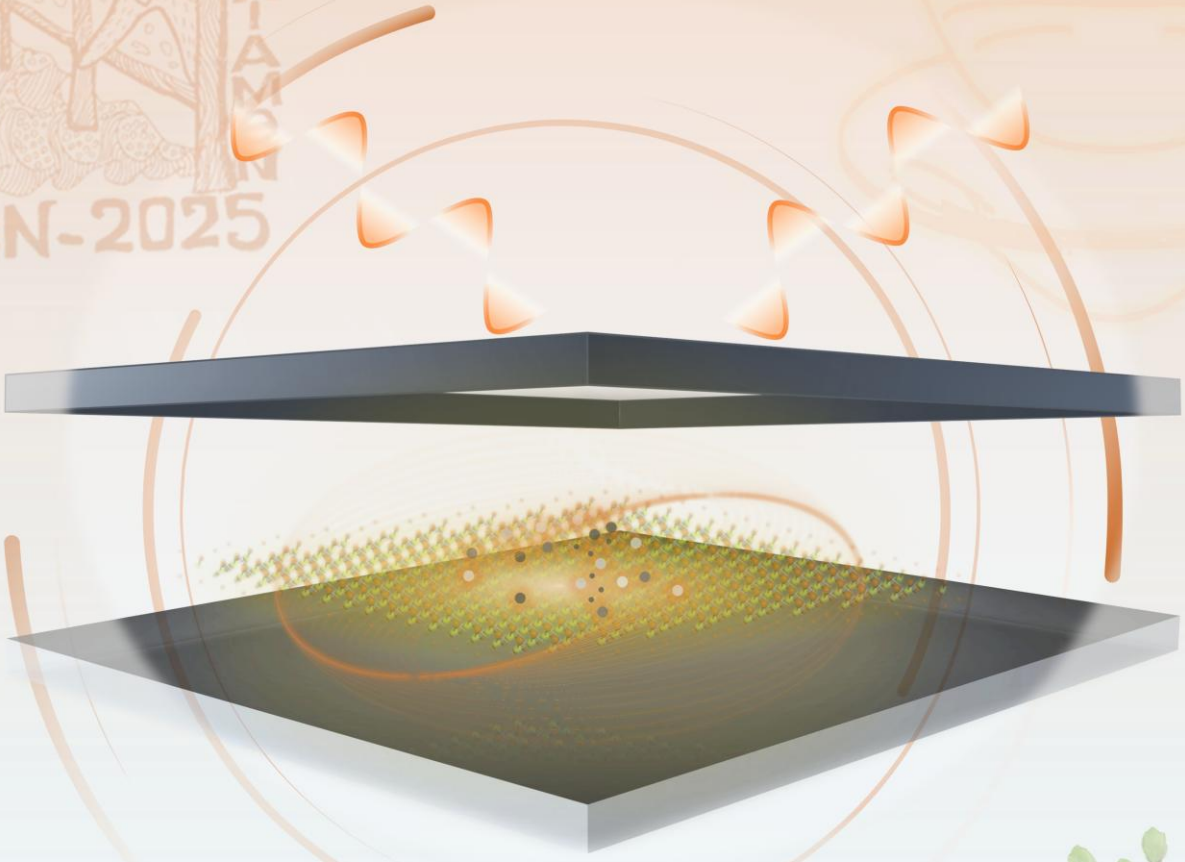
Book of Abstracts

25th
edition of the

PHYSICS OF LIGHT-MATTER COUPLING IN NANOSTRUCTURES



8-13 April 2025
Xiamen, China

Welcome to PLMCN25!

Dear Conference Participants,

In this booklet, you will find a collection of abstracts submitted to the 25th edition of the International Conference on Physics of Light-Matter Coupling in Nanostructures. As an annual conference originating in Europe, we are deeply honored to celebrate PLMCN's 25th anniversary here in Xiamen, China.

I have attended the PLMCN conferences almost every year since 2010. It is not only a wonderful opportunity to exchange our understanding of light-matter coupling in nanostructures, but also a joyous gathering of old friends. We are committed to preserving the core spirit of PLMCN and passing it on to the next generation of researchers.

I would like to express my sincere gratitude to Long Zhang, Song Luo, Haiyan, Giuseppe Eramo, and Salvatore Monteleone, who made this event possible. There are many other wonderful volunteers, who also made incredible contributions.

In closing, I invoke an ancient Chinese proverb: 'Is it not delightful to have friends coming from afar?' I wish you all a pleasant stay in Xiamen and great success in your endeavors!

Enjoy your PLMCN!

Zhanghai Chen

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Conference Chair: Zhanghai Chen (Xiamen University, China)

Conference Chair: Alexey Kavokin (Moscow Institute of Physics and Technology, Russia; St-Petersburg State university, Russia)

Program Committee Chair: Long Zhang (Xiamen University, China)

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Xiulai Xu (China)

Contents

Conference Guide

Access to the campus：

Access to the campus during the conference has been arranged for all attendees. International participants can enter using facial recognition, while domestic participants are required to bring their ID cards for initial entry.

Accommodation：

On campus Hotels

- Yifu Building
- Jianwen Building
- Keli Building
- Wutong Building

Address: Xiamen University No. 422 Siming South Road Siming District, Xiamen, Fujian, China (福建省厦门市思明区思明南路422号)

Distance to the conference venue: 5~10 minutes by walk.

Off campus Hotel

- X Future Hotel (free shuttle between the hotel and conference venue provided)

Address: No.158, Zeng cuo an North Road, Siming District, Xiamen, Fujian China.
福建省厦门市思明区曾厝垵北路158号

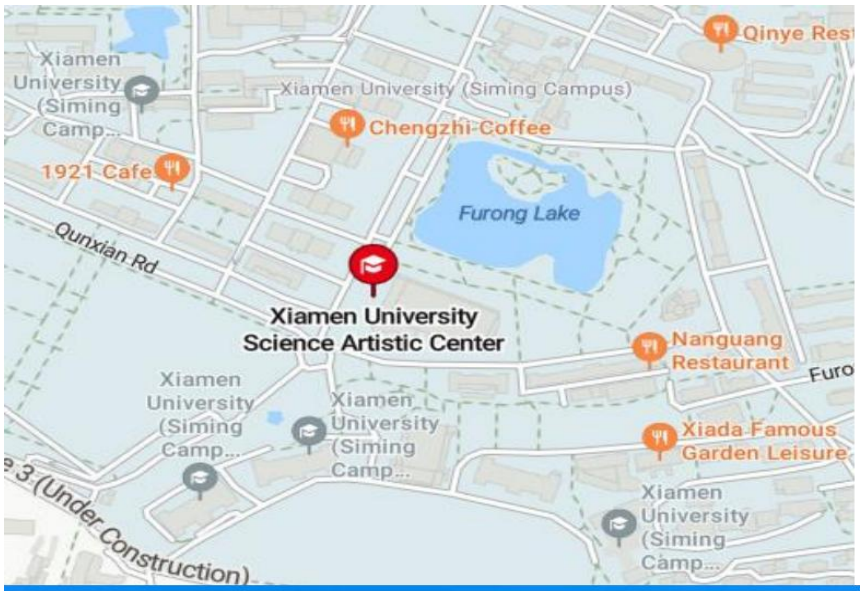
Note: Please be aware that taxis are NOT allowed to enter the campus. If you stay at other hotels, please take a taxi to the South Entrance near Nanputuo Temple and walk to the conference venue, which will take approximately 10 minutes.

请打车至南普陀寺附近校门，步行5分钟至会场。

Conference Venue：

Science and Art Center Xiamen University No. 422 Siming South Road, Siming District, Xiamen, Fujian 361005, China

福建省厦门市思明区思明南路422号厦门大学 科学艺术中心



Activities

Day	Activities	Extra Activities
04/08 TUE	Registration	
04/09 WED	Full day work	18:30-20:30 Banquet
04/10 THU	Full day work	Free time
04/11 FRI	Excursion Full Day to Gulangyu Island	16:15-18:15 Poster Session 18:30-20:30 Dinner Beachfront Restaurant
04/12 SAT	Full day work	Free time
04/13 SUN	Full day work	Free time
04/14 MON	Departure	

Talks

The scientific program of the conference will start at 8:20 AM on April 9 and end at 6 PM on April 13. It consists of 4 keynote talks, 44 invited talks, 33 oral talks, and 30 poster presentations. The official language of the conference is English, no translation or interpreting facilities will be available. No recording or streaming will be performed.

Note for participants

Please silence your mobile phone while you are in the meeting room. Audio or video recordings are not permitted during the scientific sessions.

Note for speakers

To avoid any technical issues, please test your presentation 5 minutes before the session of your talk. Keynote talks are 35 minutes including at least 5 minutes of discussion, Invited talks are 25 minutes including at least 5 minutes of discussion and oral talks are 15 minutes including 2 minutes of discussion. To ensure all the sessions can be completed on time, please stick to the allotted time. The volunteers will give you a signal 2 minutes before the start of the discussion time to remind you to conclude your talk swiftly.

Note for poster presentations

The poster session is arranged in the exhibition hall on the first floor of the Science and Arts Center. The poster size should be 90 cm (width)×110 cm (height). The conference provides poster printing services.

Webpage:

The official conference website in English: https://events.mifp.eu/PLMCN-2025/
The official conference website in Chinese: https://www.plmcn2025.com/

Organizers:

Xiamen University, China
Mediterranean Institute of Fundamental Physics, Italy

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Name badge:

Each participant will receive a conference name badge upon registration, which should be worn during the scientific and social program for identification purpose.

Public transportation:

Shuttle services are provided. Please feel free to contact our volunteers for advice.

Xiamen is a significant port city and economic hub located on the southeastern coast of China, in Fujian Province. With a population of approximately 5 million, Xiamen has long been an important gateway for China's foreign exchanges. Its advantageous geographical location, coupled with its coastal and mountainous terrain, has earned it the reputation of a "Garden City on the Sea." Xiamen's history dates back to the Tang and Song dynasties. During the Ming and Qing dynasties, it became a major maritime trading port. In the mid-19th century, it became one of China's first five treaty ports opened to foreign trade. This exposure fostered Western cultural influences, contributing to its unique blend of Chinese and Western architectural and cultural styles. Today, Xiamen is a modernized Special Economic Zone (SEZ) and a highly livable city, renowned for its culture, beautiful scenery, and appeal to tourists worldwide. Whether pursuing academics at Xiamen University or exploring its coastline, visitors find Xiamen a place of inspiration and opportunity.

Etymology

The name "Xiamen" first appeared during the Ming Dynasty, meaning "the gate of a grand mansion," symbolizing its strategic position as a gateway to Fujian's coastal regions. Historically, Xiamen was also called "Jiahe Islet" due to its geographical location and played a crucial role in the defense of southeastern China.

Geography and Climate

Xiamen consists of the main Xiamen Island, surrounding islets, and areas along the northern banks of the Jiulong River. It features picturesque bays, beaches, and islands. The highest peak in the region is Tianzhu Mountain, standing at 1,175 meters. The city enjoys a warm and humid subtropical monsoon climate, with an average annual temperature of around 21°C, making it an ideal place for living and tourism.

Xiamen University (XMU), one of China's most prestigious universities, located in Xiamen, Fujian Province. Renowned as "one of China's most beautiful campuses", it was founded in 1921 by Tan Kah Kee, a celebrated patriotic leader of overseas Chinese. As the first modern Chinese university established through overseas Chinese philanthropy, XMU has evolved over its century-long history into a comprehensive research institution with robust academic programs and global partnerships.

Historical Development

The university's name reflects its host city's spirit of openness. In 1919, Tan Kah Kee mobilized fundraising among Southeast Asian overseas Chinese, culminating in XMU's founding in 1921. Initially comprising four faculties—Arts, Sciences, Law, and Business—it was restructured in 1952 to become a national hub for marine science, economics, chemistry, and mathematics. Today, XMU maintains leadership in multiple disciplines worldwide.

College of Physical Science and Technology

The physics discipline at XMU was initiated in 1923, with the Department of Physics formally established in 1924, making it one of China's earliest institutions to systematically provide physics education. The department began postgraduate enrollment in 1978 and developed distinctive strengths in semiconductor physics and other fields. In 1999, the School of Physics and Mechanical & Electrical Engineering was established, which was renamed in 2015 as the School of Physical Science and Technology. The school now comprises departments including Physics and Astronomy, forming a comprehensive disciplinary system covering theoretical physics, condensed matter physics, optics, and more.

Campus and Locations

Xiamen University has four campuses: Siming, Xiang’an, Zhangzhou, and Malaysia. The Siming Campus, located in central Xiamen, is the university’s oldest and most well-known campus, featuring traditional architecture and key academic departments. The Xiang’an Campus, on Xiamen’s eastern coast, focuses on research and innovation in fields such as medicine and marine sciences. The Zhangzhou Campus, across the bay

in Fujian Province, provides a spacious learning environment, while the Malaysia Campus extends XMU's academic influence internationally. Together, these campuses reflect Xiamen University's commitment to excellence in education and research.

Program

Program of PLMCN2025

Tuesday, April 8th: Full day registration (Science and Arts Center, 2F)

Lunch: Buffet in Yifu building (1F, Boxue Cafe)

Dinner: Buffet in Yifu building (1F, Boxue Cafe)

Wednesday, April 9th (Science and Arts Center, 2F, Concert Hall)

Session 1. 08:20-9:40. Quantum Optics of Excitons and Polaritons. Chairman: Zhanghai Chen

Time	Duration	Speaker & Title
08:20	20’	Opening Speech: Yancheng You, Zhanghai Chen, Alexey Kavokin
08:40	30’+5’	Wang Yao | Keynote Hybrid Moiré Excitons in Twisted Homobilayer TMDs
09:15	20’+5’	Alexey Kavokin Entanglement of Exciton Polariton Condensates

Coffee Break: 09:40-10:10

Session 2. 10:10-11:40. Quantum Optics of Excitons and Polaritons. Chairman: Wang Yao

Time	Duration	Speaker & Title
10:10	30’+5’	Mark Fox | Keynote Purcell-Enhanced Quantum-Dot Single-Photon Sources
10:45	20’+5’	Jin Liu Semiconductor Cavity Quantum Electrodynamics
11:10	13’+2’	Hui Li Ultrafast Dynamics of Exciton Polaritons at Room Temperature
11:25	13’+2’	Jiaxin Zhao Exciton-Polariton Interactions in Van der Waals Superlattices

Lunch: Buffet in Yifu building (1F, Boxue Cafe)

Session 3. 14:00-15:50. Excitons & Exciton Polaritons. Chairman : Alexey Kavokin

Time	Duration	Speaker & Title
14:00	30’+5’	Sven Höfling | Keynote Telecom Wavelength Quantum Dot Single-Photon Sources for Quantum Technologies
14:35	20’+5’	Jesus Zuniga-Perez In-Plane Polaritons: From Edge-Emitting Polariton Lasing to Long-Distance Propagation
15:00	20’+5’	Pavlos Savvidis ProtoTopic Polariton Superfluid Qubit Analog in an Annular Trap
15:25	20’+5’	Fabrice Laussy Quantum Characterization of a Polariton BEC

Coffee Break: 15:50-16:20

Session4. 16:20-17:45. Quantum Optics of Nano&Micro Cavities. Chairman: Pavlos Savvidis

Time	Duration	Speaker & Title
16:20	30’+5’	Yuri Kivshar | Keynote Chiral Metaphotonics and Mie-tronics
16:55	20’+5’	Xiulai Xu Mode and Polarization Control of Photonic Molecules
17:20	20’+5’	Said Rodriguez Continuous-Wave Nonlinear Polarization Control and Signatures of Criticality in a Perovskite Cavity

Banquet: Yifu Building (2F, Banquet Hall)

Violin Performance by Professor Feng Li

Thursday, April 10th – Session A (Science and Arts Center, 1F, Conference Room No.1)

Session A1: 08:30-10:00. Dissipative Coupling and Organics Polaritons. Chairmen: Yuri Kivshar

Time	Duration	Speaker & Title
08:30	20'+5'	Jiang Xiao Interpreting S-Parameter Spectra in Coupled Resonant Systems - The Type of Probing Configurations
08:55	20'+5'	Dmitry Solnyshkov Topological Polaritonics with Organic Materials
09:20	20'+5'	Hongbing Fu Realization of Exciton-Mediated Optical Spin-orbit Interaction in Organic Microcrystalline Resonators for Circularly Polarized Electroluminescence
09:45	13'+2'	Henri Lyyra Criteria for Polaritonic Enhancement of OLEDs Beyond the Single-Excitation Case

Coffee Break: 10:00-10:30

Session A2:10:30-11:50. Quantum Dots& Quantum Light Sources. Chairman: Jin Liu

Time	Duration	Speaker & Title
10:30	20'+5'	Luca Sapienza Quantum Photonic Devices with Integrated Quantum Dots
10:55	20'+5'	Alexey Toropov Single-Photon Emission at 1.55 μm Wavelength in a Metamorphic Quantum Dot Microcavity Under Resonant Coherent Excitation
11:20	13'+2'	Yuriy Serov Quantum Dots Anisotropy as a Resource in Multiphoton Entanglement
11:35	13'+2'	Maxim. Rakhlin Fiber-Coupled Single-Photon Source Based on InAs/GaAs Quantum Dots in Cylindrical Microresonators

Lunch: Buffet in Yifu building (1F, Boxue Cafe)

Session A3: 14:00-15:15. Quantum Dots& Quantum Light Sources. Chairman: Sven Höfling

Time	Duration	Speaker & Title
14:00	20'+5'	Elena Del Valle Multiphoton Emission from a Single-Photon Source and Single-Photon Emission from Multiple Levels
14:25	20'+5'	Moritz Cygorek Phonon Effects on Quantum Emitters and Novel Tools for Fast yet Exact Simulation
14:50	20'+5'	Xujie Wang A Pure-State Model for Resonance Fluorescence of a Two-Level Quantum Emitter

Coffee Break: 15:15-15:45

Session A4: 15:45-17:40. Polariton Condensation. Chair: Elena Del Valle

Time	Duration	Speaker & Title
15:45	20'+5'	Jianqiang You Cavity Magnonics and Quantum Magnonics
16:10	20'+5'	Xinfeng Liu Exciton Polariton Condensation from BIC at Room Temperature
16:35	20'+5'	Yong-Hoon Cho Room-Temperature Polariton Condensation and Control in GaN-Based Whispering Gallery Mode and Superscar Mode Microcavities
17:00	20'+5'	Qing Zhang Room Temperature Exciton-Polariton Condensation in Perovskite Microcavities
17:25	13'+2'	Bo Han Exciton Polariton Condensate in the van der Waals Magnet CrSBr
17:40	13'+2'	Qijun Ren | Sponsor T.B.C

Dinner: Buffet in Yifu building (1F, Boxue Cafe)

Thursday, April 10th– Session B (Science and Arts Center, 2F, Concert Hall)

Session B1: 08:30-10:10. Quantum Optics of 2D Materials. Chairmen: Daniele Sanvitto

Time	Duration	Speaker & Title
08:30	20'+5'	Qihua Xiong Manipulating Nonlinear Interactions in TMD Materials and Microcavities
08:55	20'+5'	Shiwei Wu Magnetic Polymorphism in 2D Layered Antiferromagnets
09:20	20'+5'	Yu Ye Exciton Behavior in Magnetic Semiconductor CrSBr and Its Related Optoelectronic Devices
09:45	20'+5'	Yang Xu Interplay between Moiré Superlattices and Rydberg Excitons

Coffee Break: 10:10-10:40

Session B2: 10:40-11:55. Polariton Supersolid Chairmen: Qihua Xiong

Time	Duration	Speaker & Title
10:40	20'+5'	Dario Gerace Theory of Polariton Condensation in Multi-Band Photonic Crystal Waveguides
11:05	20'+5'	Guillaume Malpuech Observation of a Supersolid Phase in a Spin-Orbit Coupled Exciton-Polariton Bose-Einstein Condensate
11:30	20'+5'	Daniele Sanvitto Quantum Fluids of Light: From Condensation to Emergent Supersolidity

Lunch: Buffet in Yifu building (1F, Boxue Cafe)

Session B3: 14:00-15:45. Exciton Polaritons in TMDs Chairmen: Guillaume Malpuech

Time	Duration	Speaker & Title
14:00	20'+5'	Tatiana V. Shubina Excitons and Exciton-Polaritons in Strained Nanostructures of Transition Metal Dichalcogenides
14:25	20'+5'	Shunping Zhang Plasmonic Nanocavity: Ultimate Field Enhancement for Plasmon-Exciton Coupling
14:50	20'+5'	Chenjiang Qian Exciton-Photon-Phonon Interactions in Hybrid 2D-Material Nanophotonic Cavities
15:15	13'+2'	Zheng Sun Quantum Dynamics of Polaron Polariton In a Doped $MoSe_2$ Based Microcavity
15:30	13'+2'	Xin Li Van der Waals Exciton Polaritons with Linewidth Approaching Homogeneous Limit

Coffee Break: 15:45-16:15

Session B4: 16:15-17:55. Excitons and Electrons in 2D system. Chairmen: Shiwei Wu

Time	Duration	Speaker & Title
16:15	20'+5'	Mikhail Glazov Light-Assisted Exciton Propagation in 2D Semiconductors
16:40	13'+2'	Hongyi Yu Engineering Topological Exciton Structures in Two-Dimensional Semiconductors by a Periodic Electrostatic Potential
16:55	13'+2'	Qingjun Tong Non-Hermitian Theory of Valley Excitons in Two-Dimensional Semiconductors
17:10	13'+2'	M.A. Bastarrachea Magnani Ultra-Strong Trion Polaritons
17:25	13'+2'	Dmitry Efimkin Giant Resonant Skew Scattering of Plasmons in a Two-Dimensional Electron Gas
17:40	13'+2'	Dongxue Chen Excitonic Insulator in 2D Moiré Superlattices

Dinner: Buffet in Yifu building (1F, Boxue Cafe)

Friday, April 11th, Excursion, Poster Session, and Beachfront Dinner

Excursion: One-Day Gulangyu (鼓浪屿) Island Tour

8:00 Depart: Science & Art Center (conference venue)

08:00 - 09:50 Transfer: Bus to Xiamen International Cruise Center (Dongdu Pier)

09:50 - 10:10 Ferry: 20-min ferry to Gulangyu Island

10:10 - 10:40 Gulangyu Walk: Past historical consulates & churches (photo stop at Catholic Church)

10:40 - 11:10 Longtou Street: Explore alleys & local atmosphere

11:10 - 12:10: Shuzhuang Garden & Ancient Piano Museum

12:10: Lunch: Buffet at Gulangyu Villa

Until 15:40: Free time on Gulangyu Island

15:40: Ferry: Depart for Xiamen

Approx. 16:00 Arrive: Xiamen International Cruise Center

16:00 Transfer: Bus to Linjia Beachfront Restaurant

16:15 - 18:15 Poster Session: Drinks & Cookies

18:30 - 20:30 Dinner: Linjia Beachfront Restaurant

21:00: Return: Buses to on-campus & X-Future hotels

Saturday, April 12th (Science and Arts Center, 2F, Concert Hall)

Session1: 08:30-10:10. Quantum Optics & Topological Polaritons. Chairmen: Ivan Savenko

Time	Duration	Speaker & Title
08:30	20'+5'	Xuehua Wang Artificial Room-temperature Quantum States
08:55	20'+5'	Sebastian Klembt Topological Edge and Corner Modes in Polariton Lattices
09:20	20'+5'	Wenjing Liu Reconfigurable Topological Exciton Polaritons
09:45	20'+5'	Rui Su Polariton Spin Hall Effect in Perovskite Microcavities

Coffee Break: 10:10-10:40

Session2: 10:40-11:45. Quantum Optics of 2D materials. Chairmen: Yu Ye

Time	Duration	Speaker & Title
10:40	20'+5'	Jun Zhang Spin-Charge-Lattice Interactions in 2D Magnets
11:05	20'+5'	Kaiqiang Lin Electric Tunable Multi-Valley van der Waals Quantum Wells
11:30	13'+2'	Yunan Gao Quadrupole Interlayer Excitons in $WSe_2/MoSe_2/WSe_2$ Heterotrilayers

Lunch: Buffet in Yifu building (1F, Boxue Cafe)

Session3: 14:00-15:35. Quantum Optics & Manybody Physics. Chairmen: Mikhail Glazov

Time	Duration	Speaker & Title
14:00	20'+5'	Pavlos Lagoudakis T.B.C
14:25	20'+5'	Ivan Savenko On the Light-Matter Coupling in 2D Superconducting Thin Films
14:50	13'+2'	Sergei V. Koniakhin Universal Condensation Threshold Dependence on Pump Beam Size for Exciton-Polaritons
15:05	13'+2'	Meng Sun Bogoliubov-Mediated Light Absorption Process in Multi-Component BEC
15:20	13'+2'	Sanja Djurdjic Mijin Towards the Use of Sound for Time-bin Encoding of Photonic Qubits for Secure Quantum Communication

Coffee Break: 15:35-16:05

Session4: 16:05-17:35. Polariton Lattice Chairmen: Sebastian Klembt

Time	Duration	Speaker & Title
16:05	20'+5'	Michael Fraser Floquet Optical Lattices for Exciton-Polariton Condensates
16:30	20'+5'	Hai Son Nguyen Polaritonic Metasurface Based on Halide Perovskite
17:55	20'+5'	Xuekai Ma Polariton Mode Manipulation Near Non-Hermitian Exceptional Points
17:20	13'+2'	Feng Jin Topological Exciton-Polaritons in Halide Perovskite Microcavities

Dinner: Buffet in Yifu building (1F, Boxue Cafe)

Sunday, April 13th (Science and Arts Center, 2F, Concert Hall)

Session1: 08:30-10:00. Quantum Optics and Manybody Physics. Chairmen: Fabrice Laussy

Time	Duration	Speaker & Title
08:30	20'+5'	Fengcheng Wu Quantum Geometry Probed by Chiral Excitonic Optical Response of Chern Insulators
08:55	20'+5'	Qingdong Jiang Symmetry-Breaking Vacuum Quantum Light-Matter Interactions
09:20	20'+5'	Zhiyuan Sun Floquet Engineering of Many-Body States by the Ponderomotive Potential
09:45	13'+2'	Alberto Muñoz de las Heras Improving Quantum Metrology Protocols with Programmable Photonic Circuits

Coffee Break: 10:00-10:30

Session2: 10:30-11:30. Quantum Optics and Manybody Physics Chairmen: Dario Gerace

Time	Duration	Speaker & Title
10:30	13'+2'	Feng Li Wave Chaotic Dynamics in Optical Microcavities in Curved Space
10:45	13'+2'	Weihang Zhou Cavity-Enhanced Superfluorescence in Perovskite Microcavities
11:00	13'+2'	Huawen Xu Nonreciprocal Exciton Polariton Ring Lattices
11:15	13'+2'	Vladimir Al. Osipov Bi-Self-Trapping of Excitons via Long-Lived Phonon Modes and Their Superfluorescent Markers

Lunch: Buffet in Yifu building (1F, Boxue Cafe)

Session3: 14:00-15:00. Polaritons in Perovskite and Organics. Chairmen: Xuekai Ma

Time	Duration	Speaker & Title
14:00	13'+2'	Xiaoze Liu Versatile Exciton-Photon Coupling in Two-Dimensional Semiconductors
14:15	13'+2'	Jun Wang Exciton-polariton Vortex Lasing in Perovskite Kagome Lattices at Room Temperature
14:30	13'+2'	Emmanouil G. Mavrotsoupakis Topological Photonics in Anisotropic 2D Hybrid Perovskite Microcavities
14:45	13'+2'	Shaocong Hou Design Molecular and Hybrid Chiral Excitonic Materials

Coffee Break: 15:00-15:30

Session4: 15:30-17:15. Quantum Optics and Devices. Chairmen: Feng Li

Time	Duration	Speaker & Title
15:30	13'+2'	Nathan Seet Exciton-Polariton Dynamics with the Nonlinear Maxwell-Bloch Finite Difference Time-Domain (FDTD) Algorith
15:45	13'+2'	Shula Chen Two-Dimensional Light-Emitting Devices towards On-Chip Photonics
16:00	13'+2'	Zhihui Chen Study on the regulation and mechanism of nonlinear optical second and third harmonics in low symmetry two-dimensional materials
16:15	13'+2'	Zu-En Su Continuous and deterministic all-photonic cluster state of indistinguishable photons
16:30	13'+2'	Muhammad Zubair Nawaz Next Generation Wearable Sensors for Real-Time Health Monitoring
16:45	13'+2'	Poster Awards, Closing & Annoucement of PLMCN2026

Dinner: Buffet in Yifu building (1F, Boxue Cafe)

Abstracts

Hybrid moiré excitons in twisted homobilayer TMDs

Wang Yao[a]

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Hybrid exciton in moiré superlattices of two-dimensional semiconductors inherits the electric dipole, strong moiré trapping, and stacking optical selection rules from its interlayer part, whereas an intralayer part is typically expected to enhance optical coupling strength. In this talk, I will discuss hybrid moiré excitons hosted by homobilayers TMDs (e.g. MoTe2) of near 0° twisting. Because of the stacking dependent interfacial electrical polarization, interlayer excitons are trapped at the MX and XM stacking regions with opposite layer configuration (and therefore opposite electric dipole), where trapping energy can largely compensate the binding energy difference from an intralayer exciton, leading to their hybridization [1]. The C3 rotational symmetry of the local registries, however, dictates that the hybridized intralayer component has a p-wave envelope, leading to a long radiative lifetime. We note the important role of electron-hole Coulomb exchange (or Forster type non-radiative multipole-multipole coupling) of the intralayer component, which qualitatively reshape the properties of valley excitons in a variety of context including the homobilayer moiré [2,3], enabling coherent hopping of hybrid excitons between moiré traps laterally separated over 10 nm and/or across layers, where their kinetic propagation is completely suppressed [4]. Valley-flip hopping channels are found as significant as the valley-conserving ones, leading to rich possibilities to tailor valley-orbit-couplings and introduce non-trivial topology to the moiré exciton superlattice. Such homobilayers also offer a platform to explore dipolar ordering of long-lived hybrid moiré excitons [5], where spontaneous C3 symmetry breaking manifests a unique optical signature [1].

The works are supported by the National Key R&D Pro- gram of China (2020YFA0309600), the Research Grant Council of Hong Kong (AoE/P-701/20, HKU SRFS2122- 7S05, A-HKU705/21), and New Cornerstone Science Foundation.

References

[1] Hongyi Yu and Wang Yao, Phys. Rev. X 11, 021042 (2021).
[2] Ci Li and Wang Yao, Phys. Rev. B 110, L121407 (2024).
[3] Ci Li and Wang Yao, 2D Mater. 11, 015006 (2024).
[4] Huiyuan Zheng, Ci Li, Hongyi Yu and Wang Yao, arXiv preprint arXiv:2410.03443 (2024).
[5] Haochen Wang and Wang Yao, in preparation.

Entanglement of exciton-polariton condensates

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For a long time, the general believe in the polaritonics community was that the quantum coherence cannot be preserved in macroscopic bosonic condensates of exciton-polaritons for a time exceeding the single-polariton life-time. This was based mostly on the similarity of polariton condensates to laser modes, which may be treated as classical coherent light. Experiments contradicted this intuition, showing that the spatial coherence of polariton condensates is extremely robust, and, in particular, polariton vortices with specific winding numbers may live as long as the condensate exists. The sceptics are never discouraged, and their next claim was that though a single polariton condensate may keep its coherence for a long time, any superposition of two eigen-states of trapped polariton condensates (that is a polariton qubit) would not survive longer than a single polariton lifetime. Our experiments on quantum beats of trapped polariton condensates provide evidence that this statement is also wrong. The T2 coherence time of a superposition of two polariton condensates in an elliptical trap appeared to be only 30% shorter than T1 coherence time of a stationary state of the condensate, with both times being on a nanosecond scale. The third claim of polaritonic sceptics concerned an entangled state of two trapped polariton condensates, each being in a superposition state. Sceptics were confident that the life-time of this entangled state (even if one manages to generate it) would be as short as the emission time of a single photon by the system of two condensates, i.e. something on a femtosecond scale. To check if this is true, we have studied two exciton-polariton condensates in coupled elliptical traps. We verified that, initially, both condensates occupied stationary eigen-states of the corresponding traps, and the whole system was in a coherent state. Then we perturbed the system by sending non-resonant control laser pulses in carefully chosen locations. Clouds of electron-hole pairs and excitons created by the femtosecond control pulses generated the time-dependent perturbation potential for coupled polariton condensates. This perturbation helped transferring the system from the initial pure state to a final entangled state. The negativity of the density matrix of the system measured by means of time-resolved interferometry jumped from 0 to about 30% under the effect of control pulses. We conclude that the quantum entanglement in a system of two coupled polariton condensates is indeed possible. The entangled state is not destroyed by radiative decay of exciton-polaritons. In contrast, it is stabilized due to the stimulated scattering of pairs of excitons from two reservoirs to two condensates. Therefore, trapped polariton condensates can be used for quantum computation. Furthermore, we have built the single-qubit Hadamard and Pauli-Z gates characterized by fidelities of 0.95 and 0.97, respectively, and a double-qubit CNOT gate characterized by a fidelity of 0.90.

Purcell-enhanced quantum-dot single-photon sources

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Efficient single-photon sources are required for applications in quantum technologies such as quantum-key distribution and photonic quantum computing. Chip-based schemes rely on the integration of the single-photon source with advanced quantum-optical circuits. In this presentation, I will review progress at the University of Sheffield on using the Purcell effect to enhance the emission properties ofInAs quantum-dot (QD) single-photon emitters integrated into photonic chips. I will first present results for InAs/GaAs quantum dots emitting around 900 nm. The small modal volumes in photonic crystal cavities enables very large Purcell factors to be achieved, leading to radiative lifetimes as short as 23ps with very high single-photon purity and indistinguishability [1]. Resonant or quasi-resonant excitation is essential to avoid the phonon bottleneck that can limit the lifetimes. The coherence of the photons is ultimately limited by phonon coupling [2] and the photon statistics can be transformed between anti-bunched, bunched, or Poissonian by spectral filtering [3]. Fast emission can also be achieved in waveguides, and glide-plane designs facilitate chiral coupling. By operating in the slow-light regime of a glide-plane waveguide, we have observed lifetimes as short as 60 ps for a non-chiral QD and a Purcell factor of 5 for a chiral QD [4]. These techniques have recently been adapted for InAs/InP quantum dots emitting in the telecom C-band range around 1550 nm. By using a photonic cavity and phonon-sideband pumping, we observed a Purcell-enhanced lifetime reduction from 1.7 ns for dots in the bulk to 300 ps for a dot coupled to a photonic cavity [5].

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Semiconductor Cavity Quantum Electrodynamics

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Semiconductor quantum emitters, especially epitaxial quantum dots (QDs) with large optical oscillator strength, are one of the most promising candidates for exploring fundamental quantum physics in solid-state and building quantum photonic devices on-chip. In this talk, I will discuss the breakthrough of scalable and deterministic coupled cavity quantum electrodynamic systems (cQED) based on single-photon hyperspectral imaging[1]. With deterministically coupled QD-microcavity systems, as shown in Fig.1, we've observed the long-sought-after dynamic resonance fluorescence in cavity quantum electrodynamics[2] and realized quantum photonic devices with state-of-the-art performances, including bright sources of entangled photon pairs[3], single-photon sources carrying orbital angular momentum[4] and stimulated emission assisted single-photon sources[6]. We finally envision long-distance quantum networks based on telecom band QDs via hybrid integration technology[7].

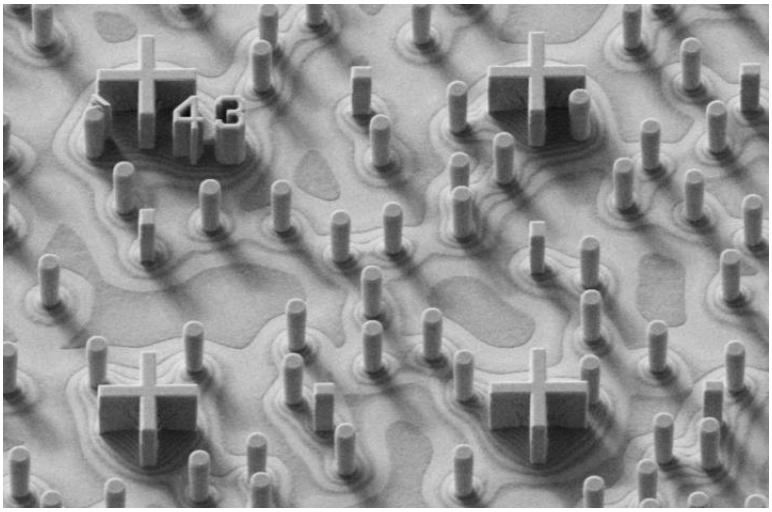

Fig. 1. Deterministically coupled QD-micropillar cQED systems.

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Ultrafast Dynamics of exciton polaritons at room temperature

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Exciton polaritons have emerged as a powerful platform for developing novel optoelectronic devices, demonstrating vast potential in fields such as information processing and quantum communication. Leveraging their unique properties, researchers have successfully realized ultra-low-threshold micro/nano lasing, switching, and logic gate functionalities. The ultrafast dynamics of polaritons play a pivotal role in determining the performance of these devices. To address the challenge of observing room-temperature dynamics of exciton-polaritons, our team have developed femtosecond angle-resolved micro-spectroscopy imaging technology, enabling multi-dimensional, ultra-high temporal precision measurements of micro-region luminescence.

Using this advanced technique, we conducted a systematic investigation into the room-temperature ultrafast dynamics of exciton-polariton condensates in microcavities, uncovering key processes such as condensation formation, relaxation, and parametric scattering under non-resonant excitation [1-4]. Notably, we achieved the first experimental observation of bosonic cascading dynamics in exciton polaritons [5]. Furthermore, by employing precise control of femtosecond optical fields, we achieved accurate manipulation of the coupling processes between condensates [6]. We also proposed a novel physical mechanism based on the parametric processes of the photonic component in the quasiparticles, enabling the realization of a room-temperature femtosecond ultrafast BEC switch with ultra-high extinction ratios [7]. We have achieved AND, OR, and NOT temporal logic gate functionalities in localized exciton polaritons [7], marking a significant step forward in the development of polariton-based ultrafast optoelectronic devices.

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Exciton polariton interactions in Van der Waals superlattices

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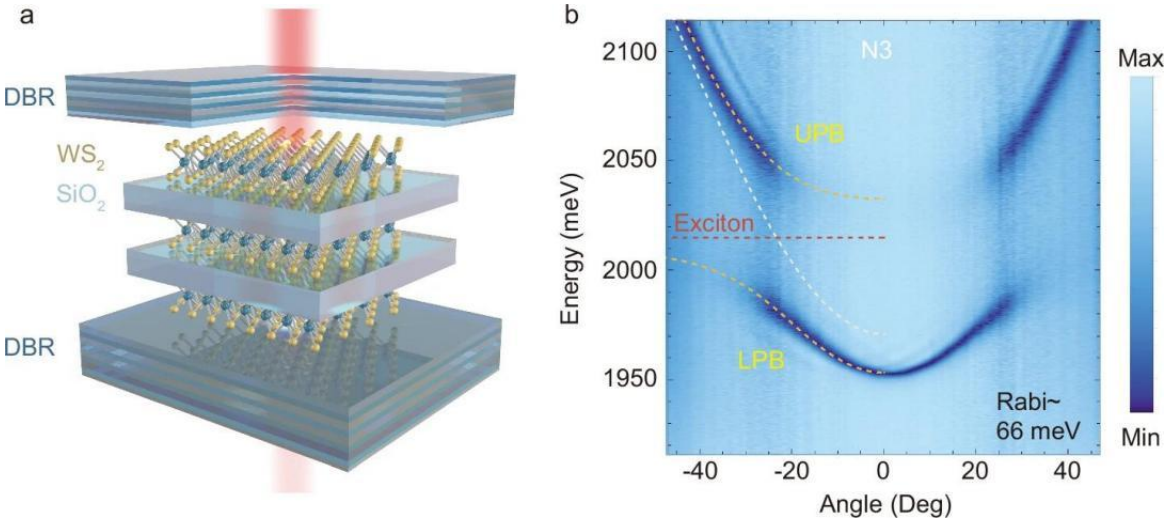
Monolayer group-VI transition-metal dichalcogenides (TMDs) have emerged as a promising class of 2D semiconductors, garnering research interest due to their sizable direct bandgap and exceptional optical and electronic properties. The tightly bound excitons in monolayer TMDs, with their large oscillator strength, make these materials ideal for exploring light-matter interactions in the strong coupling regime when integrated with optical cavities. Additionally, the layered structure of monolayer TMDs allows for the fabrication of van der Waals heterostructures through vertical stacking, enabling innovative strategies for controlling strong light-matter interactions.

In this work, we demonstrate systematic control of the coupling strength by embedding multiple WS_2 monolayers within a planar microcavity [1]. To further advance monolayer TMD-based spintronic devices, we investigate strong spin-dependent interactions and effective spin transport mechanisms [2]. We present the operation of all-optical polariton spin switches by incorporating a WS_2 superlattice into a planar microcavity. Our results reveal spin-anisotropic polariton nonlinear interactions in a WS_2 superlattice at room temperature.

As a proof of concept, we use these spin-dependent interactions to realize various spin switch geometries under ambient conditions, achieving intrinsic sub-picosecond switching times and compact device footprints [3]. These findings provide fresh insights into the manipulation of polarization states in polaritonic systems and underscore the potential of atomically thin semiconductors for next-generation information processing technologies.



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Telecom Wavelength Quantum Dot Single-Photon Sources for Quantum Technologies

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Semiconductor quantum dots integrated in resonators are a promising candidate as resources in photonic quantum technologies. Here, we present an overview of recent developments in our group on the engineering of single-photon sources for quantum photonic applications made from III-V semiconductor quantum dots grown by molecular beam epitaxy.

By integrating InAs/InP quantum dots into circular Bragg grating resonators (see fig. 1), Purcell-enhanced single-photon emission with a Purcell factor of ≈7 in the telecom C-band was achieved. [1] Low multi-photon emission probabilities are obtained, and Hong-Ou-Mandel two-photon interference is demonstrated. By further improving the epitaxial growth and photonic design, we were able to obtain record two photon interference visibilities of ≈72 %. While this is still far from best values achieved at shorter wavelength, it manifests an important improvement for telecom C-Band quantum dot single photon sources.

For an unweighted mapping of the quantum dot polarization state directly into the outcoupled photon polarization, a symmetric cavity and a well placed quantum dot are essential. For instance, a displacement with regard to the cavity center strongly determines the polarization characteristics from quantum dots in circular Bragg grating resonators, as the symmetry of the coupled QD-cavity system is broken, and the quantum dot will couple differently strong to the degenerate fundamental resonator modes. [2] We therefore employ deterministic placement techniques also for the telecom C-Band quantum dots.

Furthermore, we demonstrated that GaSb quantum dots are a scientifically rich alternative material system for the generation of single-photons in the telecom S-band [3] promising strain-free spin physics, but in the telecommunication wavelength range [4].

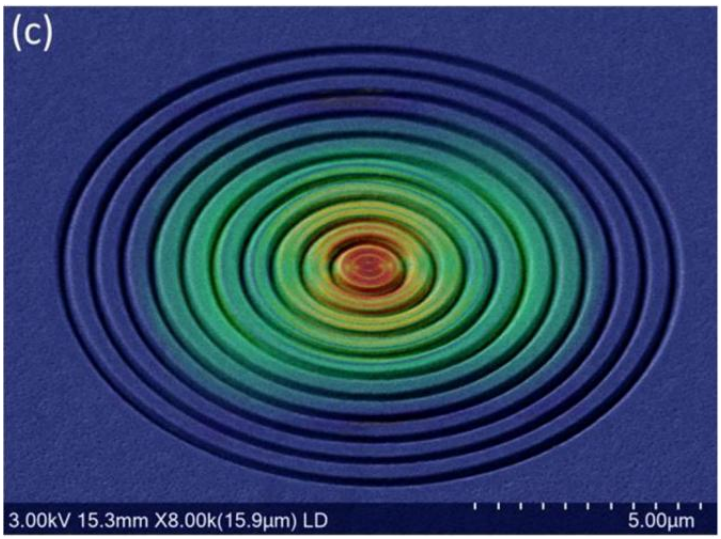

Fig. 1: Scanning electron microscopy image of a fabricated bullseye resonator overlain with a logarithmic contour plot of the electric field intensity distribution of the fundamental resonator mode. (adapted from Ref [3])

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In-plane polaritons: from edge-emitting polariton lasing to long-distance propagation

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Microcavity exciton-polaritons and associated polariton lasers were initially demonstrated in vertical microcavities. In those structures the photonic mode is confined between two distributed Bragg reflectors disposed below and above the active region, which provides the necessary excitons. In the last years the horizontal geometry, where photons are confined by total internal reflection within a waveguide structure, has gained increasing interest, given that it provides access to fast propagating polaritons that still retain large excitonic fractions and, therefore, large nonlinear interactions [1].

In this talk we will illustrate the differences between exciton-polaritons and polaritons lasers in the vertical and waveguide geometries [2]. We will focus on edge-emitting GaN polariton lasers where vertical GaN/air distributed Bragg reflectors are employed to define in-plane cavities of different lengths, typically from tens of μms to several hundreds of μms, so much shorter than standard GaN-based edge-emitting lasers operating in the weak-coupling regime. After assessing the strong-coupling regime in these structures [3] we will first demonstrate CW polariton lasing operation at low temperature (70K). We will show that polariton lasing can be achieved when pumping even a small fraction of the cavity, much shorter than 50% of the total length [4], which would be impossible in a standard laser. Subsequently we will show that when the polariton gain is spectrally broadenend, the laser emission becomes inherently multimode, with about ten modes participating in the nonlinear emission. At threshold the nonlinear emission is accompanied by a renormalization of the waveguide polariton dispersion, with a larger blueshift for polaritons displaying larger excitonic fractions, resulting in equally frequency-spaced modes whose spectral envelope can be reproduced by a bright soliton wave function [5]. This mode-locked polariton laser, which operates up to room-temperature, constitutes a first demonstration of strong polariton nonlinearities in large bandgap semiconductors.

Finally, the possibility of exploiting this geometry with new active polariton materials will be discussed and put into perspective comparing them with the active materials being currently used for waveguide polaritons.

This work is the result of a long-term collaboration with teams in L2C (T. Guillet), C2N (S. Bouchoule), Institut Pascal (G. Malpuech) and NTU (W. Gao). Funding by the French National Research Agency (ANR-11-LABX-0014, ANR-21-CE24-0019-01) and by the National Research Foundation, Prime Minister's Office, Singapore under its Campus for Research Excellence and Technological Enterprise (CREATE) programme though project N-GAP (NRF2023-ITC004-001) is greatly acknowledged.

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Prototype Polariton Superfluid Qubit Analog in an Annular Trap

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Exciton-polaritons are hybrid light-matter quasi-particles resulting from the strong coupling of semiconductor excitons and microcavity photon. Being bosons polaritons can exhibit macroscopic spatial coherence and form out-of-equilibrium condensates exhibiting superfluid behavior when pumped above threshold. A promising recent theoretical proposal for polaritonic qubit utilizes split-ring polariton-condensate in an annular ring involving quantized circular currents[1,2]. This system relies on the formation of vortices in superfluids arising from the quantization of circulation, where the phase accumulation around a supercurrent loop can only take discrete values. Closely related physics governs the principles of operation of superconducting flux or phase qubits involving superconducting loops interrupted by Josephson junction.

Here we show that, under appropriate conditions, optically trapped out-of-equilibrium polariton condensates can populate two well-characterized states corresponding to the clockwise and counterclockwise circulating currents. We demonstrate coherent coupling between these states, due to the partial reflection of the circulating superfluid from a weakly disordered laser potential or an external control laser beam, while simultaneously maintaining long coherence times. We can control the coupling and thereby the energy splitting between the two eigenmodes of the system. Inspired by the theoretical proposal to realise qubit analogs and quantum computing with two-mode BECs[4], we formally identify the two polaritonic eigenmodes with the basis states of a qubit. Supplemented with controllable coupling between individual polaritonic qubits, such systems hold great potential for simulating a subset of quantum algorithms that do not rely on entanglement.

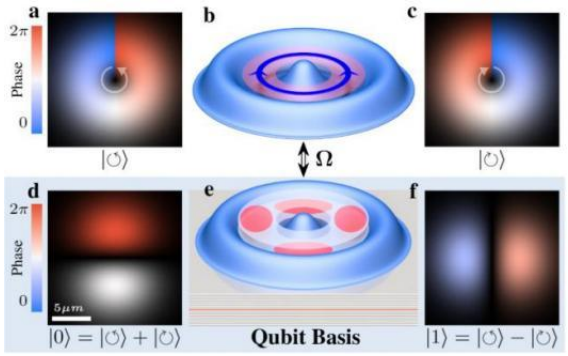

Figure 1: Polaritonic qubit analog

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Quantum characterization of a polariton BEC

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Polariton BEC is one of the oldest topics of microcavity physics and remains actively investigated [1]. In this talk, I will discuss quantum-optical characterizations of the phenomenon, beyond the usual two-photon statistics $g^{(2)}$ [2]. I will introduce a more general two-photon spatial correlation spectrum [3], thereby providing—in space—a counterpart of the two-photon frequency correlation spectrum which unveils virtual processes [4]. I will also discuss the quantum state of the system and whether it develops a phase as expected from the order parameter $\langle\psi\rangle$ of the phase transition. I will show how various multi-particle observables can inform on this question and result in surprising predictions for how bosons distribute themselves in real space [5]. On the basis of these results, I will discuss whether polariton condensates are a useful resource for quantum information processing and challenge the notion of "polariton qubits". On a more uplifting note, I will present an interpretation that 'explains' boson correlations, offering a fitting tribute to the 100th anniversary of Einstein's *Quantentheorie des einatomigen idealen Gases.*

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Chiral metaphotonics and Mie-tronics

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Nanophotonics plays an important role in the rapid development of high-performing ultrafast subwavelength optical devices integrated on optical chips with densely packed functional elements. Nanophotonics underpins the rapid progress in wearable and flexible metadevices for novel biosensors of high accuracy and comfort in device-on-chip solutions for on-site data processing. The recently emerged *Mie resonant metaphotonics* (or Mie-tronics) provides novel opportunities for subwavelength optics traditionally based on plasmonic structures [1]. Mie-tronics employs resonances in high-index dielectric nanoparticles and structured dielectric surfaces. In this talk, we present a very brief summary of the recent advances underpinning this rapidly developing area of research and also discuss some future trends in a design of all-dielectric resonant structures with high quality factors for efficient resonant spatial and temporal control of light, including generation of nonlinear and structured light and *chiral metaphotonics*.

As the first example, we demonstrate that chiral response can be achieved in resonant metasurfaces with a monoclinic lattice symmetry (the so-called Bravais oblique lattices) where the mirror symmetry is broken by the lattice asymmetry and by a substrate, while each individual meta-atom remains fully achiral. We describe the underlying mechanism by introducing the mode chirality parameter as a quantitative measure of the lattice chiral eigenmodes. We confirm experimentally selective linear and nonlinear chiral interaction of resonant silicon metasurfaces with circularly polarized light [2]. In addition, we demonstrate, both theoretically and experimentally, that a monoclinic metasurface can convert linearly polarized light into elliptically polarized light not only in the linear regime but also in the nonlinear regime with the resonant generation of the third-harmonic field. We reveal that the ellipticity of the fundamental and higher-harmonic fields depends critically on the angle of the input linear polarization, and the effective chiral response of a monoclinic lattice plays a significant role in the polarization conversion [3].

In the strong-coupling regime, the interaction between light and matter reaches a hybridization state where the photonic and material components become inseparably linked. Using tailored states of light to break symmetries in such systems can underpin the development of novel non-equilibrium quantum materials. Chiral optical cavities offer a promising way for this, enabling either temporal or spatial symmetry-breaking, both of which are unachievable with conventional mirror cavities. For spatial symmetry-breaking a cavity needs to discriminate the handedness of circularly polarized light, a functionality that can only be achieved with metamaterials. Recently, we have suggested and demonstrated experimentally a chiral transition metal dichalcogenide (TMDC) metasurface with broken out-of-plane symmetry, allowing for a selective formation of self-hybridized exciton-polaritons with specific chirality [4]. Our metasurface cavity maintains maximum chirality for oblique incidence up to 20°, significantly outperforming all previously known designs, thereby turning the angle of incidence from a constraint to a new degree of freedom for sub-nanometer-precise control of resonance wavelengths. Moreover, we study the *chiral strong-coupling regime* in nonlinear experiments and show the polariton-driven enhancement of chiral third-harmonic generation.

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Mode and Polarization control of photonic molecules

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Polarization of photons plays a key role in quantum optics and light-matter interactions, however, it is difficult to control in nanostructures. Here we demonstrate a polarization control of photons using photonic molecules (PMs) composed of two coupled photonic crystal nanobeam cavities. With an evanescent wave coupling, PMs directly control the local optical field that couples with the emitter, indicating a high efficiency in polarization control. The coupling between PMs is influenced by two primary factors: the air gap d and the relative displacement s between the cavity centers. These two parameters are tuned continuously for high controllability. As shown in Fig. 1, the supermodes include the symmetric (S) and anti-symmetric (AS) modes are obtained, identified by whether their electric field profiles have the same phase or a π-phase difference. Conventionally, the S and AS mode are linear superpositions of each single cavity and their eigenenergies are $\omega_0 \pm g$ with a symmetric splitting. However, the Hermitian coupling is only valid for a small coupling strength g with a large gap. As the gap d decreases, non-trivial effects arise resulting in an evanescent wave coupling dominated. The evanescent wave enables the control of polarization by introducing a phase shift between the in-plane and out-of-plane electric field at the boundary of dielectrics, which show a significant potential for applications in spin-resolved cavity quantum electrodynamics in future.

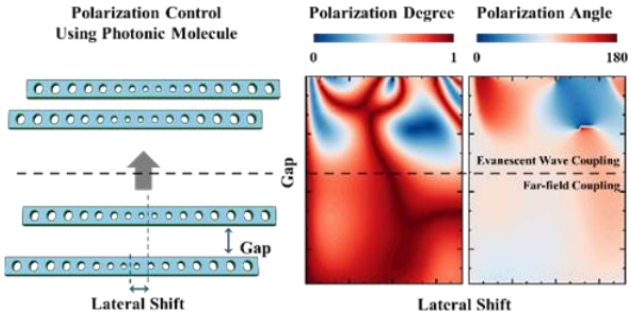

Figure 1 Polarization control in photonic molecules.

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Continuous-Wave Nonlinear Polarization Control and Signatures of Criticality in a Perovskite Cavity

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Halide perovskites have emerged as promising photonic materials for fundamental physics studies and technological applications. Their potential for nonlinear optics has also drawn great interest recently; yet, to date, continuous-wave (CW) nonlinearities have remained elusive. Here we demonstrate CW nonlinear phenomena in a CsPbBr3 perovskite cavity. We first demonstrate optical bistability --- the hallmark of single-mode coherent nonlinear optics. Next we exploit the interplay of nonlinearity and birefringence to demonstrate nonlinear control over the polarization of light. Finally, by measuring the optical hysteresis of our cavity as a function of temperature, we find a dramatic enhancement of the nonlinearity around 65 K. This enhancement is indicative of a phase transition in CsPbBr3. Our results position CsPbBr3 cavities as an exceptional platform for nonlinear optics, offering strong CW nonlinearity and birefringence which are furthermore tunable. Moreover, our approach to uncover signatures of a phase transition of matter via optical hysteresis measurements is promising for exploring strongly correlated states of light-matter systems.

Interpreting S-Parameter Spectra in Coupled Resonant Systems - The Role of Probing Configurations

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Abstract: The S-parameter S21 is a vital metric for assessing the resonant characteristics of various systems; however, its accuracy is heavily contingent upon the probing setup employed. Our theoretical and simulation studies reveal that while point-probe or weak probes preserve the integrity of the S21 spectrum and accurately represent system resonances, multi-point and strong probes can introduce significant inaccuracies, leading to misleading phenomena such as repulsive level anti-crossings or attractive level crossings in otherwise uncoupled systems. This finding emphasizes the critical need for careful selection of probing techniques to ensure precise resonance evaluation.

Additionally, we investigate a system of two oscillators coupled to an open channel, where adjustable coupling—coherent, dissipative, or hybrid—can be manipulated via a tunable phase. This setup facilitates the observation of distinct energy level behaviors; coherent coupling results in level repulsion, while dissipative coupling leads to level attraction.

Notably, under dissipative coupling, one eigenmode transitions to a dark mode, becoming resistant to external perturbations. By utilizing tunable coupling through the open channel, we propose a novel approach for effectively exciting and extending the lifetime of this dark mode, with potential applications across optical, acoustic, and magnetic systems for mode storage and signal processing.

Topological polaritonics with organic materials

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Organic materials exhibit excitonic resonances capable of showing strong light-matter coupling at room temperature. We present a review of our recent results on organic microcavities with 4 different materials (perylene, DPAVBi, TTPSB, and BPDBNA polymers). We demonstrate emergent optical activity [1] (also called Rashba-Dresselhaus spin-orbit coupling [2]) stemming from the strong birefringence of organic materials embedded in a cavity. Using the advantages of photonics, we extract the Berry curvature and the quantum metric for Hermitian [1] and non-Hermitian systems [3]. We demonstrate that the spin-orbit coupling leads to the formation of topological valleys capable of helical lasing [4]. We also show that selective strong coupling, present in organic materials, leads to a strong non-Hermiticity and creates exceptional points [3].

In a different non-Hermitian configuration, photonic spin-orbit coupling allows us to observe dual orthogonally-polarized lasing from imaginary Fermi arcs [5]. We also demonstrate ultrafast switching between bands, enhancing the polariton interactions by an applied electric field [6]. Finally, we use the topological valleys to fabricate circular-polarized light-emitting diodes with a very high luminance [7].

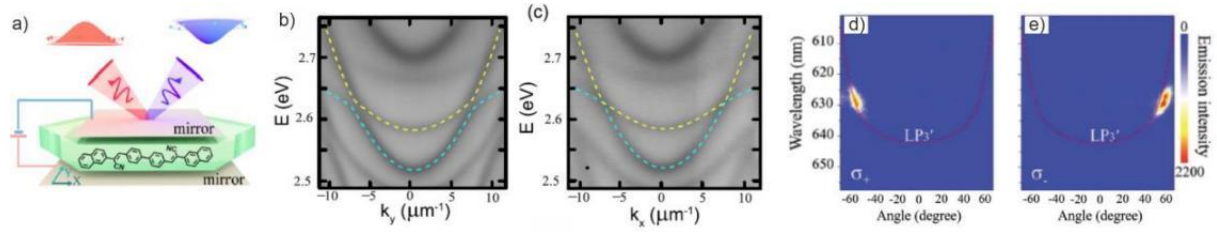

Fig. 1: a) Typical microcavity with an organic active region, demonstrating circular-polarized emission; b)Anticrossing of photonic and polaritonic branches due to emergent optical activity; c) Crossing of photonic and polaritonic branches due to non-Hermiticity; d), e) Circular-polarized lasing from topological valleys.

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Realization of exciton-mediated optical spin-orbit interaction in organic microcrystalline resonators for circularly polarized electroluminescence

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The ability to control the spin-orbit interaction (SOI) of light in optical microresonators is of fundamental importance for future photonics. Organic microcrystals, due to their giant optical anisotropy, play a crucial role in spin-optics and topological photonics. We demonstrated controllable and wavelength-dependent Rashba– Dresselhaus (RD) SOI, ascribed to the anisotropic excitonic response in an optical microcavity filled with an organic microcrystalline. We investigated the transition of the spin-splitting from twice winding caused by the splitting of the transverse-electric (TE) and transverse-magnetic (TM) modes to once winding caused by the RD effect. The interplay of the two allows engineering of the SOI oflight in organic microcavities toward exploiting nonmagnetic and low-cost spin-photonic devices.

Circularly polarized (CP) electroluminescence from organic light-emitting diodes (OLEDs) has aroused considerable attention for their potential in future display and photonic technologies. Currently, the development of CP-OLEDs relies largely on chiral-emitters, which not only remain rare owing to difficulties in design and synthesis but also limit the performance of electroluminescence. Here, we demonstrate a chiral-emitter-free microcavity CP-OLED with a high dissymmetry factor (g_{EL}) and high luminance by embedding a thin two- dimensional organic single crystal (2D-OSC) between two silver layers which serve as two metallic mirrors forming a microcavity and meanwhile also as two electrodes in an OLED architecture. In the presence ofthe RD effect, the SOIs in the birefringent 2D-OSC microcavity result in a controllable spin-splitting with CP dispersions. Thanks to the high emission efficiency and high carrier mobility of the OSC, chiral-emitter-free CP- OLEDs have been demonstrated exhibiting a high g_{EL} of 1. 1 and a maximum luminance of about 60000 cd/m^2, which places our device among the best performing CP-OLEDs.

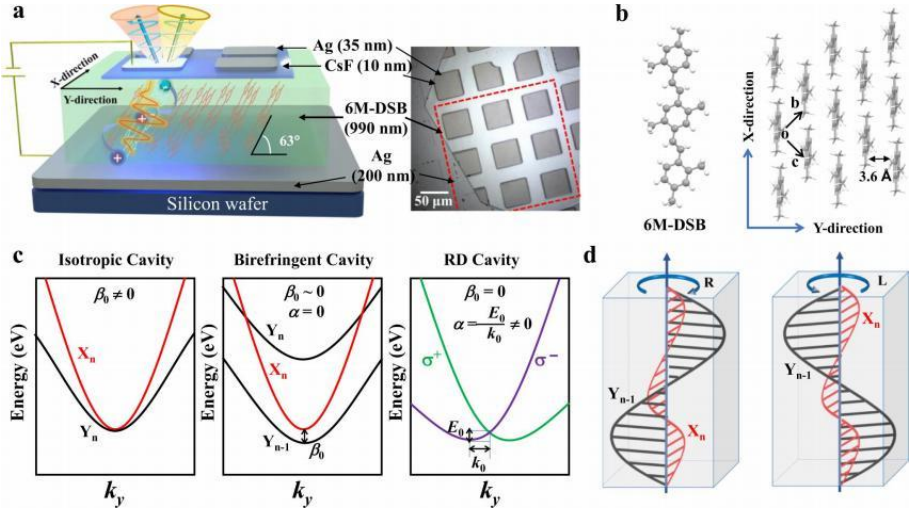

Figure 1. a, Schematic diagram of the microcavity CP-OLED device structure. **b** Left: Molecular structure of 6M-DSB. Right: brickwork molecular packing arrangement within the (001) crystal plane, viewed perpendicular to the microribbon top-facet. **c** Left: two orthogonally linearly polarized modes with the same parity in an isotropic microcavity. Middle: the dispersion of two orthogonally linearly polarized modes in an anisotropic microcavity. Right: RD SOI emerges when two orthogonally linearly polarized modes with opposite parity are resonant. **d** The resonant X- and Y-polarized cavity modes of opposite polarity. The 6M-DSB crystal in the microcavity hence acts as a half-wave plate, and the intrinsic mode polarization of the light-emitting side of the mirror turns into a circle, corresponding to left-handed and right-handed circular polarizations, respectively..

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Criteria for Polaritonic Enhancement of OLEDs Beyond the Single-excitation case

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In this talk, we report our experimental results of microcavity Organic light-emitting diodes (OLEDs) and analytical partition of the parameter subspaces where polaritons can and cannot enhance microcavity OLEDs.

OLEDs have several advantages compared inorganic LEDs and other traditional lighting technologies: they can be made out of sustainable materials using low-energy intense processes, and their light weight and flexibility allows foldable high-resolution displays and topographically adaptive touch user interfaces. Fundamental challenge for practical OLEDs is that under electrical excitation 75 % of the formed excitons will be in the non- or slow-emitting triplet state which leads to efficiency roll-off – their efficiency decreases when increasing the injection current. This limits their brightness and lifetime and therefore different strategies to modify the molecular energy level dynamics have been developed to harness the triplet population.

We study the potential for OLED enhancement by integrating the organic molecules in an optical microcavity. In the strong light-matter coupling regime, polaritons can be used to engineer the energy level landscape and dynamics. First, we fabricated a series of microcavity OLEDs to study the polaritonic enhancement under electrical excitation for the first time. The cavity thicknesses of the OLEDs were varied to achieve different polariton energies for each device. The measurement results showed that inducing strong coupling or tuning the polariton energies close to the triplet state did not modify the molecular dynamics of the fluorescent TDAF emitter [1].

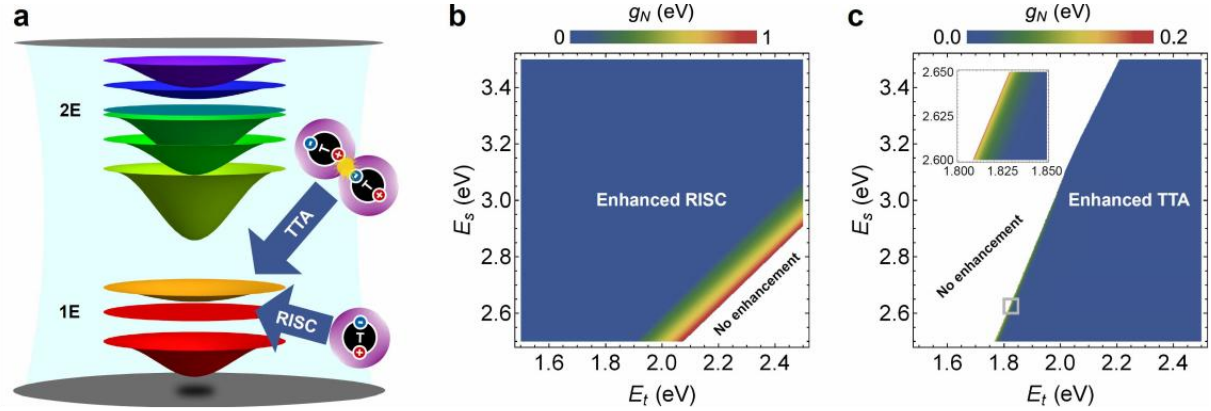

Fig 1. Parameter regimes for polaritonic enhancement. a: The energy level diagram of organic semiconductor in microcavity. Increasing the rates of reverse intersystem crossing (RISC) and triplet-triplet annihilation (TTA) enhances the OLED efficiency. RISC harnesses the energy of one triplet by converting it into emitting singlet state, and in TTA two triplets combine into a singlet. **b and c:** The color map shows the smallest light-matter coupling g_N that enhances the RISC and TTA rates for a given combination of the singlet and triplet energies (E_s and E_t). The white regions correspond to no polaritonic enhancement.

The absence of the expected enhancement motivated our in-depth theoretical investigation of the conditions for polaritonic enhancement [2]. We developed a theoretical model for polaritonic OLED processes in multi-excitation case to simultaneously study the effects of reverse intersystem crossing (RISC), triplet-triplet annihilation (TTA), and singlet-singlet-annihilation (SSA) for the first time. The model allows characterizing the parameter subspaces where the RISC and TTA rates can be enhanced by the strong coupling, see Fig. 1 b and c.

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Quantum Photonic Devices with Integrated Quantum Dots

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Integrated photonic devices are at the basis of all-optical chips, essential ingredients for quantum information technology applications. In such devices, one of the key features relies on the control of the emission properties of integrated solid-state quantum emitters and, most importantly, the spontaneous emission dynamics. In this way, one can control, for instance, the single-photon emission repetition rate and improve the coherence of the emitted quantum light, by reducing the spontaneous emission lifetime.

One of the challenges to face when dealing with solid-state emitters embedded within high-index materials is the extraction of quantum light and the control on its propagation.

To this end, we show that metallic nano-rings (see Fig.1) can be implemented to increase the extraction efficiency of single photons emitted by InAs quantum dots, thanks to the focusing effect of the plasmonic device [1-3]. We also show that such a device is scalable and gives broadband (over 60 nm) operation, as opposed to narrowband cavity-based geometries.

Furthermore, with the aim of controlling the angular momentum of the emitted quantum light, we demonstrate the potential of nano-photonic devices characterized by a bio-inspired deterministic aperiodic structure (see Fig.2), based on spiral geometries [4], as a platform for cavity quantum electrodynamics experiments [5].

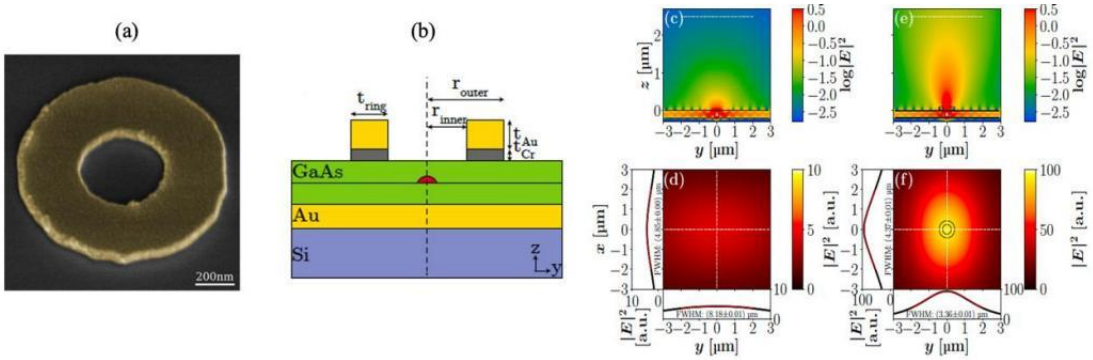

Fig.1: (a) False-colour scanning electron micrograph image of a fabricated nano-ring. (b) Schematic of the nano-ring device with gold back reflector (not to scale). (c,d,e,f) Color plot of the side (*zy* plane) profile of the squared electric field of a dipole emitter obtained by finite-difference time-domain simulations

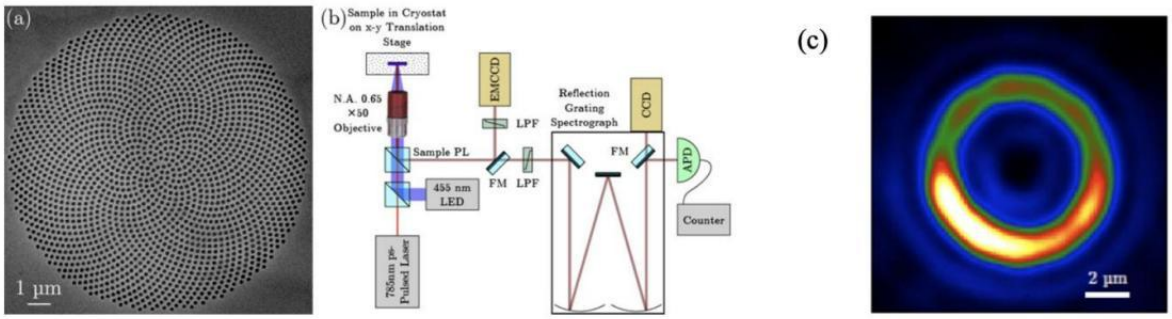

Fig.2: (a) Scanning electron micrograph of a suspended silicon nitride membrane with an etched aperiodic pattern of air holes. (b) Schematic of the confocal micro-photoluminescence setup (not to scale) (c) Photo-luminescence image of the optical modes confined by an aperiodic nano-photonic device.

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Single-photon emission at 1.55 μm wavelength in a metamorphic quantum dot microcavity under resonant coherent excitation

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Single-photon sources that emit photons "on demand" at telecommunication wavelengths are critical elements for the creation of quantum fiber-optic networks [1]. Such photons can serve as "flying qubits", allowing quantum information to be transmitted over relatively long distances via optical fiber. Self-organized InAs/GaAs quantum dots (QDs) in microcavities, which are most widely used to create single-photon sources, demonstrate near-ideal indistinguishability and purity of single photons, as well as high end-to-end efficiency of their generation under pulsed optical pumping (57% [2]). However, such QDs emit efficiently only at wavelengths of 900–1000 nm, beyond the standard telecommunication ranges. Mastering other wavelengths, including those corresponding to telecommunication frequencies, remains an unsolved problem [3].

We present an original solution to the problem of creating efficient single-photon sources for the telecom C-band (1.55 μm), using molecular beam epitaxy (MBE) in combination with photolithography, ion-plasma etching and deposition of dielectric layers. The developed design of a columnar hybrid optical microcavity is based on the use of a metamorphic buffer, which made it possible to match the crystal lattice parameters of the GaAs (001) substrate and the InGaAs active region, in which InAs/InGaAs QDs are formed (Fig. 1a). The lower mirror of the cavity, a distributed Bragg reflector $Al_{0.9}Ga_{0.1}As$/GaAs, is formed during the MBE growth of the initial heterostructure, while the upper mirror consists of several pairs of layers of deposited Si/SiO_2 dielectric materials. The structures implement a resonant coherent mode of pulsed excitation of a single QD, which ensures, at a pump power corresponding to the first Rabi oscillation (π-pulses), record-high parameters of single-photon radiation at a wavelength of 1.55 μm: an average photon emission frequency of 5.8 MHz (in a single-mode optical fiber at a pump frequency of 80 MHz) and a single-photon emission purity of ~95% ($g^{(2)}(0) \sim 0.05$) (Fig. 1b).

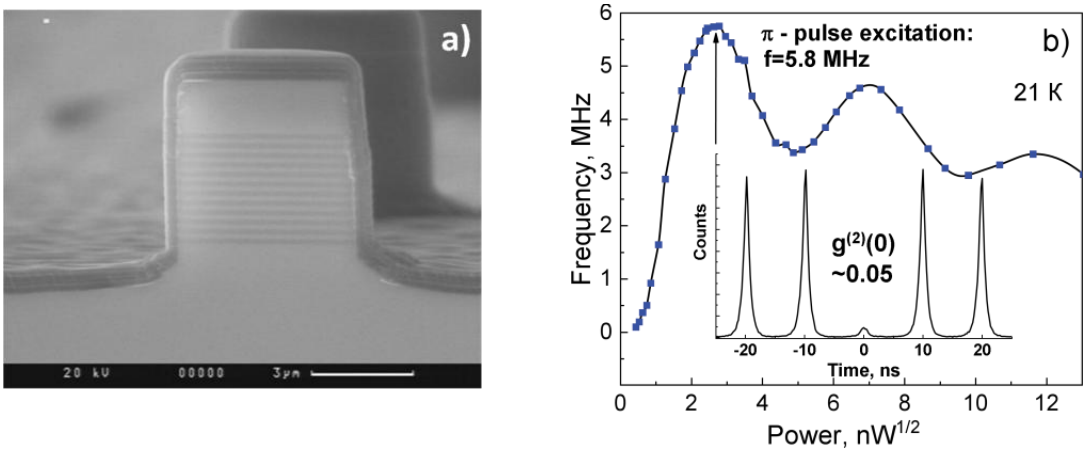

Fig. 1: a) Scanning electron microscopy image of the cross-section of the hybrid microcavity. b) Photon generation frequency as a function of the average power of the resonant coherent pulsed pump. The inset shows the second-order correlation function $g^{(2)}$ measured under π-pulse excitation conditions.

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Quantum dots anisotropy as a resource in multiphoton entanglement

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Multiphoton entangled states, including linear cluster states, are a promising resource for optical quantum information technologies, indispensable for the implementation of measurement-based quantum computing. Such states can be obtained in the emission of a single charged semiconductor quantum dot (QD), on which one of the most mature technologies of single-photon generation is based. In this case, the cluster is realized due to the sequential entanglement of the emitted photons polarization with the precessing spin of a resident charge carrier in the QD [1]. Several groups have demonstrated the feasibility of such a process [2], and a modification of the cluster state generation protocol has recently been proposed that also provides control over the topology of the resulting multiphoton entangled state [3]. As a result of our previous studies, a significant anisotropy of the spin-photon entanglement process was experimentally discovered and theoretically explained [4]. The anisotropy arises due to the symmetry properties of the heavy-hole wave function and its Zeeman Hamiltonian in a QD belonging to the C_{2v} symmetry group, which is typical for self-organized InAs/GaAs QDs. In this work, we generalize the previously obtained results to the case of QDs of different symmetries and analyze the possibility of using the discovered anisotropy to control the topology of multiphoton entanglement.

The degree of spin-photon entanglement was determined from correlation measurements of photoluminescence of a single QD placed in a columnar microcavity in an external magnetic field. It turns out to be less than unity due to the processes of longitudinal spin relaxation and, more importantly, due to spin dephasing in the statistical ensemble of single-photon detection events. One of the reasons for spin dephasing is fluctuations in the precession times of an electron and a hole in a QD between two successive photon emission events. However, these fluctuations are correlated in the cluster state generation protocol, because the total precession time of the trion state and then of the resident charge carrier to the next excitation event is fixed by the excitation pulse repetition period. As a result, the dephasing of the electron spin and the hole spin in the statistical ensemble of events can partially compensate each other if their spin dynamics occur in the same direction in an external magnetic field. The spin dynamics of the trion state depends on the initial spin orientation of the photoexcited charge carrier, which appears in the excitation act rotated from the resident spin around the optical axis. The rotation angle is determined by the excitation polarization, so polarization control allows achieving the forementioned compensation for both negatively and positively charged QDs of any symmetry. The degree of compensation depends on the ratio of the electron and hole effective transverse g-factors and is maximal if the g-factors are equal. For a QD of a certain symmetry with comparable high-symmetry and low-symmetry contributions in the Zeeman Hamiltonian of a heavy hole, its effective g-factor is substantially anisotropic, which makes it possible to influence the degree of compensation by choosing the direction of the applied transverse magnetic field.

Another important consequence of the polarization-dependent spin rotation is the ability to control the topology of the resulting multiphoton entangled states. This rotation occurs around the structure growth axis and, in combination with the precession of the resident spin in an external transverse magnetic field, makes it possible to completely control the spin state of the QD on the Bloch sphere by the time of photon emission. Such control is necessary for generating multiphoton entangled states with a topology different from a linear cluster, and, taking into account the revealed anisotropy, can be implemented without using additional pulses proposed for this purpose in [3]. Thus, it is shown that the anisotropy of QDs is a significant resource in obtaining multiphoton entangled states, allowing both to increase the degree of entanglement and to simplify the protocol for generating states with a complex topology.

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Fiber-coupled single-photon source based on InAs/GaAs quantum dots in cylindrical microresonators

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Modern single photon sources (SPS) based on cylindrical microresonators with quantum dots (QDs) are characterized by a fairly reproducible manufacturing technology and allow obtaining pure single-photon radiation with the highest intensity achievable at present [1]. The radiation of such SPS can be efficiently introduced into a single-mode optical fiber, but their monolithic integration with photonic integrated circuits (PICs) is difficult to implement in practice, since the directions of light propagation in a cylindrical microresonator (vertical) and a planar integrated waveguide (horizontal) are mutually perpendicular. A possible solution is to use a hybrid technology for integrating SPS and PICs [2], the key advantages of which are the possibility of independent optimization and preliminary testing of integrated components. The introduction of single-photon radiation into the integrated waveguide of the FIS, for example, can be implemented using a classical single-mode optical fiber [3] or a polymer waveguide created using the technology of additive manufacturing of polymer waveguides of arbitrary shape [4].

Our technology is based on individual semiconductor QDs in microcavities that are directly coupled to single-mode fibers. We demonstrate the successful integration of our source in a compact closed-loop He cryostat operating at a base temperature of 2.4K. The manufactured structure consisted of self-organized InAs/GaAs QDs, which were grown using molecular beam epitaxy and placed in a columnar microresonator with GaAs/ $Al_{0.9}Ga_{0.1}As$ distributed Bragg reflectors (DBR). The surface density of InAs QDs varied within the area of the epitaxial structure in the range of 10^8-10^9 cm^{-2}. Additional protective planarizing layers based on polyamide were applied on top of the manufactured microresonators, ensuring stabilization of the SPS characteristics and its effective coupling with optical fibers without the risk of mechanical damage. Besides, the structure under study contains an additional protective layer of gold with square holes (apertures), inside which arrays of microresonators are located. The functionality of the additional metallization layer is to take on the main part of the pressure from the ferrule with the attached optical fiber to minimize mechanical deformations of individual microresonators. A single-mode fiber with a numerical aperture of 0.13 was combined with a pre-selected microresonator using a universal platform for micro-mounting crystals (FinePlacer). The coupling of a microresonator with a single-mode fiber made it possible to realize single-photon emission using LO-phonon-assisted quasi-resonant excitation with $g^{(2)}(0) = 0.04$, degree of indistinguishability of 0.83 and end-to-end efficiency of 4%. The obtained results demonstrate the applicability of the developed structures with QDs as effective photon sources for the implementation of integration with photonic chips.

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Multiphoton emission from a single-photon source and Single-photon emission from multiple levels

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Detecting more than one photon at a time from a single-photon emitter is usually regarded as accidental, undesired and something to be suppressed. Such multiphoton emission can turn out, however, to be even more fundamental and interesting than the single-photon emission, which is a particular case of a pervading quantum phenomenon: interferences of probability amplitudes. In a coherently driven system, the multiphoton suppression indeed arises from quantum interferences between virtual multiphoton fluctuations and the mean field in a Poisson superposition of all number states [1]. With such a picture in mind, one can control the multiphoton dynamics of a two-level system by disrupting these quantum interferences through a precise and independent homodyne control of the mean field [2]. With experimental coauthors [SK Kim et al, Ref. 2], we show that, counterintuitively, quantum fluctuations always play a major qualitative role, even and in fact especially, when their quantitative contribution is vanishing as compared to that of the mean field. Our findings provide new insights into the paradoxical character of quantum mechanics and open pathways for mean-field engineering as a tool for precision multiphoton control [3,4].

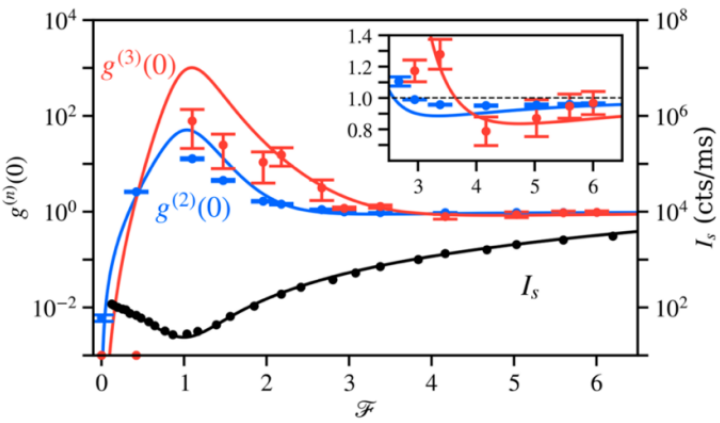

Figure from [2]: Experimental points and theoretical curves for the homodyned resonance fluorescence signal vs the LO field amplitude $\mathcal{F}$. At $\mathcal{F}$=1, the external field cancels the mean field of the system laying bare its quantum multiphoton fluctuations (manifesting as strong superbunching). For a sizable coherent field, one can suppress n-photon emission independently. The cases n=2 and n=3 are shown and magnified, confirming the transition from two-photon suppression to three-photon suppression.

If, on the other hand, one is really interested in perfect single photon sources [5], one can turn to a system of multiple levels arranged in a circular one-way cascade under incoherent excitation [6,7]. Even though the pump is continuous, the final local temporal second-order correlations ofthe photon stream resemble those of a pulsed laser drive, also similar to spatial correlations in liquids. We discuss how the rich correlations that result from what appears to be an extremely simple implementation, are essentially those which have been obtained from complex architectures relying on strongly correlated, many-body physics or cavity QED effects.

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Phonon effects on quantum emitters and novel tools for fast yet exact simulation

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Achieving near-unity fidelity in quantum light sources is often challenging due to the unavoidable interaction of emitters with their environment. However, understanding these environmental influences opens the possibility of mitigating their effects or even harnessing them through specially designed, robust driving protocols. In systems like quantum dots coupled to phonons, this coupling is so strong that advanced methods are necessary to capture various environment-induced phenomena, including dephasing, phonon-assisted transitions, renormalization of the light-matter coupling, and the emergence of strong system-environment correlations. While numerically exact path integral approaches account for all these effects, they have traditionally been computationally intensive. Recent advances combining these methods with tensor network techniques, along with their integration into freely available software, have significantly simplified their use.

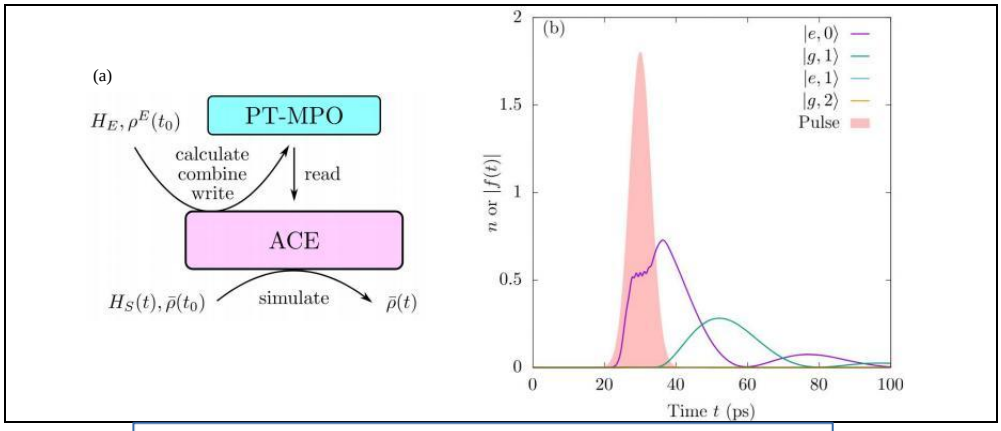

Fig. 1: (a) ACE as a "black box" computational framework.

In this talk, I will review recent studies on the effects of phonons, including their impact on biexciton state preparation protocols [1], cooperative emission from multiple quantum emitters, and the simultaneous interaction of quantum dots with phonon and photon environments. Additionally, I will highlight recent advancements in process tensor matrix product operators (PT-MPOs) and introduce ACE [2,3], a computational framework based on PT-MPOs that serves as an easy-to-use "black box" simulator for general open quantum systems. Finally, I will demonstrate the practical applications of this framework in current research topics.

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A pure-state model for resonance fluorescence of a two-level quantum emitter

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Resonance fluorescence (RF) of a two-level-emitter (TLE) under weak monochromatic excitation has been known for decades to display simultaneously anti-bunching in the photon number statistics and the driving laser's linewidth. Anti-bunching implies photons were spontaneously emitted and must therefore possess a bandwidth no less than $1/(2\pi T_1)$, a limit imposed by the TLE's radiative lifetime T_1. To explain this phenomenon, we develop a pure-state description for the joint quantum system of the TLE and its light emission (not the excitation laser) by treating TLE's interaction with the light field a purely coherent process. We view the resulting RF as a stream of phase-locked lifetime-limited broadband single photons that are entangled in time-energy domain. It is the interference of these broadband photons that gives rise to the "sub-natural" linewidth that is superimposed upon the so-called "incoherently scattered light". Moreover, we start from the pure-state form shown in Fig. 1 and successfully derive explicit dependencies of the first-order coherence of the RF, and the second-order photon bunching after passing the RF through an asymmetric Mach-Zehnder interferometer (AMZI), on the excitation power [1]. These dependencies are verified in quantum dot (QD) micropillar device [1]. Furthermore, we report observation of the Mollow triplets under few-photon excitation [2] as well as examining the applicability of the pure-state model in the resonance fluorescence under a detuned excitation [3].

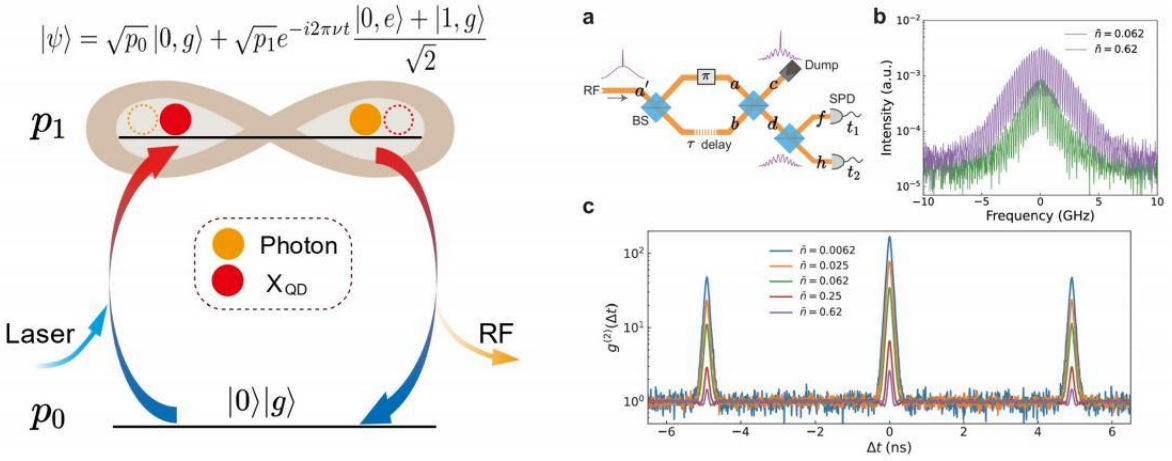

Fig. 1: The pure-state model (left panel) and experimental observation of photon super-bunching after the RF signal passing through a π-phased asymmetric Mach-Zehner interferometer (right panel).

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Cavity magnonics and quantum magnonics

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Abstract

Cavity magnonics and quantum magnonics have emerged as new directions of research in recent years. This talk focuses on some advancements in these two areas. First, I will show the bistability of magnon polaritons in a cavity magnonic system due to the magnon Kerr effect, as well as the results on multistability, including the observation of the transition from bistability to tristability and the effect with an extremely long memory time. Second, I will demonstrate the quantum control of a single magnon, including the deterministic generation of a single-magnon state and its coherent superposition with the vacuum (zero-magnon state). Also, I will show some new results on quantum nonlinear magnonics.

Exciton polariton condensation from BIC at room temperature

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Abstract

Exciton–polaritons (polaritons) resulting from the strong exciton–photon interaction stimulates the development of novel low-threshold coherent light sources to circumvent the ever-increasing energy demands of optical communications. Polaritons from bound states in the continuum (BICs) are promising for Bose–Einstein condensation owing to their theoretically infinite quality factors, which provide prolonged lifetimes and benefit the polariton accumulations. However, BIC polariton condensation remains limited to cryogenic temperatures ascribed to the small exciton binding energies of conventional material platforms. Herein, we demonstrated room-temperature BIC polariton condensation in perovskite photonic crystal lattices. BIC polariton condensation was demonstrated at the vicinity of the saddle point of polariton dispersion that generates directional vortex beam emission with long-range coherence. We also explore the peculiar switching effect among the miniaturized BIC polariton modes through effective polariton−polariton scattering. Our work paves the way for the practical implementation of BIC polariton condensates for integrated photonic and topological circuits.

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Room temperature polariton condensation and control in GaN-based whispering gallery mode and superscar mode microcavities

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Semiconductor microcavities enable the utilization of the hybrid nature of exciton-cavity polaritons. Since semiconductor cavities with ultralow disorder are essential for controlling the polariton formation, two-dimensional cavities with III-As material system have been predominantly used, despite requiring cryogenic temperatures. To overcome this temperature limitation, wide-bandgap semiconductors such as perovskites, ZnO, and GaN-based systems are promising candidates for generating room-temperature polaritons owing to their large exciton binding energy and high oscillator strength. However, fabricating III-nitride-based planar microcavities with high-quality distributed Bragg reflectors remains challenging due to the low refractive index contrast and the significant lattice mismatch between AlN and GaN. In this study, we utilized selectively grown GaN hexagonal microrod [1, 2] and triangular prism [3] microcavities via metal-organic chemical vapor deposition, significantly reducing disorder from an excitonic perspective through dislocation bending and from a photonic perspective through well-defined crystal facets. We successfully grew hexagonal and triangular GaN microcavity structures with excellent surface morphology, which exhibit clear whispering gallery and superscar modes, respectively. Finite-difference time-domain simulations revealed the optimal conditions for these structures to generate high-quality optical modes. Room-temperature polariton condensation was observed through spatially-resolved and angle-resolved optical spectroscopic measurements using a micro-photoluminescence system.

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Room temperature exciton-polariton condensation of perovskite microcavities

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Halide perovskites have emerged as promising room-temperature polaritonic platforms thanks to their large exciton binding energies and superior optical properties. However, currently, inducing room-temperature non-equilibrium polariton condensation in perovskite microcavities requires optical pulsed excitations with high excitation densities. Herein, we demonstrate continuous-wave optically pumped polariton condensation with an exceptionally low threshold of ~0.53 W cm^{-2} and a narrow linewidth of ~0.5 meV. Polariton condensation is unambiguously demonstrated by characterizing the nonlinear behavior and coherence properties. We also unveil the trapping potential landscape strategy to facilitate polariton relaxation and accumulation. Based on the structure, we further demonstrated a high-efficiency parametric scattering.

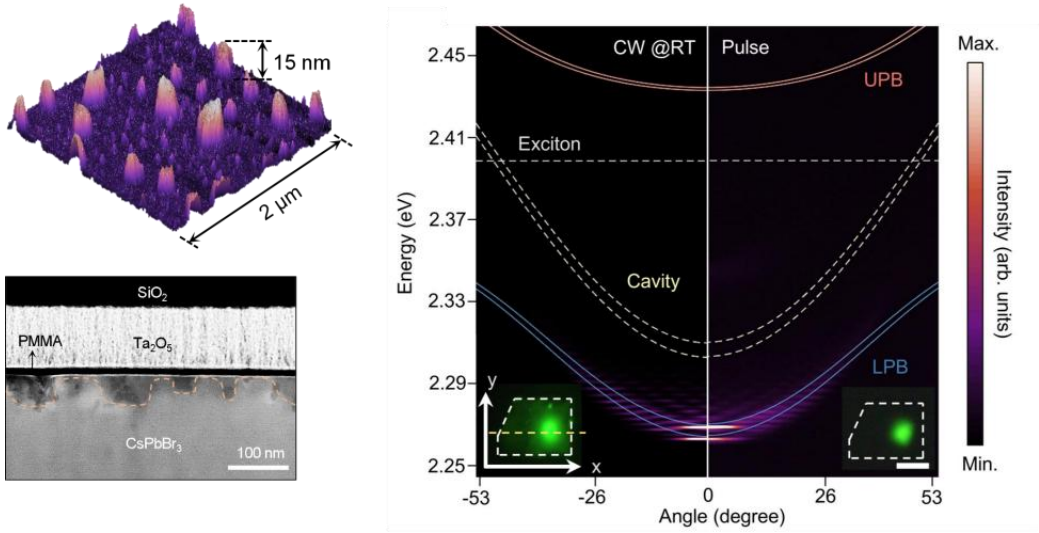

Figure. Room temperature exciton-polariton condensation of perovskite microcavities.

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Exciton-polariton condensate in the van der Waals magnet CrSBr

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Van der Waals magnets are an emergent material class of paramount interest for fundamental studies in coupling light with matter excitations, which are uniquely linked to their underlying magnetic properties. Among these materials, the magnetic semiconductor CrSBr is possibly a first playground where we can study simultaneously the interaction of photons, magnons, and excitons at the quantum level [1]. Here we demonstrate a coherent macroscopic quantum phase, the bosonic condensation of exciton-polaritons, which emerges in a CrSBr flake embedded in a fully tunable cryogenic open optical cavity. The Bose condensate is characterized by a highly non-linear threshold-like behavior, and coherence manifests distinctly via its first and second order quantum coherence. We find that the condensate's non-linearity is highly susceptible to the magnetic order in CrSBr, and encounters a sign change depending on the antiferro- and ferromagnetic ordering. Our findings open a route towards magnetically controllable quantum fluids of light, and optomagnonic devices where spin magnetism is coupled to on-chip Bose-Einstein condensates.

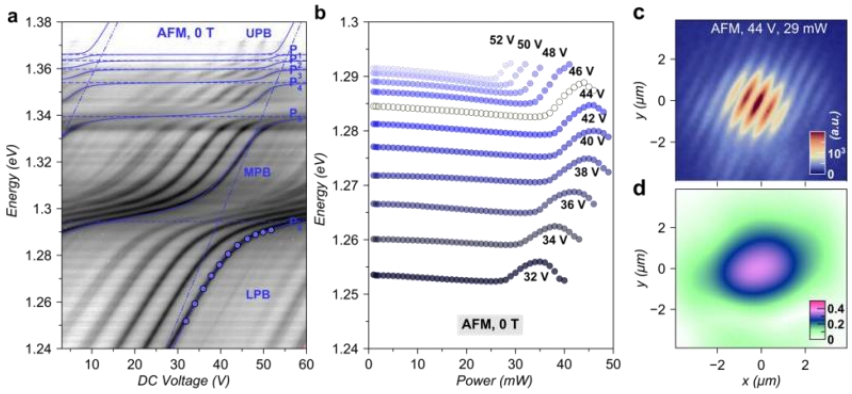

Fig. 1: Non-linear exciton-polariton condensate in a CrSBr flake placed in the cryogenic open optical cavity. **a.** Polariton energy as a function of the cavity detuning (piezo voltages). **b.** Pump power dependent lower polariton branch (LPB) nonlinearity at different cavity detuning scenarios. **c.** spatial interference and **d.** first-order correlation of the condensate at 29 mW pump power for 44 V detuning in a.

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Manipulate Exciton and Polariton Quantum Fluids ofLight in TMD Materials

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Monolayer group VI transition metal dichalcogenides (TMDs) are emerging two-dimensional (2D) semiconductors with a sizable direct bandgap and exceptional physical properties. The tightly bound excitons with giant oscillator strength render monolayer TMDs as an ideal platform to investigate the fundamental properties of excitons and their strong light-matter interactions when they are integrated with optical cavities. In this talk, we will present our recent discovery of ultrafast exciton fluids in TMD monolayers, when the trions are suppressed by a backgate. The neutral exciton emission was observed to rapidly extend the entire sample region below 150 Kelvin. This observation suggests that the exciton propagate through the entire region with tens of micrometers within their finite lifetime, beyond any possible diffusion-controlled motion. The exciton fluids propagate with a velocity ~ 6% of the speed of light. Secondly, we will discuss the progress on the exciton polariton formation and the ultrafast dynamics in TMD microcavity devices, using WS_2 as a model cavity system. Finally, we will conclude the talk by discussing the artificial landscape approach to manipulate the polariton nonlinearity.

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Magnetic polymorphism in 2D layered antiferromagnets

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Abstract:

Polymorphism, commonly denoting the variety of molecular or crystal structures, is a vital element in many natural science disciplines. In van der Waals layered antiferromagnets, a new type of magnetic polymorphism is allowed by having multiple layer-selective magnetic structures with the same total magnetization. However, resolving and manipulating such magnetic polymorphs remain a great challenge. In this talk, I will report the use of phase-resolved magnetic second-harmonic generation microscopy to elucidate such magnetic polymorphism in the 2D semiconducting layered antiferromagnet chromium sulfur bromide (CrSBr), and demonstrate how the magnetic polymorphs can be deterministically switched in an unprecedented layer-selective manner [1]. With the nonlinear magneto-optical technique unveiling the magnetic symmetry information through the amplitude and phase of light, we could unambiguously resolve the polymorphic spin-flip transitions in CrSBr bilayers and tetralayers. Remarkably, the deterministic routing of polymorphic transitions originates from the breaking of energy degeneracy via a magnetic "layer-sharing" effect: the spin-flip transitions in a tetralayer are governed by the laterally extended bilayer, which acts as a "control bit". We envision such controllable magnetic polymorphism to be ubiquitous for van der Waals layered antiferromagnets, and could lead to conceptually new design and construction of spintronic and opto-spintronic devices for probabilistic computation and neuromorphic engineering.

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Exciton behavior in magnetic semiconductor CrSBr and its related optoelectronic devices

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CrSBr, with its strong exciton resonance and interplay between magnetic, optical and electrical properties, is a promising material for optoelectronics. Combining optical characterization techniques as well as scanning transmission electron microscopy-energy loss spectroscopy, we reveal the anomaly of the exciton energy blue-shifting with thickness thickening in CrSBr. Further combined with the sub-picometer spatial resolution of scanning transmission electron microscopy, the localized nature of excitons in CrSBr is confirmed. In the constructed $MoSe_2$/CrSBr heterostructure, we reveal the presence of localized excitons, which are represented by a new photoluminescence emission feature X*. Our results suggest that X* originates from excitons confined by intrinsic defects in the CrSBr layer. Finally, taking advantage of the intrinsic anisotropy and unique spintronic coupling of CrSBr, we construct a CrSBr tunneling device in which the linear color-division ratio of the photocurrent reaches up to 60 at 1.65 K and the photoresponse is significantly enhanced with the increase of the magnetic field. In addition, the unique spin-charge coupling generates a photocurrent dependent on the photon energy, which is modulated by an external magnetic field. Our results shed light on the possibility of constructing multi-parameter controlled optoelectronic devices based on the CrSBr exciton properties of van der Waals magnets.

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Interplay between moiré superlattices and Rydberg excitons

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The Rydberg excitons, first discovered in 1950s, are higher-order excited Coulomb bound states of electron-hole pairs. They are characterized by large spatial extensions and significantly enhanced sensitivity to the surroundings, holding promise for a wide range of quantum applications. However, their potential remains largely unexplored. In this talk, I would discuss some new perspectives on studying the Rydberg excitons in 2D semiconductors and their interplay with moiré superlattices. First, I will introduce a recently developed Rydberg exciton sensing technique for detecting the correlated electronic states in 2D moiré superlattices, such as the WSe_2/WS_2 moiré heterobilayer and the magic-angle twisted bilayer graphene (TBG) [1-3]. In the latter case, we resolve the correlated Chern insulators (CCIs) under finite magnetic fields and unveil their direct link with the zero-field normal states, the "cascade transitions" [4]. Second, I would discuss the observation of Rydberg moiré excitons, which are moiré-trapped Rydberg excitons in monolayer WSe_2 adjacent to small-angle TBG [5]. These Rydberg moiré excitons manifest as multiple energy splittings, pronounced red shifts, and narrowed linewidths in the reflectance spectra. We attribute these observations to the spatially varying charge distribution in TBG, which creates a highly tunable periodic potential landscape (moiré potential) for trapping and manipulating the Rydberg excitons.

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Theory of polariton condensation in multi-band photonic crystal waveguides

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Elementary excitations emerging from the strong light-matter coupling between quantum well excitons and low-loss photonic eigenmodes supported by periodically patterned planar waveguides have been originally predicted in Ref. [1]. Recently, such photonic crystal polaritons have allowed to experimentally achieve polariton condensation in a bound-state in the continuum (BIC), displaying peculiar emission characteristics in both real and reciprocal space [2].

In this talk, the generalized Hopfield theory of polaritons in periodically patterned multi-layers [3] will be reviewed; it will be then shown how the rich phenomenology arising in these heterostructures under incoherent non-resonant pumping is reproduced by a multi-band theory, inspired from the non-equilibrium Gross-Pitaevskii formulation that is typically employed to analyze polariton condensation [4]. It is shown that numerical simulations closely reproduce polariton condensation in one-dimensional photonic crystal waveguides [5], as shown in Figure.

When considering spontaneous nonlinear scattering from the polariton condensate into iso-energetic side-branches at high momentum, peculiar periodic modulations are predicted to occur on top of the condensate profile, whose periodicity is not related to the underlying photonic crystal lattice [6], as displayed in Figure. The potential implications of these theoretical results in terms of a transition to a supersolid phase of the polariton field, a prime for polariton condensates, will be discussed also in relation to recent experimental evidence [7].

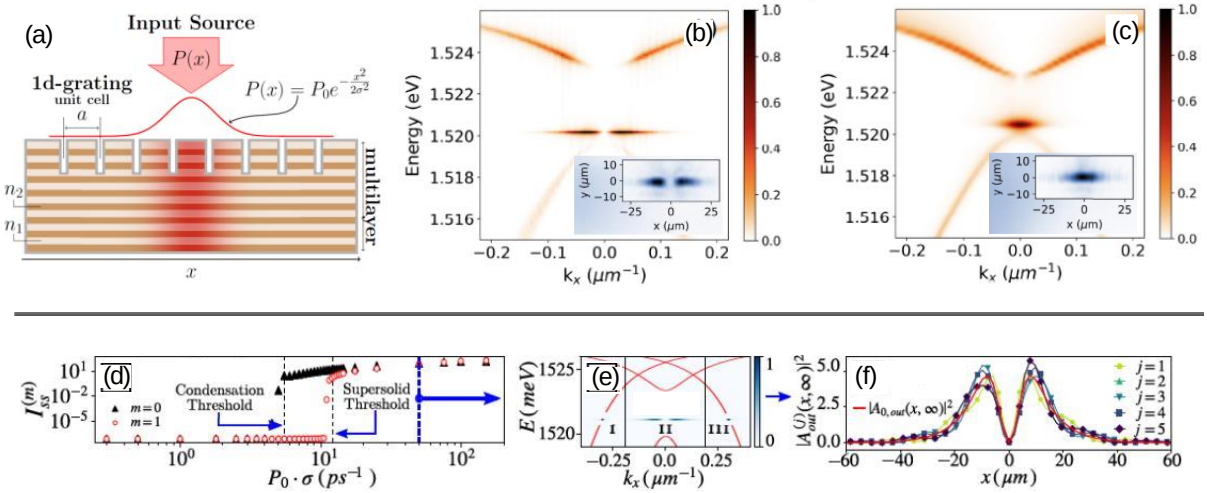

Figure. (a) Schematic representation of the driven photonic crystal waveguide with embedded quantum wells, supporting photonic crystal polaritons. The calculated emission for (b) dark (i.e., BIC) polariton condensate, as well as (c) the bright one, with the insets showing the corresponding real-space images captured in experiments (figure panels adapted from Ref. [5]), as obtained from the theoretical formulation reported in Ref. [4].
(d) Calculated emission as a function of pumping rate, distinguishing the contributions from the condensate (m=0 mode, around normal incidence) and side branches (*m*=1 modes), as indicated on the calculated dispersion in (e); periodic modulations appear in real space on top of the polariton condensate profile, with a random phase as a function of the different realizations (*j*), an indication of spontaneous breaking of translational symmetry [6].

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Observation of a supersolid phase in a spin-orbit coupled exciton-polariton Bose-Einstein condensate.

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In Bose-Einstein condensates, spin-orbit coupling [1] produces supersolidity [2, 3]. It is a peculiar state of matter, which, in addition to the superfluid behaviour of weakly interacting Bose condensates, shows a periodic modulation of its density typical for crystals [4] and called stripe phase [1–3]. Here, we report the fabrication of a new type of samples allowing to achieve room-temperature supersolidity for a quantum fluid of light [5]. The structure is an optical microcavity filled with a nematic liquid crystal (LC) sandwiched between two layers of the organic polymer MeLPPP. We demonstrate the formation of cavity exciton-polaritons in the presence of Rashba-Dresselhaus spin-orbit coupling (RDSOC) [6], which is tuned by external voltage controlling the LC birefringence. In the RDSOC regime, we demonstrate exciton-polariton condensation [7] in the two distinct degenerate minima of the dispersion. The condensate real space distribution shows both density and polarization stripes located randomly in single-shot experiments despite the presence of a random disorder potential. This demonstrates the immunity of stripes against disorder (superfluidity) and the spontaneous breaking of translational invariance. We also report the random appearance of vortices (Kibble-Zurek mechanism) limiting the condensate coherence. The possibilities offered by this platform to tune the particle dispersion and to perform full state tomography [8], including time-resolved [9], open wide perspectives for detailed future studies of the static and dynamical behaviour of supersolids and of quantum fluids in presence of SOC and topologically non-trivial bands.

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Quantum fluids oflight: from condensation to emergent supersolidity

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Polaritons are quasiparticles emerging from the hybridization of confined photons and excitons in semiconductor structures, which have demonstrated a wide range of remarkable macroscopic quantum phenomena, including superfluidity, quantized circulation, quantum turbulence, and topological effects. [1-3]

By structuring polariton waveguides, we engineered their dispersion and achieved polariton condensation into topologically protected states with significantly reduced dissipation. [4] Moreover by leveraging on the negative mass dispersion of polariton condensing into bound states in the continuum (BIC), we can obtain full optical control of quantum fluid molecules. [5] These artificial polaritonic molecules exhibit coherent hybridization, nontrivial topological characteristics, and can be scaled to form extended mono- and diatomic chains featuring tunable non-Hermitian band structures. Ballistic and evanescent coupling can be obtained in the same structure thanks to the strong anisotropic character of the 2D dispersion and studied as a function of the angle between the coupled condensates. [6] Furthermore, we explored the possibility of generating artificial gauge fields in these waveguides by spatially varying the grating filling factor, effectively producing synthetic electric fields.

Finally, we present the recent experimental observation of emergent supersolidity in multimode polariton waveguides—an exotic phase of matter characterized by simultaneous superfluid and crystalline orders. This novel quantum phase, realized through parametric processes, provides new opportunities for studying complex collective behaviors and emergent phenomena in driven-dissipative quantum systems. [7,8]

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Excitons and exciton-polaritons in strained nanostructures of transition metal dichalcogenides

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The efficiency of 2D light emitters of transition metal dichalcogenides (TMD) depends on the order and energy splitting between bright and dark (spin- or momentum-forbidden) exciton states. In the monolayer limit, MoS_2 is a direct-gap semiconductor, but this useful property is realized only in a narrow range of lattice deformation less than ±0.5%. Otherwise, the indirect IX exciton can be the lowest, which degrades the optical properties. The same applies to the position of spin-forbidden exciton. In this work, the effect of strain on the excitons and exciton-polaritons was studied using micro-spectroscopy in MoS_2 nanostructures, where they are well diagnosed due to the small intrinsic splitting of bright and dark excitons.

For MoS_2 monolayers, it was found that without deformation, the bright exciton is the lowest in the A series (1.9 eV), and the splitting energy of ~2 meV can be increased several times at a compressive strain of 0.2-0.3%. In a bilayer, the strain lifts off the degeneracy associated with an even number of layers [1]. The PL linewidth in monolayers in boron nitride claddings decreases to 4 meV at low temperatures, which is significantly less than in structures without them. The MoS_2/hBN experiences tensile strains of ~0.2%, which causes a long-wavelength shift of the PL peaks by 15 meV. However, the temperature dependences ofthe characteristic PL decay times still correspond to the location of the dark exciton above the bright one. This indicates a weak effect of tensile strain, in contrast to compression, on the value of spin-orbit splitting in the conduction band.

Multi-walled TMD nanotubes exhibit strong exciton resonances and can additionally support whispering gallery modes (WGM). The nanotubes experience an inherent tensile strain (~ 1%), which results in a flattening of the cross-section. The gap between its walls acts similarly to the barrier width in a double-well potential, which leads to a splitting of the optical modes into symmetric and antisymmetric components that are shifted in opposite directions in energy [2]. We use this phenomenon as an optomechanical method to tune optical modes to exciton resonances to form exciton-polaritons in a single nanotube. In the strong coupling regime, the Rabi splitting values are 40 and 60 meV for A and B excitons, which are comparable to the values for a monolayer in an external resonator. The splitting value excludes the influence of dark excitons which occurs between the upper and lower polariton branches. Such nanotubes are promising for using in nanophotonics [3].

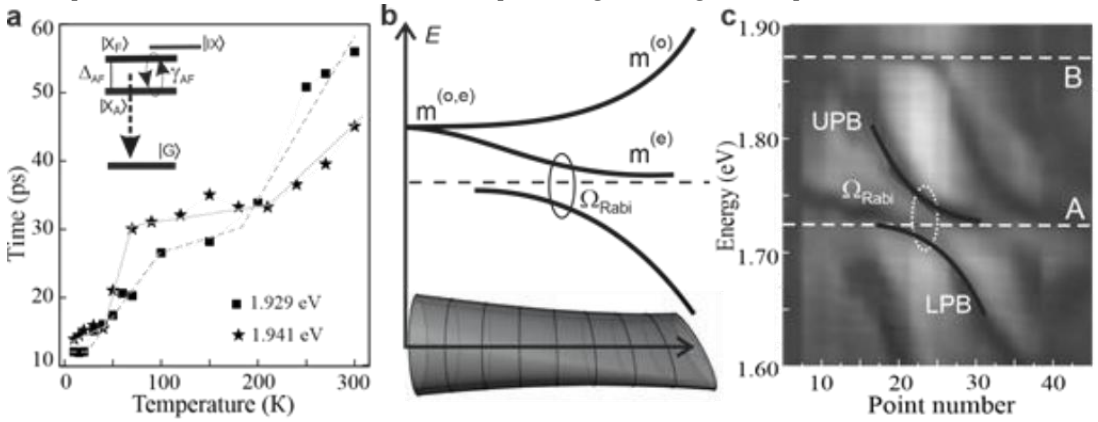

Fig. 1: (a) Temperature dependences ofthe characteristic PL decay time in a MoS_2/hBN monolayer. The time increases if the dark exciton X_F is above the light exciton X_A, as shown in the inset. (b) Schematic of the WGM splitting with formation of exciton-polaritons when the gap in the tube cross-section decreases. (c) Micro-reflection showing the anticrossing of polariton branches in a MoS_2 nanotube.

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Plasmonic nanocavity: Ultimate field enhancement for plasmon-exciton coupling

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Plasmonic nanocavity is capable of concentrating optical field into a deep subwavelength regime, which produce enormous electric field enhancement. In the past few years, we figure out how to quantitatively probe the quantum limited field enhancement in the plasmonic nanocavity [1-2] using 2D materials. At resonance, the averaged electric field enhancement over the hot spot can reach as high as 1214 times and the hottest point reach 1644 times. Such strong field enhancement is the base for strong plasmon-exciton coupling [3-4] when metallic nanoparticle is deposited on top of few layer 2D semiconductor. Dark-field scattering spectroscopy is a common technique to characterize such plexcitonic system but it always reveals a larger Rabi splitting. This leads to some suspicions of whether there is a true strong coupling or not. Since the plasmon usually has much stronger dipole moment than the exciton, the scattering from the coupled system is mainly contributed from the plasmon part, while the absorption in the coupled system is contributed from both the plasmon and the exciton. By correlating the scattering and absorption from the same nanocavity, and putting them into one framework, we are able to extract the spectral response from either the plasmon channel or the exciton channel [5]. The exciton channel possess a much smaller Rabi splitting than the plasmon channel. This is why the dark-field scattering always has a large spectral Rabi splitting. Recently, we go further to exploit the plexciton luminescence from such coupled system [6]. To remove the influence of the background exciton around the nanocavity, we use a bright mode that have large fluorescence enhancement (2.1×10^4 times) so that light emitting from the coupled system is far beyond the surrounding background. Then, we can observe the plexciton emission from the lower branch and the exciton reservoir (uncoupled states), clearly demonstrating their coupling.

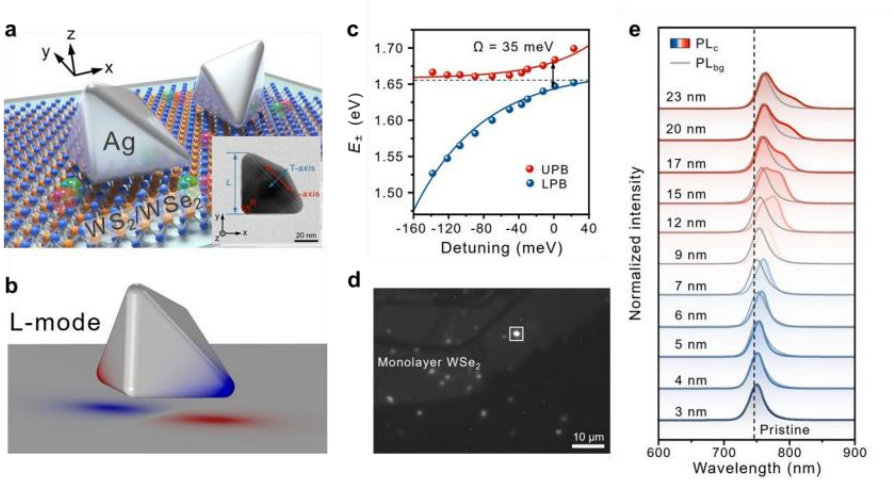

Fig. 1: (a) Schematic of nanobipyramid-over-mirror; (b) charge plot of the plasmon mode; (c) Energy of the upper plexciton branch (UPB) and lower plexciton branch (LPB) as a function of detuning. (d) PL imaging of the measured system; (e) PL spectra of the coupled system for different alumina coating.

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Exciton-Photon-Phonon Interactions in Hybrid 2D-Material Nanophotonic Cavities

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2D materials such as monolayer transition metal dichalcogenides are ideally suited as the active emitters for nanophotonic cavities, since they host a variety of excitonic transitions with rich exciton-photophysics. Moreover, 2D materials can be assembled into heterostructures via van der Waals bonding, and the atomical thickness of material results in the sensitivity and strong coupling to the multi-physics local environment. Therefore, 2D-material nanophotonic cavity paves the way to the coupling between different physical degrees of freedom. However, the common pick-and-place method introduces disorders that perturb the excitonic quality in 2D materials. Meanwhile, perforating nanophotonic structures in 2D flakes results in complex effects and limits the cavity Q-factor ~ 10^3. We fabricated hybrid nanobeam cavities with high Q-factor ($>10^4$) and integrate the pristine hBN-encapsulated 2D materials with controllable cavity-material overlap [1]. Based on this platform, we observed novel light-matter interactions for the unique quantum emitters in 2D materials [2]. Moreover, the photonic crystal is also phononic crystal, and thereby, the nanophotonic cavity also hosts the nanomechanical modes with phonon vibrations. We observe the phononic hybridization between the atomic lattice phonons and cavity nanomechanical phonons in the light-matter interaction [3]. Such multi-modal couplings provide novel methods to interface emitters, photons, and phonons as a hybrid solid-state quantum system [4].

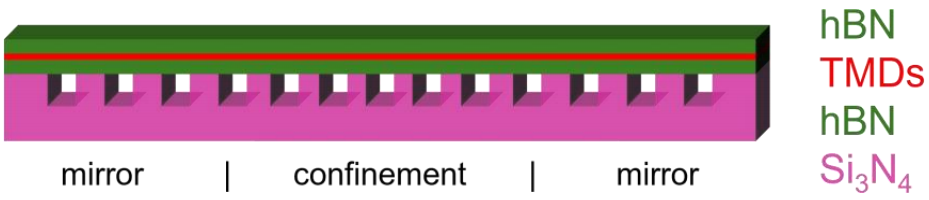

Fig. 1 Schematic of the hybrid 2D-material nanophotonic cavity

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Quantum Dynamics of Polaron Polariton In a Doped $MoSe_2$ Based Microcavity

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The behavior of a mobile quantum impurity within a degenerate Fermi system is a crucial issue in many-body physics. When an exciton or polariton is generated optically in a two-dimensional electron system confined in a microcavity, it creates innovative possibilities due to the interaction between the cavity and an exciton accompanied by a polarized electron-hole cloud in the Fermi Sea, resulting in a theoretical many-body quasiparticle known as a polaron polariton [1]. In this study, we conduct cavity spectroscopy on gate-tunable monolayer $MoSe_2$, which reveals both strongly repulsive and attractive polarons, alongside a non-perturbative connection with a single microcavity mode. As the electron density rises, the oscillator strength—derived from the polariton splitting—shifts progressively from the higher-energy repulsive exciton-polaron resonance to the lower-energy attractive exciton-polaron state [2]. By manipulating the interactions between attractive and repulsive polarons, we investigate the nonequilibrium behavior of impurities interacting with the Fermi Sea. Our time-resolved measurements capture the quantum evolution of a fermionic many-body system, showcasing the real-time formation dynamics of quasiparticles as they transition between attractive and repulsive states throughout the Fermi Sea. These time-domain techniques, applied to strongly interacting quantum gases, provide insights into the dynamics of quantum matter under nonequilibrium conditions [3].

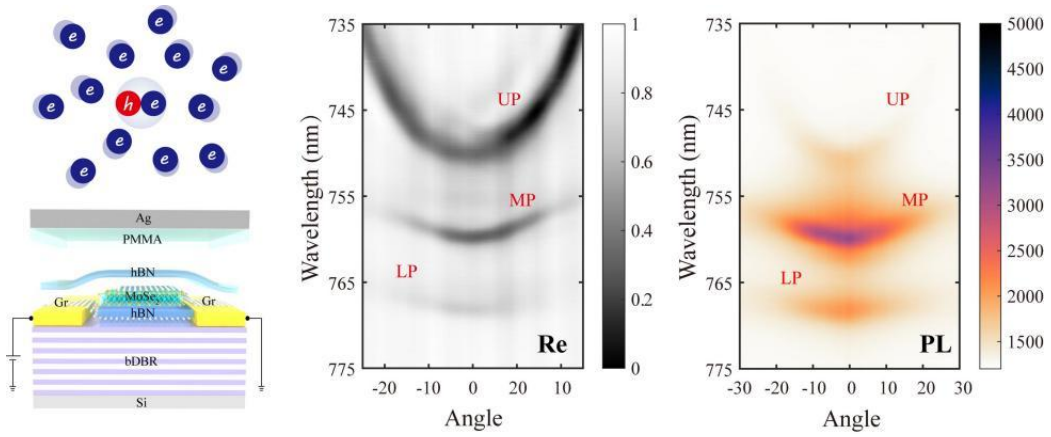

Figure 1: Schematic diagram showing the polaron and polaron-polariton device, along with angle-resolved reflectivity and photoluminescence measurements.

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Van der Waals exciton polaritons with linewidth approaching homogeneous limit

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Van der Waals (VdWs) semiconductors have provided a new platform to extend the physics and applications of cavity exciton polaritons, thanks to their flexibility of integration, large oscillator strength, and novel moiré physics. However, the inhomogeneous broadening of excitons originating from strain, defect, or interface fluctuation, has been an obstacle to further exploring coherent quantum phenomena and devices in this community. In our work, we systematically study polariton linewidth in a strongly coupled TMDCs-cavity system. The large inhomogeneous broadening of exciton, strong oscillator strength, and tunable Rabi splitting render this system a flexible platform to explore the correlation between the inhomogeneous broadening of polariton and Rabi splitting. we show that the contribution of exciton inhomogeneous broadening to polariton linewidth can be fully suppressed by increasing Rabi splitting. The results can be well reproduced theoretically, by modeling the exciton photon coupling using a non-Hermitian Hamiltonian. Our findings not only shed new light on the development of coherent Van der Waals polariton devices but also demonstrate a general conclusion on the correlation between the inhomogeneous broadening of a solid-state oscillator and linewidth of its corresponding light-matter hybrids. Moreover, our finding can also facilitate the scalability of VdWs exciton polaritons by incorporating TMDCs grown by the chemical vapor deposition method, whose large inhomogeneous broadening could be suppressed by optimizing Rabi splitting.

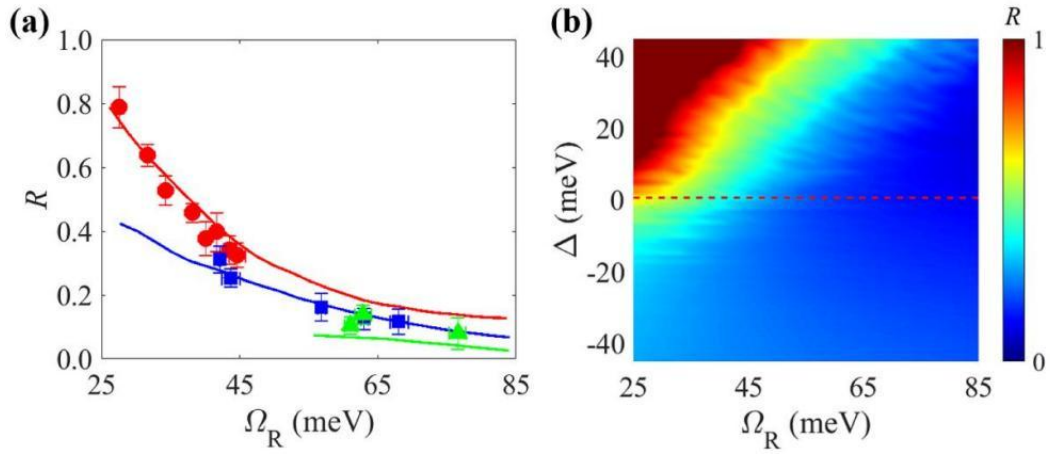

Fig. 1: (a) Suppression of inhomogeneous broadening (quantified by R) as a function of Rabi splitting. The phase diagram for R with varying detuning (Δ) and Rabi splitting (Ω_R).

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Light-assisted exciton propagation in 2D semiconductors

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Tightly bound excitons mediate exceptionally strong light–matter coupling in two-dimensional semiconductors based on transition metal dichalcogenides (TMDCs). This coupling influences fundamental excitonic parameters, such as lifetime and fine-structure splitting, and can be controlled by engineering van der Waals heterostructures with embedded TMDC monolayers [1–3]. In this work, we demonstrate that exciton–light interactions can significantly affect exciton propagation.

First, we study exciton energy spectra and their propagation in moiré superlattices formed in TMDC heterobilayers. In such structures, an effective, moiré, potential acting on excitons arises. Usually, excitons are considered to be localized in such a potential. We show that the coupling of optically active excitons with an induced electromagnetic field produces energy dispersion that is linear in the wave vector even if the quantum-mechanical tunneling between the localization sites is suppressed. The effect can be described as a result of the processes of virtual generation-recombination of excitons at the localization sites. We study exciton propagation in moiré superlattices with allowance for the light-exciton interaction both in semiclassical diffusion and in the hopping regime. In the latter case, that the temperature dependence of the exciton diffusion coefficient is described by the power law rather than by an exponential function of the temperature [4].

Second, motivated by recent experiments on superfluid-like exciton propagation [5] we discuss possible origin of exciton ultrafast propagation in van der Waals heterostructures with TMDC monolayers. We propose a model of ultrafast exciton transport based on the formation of waveguide modes in these heterostructures, where radiative transfer via these modes eventually induces exciton luminescence far from the excitation spot [6].

This work was supported by the RSF grant 23-12-00142.

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Engineering topological exciton structures in two-dimensional semiconductors by a periodic electrostatic potential

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We propose to engineer topological exciton structures in semiconducting transition metal dichalcogenides through momentum-dependent couplings between Rydberg states, which can be realized by a periodic electrostatic potential. Such potentials can be introduced and tuned by modulating the spatial charge distribution in adjacent layers. The nontrivial topology is characterized by nonzero spin Chern numbers of exciton bands as well as the emergence of in-gap counterpropagating valley-polarized edge states. Topological phase transitions can happen by tuning the landscape and wavelength of the periodic electrostatic potential. The proposed scheme can apply to excitons with various spin, valley and layer configurations. For bright monolayer excitons with the two valleys coupled by the electron-hole exchange interaction, the exchange strength can offer further tunability to the topological structure.

Non-Hermitian theory of valley excitons in two-dimensional semiconductors

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Electron-hole exchange interaction in two-dimensional transition metal dichalcogenides is extremely strong due to the dimension reduction, which promises valley-superposed excitonic states with linearly polarized optical emissions. However, strong circular polarization reflecting valley-polarized excitonic states is commonly observed in helicity-resolved optical experiments. Here we present a non-Hermitian theory of valley excitons by incorporating optical pumping and intrinsic decay, which unveils an anomalous valley-polarized excitonic state with elliptically polarized optical emission. This novel state arises from the non-Hermiticity induced parity-time (PT)-symmetry breaking, which impedes the experimental observation of intervalley excitonic coherence effect. At large excitonic center-of-mass momenta, the PT-symmetry is restored and the excitonic states recover their valley coherence. Interestingly, the linear polarization directions in optical emissions from these valley-superposed excitonic states are non-orthogonal and even become parallel at exceptional points. Our non-Hermitian theory also predicts a non-zero Berry curvature for valley excitons, which admits a topological excitonic Hall transport beyond the Hermitian predictions.

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Ultra-strong trion-polaritons

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Trion-polaritons [1, 2], which result from the hybridization between confined photons and charged excitons in a microcavity semiconductor, have become a fertile and promising ground for the realization of strong polaritonic interactions and the creation of polaritonic quantum many- body states [3–5], thanks to the presence of tunable molecular resonances, the so-called polariton Feshbach resonances [6]. This work presents the development of a quantum field theoretical formalism for studying trion-polaritons in the ultra-strong light-matter coupling regime [7]. USC has become attractive in recent decades as it enables faster response of polaritonic states and efficient processing in quantum information protocols [8, 9]. Here, a new class of many-body states is predicted that results from the intriguing interplay between Fermi exciton-polarons and virtual photons [10] in a still unexplored field of light-matter interactions and Feshbach physics that lies in the convergence between the techniques of atomic physics, condensed matter, and quantum optics.

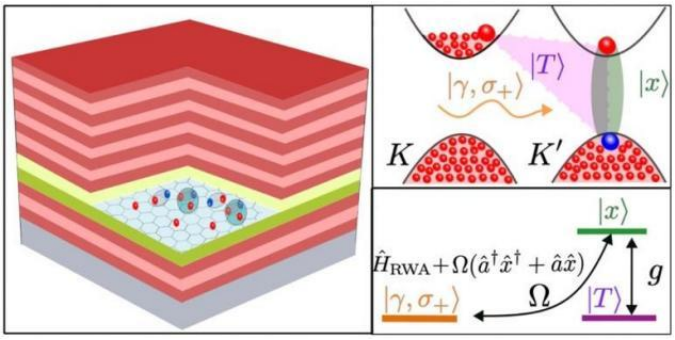

Fig. 1: *Schematic depiction of a 2D semiconductor doped with itinerant electrons and coupled to a high-finesse cavity in the USC regime.*

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Giant resonant skew scattering of plasmons in a two-dimensional electron gas

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Electron skew scattering by impurities is one of the major mechanisms behind the anomalous Hall effect in ferromagnetic nanostructures. It is particularly strong at the surface of topological insulators where electron dynamics is governed by the spin-1/2 Dirac equation. Motivated by recently discovered mappings between hydrodynamics and the spin-1 Dirac equation, we consider the scattering of plasma waves -- propagating charge density oscillations -- excited in graphene off a non-uniform magnetic field created by an adjacent circular micromagnet. The calculated scattering amplitude not only exhibits a giant asymmetry, or skewness, but is resonantly enhanced if the frequency of the incoming wave matches the frequency of the chiral trapped mode circulating the micromagnet in only one direction. Furthermore, if the frequency of the incoming plasma wave is a few times larger than the Larmor frequency, the angular distribution of its forward scattering is almost indistinguishable from that of a Dirac electron at the surface of a topological insulator scattering off a magnetic impurity. The micrometer scale of the proposed setup enables direct investigations of individual skew scattering events previously inaccessible in electronic systems.

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Excitonic insulator in 2D moirésuperlattices

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An exciton is a bound state formed by an electron and a hole through Coulomb interaction. In the 1960s, Nobel laureate in Physics, Mott, proposed that when the binding energy of an exciton exceeds the band gap of a semiconductor, a new phase of matter—the excitonic insulator—might emerge. In conventional semiconductors, the binding energy of excitons is typically much smaller than the band gap; However, in two-dimensional materials, particularly in moiré superlattices, the binding energy of excitons can potentially exceed the single-particle band gap of the system, leading to the formation of an excitonic insulator. The speaker utilized the characteristics of moiréflat bands in two-dimensional moirélattices to significantly suppress the kinetic energy of charge carriers, enhance the interactions between excitons, and successfully observed the excitonic insulator in this system, maintaining its transition temperature at nearly 100 K [1]. This discovery provides a new experimental platform for studying various quantum phenomena based on the Bose-Hubbard model, such as excitonic Mott insulators, excitonic superfluids, and excitonic Bose-Einstein condensates.

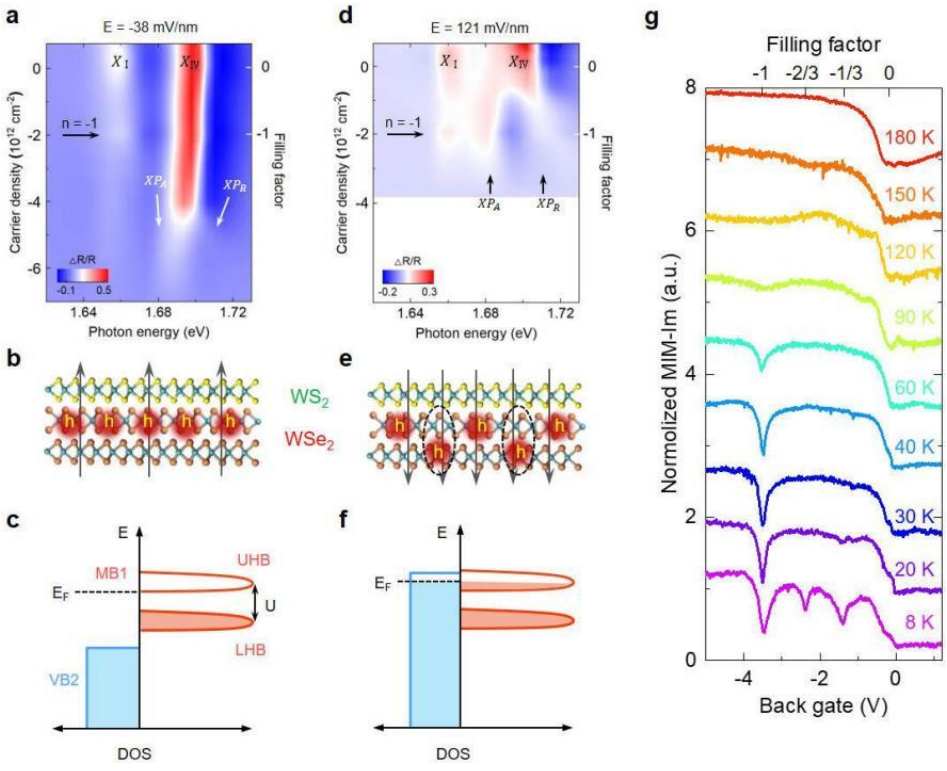

Fig. 2. Electric field regulation and temperature dependence of exciton insulators. (a-c) Reverse electric field without exciton insulator; (d-f) positive electric field with presence of exciton insulator; (g) temperature dependence of exciton insulator.

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Artificial room-temperature quantum states

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Abstract: Room-temperature (RT) quantum state is the key foundation for the development of high-performance micro-nano quantum optoelectronic devices, quantum computation and solid-state quantum chips. However, it is extremely difficult for the quantum states to survive at the RT due to the huge dissipation. The potential solution is to constructing artificial RT quantum states by strong coupling between emitters and photons. Over the past more than two decades, the only method of achieving the RT strong coupling quantum state is to greatly improve the exciton-photon coupling strength for overcoming the huge dissipation. The plasmonic microcavities has been applied for this purpose[1-3]. I will firstly introduce the critical criteria and diversity of the RT strong coupling[4,5]. Then, I will present how to realize the RT single qubit formed by the strong coupling of a single exciton with a single metal nanoparticle[6]. However, the RT strong coupling achieved by enhancing the coupling strength is accidental events with very low probability of less than 1% due to harsh critical conditions. To overcome this challenge, we present a highly-efficient approach for achieving the room-temperature strong coupling by reducing the critical coupling strength at the exceptional point based upon the damping inhibition and matching of the coupled systems[7]. In contrast to the method of enhancing the exciton-photon coupling strength, our strategy can dramatically relax the harsh critical conditions and significantly improves the experimental success rate of the RT strong coupling from about 1% to 80%, which will boost advance in the RT strong coupling quantum states and the quantum devices.

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Topological edge and corner modes in polariton lattices

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Topological Photonics is an emerging and novel field of research, adapting concepts from condensed matter physics to photonic systems adding new degrees of freedom. After the first demonstrations of topological photonic insulators [1,2], the field has moved on to study and exploit the inherent non-hermiticity of photonic systems and the interplay with their topological nature. In my talk, I will attempt to give an overview about the quickly emerging field of topological photonics. In this context, I will discuss topological lasers as a prime example of using topological concepts potentially for new technologies in the broad context of synthetic (photonic) matter. Examples will be given from novel photonic lattice devices resulting from the coupling of individual vertical III-V semiconductor microresonators. Here, the so-called exciton-polaritons hybrid states of light and matter can emerge in the strong coupling regime. By choosing precise lattice geometries we are able to tailor optical band structures realizing novel photonic lattice. The specific geometry as well as the hybrid light-matter nature allow for ways to break time-reversal symmetry and implement topologically non-trivial systems. We were able to experimentally demonstrate the first exciton-polariton topological insulator, manifesting in chiral, topologically protected edge modes [3]. In order to study topological effects in combination with optical non-linearities, so-called topological lasers have been envisaged and realized. We have presented the first experimental demonstration of a topological insulator vertical cavity laser array [4], using the crystalline topological insulator model (see Fig. 1). Following this works, I will discuss recent advances towards electrical operation and lasing from a topological defect [5]. In addition, so-called corner modes, fully localized higher-order topological defects in two-dimensional lattices in breathing Kagome and 2D-SSH lattices are discussed, with a particular focus on the robustness against (deterministic) fabrication imperfections. Finally, I will discuss recent advances in using polarization degrees of freedom in the context of artificial gauge fields and the spin quantum hall effect of light.

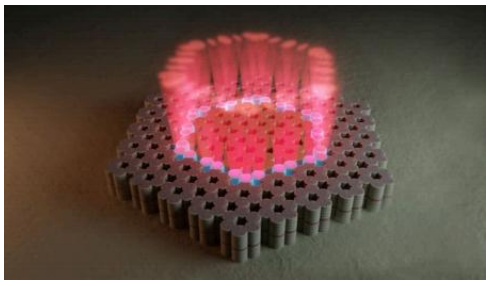

Fig. 1: Schematic drawing of a topological vertical-cavity surface-emitting laser array.

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Reconfigurable topological exciton polaritons

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Exciton-polaritons are half-light half-matter quasiparticles resulted from the strong coupling between excitons and photons. Exhibiting both high spatial and temporal coherence and strong inter-particle interactions, exciton polaritons serve as a unique platform for studying macroscopic quantum phenomena such as Bose-Einstein condensation and optical nonlinearities. In topological photonics, specifically, strongly coupling with excitons provides powerful toolbox for statically or actively engineer the topological properties of photonic structures. Here we demonstrate topological exciton polaritons in two-dimensional semiconductors coupling with non-trivial photonics crystals. By carefully tailoring the photonic nanostructure and material properties, we realized topological exciton polaritons with reconfigurable topological properties.

Polariton spin Hall effect in perovskite microcavities

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Abstract:

Cavity exciton polaritons are bosonic quasiparticles resulted from the hybridization of excitons and confined cavity photon modes. With part-light and part-matter nature, they inherit the combined advantages from their components, such as a low effective mass, fast propagation over long distances from their photonic components, strong nonlinearity and unique spin properties. These advantages allow them to be ideal information carriers towards next generation spintronic applications. In this talk, I will discuss our recent progress in realizing polariton spin hall effect in a Rashba-Dresselhaus regime. By introducing liquid crystals into perovskite microcavities, we achieved synthetic photonic spin-orbit coupling controlled by external voltages, which further leads to spin-split bands with a high purity of ~0.9. Under a resonant excitation, we observed permanent spin separation over macroscopic distances at room temperature [1]. Furthermore, by tuning the external voltage with gap openings, we observed tunable trembling motion or Zitterbewegung of exciton polaritons [2].

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Spin-Charge-Lattice Interactions in 2D Magnets

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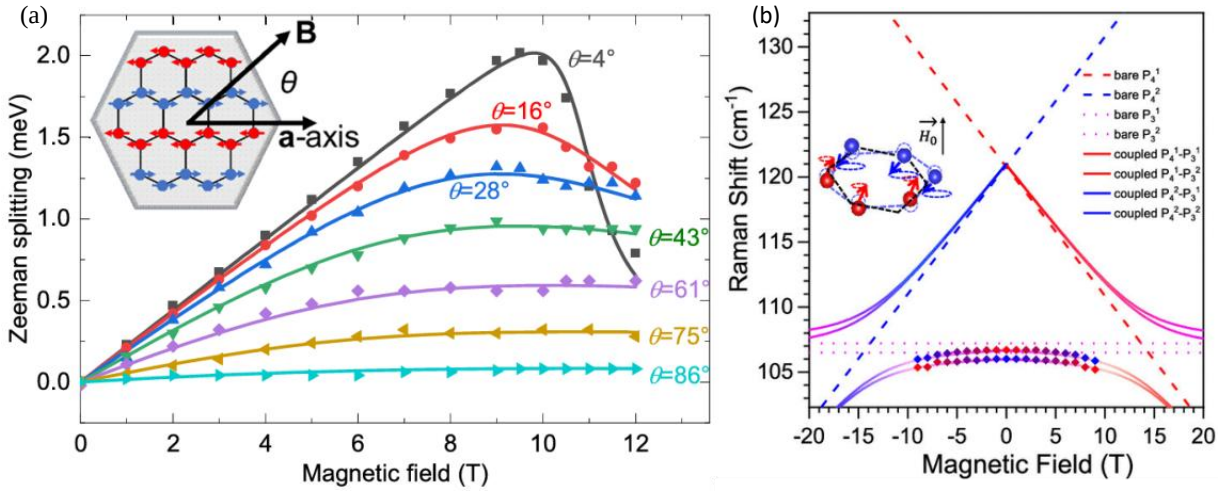
The interaction of spin-charge-lattice degrees of freedom leads to various emergent correlation phenomena, such as high-transition-temperature (Tc) superconductivity and Quantum Hall effect. Recent studies of two-dimensional (2D) magnetic materials, for example $TMPX_3$ (TM = 3dTMs; X = chalcogens), exhibit a variety of magnetic orderings: ferromagnetic (FM), zig-zag antiferromagnetic (AF), Neel AF, stripy AF and all three key magnetic Hamiltonians, i.e., Ising, XY, and Heisenberg types, are realized in $TMPX_3$. These novel 2D magnetic provide a new platform for studying the interaction of spin, charge, lattice.

In this report, we will report our recent work on the $TMPX_3$ investigated by the optical method. In $NiPS_3$, we find the dipole of the Zhang-Rice exciton is aligned with the Néel vector, as confirmed by the angle-resolved and polarization-resolved magneto-optical photoluminescence (PL) spectra of $NiPS_3$ in the Voigt geometry. In addition, the spin-dipole interaction also can be applied to detect the magnetic field transition of the XY-type antiferromagnet. In MnPS3, by temperature-dependent Raman measurements, we obtain three phase transition temperatures of MnPS3. The transition temperature around 80 K corresponds to the transition from the antiferromagnetic to the paramagnetic phase; the transition near 120 K is associated with a second magnetic phase transition resulting from two-dimensional spin critical fluctuations; and the transition at approximately 55 K is linked to the unbinding of spin vortices. We investigate magnon-phonon coupling in $FePS_3$ using near-resonant magneto-Raman spectroscopy under relatively small magnetic fields ($|H_0| \leqslant 9$ T). Under near-resonant excitation, we observe more pronounced coupling effects that are absent under non-resonant excitation: three optical phonons sensitive to the applied magnetic field are resolved, two of which exhibit frequency anti-crossing coupling with magnons, while the other coupled phonon displays a polarization-coupled character without frequency anti-crossing. Moreover, our polarized Raman results indicate polarization transfer between coupled magnon-phonon modes. Based on a modified theoretical model, we can effectively explain the measured Raman spectra. Our work demonstrates that Raman and PL spectroscopy are effective tools for detecting spin order in 2D magnets due to the interaction of spin, charge, and lattice degrees of freedom.



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Electric tunable multi-valley van der Waals quantum wells

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The emergence of van der Waals (vdW) heterostructures has opened new pathways in quantum confinement engineering, advancing beyond traditional semiconductor quantum wells. While conventional quantum wells have been fundamental to IR detection and laser technologies, their fabrication complexity due to lattice matching requirements has limited broader applications. Our research introduces an investigation of electrically controllable intersubband transitions in atomically thin WSe_2 structures. Through systematic experiments, we demonstrate an exceptional electric field-induced modulation of valley-specific Raman signatures, achieving remarkable energy shifts exceeding 100 meV. By examining WSe_2 configurations ranging from trilayer to septuple-layer structures, we establish comprehensive insights into quantum-confined Stark effects, characterizing key parameters including dipole characteristics and polarization responses. Furthermore, we explore the manipulation of these quantum states through the twist angle in artificially constructed multilayers. These findings establish a robust framework for developing atomically precise optoelectronic devices, particularly in applications such as reconfigurable infrared sensors and ultra-compact spectroscopic systems.

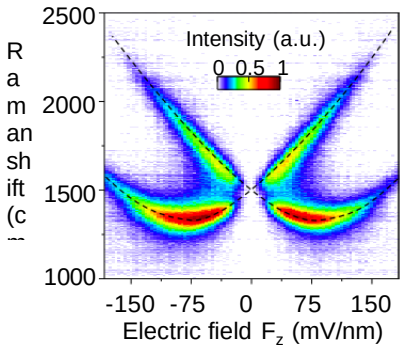

Fig. 1: **Nonmonotonic electric-field dependence of intersubband transitions in natural four-layer WSe_2.**

Quadrupole interlayer excitons in WSe2/MoSe2/WSe2 heterotrilayers

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Recently, a new exciton species of quadrupole exciton (QX) has been discovered in two-dimensional (2D) transition-metal dichalcogenide (TMD) heterotrilayers. Here, we report photoluminescence spectroscopy evidences ofthis exciton and further its transition to Stg-DXs in WSe2/MoSe2/WSe2 heterotrilayers when exciton intensity increased.

Ref:

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Rev. B, L201402 (2024)

On the light-matter coupling in 2D superconducting thin films

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We build a theory of electromagnetic field-induced transport in two-dimensional (2D) superconducting thin films and monolayers at low and finite temperatures. This theory shows that an external electromagnetic field's frequency and polarization can control the Cooper pairs' current, allowing for achieving both longitudinal and transverse (Hall) currents of Cooper pairs. Light absorption of a uniform electromagnetic field with a frequency larger than the superconducting gap is forbidden in pure superconductors. Finite absorption can occur only if electron scattering by impurities is considered. In recent works [1-3], the issue of absorption of EM radiation in isotropic superconductors with built-in superconducting currents was studied. We are constructing a theory of the nonlinear response of isotropic 2D superconductors in the presence of a built-in constant supercurrent at various frequencies and temperatures.

This research aligns with the recent study of the superconducting diode effect [4]. We also propose the optical diode (photodiode), which (i) allows for optical control of the signal propagation in the system and (ii) is magnetic field-free, as opposed to the superconducting diode, where the magnetic field is necessary. The frequency of the control field depends on the superconducting gap. For conventional superconductors, it lies in terahertz (THz) and sub- THz regions. However, the effect we propose is general as it does not impose any substantial restrictions on the material or the frequency of the field, which can vary in quite a broad range. Moreover, this theory can be used for any 2D superconductors, including conventional and high-temperature superconductors.

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Universal condensation threshold dependence on pump beam size for exciton-polaritons

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Exciton-polariton condensates in high-quality semiconductor microcavities are subject of extensive studies [1]. The interest in this "quantum fluids of light" system is not only fundamental but is also stimulated by perspectives for practical applications, such as optical computing, polariton simulators [2] etc. A way to create polariton condensate is incoherent pumping creating hot exciton reservoir. Then excitons relax to the low-energy state and condense if the gain overcomes losses [1]. From the theoretical viewpoint, the physical processes can be modeled using two equations, one for the reservoir kinetics and another one (driven-dissipative Gross-Pitaevskii equation) for the condensate order parameter [3]. The corresponding laser power at which the condensation occurs (pumping threshold) is a function of microcavity parameters as well as the pumping profile.

In the theoretical part of this study, conducted with O.I. Utesov, we start with formulating an effective complex Ginzburg-Landau equation (cGLE) near the threshold based on the stationary reservoir assumption. Aiming for the description of the condensate wave function under the Gaussian pumping, we substitute it with the parabolic gain "pseudopotential." The latter allows for an analytical perturbative solution of the corresponding cGLE and provides an accurate description of the Gaussian profile problem. As the primary outcome of our analytical approach, we propose a very compact analytical expression for the pumping threshold as a function of microcavity parameters and of the pumping beam size. This function is characterized by a single healing length-like scale parameter ξ only dependent on the polariton spectral line properties. The obtained approach allows finer consideration time-delay two-spot synchronization [4] and real space collapse effects [5].

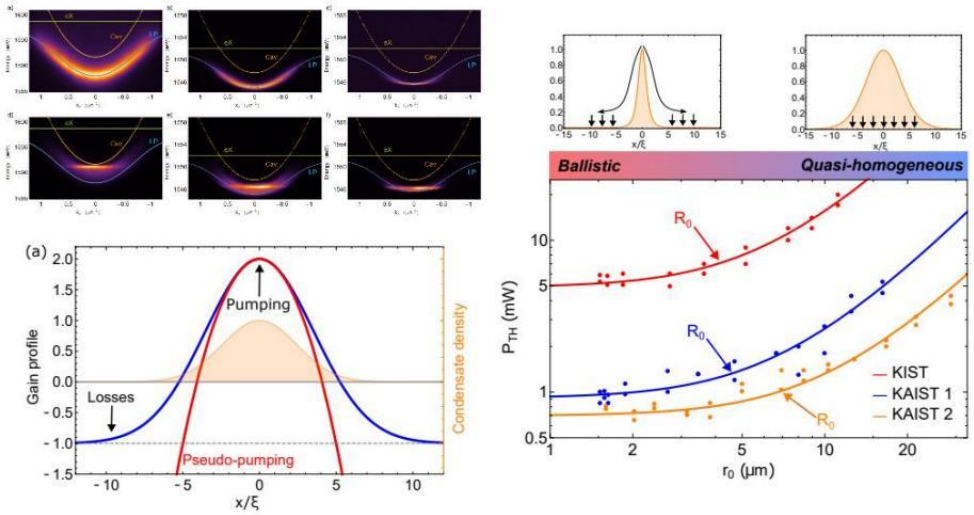

Fig. 1. Polarion condensation, pseudo-pumping approximation and universal condensation threshold law.

In the experimental part of the study, performed in KAIST, threshold pumping intensity was measured for three different samples in the continuous pumping regime as a function of the spot size. The corresponding data were explained using the analytically predicted dependence, and a faithful agreement was observed. It implies that the developed approach is efficient for creating condensates with required properties, e.g., size in real space.

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Bogoliubov mediated light absorption process in multi-component BEC

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We investigate the light absorption process in a coherently coupled two-component Bose-Einstein condensate model with z_z symmetry in different dimensionality at zero temperature. As the analogue of phonon in the solid-state physics, the elementary excitation of the Bose-Einstein condensate is described by Bogoliubov quasiparticle or bogolon for short. Due to the small magnitude of the sound velocity of the bogolon, the light absorption process is prohibited by the conservation of energy and momentum. To surmount this depression, the additional degree of freedom must be considered inside of the simple Bose gas model. In this article, we develop a microscopical theory of electromagnetic power absorption by a two-component Bose-Einstein condensate and investigate the absorption rate dependence in different dimensions. Our calculation shows the possibility of manipulating the absorption property by tuning the parameters of the condensates.

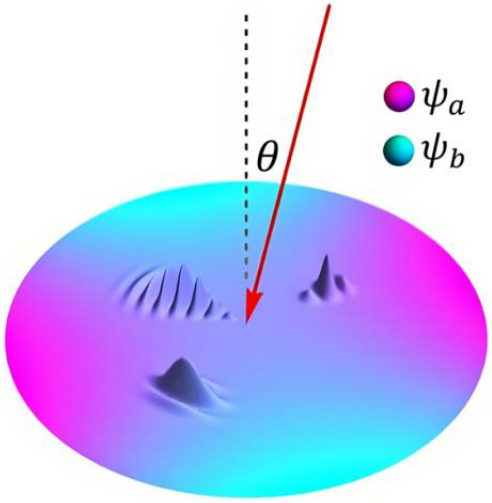

Figure 1: Schematic diagram. The light (red) is approximately perpendicular shading onto the two-component Bose-Einstein condensate.

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Towards the use of sound for time-bin encoding of photonic qubits for secure quantum communication

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Photons possess a number of information carrying degrees of freedom that can be used to encode data qubits making them excellent carriers of information. Currently, most quantum communication protocols are using photon polarization state as a degree of freedom by converting a qubit of information into different photon polarization directions. However, this type of encoding suffers from decoherence via polarization mode dispersion in optical fibers, which hinders its use for long-distance secure quantum communication using the existing telecommunication infrastructure. In this work, we demonstrate progress towards efficient time-bin encoding, via dynamic real-time control, using radio-frequency (RF) surface acoustic waves (SAWs), of the optical emission from quantum dots (QDs) embedded in epitaxially grown core-shell GaN/InGaN nanowire (NW) heterostructures[1]. The SAWs are excited on the surface of a piezoelectric $LiNbO_3$ crystal equipped with an acoustic delay line onto which the NWs were mechanically transferred[2,3]. Luminescent QD-like exciton localization centers, induced by indium content fluctuations within the InGaN nanoshell, are identified as efficient sources of single-photons. These quantum emitters are optically characterized by spatially and polarization resolved micro-photoluminescence as well as photon correlation spectroscopy. Such experiments reveal the appearance of narrow highly linearly polarized emission lines associated with quantum confined exciton (X) and biexciton (XX) exhibiting pronounced photon antibunching[2,3]. When perturbed by the propagating SAW, the NW-QDs are periodically strained and their excitonic transitions are dynamically modulated by the acousto-mechanical coupling, giving rise to spectral fine-tuning of the emitted light within a ~2 meV bandwidth at the acoustic frequency of ~330 MHz. This outcome is further combined with spectrally filtered detection for temporal control of the emitted photons[2]. The stroboscopic measurements performed on our SAW-driven single-photon NW-QD sources under time-resolved detection synchronized with the SAW show weak changes in the emission intensity during the decay of both X and XX luminescence. The amplitude of these oscillations scales with the strength of the SAW piezoelectric field. For sufficiently high acoustic powers resulting in stronger field values, these intensity oscillations become more pronounced making it possible to track their temporal evolution. Their appearance takes place at a well-defined acoustic phase corresponding to the maximum longitudinal SAW piezoelectric field component. We thus relate these oscillations to the field assisted simultaneous transfer into the probed NW-QD emitter of electron and holes which are optically generated in the surrounding InGaN region[3]. The experimentally observed simultaneous injection of the two carrier species into the QD confined energy levels significantly differs from the previous findings reported in other QD systems, in which the SAW-regulated spatio-temporal carrier dynamics leads to preferential sequential carrier injection or extraction[4,5]. In addition, by employing the acoustic phonon of a specific waveform, the resulting SAW-mediated fine-tuning of the NW-QD emission energy can be combined with spectral filtering to achieve more complex temporal sequence of the emitted photons. In this way, by collecting the light at different energies of the SAW-driven NW-QD spectral response, we are able to control the time sequences ofthe emitted single photons. Such control of the photon emission or arrival time can be used as a degree of freedom to encode an information qubit on a photon. The advantage of this encoding scheme is its robustness against decoherence, making it better suited for fiber optics applications. Moreover, the observed excitonic complexes suggest that our NW-QD system is promising for achieving still challenging room-temperature production of entangled photon pairs via XX-X radiative cascade. Altogether, this study opens the door to the use of sound for scalable integration of group III-nitride-based quantum emitters in future quantum information technologies.

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Floquet optical lattices for exciton-polariton condensates

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Temporal modulation of microcavity exciton-polariton condensates – a macroscopically coherent, hybrid state of cavity photons and quantum well excitons - can be used to controllably drive condensate dynamics, enabling the study of open-dissipative superfluidity and the formation of topological phases. We have used off-resonant driving by the interference of two GHz frequency-offset, structured lasers to demonstrate both transverse [1] and longitudinal [2] dynamics.

In this presentation, I describe the creation of a one-dimensional optical lattice (Fig. 1b) by the angled interference of two quasi-1D beams (Fig. 1a) which drives the formation of tunable artificial bandstructures for polaritons (Fig. 1c). By further introducing a frequency offset between the two lasers, the optical lattice becomes dynamical, leading to the formation of two-dimensional Floquet-Bloch bands where time plays the role of a synthetic second dimension. The temporal driving causes the bandstructure to become non-reciprocal and acquire a universal tilt connected to the non-trivial topology of the Floquet–Bloch bands.

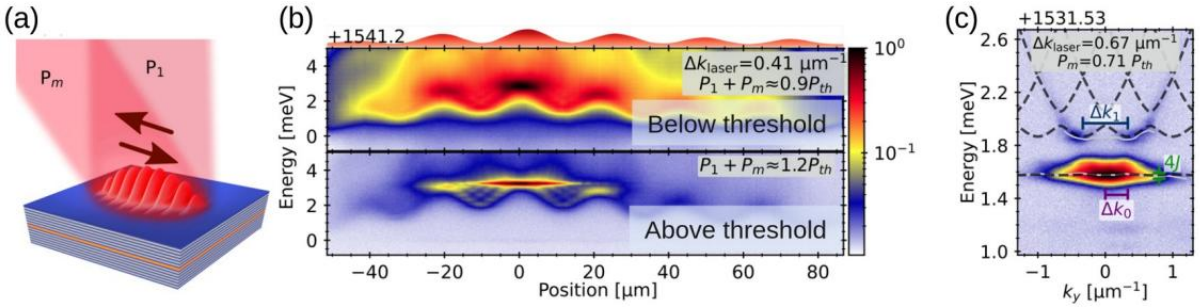

Fig. 1: Pumping a polariton microcavity with (a) two angled lasers creates (b) an optical lattice for polaritons driving (c) the formation of synthetic band-structures.

Dynamical, incoherent manipulation via pump-induced reservoirs is shown to be a versatile method for driving dynamical states of polariton condensates and holds promise for the engineering of robust non-linear, topological phases of light.

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Polaritonic Metasurface Based on Halide Perovskite

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Exciton-polaritons are half-light, half-matter excitations arising from the strong coupling regime between cavity photons and excitons of semiconductors. Behaving as superlative non-linear photons due to their hybrid nature, exciton-polaritons have been providing a fruitful ground for studying quantum fluid of light and realizing prospective all-optical devices.

In this presentation, we present experimental studies on exciton-polaritons in resonant metasurfaces, which are composed of sub-wavelength lattices of perovskite pillars (see Figure). Room temperature polaritons are demonstrated with a remarkable Rabi splitting in the 200 meV range. We show that polaritonic dispersion can be tailored on-demand. This includes creating linear, slow-light, and multi-valley shaped dispersions [1]. Moreover, we demonstrate that the strong coupling regime between perovskite excitons and photonic bound states in the continuum (BIC) leads to the formation of polariton-BIC that preserves the topological nature of its photonic component [2]. Finally, we observe experimentally the ballistic propagation of polaritons over hundreds of micrometers at room temperature, even with large excitonic components, some up to 75%. This long-range propagation is enabled by the high homogeneity of the metasurface, and by the large Rabi splitting which completely decouples polaritons from the phonon bath at the excitonic energy [3]. Our results suggest a new approach to study exciton-polaritons and pave the way for the development of large-scale and low-cost integrated polaritonic devices operating at room temperature.

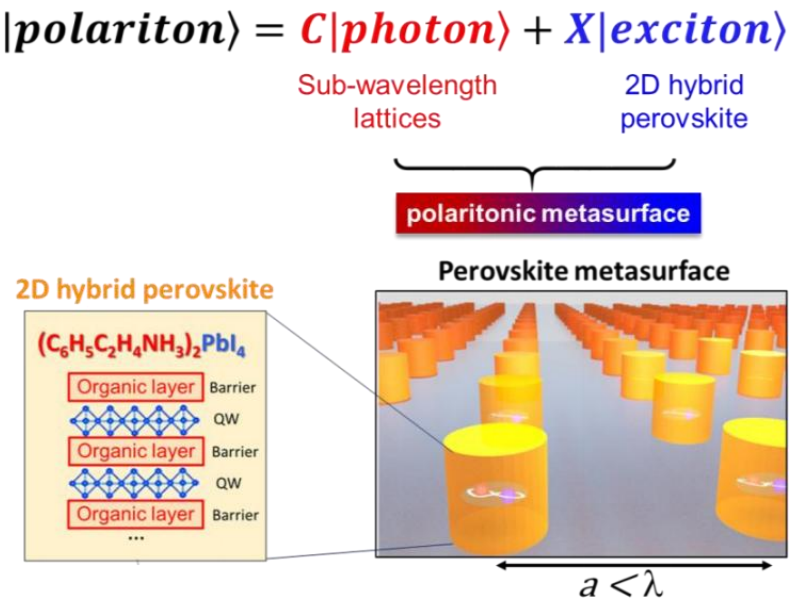

Figure: Illustration of polariton metasurface made of sub-wavelength lattices of perovskite pillars

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Polariton mode manipulation near non-Hermitian exceptional points

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Non-Hermitian physical systems allow distinctive counter-intuitive phenomena, the non-Hermitian exceptional point for instance, and have triggered great interest. Microcavity polaritons are a natural driven-dissipative physical system with non-Hermitian Hamiltonian. After the first demonstration of the exceptional point in microcavity polaritons [1], the optical manipulation of the polariton modes in the vicinity of the exceptional point becomes seductive for incoherent control of light.

In our recent works, we demonstrate the existence of an exceptional point in a double-well polariton potential. By properly controlling the optical excitation, the polariton condensate can be loaded into one potential well and then switched off by an additional optical excitation in the other well, which surprisingly induces additional loss into the system close to the exceptional point [2]. We further show that the exceptional point and the surrounding Riemann surface can be manipulated by nonlinearity and saturable gain of a polariton condensate [3], see Fig. 1 below. In multiple potential wells, a polariton condensate can be localized in a specific potential well due to the non-Hermiticity and the localization is optically controllable [4].

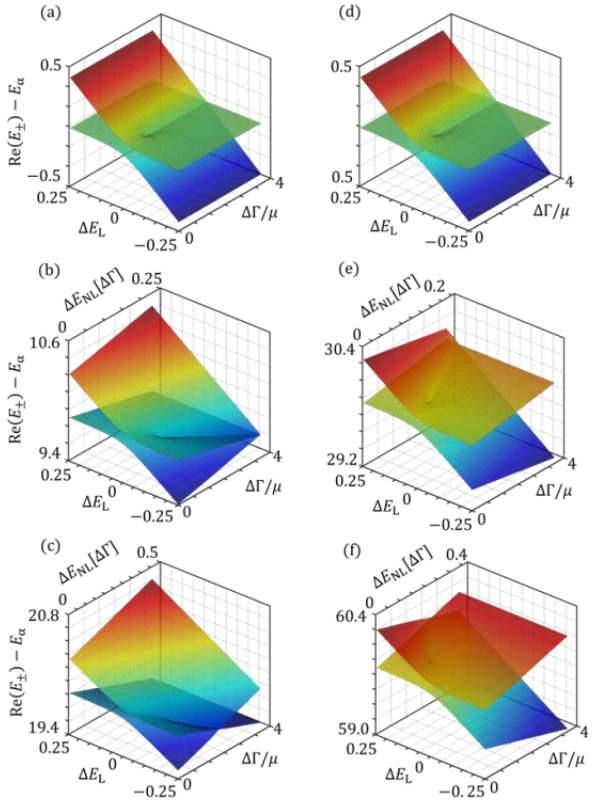

Fig. 1: Nonlinearity-induced rotation of Riemann surfaces containing an exceptional point. The Kerr nonlinearity increases from top to bottom: (a-c) without saturable nonlinearity and (d-f) with saturable nonlinearity.

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Topological exciton-polaritons in halide perovskite microcavity

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Abstract:

Topological exciton-polaritons, a growing class of topological photonic systems characterized by their hybrid nature as part-light, part-matter quasiparticles, represent a promising platform for exploring novel topological phenomena. Here, we report the experimental observation of valley-polarized topological exciton-polaritons and their valley-dependent propagation at room temperature employing a two-dimensional (2D) valley-Hall perovskite lattice[1]. Additionally, we investigate the topological polaritonic state in an aperiodic lattice design and realize a C_{4v} symmetric topological disclination (TD) laser protected by the real-space topology[2].

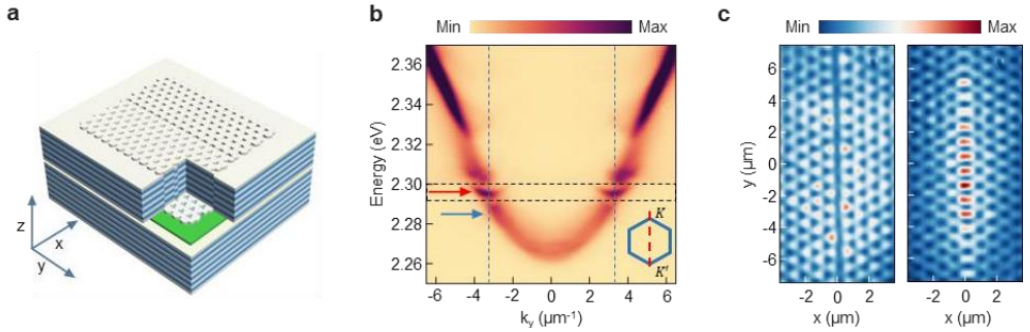

Fig. 1: a, Schematic of topological valley-Hall lattice microcavity. **b,** Polariton dispersions of the topological area along (*K* to *K*9). **c**, Real-space images of the bulk state and topological valley state.

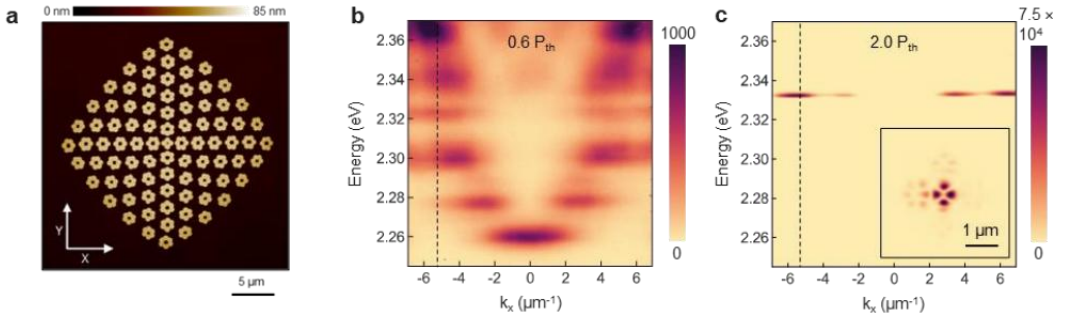

Fig. 2: a, AFM image of the polaritonic TD lattice. **b** and **c,** Polariton dispersions of the TD lattice with the excitation power at #=0.6 #$_{th}$ and #=2.0 #$_{th}$. Inset of **c** shows the real-space image of polariton lasing at TD state.

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Quantum Geometry Probed by Chiral Excitonic Optical Response of Chern Insulators

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Abstract

We theoretically derive the sum rule for the negative first moment of the absorptive optical conductivity with excitonic effects and establish its connection to the quantum weight K and Chern number C of the ground state. Applying this framework, we investigate the excitonic optical response of the Chern insulator at hole filling factor $\nu=1$ in twisted bilayer $MoTe_2$. A single chiral exciton state, which selectively absorbs circularly polarized light of a specific handedness, dominates the optical sum rule. The chiral exciton state comprises two types of interlayer electron-hole transitions, which cancel out the total out-of-plane dipole moment. The absorption spectrum shows nearly perfect magnetic circular dichroism, which can be attributed to the nearly saturated bound $K \geq |C|$ of the Chern insulator under study. Our work illustrates the potential of using excitonic optical responses to probe quantum geometry encoded by K and C of Chern insulators in moiré superlattices.

Symmetry-Breaking Vacuum Quantum Light-Matter Interactions

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The ability to control quantum states of matter on demand is essential for realizing quantum technologies. While electromagnetic radiation is a widely used method for controlling phases of matter, it often induces unstable nonequilibrium states. Additionally, radiation increases local temperatures, which can destroy many quantum effects. In contrast, microcavities can significantly enhance the coupling strength between light and matter. In the strong-coupling regime, quantum fluctuations within a vacuum microcavity can dramatically alter the material properties. Therefore, utilizing the vacuum microcavity to engineer quantum states of matter can overcome the difficulties of using electromagnetic radiations and has become an emerging frontier with great potential.

In this talk, I will present various fascinating phenomena arising from the interplay of vacuum quantum fluctuations and symmetry breaking, including the repulsive Casimir effect, the quantum atmospheric effect, and vacuum-cavity-engineered band structures, topologies, and magnetism in quantum materials.

Floquet engineering of many-body states by the ponderomotive potential

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The ponderomotive force is an effective static force that a particle feels in an oscillating field, whose static potential may be called the ponderomotive potential. We generalize this notion to the static potential felt by collective degrees of freedom in periodically driven quantum many-body systems, and propose it as a convenient tool to engineer their non-equilibrium steady states beyond the single particle level. Applied to materials driven by light, the ponderomotive potential is intimately related to the equilibrium optical conductivity, which is enhanced close to resonances. We show that the ponderomotive potential from the incident light may be used to induce exciton condensates in semiconductors, to generate attractive interactions leading to superconductivity in certain electron-phonon systems, to create additional free energy minima in systems with charge/spin/excitonic orders, and to favor exciton-polariton condensates in cavities. These effects are presented with experimentally relevant parameters.

References: PRB 110, 104301 (2024)， PRL 133, 217002 (2024)

Improving quantum metrology protocols with programmable photonic circuits

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Photonic quantum metrology enables the measurement of physical parameters with precision surpassing classical limits by using quantum states of light [1]. However, generating states providing a large metrological advantage is hard because standard probabilistic methods suffer from low generation rates [2]. Deterministic protocols using optical non-linearities offer a path to overcome this problem, but they are currently limited by the errors introduced during the interaction time, which grows with the number of photons [3,4]. Thus, finding strategies to minimize the interaction time of these non-linearities is still a relevant question. In our recent work [5], we introduce and compare different deterministic strategies based on continuous and programmable Jaynes-Cummings and Kerr-type interactions, aiming to maximize the metrological advantage while minimizing the interaction time. We find that programmable interactions provide a larger metrological advantage than continuous time evolution at the expense of slightly larger interaction times. We show that while for Jaynes-Cummings non-linearities the interaction time grows with the photon number, for Kerr-type ones it decreases, favoring the scalability to large photon numbers. Finally, we also optimize different measurement strategies for the deterministically generated states based on photon counting and homodyne detection. We also discuss possible implementations of our proposal in cavity-QED setups.

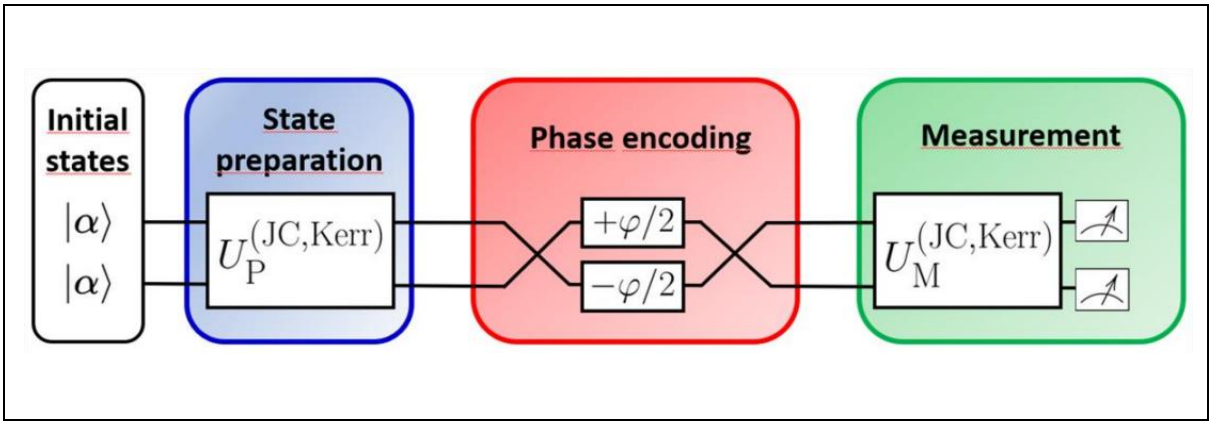

Fig. 1: Sketch of the estimation process of a parameter φ involving two optical modes. Two coherent initial states $|\alpha\rangle$ are employed as the input of a state preparation step that involves the unitary operator $U^{(JC,\ Kerr)}{}_{P}$. In the continuous approach, this represents the time evolution under the Jaynes-Cummings (JC) or Kerr Hamiltonian. In the programmable approach, it corresponds to a parametrized quantum circuit (PQC) determined by an optimization loop aimed at maximizing the quantum Fisher information (QFI). The prepared state is then sent through a Mach-Zehnder interferometer (MZI) where a phase difference φ is encoded between the two modes. While in the continuous approach the measurement takes place immediately after phase encoding, in the programmable approach one introduces an additional PQC described by the unitary $U^{(JC,\ Kerr)}{}_{M}$ to prepare an optimal measurement. In this step, one aims at maximizing the classical Fisher information (CFI).

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Wave chaotic dynamics in optical microcavities in curved space

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The whispering gallery mode (WGM) microcavity is one of the essential components in photonic chips, playing a critical role in light sources, filters, isolators, routers, sensors, while demonstrating a series of novel physical effects such as classical and quantum chaos, parity-time reversal symmetry, and non-Hermitian exceptional points. We conducted a series of explorations on the photonic dynamics of WGM microcavities in curved spaces, demonstrating single-mode lasing in curled nitride microdisks. Further, we established a theoretical model of microcavity photonic dynamics on non-flattenable surfaces, revealing the significant role of curved surfaces in reshaping photon trajectories, regulating mode types, tuning dissipation mechanisms, and enabling chaos and non-Hermitian properties in microcavity systems. Furthermore, we revealed that the stable and chaotic motions of photons in the microcavity exhibit very different responses to the variation spatial curvature. As the spatial curvature increases, the Husimi wavepackets of stable modes rise along with the island structure in the phase diagram, resulting in an increase of quality factor. In contrast, chaotic modes diffuse more rapidly in the phase diagram, with their Husimi wavepackets staying at a constant height and interacting with the rising island structures, showing a feature of localization and hybridization, leading to a decrease of quality factor. These phenomena reflect the unique mechanisms of wave packets in curved spaces, highlighting the features of chaotic motion under the framework of quantum mechanics. We also established a consistent model of non-Euclidean polygonal microcavities with joint geometric curvatures, in which unique phase transitions involving hyperbolic fixed points are investigated. These results demonstrate that microcavity optical systems can serve as excellent optical simulators for chaotic motion in curved spaces and quantum mechanical frameworks, providing new insights for constructing valuable photonic chips based on these principles.

Cavity-enhanced Superfluorescence in Perovskite Microcavities

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Quantum correlations among emitters play an essential role in light-matter interactions. For dipole ensembles with quantum correlations, they are well known to radiate in the form of superfluorescence (SF). Even more interestingly, when coupled with optical microcavities, stimulated emission from correlated dipoles can be triggered, leading to the generation of cavity-enhanced superfluorescence (CESF). In sharp contrast to conventional lasers, CESF is exempt from the stringent requirement of population inversion and thus serves as a promising candidate for the next generation of high-performance light sources with exceptional power efficiency and coherence. More importantly, CESF is essentially a macroscopic coherence state with coherence for both light and matter. It provides an ideal testing bed for the study of ultrafast phase transition between macroscopic coherence regime and the incoherent classical state in light-matter interaction systems. Probing, understanding, and manipulating such macroscopic coherence state lies in the heart of many-body physics.

In this talk, I will show you our recent results on CESF in $CsPbBr_3$ microcavities. We prepared two types of samples: planar microcavities with single-crystal $CsPbBr_3$ thin film embedded as gain medium and $CsPbBr_3$ quantum dot-assembled superlattices. CESF from these samples were identified and characterized using two different experimental techniques: time-resolved photoluminescence and second-order photon correlation function measurements. In the time-resolved photoluminescence measurements, we observed clear threshold behaviors in the power dependence of both emission intensity and the lifetime. Burnham-Chiao ringing, a feature that has been widely regarded as evidence of superfluorescence, was also clearly observed. In second-order photon correlation measurements, the correlation function $g^{(2)}(t, \tau=0)$ reveals directly the ultrafast phase transition of CESF under active external perturbations, including its self-establishment, interaction with environment and fast revival. These results may open up new avenues for the study of collective phase transition behaviors in many-body systems.

Fig. 1: Transition from SF to CESF in a $CsPbBr_3$ quantum dot-assembled superlattice. (a) PL spectra for SF (blue) and CESF (red) from the same sample. (b) Power dependent behaviors for the emission intensity (blue) and lifetime (red). A threshold is found at ~6.3 $\mu J/cm^2$.

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Nonreciprocal Exciton Polariton Ring Lattices

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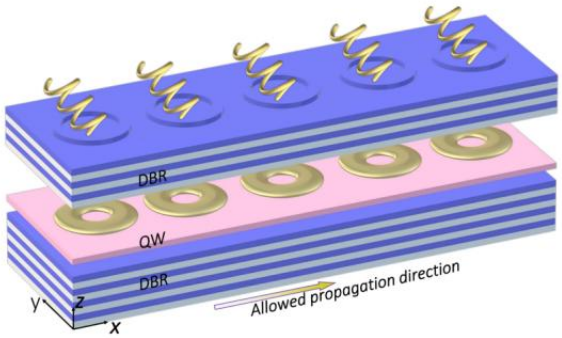
Recent experiments have shown the transfer of orbital angular momentum (OAM) from a non-resonant laser onto an exciton-polariton condensate, despite earlier views that the phase information of such a laser should be lost during the process of polariton condensation. We study with a phenomenological theory the interplay of a usual angular momentum independent gain and an angular momentum preserving gain. We find that even when the latter is much smaller, it is enough to favor condensation into a given orbital angular momentum state. This further allows a breaking of symmetry in the system, which further manifests in non-reciprocal one-way propagation in a lattice of coupled rings. Even though we consider only Hermitian reciprocal coupling between rings, the local non-Hermiticity generates an effective non-reciprocal coupling and supports a non-Hermitian topological invariant (winding number) associated to a non-Hermitian skin effect. We anticipate that such a mechanism can be useful in the growing development of schemes for computation based on polariton angular momentum modes, where a one-way feedback free coupling of basis states has not yet been available, In future work it would be interesting to consider the interplay of polariton lattices with two-site pumping and dissipation schemes that have been proposed in general quantum systems with structured reservoirs. Although in the present work we have restricted ourselves to one dimensional topological phases, our system is suitable for realizing two dimensional topological phases.



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Bi-self-trapping of excitons via the long-living phonon mode and their superfluorescent markers.

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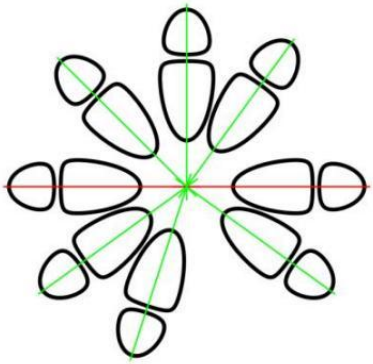
Understanding the origin of the system response offers guidance for designing single-component material devices with required properties. A notable phenomenon of room-temperature superfluorescence recently observed in hybrid perovskites at high concentrations of excitations [1] lacks of comprehensive theoretical framework. Addressing this gap necessitates a discussion grounded in non-linear and multiparticle theories [2,3]. In this talk, we present the two-step mechanism [3]: formation of two self-trapped excitons entangled via the same long-living phonon mode, and their rearrangement into a superradiating mirror-symmetric configuration (see fig. a). Based on the semiclassical equations of motion we examine the criteria for the high-temperature self-trapping and bi-self trapping of excitons. Our findings indicate that the self-trapped excitons are described by the stable phase-locked steady-state solution of the equations of motion, and at elevated exciton concentrations, they compete with the bi-self-trapped excitons. The latter are described by the Dicke model and thus responsible for the generation of the superfluorescent spectral peak. The obtained theoretical spectra (see fig. b) are in good agreement with the experimental observation.

a)



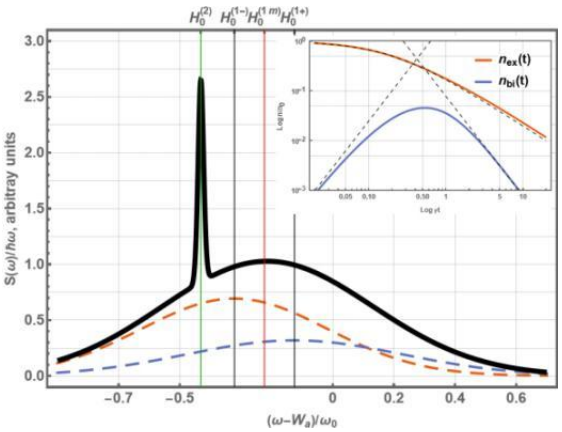


Fig. a) The mirror-symmetric configuration of two exciton packets (along the red line) in the momentum space leading to formation of bi-self-trapped excitons and other self-trapped excitons in the regime of elevated concentration of excitations. **b)** The calculated spectrum of the excitons slef-trapped via the long-living phonon mode and the superfluorescent sharp peak generated by the mirror-symmetric self-trapped excitons. In the inset the typical time-behavior (blue line) of the superfluorescent peak amplitude, log-log plot.

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Versatile exciton-photon coupling in two-dimensional semiconductors

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Key Words: two-dimensional semiconductors, exciton-photon coupling, nonlinear optics

Two-dimensional (2D) semiconductors demonstrate great potential to break the limitations of conventional quantum well systems for light-matter interactions. As an outstanding example, the transition metal dichalcogenides (TMD) monolayers provide many opportunities for the research of nonlinear light-matter interactions when the 2D excitons are strongly coupled with photonic resonators[1]. For large excitonic binding energies, TMD monolayers in Fabry-Perot cavities demonstrate robust exciton-photon coupling with coherent tunability[2] and intriguing nonlinear optics[3] from low temperature throughout room temperature. As a result, the strongly coupled exciton polaritons in TMD monolayers could lead to nonlinear valley phonon scattering, as exemplified in a plasmonic cavity[4]. Due to multiple degrees of freedom in plasmonic cavities, the coupling with various TMD exciton species enables versatile optical manipulation[5]. In addition to TMD monolayers, many more materials with 2D excitonic quantum confinements join the 2D semiconductor family, triggering emerging research attentions in a broader spectrum of exciton-photon coupling. Here I would also share some recent research progresses of the strongly interacting dipolar interactions of tilt excitons in 2D perovskites and negative refractions of exciton polaritons in 2D magnets.

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Exciton-polariton vortex lasing in perovskite kagome lattices at room temperature

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Exciton–polariton condensates in artificial lattices intuitively emulate energy-band structures and quantum many-body effects of condensed matter, underpinning constructing vortex lattices and controlling quantum fluidic circuits. Here, we harness exciton-polariton quantum fluids of light in a frustrated kagome lattice based on robust metal–halide perovskite microcavities, to demonstrate vortex lasing arrays and modulate their configurations at room temperature. Tomographic energy–momentum spectra unambiguously reveal massless Dirac bands and quenched kinetic-energy flat bands coexisting in kagome lattices, where polariton condensates exhibit prototypical honeycomb and kagome spatial patterns. Spatial coherence investigations illustrate two types of phase textures of polariton condensates carrying ordered quantized-vortex arrays and π-phase shifts, which could be selected when needed using lasing emission energy. Our findings offer a promising platform on which it is possible to study quantum-fluid correlations in complex polaritonic lattices and highlight feasible applications of structured light.

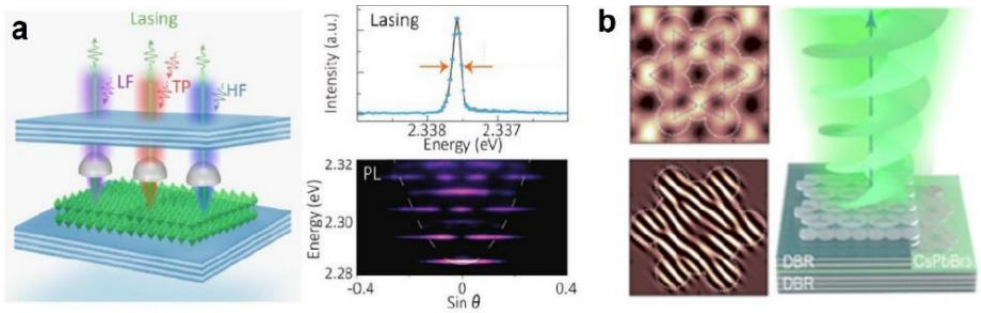

Fig. 1 Exciton-polariton lasing in perovskite kagome lattice and 3D-confined microcavity.

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Topological Photonics in Anisotropic 2D Hybrid Perovskite Microcavities

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Photonic Rashba-Dresselhaus (RD) coupling in anisotropic microcavities offers a compelling platform for realizing unconventional topological states with nonzero Berry curvature [1,2]. In this study, we explore a self-assembled two-dimensional (2D) hybrid structure composed of anisotropically oriented organic/inorganic halide perovskite layers [3] confined within a microcavity. The strong optical anisotropies of these perovskite systems, driven by significant refractive index contrasts and robust excitonic resonances at room temperature [4], enable the emergence of synthetic magnetic fields that mediate photonic and polaritonic interactions. The interplay between polarization-dependent modes and spatial inversion symmetry breaking gives rise to strong photonic RD spin-orbit coupling (SOC) [5], leading to distinct modifications in band topology and energy dispersions. These effects result in the formation of unconventional topological features, including nonzero Berry curvature and off-axis diabolical points, within the photonic and polaritonic bands. Our findings reveal the critical role of optical anisotropies in engineering synthetic gauge fields for light, providing a versatile approach for designing photonic systems with novel topological properties. By leveraging the unique properties of halide perovskites and their ability to support room-temperature excitons, this work advances the development of polaritonic platforms for applications in topological photonics and spinoptronics.

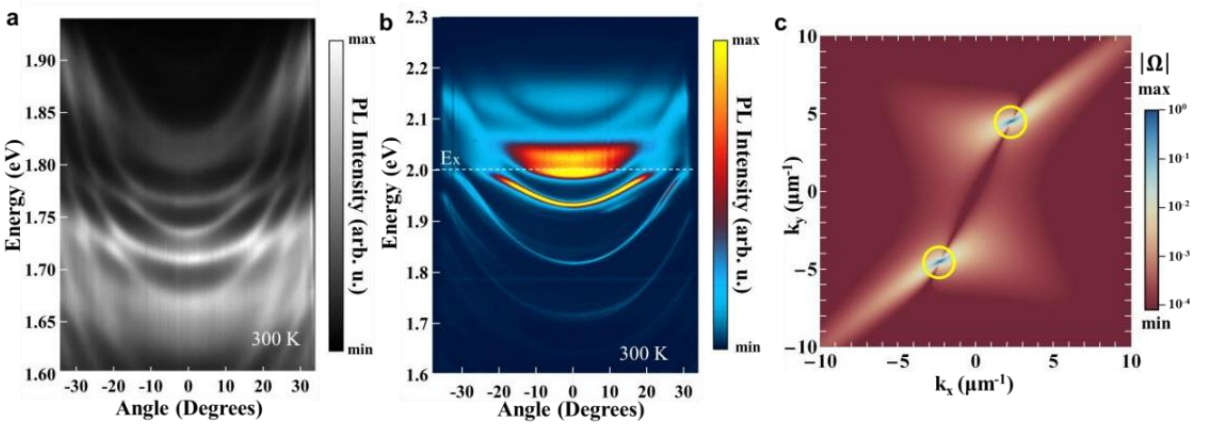

Fig. 1: (**a**) Photonic interaction and (**b**) strong coupling of perovskite microcavities. (**c**) Calculated Berry curvature and diabolical points.

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Design molecular and hybrid chiral excitonic materials

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In this talk, I will present our recent work on design chiral organic-inorganic hybrid nanomaterials by strain engineering as will as low-threshold lasing molecule by machine learning.

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Exciton-Polariton Dynamics with the Nonlinear Maxwell-Bloch Finite Difference Time-Domain (FDTD) Algorithm

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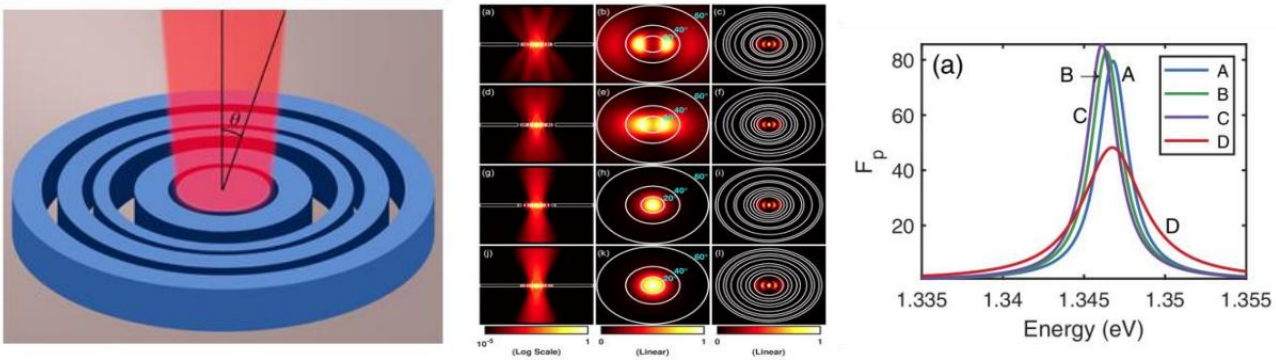
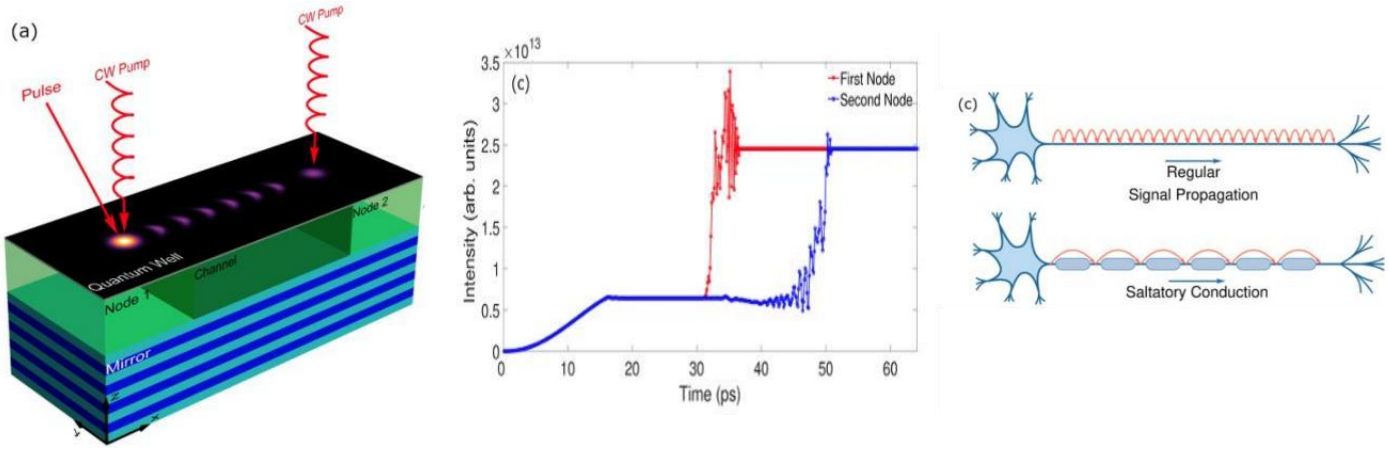
We present here an FDTD algorithm designed to predict the dynamics of exciton polaritons in spatially patterned structures.

In the linear regime, the FDTD can be used to optimize the lifetime of a cavity. Quantum dots coupled to bullseye cavities have been one of the promising candidates as single photon sources [1]. With a periodic annular Bragg grating design, a Purcell factor of about 20 have been theoretically predicted. We show here that with a FDTD developed in cylindrical coordinates, one can simulate these structures in two dimensions due to azimuthal symmetry, which drastically improves simulation run time [2]. This allows us to optimize structures by incorporating the FDTD with optimization algorithms. In doing so, we found that chirped gratings tend to produce better lifetime and Purcell enhancement. The optimization scheme is also capable in handling fabrication constraints, such as the trench widths and groove depths.



Next, we show an application of the nonlinear FDTD in describing saltatory conduction in exciton-polariton systems [3]. This is done by solving the nonlinear Maxwell-Bloch equations which include exciton-exciton interactions. Typical microcavity polaritons can only achieve propagation speed of about 1% of the speed of light. Here we theoretically predict that signals can be transferred from one node to another through bistability, allowing signals to be transferred over long distances.

While existing methods can describe polariton systems, many effects require the use of phenomenological terms such as the potential. Thus, our FDTD model is designed to circumvent them, allowing for a more accurate description of polariton dynamics.



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Two-Dimensional Light-Emitting Devices towards On-Chip Photonics

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Photonic elements have greater information-carrying capabilities compared to electronic components, making the development of high-speed, chip-integrated optical communication devices crucial for addressing interconnect bottlenecks in high-speed computing systems. Significant progress has been made in studying light sources and their transmission. Despite these advancements, achieving a satisfactory integration of photonic circuits with both light source and optical waveguide functions has remained a challenge. Here, a silver nanowire (Ag NW) waveguide-integrated light source is demonstrated driven by alternating current (AC) voltage. AgNW functions as both the electrode and waveguide to simplify the device structure, and the 2D transition metal dichalcogenides (TMDs) monolayer acts as the gain media in device. The electroluminescence (EL) can be tunably modulated via adjusting the frequency and voltage of the AC in this device, and it is also successfully coupled into the waveguide with its transmission distance up to 25 μm. The experiments of electroluminescence and waveguide transmission of different materials and their interlayer excitons have made a preliminary exploration of multiple wavelength transmission. It provides a new research platform forward in the development of chip-integrated optical communication devices, thereby hopefully addressing the interconnect bottleneck and unlocking the potential for enhanced performance and efficiency in high-speed computing systems.

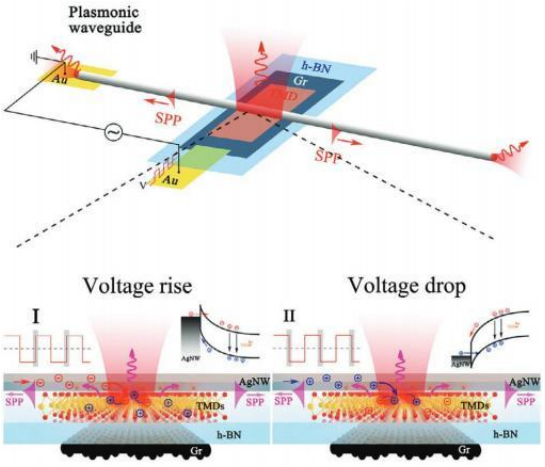

Figure1. Schematic of AC-driven 2D light-emitting devices and surface plasmonic waveguiding of EL emission.

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Study on the regulation and mechanism of nonlinear optical second and third harmonics in low symmetry two-dimensional materials

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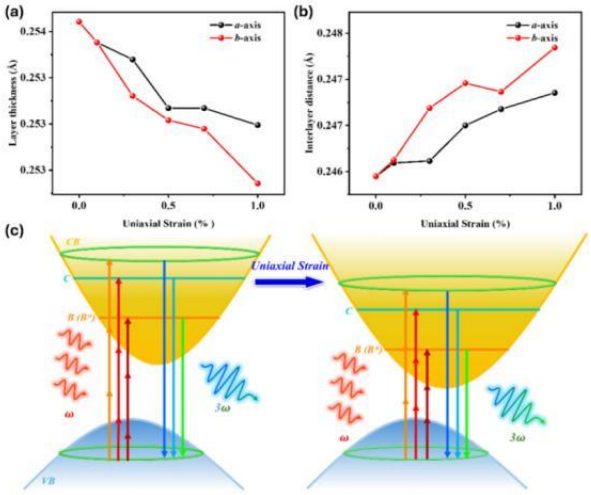
Abstract: Two-dimensional materials have become an ideal system for the study of condensed matter physics because of their simple structure, rich physical properties, convenient regulation and various combinations. Among them, a special class of two-dimensional materials with low in-plane crystal structure symmetry and in-plane anisotropy has attracted a lot of researchers' attention. At present, nonlinear optical second - and third-order polarization response dependent light modulation techniques based on low-symmetry two-dimensional materials are still in the early stage of development, and the relevant nonlinear mechanisms and regulatory mechanisms need to be further explored: (1) A limited number of low-symmetric materials have been explored, each of which typically has a narrow polarization-driven modulation spectral range and is limited by its band gap or exciton energy, which limits the available wavelengths for modulation. (2) Although two-dimensional materials have extremely high second-order and third-order nonlinear polarizability and their atomic layer thickness makes two-dimensional materials naturally meet the phase matching requirements, due to the limited interaction length, the second-order and third-order conversion efficiency of two-dimensional materials is much lower than that of traditional nonlinear optical crystals. (3) Many relevant studies have only been carried out at single wavelengths, and detailed analysis of responses over a wide spectral range is required to fully understand the nonlinear photophysical properties associated with polarization. In addition, the limited nonlinear optical anisotropy ratio and optical loss also need to be solved. In this project, starting from the discovery of low-symmetry two-dimensional materials and anisotropic nonlinear optical properties, the nonlinear optical properties of materials are regulated by energy band engineering (including strain engineering, electric field regulation and heterogeneous structure construction, etc.), and the realization of wide-band modulation in the polarization response of low-symmetry materials is expected to promote the development of integrated photonics and quantum optics.



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Continuous and deterministic all-photonic cluster state of indistinguishable photons

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Cluster states are multi-qubit entangled states that maintain their entanglement even if few of their qubits are measured, or lost [1]. Cluster states of entangled photons are resources for measurement-based quantum computing and quantum communication protocols [2–3]. Device that can deterministically generate photonic cluster states is a key for enabling these emerging technologies [4].

Here, we demonstrate a semiconductor-based quantum knitting machine that continuously and deterministically generates an indistinguishable multi-photon cluster state at a sub-GHz rate. The device realizes a protocol proposed by Lindner and Rudolph [4], in which a quantum dot (QD) confined heavy-hole (HH) is used as the photons' entangler [5-7]. We apply external in-plane magnetic field to tune the spin precession rate for achieving optimal cluster's entanglement length while synchronizing the excitation rate to be four times faster than the precession rate. This way, we realize a single cycle of a protocol which contains a single spin qubit gate followed by a spin-photon two qubit gate that repeats indefinitely, as shown in Fig.1(A).

We measured a series of correlated-photon events [7]. In one scenario, the middle two photons are disentangled from the spin and therefore the they are expected to be entangled, demonstrating a pure-photonic cluster state. In another scenario, in addition to disentangling the HH spin, we measure the polarization density matrix of the second and fourth photons while the third photon is not detected (Fig.1. B). If the third pulse does not excite the spin it continues to precess coherently, and the second and fourth photons will be emitted in a maximally entangled state. However, If the third laser pulse is deterministic, it will successfully excite the spin, and the second and fourth photons will not be entangled. The experimental results described in Fig. 1(B) agree well with the second case and demonstrate the deterministic nature of the cluster-state generation protocol.

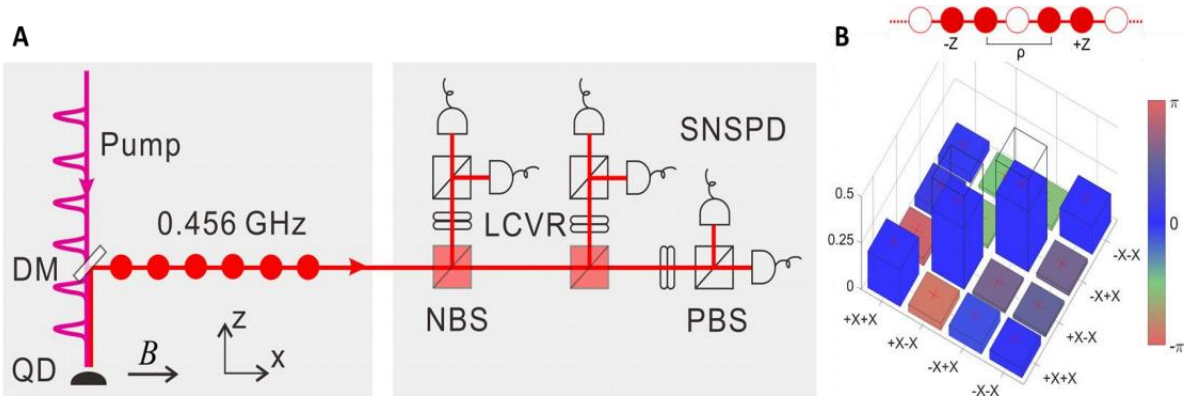

Fig.1: **A.** Schematic of the entangled cluster generation and its measurement. Left panel, the laser's repetition rate matches the hole's precession and the QD continuously emits single photons in a cluster state. Right panel, schematics of the measuring setup enabling sequential detection of up to six photons with polarization projections on 6 different bases. A time tagger synchronized with the laser, registers the photons detection times. **B.** Two-photon polarization density matrix from a correlated event of five photons schematically described in the upper panel. The first and last photons are projected on circular polarization bases and the middle photon is not detected.

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Next Generation Wearable Sensors for Real-Time Health Monitoring

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The rapid growth of wearable medical devices is driven by the increasing emphasis on home healthcare and real-time patient self-monitoring. The demand for flexible, highly sensitive, and energy-efficient photodetectors is rising, particularly for applications in photoplethysmography (PPG)-based health monitoring [1]. PPG is a non-invasive optical technique widely used to measure vital physiological parameters, including heart rate, blood oxygen saturation, and arterial stiffness, by detecting variations in blood volume through light absorption and reflection. However, commercially available wearable PPG devices typically rely on high-intensity light- emitting diodes (LEDs) and conventional photodetectors, leading to significant power consumption, frequent recharging requirements, and increased production costs [2]. Addressing these limitations requires the development of self-powered, high-sensitivity sensors with superior signal acquisition capabilities and low noise characteristics.

To meet these challenges, a new class of flexible, self-powered photosensors based on van der Waals heterojunctions (vdWHs) has been developed, utilizing a $Ti_3C_2T_x$ MXene/SbSI heterostructure. This architecture leverages the strong built-in electric field at the vdWH interface to enhance photocarrier separation, thereby improving responsivity and reducing noise current. The optimized light-matter interaction at the heterojunction further contributes to efficient carrier extraction, achieving high optical sensitivity while maintaining ultrafast response times. The suppression of dark current and the ultra-low noise equivalent power (NEP) enable the detection of weak optical signals, making the device particularly suitable for low-light sensing environments. Additionally, its mechanical flexibility ensures stable performance under deformation, making it ideal for wearable applications.

The integration of this advanced photosensor into wearable health monitoring systems facilitates continuous and real-time PPG signal acquisition without the need for external power sources, significantly enhancing user comfort and device longevity. By providing a self-powered, low-cost, and highly efficient alternative to conventional photodetectors, this technology paves the way for next-generation flexible optoelectronic devices, offering transformative potential for autonomous healthcare monitoring, biomedical diagnostics, and human– machine interfacing.

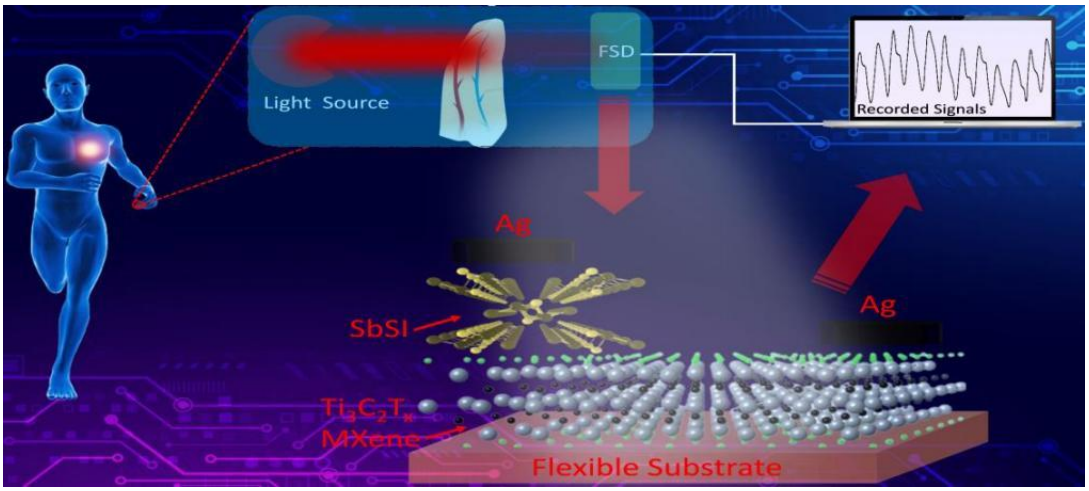

Fig. 1: Heterojunction flexible sensor model for real time health monitoring.

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Posters

Optically and remotely controlling localization of exciton polariton condensates in a potential lattice

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Exciton polaritons are inherently tunable systems with adjustable potential landscape. In this work we show that exciton polariton condensates can be selectively localized in a fixed optically induced periodic lattice with uniform potential depth, by judiciously controlling a second focused pump of very small size away from the lattice chain. Specifically, the localized polariton condensate can be tuned among different potential traps by adjusting the relative distance between the small pump spot and the potential lattice. The adjustment of the excitation position of the smaller pump spot and its combination with the fixed larger pump spot for the potential creation induce the mode selection determined by gain profile, group velocity, and potential distribution within the system. As shown in Figure 2, by precisely tuning the position of the second pump beam, the polariton condensate can be selectively localized in a desired potential trap. It can be realized in the numerical simulations due to the strong reservoir potential. As the power density of the second beam increases, the result of condensation in multiple traps (Fig. 3 (a)) will become apparent. The localization of the exciton polariton condensate and its control are independent of the orientation of the potential lattice, thus, even in slightly disordered system, one can selectively excite such localized polariton condensates. Our results illuminate a path to the remote manipulation of exciton polariton bosonic condensates in fixed integrated photonic chips and circuits.

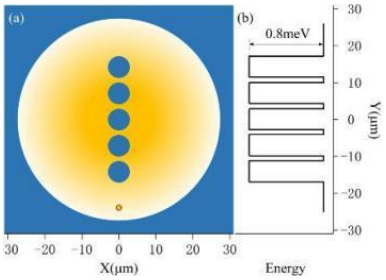

Fig. 1: Schematic diagram of the pumping configurations.

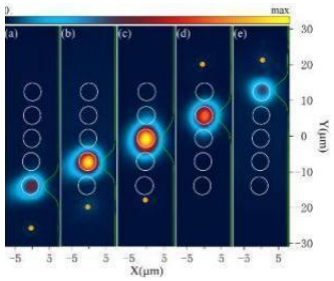

Fig. 2: Selective localization of the polariton condensate along the 1D lattice.

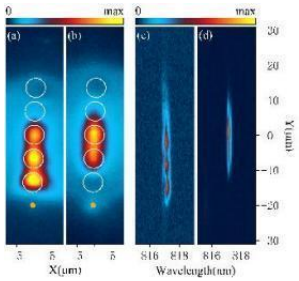

Fig. 3: The change of condensation distribution when increasing the pump.

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Active Electrical Modulation of Mid-Infrared Surface Plasmon Polaritons in Graphene-Coupled Ag Nanowires

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Advanced manipulation of photons at the nanoscale is a key research focus in nanophotonics and on-chip photonics. Surface plasmon polaritons (SPPs), emerging from light-matter coupling at dielectric-metal interfaces, exhibit exceptional field confinement [1], allowing easy manipulation and coupling with other polaritons [2]. Metal nanowires and nanoparticles are particularly effective for controlling SPPs due to their ability to provide additional dimensional confinement and enhance surface infrared absorption [3, 4]. While static modulation of SPPs has been achieved [5, 6], actively modulating SPPs in metal nanowires or nanoparticles, especially in the mid-infrared range, remains challenging. Here, we demonstrate the electrical modulation of SPPs in graphene-coupled Ag nanowires (AgNW) via electrostatic gating. Combining near-field nanoimaging and numerical simulations, we show how the wavelength, amplitude, and dissipation rate of SPPs change with varying Fermi energies. These findings advance the design of adaptive optical antennas, tunable sensors, and on-chip optoelectronic circuits, providing a foundation for next-generation nanophotonic devices leveraging low-dimensional heterostructures.

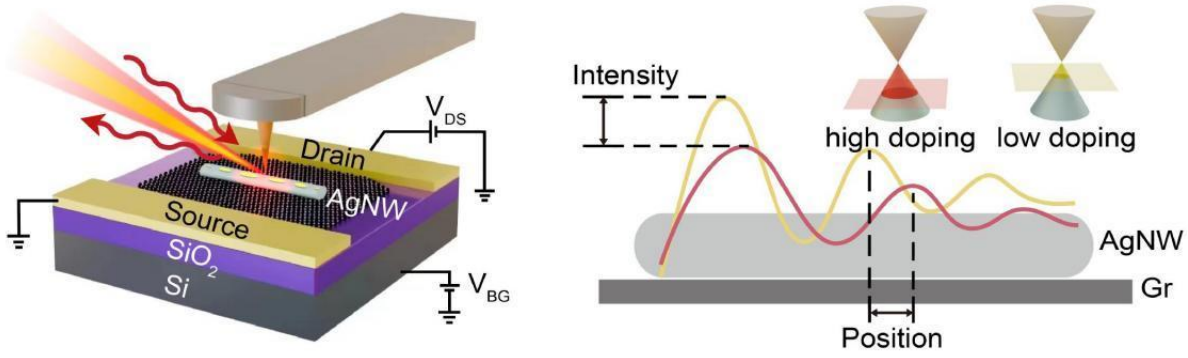

Fig. 1: Active electrical modulation of mid-IR SPPs in graphene-coupled Ag nanowires (**Left**) Schematic of a AgNW/graphene device. (**Right**) Comparison of near-field intensity line profiles along the AgNW at high and low graphene doping.

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Helical Polariton Lasing from Topological Valleys in an Organic Crystalline Microcavity

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Topological photonics provides an important platform for the development of photonic devices with robust disorder-immune light transport and controllable helicity. In previous work, we revealed the non-trivial distribution of photon energy bands in perylene crystalline microcavity, exhibiting gapped Dirac cones with non-zero Berry curvature. 1

Here, we realize helical polariton lasing from topological valleys in an organic anisotropic microcrystalline cavity. Valley states of opposite circular polarization and valley Chern number are formed by combined TE-TM SOC, linear birefringence, and optical activity (OA). Polariton lasing occurs thanks to the use of a specific organic molecule, for which polaritonic gain was previously observed.2 Adjusting exciton-photon detuning allows polariton lasing to occur specifically at the energy of the two valley states. Measuring the full 2D angular-resolved emission pattern shows a strong anisotropy of lasing concentrated in the two valleys and shows a valley-contrasted circular polarization degree, locked to the emission angle. Topological protection applies in our case to the circular polarization at the band extrema. Our findings provide key insights into helical topological polariton lasers and may lead to applications of topological organic laser devices in the strong coupling regime.

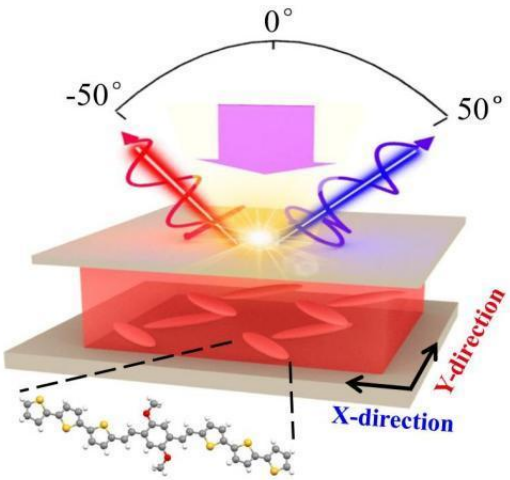

Fig. 1: Schematic ofhelical polariton lasing from topological valleys in an organic crystalline microcavity.

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Chirality-dependent dynamic evolution for trions in monolayer WS_2

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Abstract

Chirality has emerged as a fundamental concept spanning diverse fields in condensed matter and material science, encompassing spintronics, valleytronics, and quantum computations. Within monolayer transition metal dichalcogenides (TMDs), the spin and valley-polarized excitons and trions can be initialized and read out by circularly polarized light (σ+ and σ-), resulting in chirality-dependent optical applications in future valleytronic devices. Understanding the nonequilibrium dynamics of spin-valley excitons/trions in TMDs is a key step in view of their technological applications. Herein, combined with pump-probe ultrafast transient transmission spectroscopy and theoretical simulations, we reveal the chirality-dependent trion dynamic in h-BN encapsulated monolayer tungsten disulfide. By resonantly pumping trions at a single valley and monitoring their temporal evolution, we identify the temperature-dependent competition between two relaxation channels driven by chirality-dependent scattering processes. At room temperature, the phonon-assisted upconversion process predominates, converting excited trions to excitons within the same valley on a sub-picosecond (ps) timescale. As temperature decreases, this process becomes less efficient, while alternative channels, notably valley depolarization process for trions, assume importance, leading to an increase of trion density in the unpumped valley within a ps timescale. Our time-resolved valley-contrast results provide a comprehensive insight into trion dynamics in 2D materials, thereby advancing the development of novel valleytronic devices.

Key words

Chirality; transient transmission spectroscopy; trion dynamics, transition-metal dichalcogenides; many-body interaction

Realizing mott insulator polariton in $MoSe_2/WS_2$ without graphite gates

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Abstract

Moiré lattices have emerged as a powerful platform for developing solid-state quantum simulators due to their strong electron correlations.Exciton polaritons, with their hybrid light- matter nature, exhibit enhanced nonlinear optical responses, making them ideal candidates for exploring quantum many -body phenomena. In this work, we demonstrate the formation of exciton polaritons in the Mott insulating regime of a moiré heterobilayer composed of angle- aligned $MoSe_2$ /WS_2 . The interplay between charge ordering, spatially correlated excitons, and cavity photons in this system is promising for probing and controlling many-body interactions. Furthermore, we introduce a gate-tunable architecture that replaces conventional graphite gate with a top silver mirror, eliminating detrimental optical absorption by the gate. We believe this platform will open new pathways for engineering strongly correlated polaritonic states and paves the way for studying nonlinear quantum phenomena.

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