layers, while preserving the advantages of lightweight polymer-based structures.

The results confirm that industrial-grade graphene coatings represent a promising enabling technology for next-generation electronic packaging, combining electromagnetic shielding, thermal management, and sensing capabilities within a scalable and cost-effective solution. Such multifunctional materials can contribute to reducing system complexity, weight, and volume while improving reliability in future heterogeneous integration platforms.

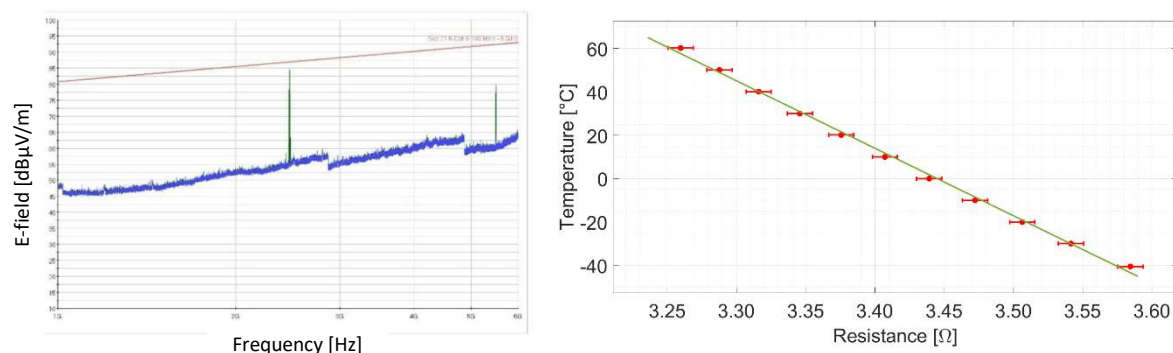


Fig.1 (left) Measured radiated emission in the range 1–6 GHz compared to the limits (red line) for aeronautical applications. Green curve: no coating; blue curve: double graphene coating; (right) Graphene-coating as a distributed temperature sensor: sensor response in the range $(-40^{\circ}\text{C}, +60^{\circ}\text{C})$, along with the uncertainty band.

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Evidence-Based Pathways from Research to Marketable Offers

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1. Abstract

A familiar moment in applied research occurs when a method, component, material, or prototype works well in the laboratory and appears “ready to sell”, but yet it is not a marketable offer: A customer must be identifiable, the problem it solves must be important enough to justify adoption, and the result must be reproducible, documented, supportable, manufacturable, and legally transferable. This talk examines that transition from the perspective of researchers who may not intend to become full-time entrepreneurs, but who do want to evaluate whether a scientific result is suited for commercialization and how. Established tools from *customer discovery*, *lean startup*, and *business model thinking* [1–3], should be treated as heuristics rather than recipes. Their enduring value is not the vocabulary of “MVP”, “sprint” or “pivot”, which can be misleading outside of software development, but it is the discipline of testing assumptions early and repeatedly, before committing major resources. This interpretation is consistent with recent evidence on a *scientific approach* to entrepreneurship: Entrepreneurs who formulate and test hypotheses seem to make better decisions under uncertainty [4], tend to terminate weak ideas faster and move towards more focused strategic change [5].

A central distinction developed in the talk is that *technology* readiness, *market* readiness, and *business* readiness are related but different and complementary. The Technology Readiness Level (TRL) provides a useful language for technical maturity [6], but it does not answer whether the solution addresses a concrete customer pain, whether market conditions support adoption, or whether the offering can be delivered at acceptable cost and risk. The *technical* readiness needs to be followed by a *commercial* readiness assessment [7], i.e. by a scientific evidence-based method of experimentation [8], and may be augmented by a stage-gate approach adapted for deep-tech academic commercialization [9]. All these provide complementary frameworks that point toward a broader, multifaceted and more current practice: It is crucial to match technical validation with evidence for customer validation, with efforts for productization, with an intellectual-property strategy, with manufacturing feasibility checks, and with a suitable route-to-market choice. For photonics products or similar, this productization gap is particularly important. The “product” may be not only just a metasurface, a laser module, a nanomaterial, a coating, a spectroscopy method, or a bio-photonic protocol, but it will likely need to include calibration, tolerances, documentation, installation, safety classification, quality control, warranty and customer support, in order to provide value to the customer.

The practical aim of this short talk is therefore to not to teach or promote entrepreneurship, but rather to guide towards tools for a decision filter: Before asking “How can we sell this?”, ask “What evidence would prove that this could (or rather should) become a product, or a service, or a license, or a partnership, or even an independent company?” The desired outcome is not business for business sake, but rather to take earlier and better decisions about which scientific insights deserve further commercialization efforts, how to prove this, and how to move on from there.

2. Acknowledgement

Co-funded by the EU Horizon Europe project 101228127. Views and opinions expressed are those of the author only and do not necessarily reflect those of the *European Union* or *European Innovation Council and SMEs Executive Agency*. Neither the European Union nor the granting authority can be held responsible for them.

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From Photon Conversion to Biomedical Innovation: Rare Earth Nanoparticles at the Interface of Nano- and Bio-Photonics

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Since first reported, luminescent rare earth doped nanoparticles have attracted a great deal of interest. In the last decade, however, the field has rapidly taken off, progressing from the basic understanding of the photophysical properties governing their nanoscale luminescence, in particular upconversion, to their use in a plethora of applications, with considerable focus in biology and medicine. This interest stems primarily from the ability to stimulate these luminescent nanoparticles with near-infrared (NIR) light as well as their diverse emission wavelengths spanning the UV to the NIR. Therefore, with a single NIR excitation wavelength, it is possible to observe higher energy luminescence, known as upconversion, or single photon NIR emission (known as down-shifted luminescence). The former upconversion process proceeds through the sequential absorption of multiple NIR photons through the long-lived $4f$ electronic energy states of the tri-positive rare earth ions. As a result, upconversion is several of orders more efficient than conventional multiphoton absorption processes. This is especially interesting for applications in theranostics (**therapy** + **diagnostics** on the same platform) where the upconverted light can be used to trigger another light activated modality (therapy) while the NIR luminescence can be used for bioimaging and thermometry (diagnostics) [1-3]. Here, we present our work on the synthesis and development of various NIR excited (and emitting) core/shell rare earth doped nanostructures/nanoplatfroms and demonstrate how their various emissions could be harnessed for applications in biology and nanomedicine.

Figures and tables should be centered or placed side by side (depending on the figure size) and located inside paper margins. Text should not wrap around figures or tables; table captions (10-point font) should be centered above tables, and figure captions (8-point font) should be centered below figures (see Fig.1). Both should appear as close as possible to where they are mentioned in the main text.

Figure 1. Top: Lifetime images of core/shell UCNPs with the shell thicknesses of 1.9, 3.5, and 5.6 nm covered by transparencies of letters “C”, “A”, and “N” in green emission. Bottom: Lifetime images of green and red upconversion emission bands under different temperatures [1].

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Numerical investigation of cell electroporation in presence of nanoparticles

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Cell electroporation is a physical phenomenon that appears at cell membrane level when the biological cell is subjected to a designed electric field. In particular, pulsed electric fields from nanosecond to microsecond pulse duration induce an increase of the cell permeability due to the formation of membrane pores. The phenomenon maybe transient, leading to a reversible electroporation useful to have a controlled molecules transport through the membrane, or permanent, having an irreversible electroporation useful to cell destroying. The efficacy of the treatment is strongly dependent on the electric field shape, uniformity and distribution. The introduction of nanoparticle around the cell is here considered to numerically investigate their influence on the cell electroporation phenomenon. The electric field distribution around the cell membrane and the surrounding medium is evaluated by time domain solving a two-dimensional finite-element Multiphysics model coupling Maxwell electromagnetic equations with the asymptotic approximation of the Smoluchowski equation, accounting for the morphological modification of the cell membrane. The results show that the nanoparticles induce a highly localized perturbation of the electric field, whose magnitude depends on the sampling region and electrical conductivity contrast. Moreover, the pore-density analysis further indicates that the nanoparticles don't induce a generalized increase in electroporation-related parameters and may locally reduce pore density near the nanoparticle-membrane interface in dependence of their shape and of the electrical and magnetic characteristics. The presented study is considered as a basis for future experimental investigations of nanoparticle-electroporation interactions.

Data-Driven Tissue Recognition: Revolutionizing Precision and Safety in Neurological Oncology Surgery

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1. Background

Accurate tissue identification remains one of the most critical challenges in oncological surgery, particularly in neurosurgery, where the boundaries between malignant tumors and functional brain tissue are exceptionally narrow. Marginum is addressing this challenge by developing ground-breaking, data-driven tissue recognition technology designed to enhance surgical precision and optimize patient outcomes.

2. Objective

This presentation introduces Marginum's innovative technology and demonstrates its specific application in brain tumor resections. The objective is to illustrate how real-time, data-driven tissue differentiation can radically improve surgical performance, maximize cancerous tissue removal, and minimize damage to healthy, vital brain structures.

3. Methods & Core Innovation

By leveraging advanced data processing, the technology provides surgical teams with immediate, reliable feedback during operations. This fills a crucial gap in current neurosurgical workflows, transitioning from subjective visual assessment to objective, data-backed identification.

The fluorescence guided surgery is shown in the Fig.1 below:

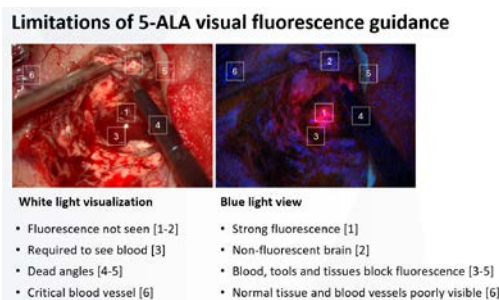


Fig.1 Pinky fluorescence under blue light

Pinky fluorescence under blue light allows doctor to see the tumor. The core innovation of Marginum is spectral analyses of reject tissue [1] and providing in real time tissue identification with immediate feedback to the doctor.

4. References

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<https://www.marginum.com/en/news/first-in-human-study-hiven-performance-and-safety-results>

Optical Physical Reservoir Computing in an FGaT/WS₂ Valleytronic Heterostructure

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1. Introduction

Physical reservoir computing (RC) maps inputs into a high-dimensional feature space via the fixed nonlinear dynamics of a physical substrate, so that only a linear readout is trained [1–3]. Monolayer WS₂ provides an optically addressable valley degree of freedom, while magnetic proximity from the above-room-temperature ferromagnet Fe₃GaTe₂ (FGaT) strongly enhances valley polarization in adjacent WS₂ [4–7]. Here we demonstrate all-optical valleytronic RC in an FGaT/WS₂ heterostructure by encoding the power-dependent, helicity-resolved responses of excitons (X⁰), trions (X^T), and charged biexcitons/quintons (Q) as reservoir states.

2. Device and valley-polarized excitonic response

The heterostructure was assembled by dry transfer onto SiO₂/Si and encapsulated with hBN. Raman spectroscopy confirms monolayer WS₂ and the A₁/E₂ modes of FGaT; magnetotransport verifies ferromagnetism with perpendicular anisotropy up to 300 K. Helicity-resolved photoluminescence (PL) at 4 K under cw 532 nm excitation resolves three channels with valley polarizations $\rho = (I\sigma^+ - I\sigma^-)/(I\sigma^+ + I\sigma^-)$ of 25% (X⁰), 33% (X^T), and 4.8% (Q)—about threefold larger for X⁰ and X^T than in monolayer WS₂. Both $\rho(X^0)$ and $\rho(X^T)$ increase with excitation power, while $\rho(Q)$ remains nearly power-independent, supplying complementary nonlinear valley features for reservoir encoding.

3. All-optical reservoir computing

Reservoir states are taken from the helicity-resolved PL response to a power-modulated input; only a ridge readout is trained. Each MNIST image is encoded into a 56-step power sequence. A bare-PL baseline reaches 74.8% accuracy, while full valleytronic features raise it to 87.5%; ablating σ^+/σ^- contrast or the Q channel lowers accuracy. For Mackey–Glass ($\tau = 17$) one-step prediction, NRMSE ≈ 0.1714 ; without valley contrast, NRMSE rises to ≈ 0.22 . Joint exploitation of valley and excitonic degrees of freedom is thus a key source of expressivity.

4. Conclusions

We demonstrated an all-optical RC platform on Fe₃GaTe₂/WS₂, where magnetic proximity and power-tunable excitonic complexes jointly provide helicity-resolved nonlinear features. 2D ferromagnet/TMD heterostructures thus offer a scalable photonic RC substrate exploiting valley, charge, and many-body degrees of freedom.

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Author index

Adigun Deborah Amos	9, 32, 49	Fang Yue	88
Aikio Sanna	62	Fatemi Surena	57
Akar Ziad Abi	57	Fazlpour Behnaz	40
Aldrigoc Martino	16	Fedorov Georgy	13, 21, 23, 33, 37, 41, 42, 43, 49, 81
Ali Fida	70	Fickler Robert	14
Alsamsam Mohammad Nour	56, 59	Filonenko Elena	36, 46, 58
Amedalor Reuben	67	Friberg Ari T.	8, 40, 48
Amenty Chivintar	33	Genevet Patrice	2
Ancel Roy Konnath	57	Gil José J.	8
Antonovič Dariuš	19	Giovinco G.	83
Arnardottir Kristin B.	65	Giuressi Dario	13, 37, 81
Asilevi Atsu L.	67	Gnatyuk O.	41, 42
Ayyagari R.	27	Goffart Steffi	9, 32
Bachmann David	64	Golberg Dmitri V.	68
Bagdonaitė Ugnė	59	Gomes Antonin Patricio	66, 75
Banijamali Ali	34	Gorbun Mikhail	23, 43
Bartolomeoa Antonio Di	16	Govind Diya	44
Belko Nikita	9, 11, 23, 32, 45, 51, 54	Grandhi G. Krishnamurthy	11
Bertoni Benedetta	13, 37, 81	Grincevičienė Š.	56
Białek Marcin	3	Gubareni Ie.	41
Bičiūnas Andrius	35, 47	Gulka Michal	61
Bramwell Alex	36, 52	Guo Tian-Long	62, 75
Buchleitner Andreas	50, 64	Hagenmuller David	3
Butkutė Renata	35	Hakala Tommi K.	14, 34, 38, 78
Cai Yangjian	39	Hakamada Yuki	46
Callegari R. David	80	Halder Atri	5, 44, 78
Calpe Roman	14, 38, 78	Halimski Ivan	45, 76
Carlo Gaia Di	13, 37, 81	Hanhisalo Martti	5
Cautero M.	13, 37	Heikkinen Janne I.	78
Cautero Giuseppe.	13, 37, 81	Hiltunen Jussi	62
Cavaliere G.	83	Horoshko Dmitri B.	7, 73
Čechavičius Bronislovas	35	Huang Youqiang	70, 88
Charrouj Nouredine	3	Huttunen Mikko J.	14
Chen Yahong	4, 8, 39, 48	Iadanza Simone	80
Chen Biao	69	Ibekwe Emmanuel Etebong	11
Chernenko O.G.	41	Ikamas K	47
Chmeliov Jevgenij	45	Indrišiūnas S.	27
Cigler Petr	61	Islam Najirul	6
Cojocari Maria	23, 83	Ito Hiroshi	25
Colja Matija	81	Ivonyak Yurii	3
Copak Jakub	61	Janonis Vytautas	21, 27, 43, 74
Couteau Christophe	57	Jelezko Fedor	7, 60
D'Olimpiob Gianluca	16	Jorudas Justinas	21, 28, 33
Dadianib Tsotne	16	Justus Jency	66
Daraei M E	47	Kamarauskas Mindaugas	35, 47
Descrovi Emiliano	75	Karpicz Renata	9, 12, 45, 54, 76
Dijken Sebastiaan van	88	Karvelis Tautvydas	59
Dinescuc Adrian	16	Kašalynas Irmantas	21, 27, 28, 33, 43, 74
Don Pathum Ranawalage	38	Kauppinen Esko	43, 49
Dong Zhen	8, 39	Kawano Shotaro	77
Dovbeshko G.	41, 42	Kazakov Alexander	3
Dudutienė Evelina	35	Keeling Jonathan	65
Durantea Ofelia	16	Keršulis Skirmantas	19
Ehret Tim	50, 64	Khalid Fooqia	70
Faellab Enver	16	Kliuchka V.	41

Knap Wojciech	3	Onodera Hiroshi	53
Koivurova Matias	17, 18, 67, 78	Otoo Isaac Appiah	51, 83
Konishi Kuniaki	46, 49, 77	Pačebutas V	47
Kopūstas Aurimas	56, 59	Pandian Santhosh	67
Kovalevskij Vitalij	28, 47	Parvulescuc Catalin	16
Kruse Jann E.	84	Pashnev Daniil	43
Kuod Chia-Nung	16	Passacantandob Maurizio	16
Kuzhir Polina	9, 11, 12, 13, 21, 23, 32, 36, 37, 41, 42, 43, 46, 49, 51, 52, 54, 58, 73, 81	Patricio-Gomes Antonin	66, 75
Kvietkauskaitė A.	56	Pelellaa Aniello	16
Laatikainen Jyrki	44	Pennanen Janna	18
Lähderanta Erkki	45	Perebeinos Vasili	20
Lamberti Patrizia	86	Pereshivko Olga	10
Łapkiewicz Radosław	58	Peshkov Vsevolod	10
Le Duc	62	Petit Laetitia	66
Lehto Vesa-Pekka	23	Pitanti Alessandro	13, 37, 81
Lempicka-Mirek Karolina	80	Plaušnaitienė Valentina	19
Leskinen Jari T.T.	23, 51	Politanob Antonio	16
Levin Roman	51	Prystawko Pawel	28, 74
Li Fangfang	66, 75	Quarshie Mariam	12, 46, 52
Li Shuang	88	Rafsanjani Nima	75
Lin Qia	80	Ramanan Pradeep	66
Lipsanen Harri	88	Rantaeskola Kaisa	48
Liu Yonglei	39	Rao A. Srinivasa	77
Liu Kaihui	80	Reduto Igor	67
Lued Chin Shan	16	Rindzevičius Paulius	12, 76
Łusakowski Jerzy	3	Roussey Matthieu	62, 66, 75
Macutkevič J.	27	Saastamoinen Kimmo	8, 44, 48, 67
Maffucci A.	83	Sakurai Haruyuki	46, 72, 77
Mahrt Rainer F.	65	Saniuk Mirosław	28
Maltanava Hanna	9, 11, 23, 32, 45, 51, 54	Saushin Aleksandr	23, 43, 49, 51
Malykhin Sergei	12, 23, 36, 46, 51, 52, 58, 76	Scherf Ullrich	65
Malysheva T.A.	41	Sehrawat Sagar	69
Mansell Rhodri	88	Selenius Mikko	23
Matoba Mizuho	49	Semenov Dmitry	23, 87
Matulienė J.	56	Sessaa Andrea	16
Matulis D.	56	Setälä Tero	5, 8, 18, 39, 40, 44, 48
Mekhael Madona	14	Sfeir Elias	57
Menon Aadya	21, 23, 49	Shan Shengyu	80
Moilanen Antti J.	34, 38, 65, 78, 80	Shatokhin Vyacheslav	50, 64
Monastyrskiy G.	42	Shevchenko Andriy	69
Mondal Tanu Prava	46	Shmeleva A.	41
Morishita Yusuke	53	Shuba Mikhail	21
Moscotin Maxim	21, 28	Shundalau Maksim	45
Moselund Kirsten	80	Sibilia S.	83
Murakami Takumi	53	Siconolfi F.	83
Nagatsuma Tadao	24	Sieni Elisabetta	86
Nardone Emanuele	33	Solonovich Nikita	36, 52, 73
Nasiri Ayda	62	Soltaneshagh Arya	51
Němec Petr	66	Špokas Aivaras	35
Nevinskas I	47	Stanionytė Sandra	35
Niemi Tapio	67	Stankevič Voitech	19
Norrman Andreas	5, 6, 8, 40, 44, 48	Stefanoa Sebastiano De	16
Novotny Lukas	80	Steiner Filip	61
Olenchuk M.	42	Stöferle Thilo	65
Omatsu Takashige	77	Strashko Artem	65
		Sultan Rizwan	52
		Sun Zhipei	70, 88
		Suvanto Sari	23, 51
		Tamarov Konstantin	9, 23

Tanaka Asami	53
Taniguchi Takashi	80
Tari L.	83
Todorov Yanko	3
Törmä Päivi	65
Tredicucci Alessandro	13, 37, 81
Tucci Vincenzo	86
Tutkus Marijonas	56, 59
Tylutki Marek	30
Uehara Kenji	53
Umansky Vladimir Y.	3
Umar Muhamad	74
Urbanovič Andžej	26, 33, 43
Urbonas Darius	65
Valkunas Leonas	76
Vertelis Vilius	19
Vetrone Fiorenzo	85
Vitulskienė Ernesta	59
Vivo Paola	11
Vizbaras D	47
Vos Winnok H. De	9
Wang Fei	39
Watanabe Kenji	80
Xue Guodong	80
Yavorskiy Dmitriy	3
Yrjänheikki Laura	38, 78
Yumoto Junji	53, 71
Zalickas Martynas	9, 54
Zaremba Mindaugas	59
Zelioli1 Andrea	35
Zhenyu Xu	43
Zhu Yimeng	39
Ziegler Jonas D.	80
Žurauskienė Nerija	19
Žvirblis M.	56