TeraMetaNano

IV Edition of the International Conference on Terahertz emission, Metamaterials and Nanophotonics

LECCE, ITALY

27 - 31 May

Castello Carlo V - Teatro Romano

Mediterranean Institute of Fundamental Physics

CNR NANOTEC INSTITUTE OF NANOTECHNOLOGY

TERAMETANANO - 4

The IV edition of **TERAMETANANO**, the **International Conference on Terahertz Emission, Metamaterials and Nanophotonics**, takes place in Lecce (Italy) from the **27th to 31st of May 2019** in the 16th-century Castle of Charles V with two special nights that will be held in an original Theatre of Roman period.

TERAMETANANO is an annual conference that gather physicists studying a wide variety of phenomena in the areas of nanostructures, nanophotonics and metamaterials, with special attention to the coupling between light and matter and in a broad range of wavelengths, going from the visible up to the terahertz.

The presentations will cover, both from an experimental and theoretical point of view, the optical and electrical properties of advanced nanoscale systems, such as two-dimensional semiconductor nanostructures, nanocrystals, transition metal dichalcogenides, hybrid systems and heterostructures.

In this edition a particular attention will be given to young researchers and PhD students which are encouraged to participate in order to promote discussions and collaborations on new ideas and challenges arising in the community. For this reason, there will be many occasions to spend time outside of the program main stream with two free afternoons and an excursion to the beautiful city of Otranto. Moreover, in addition to the oral contributions, there will be an elevator pitch session, an opportunity to present to a wide audience the contents of the work before showing it at the poster session.

Topics

- Polaritonics
- Metamaterials
- Two-dimensional crystals
- Bose-Einstein condensation
- Quantum simulators
- Terahertz spectroscopy
- Organic and hybrid semiconductors
- Perovskites
- TMDs (transition metal dichalcogenides)

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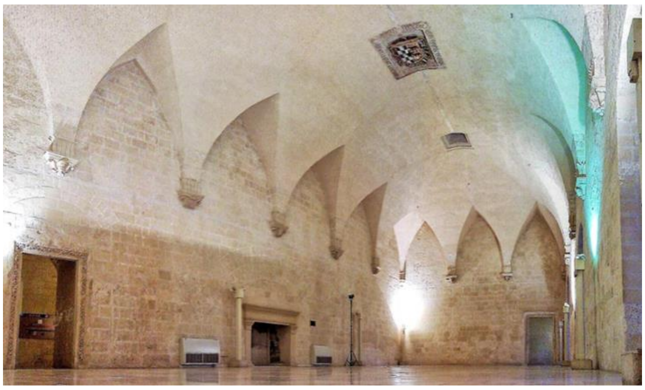
Awards Ceremony

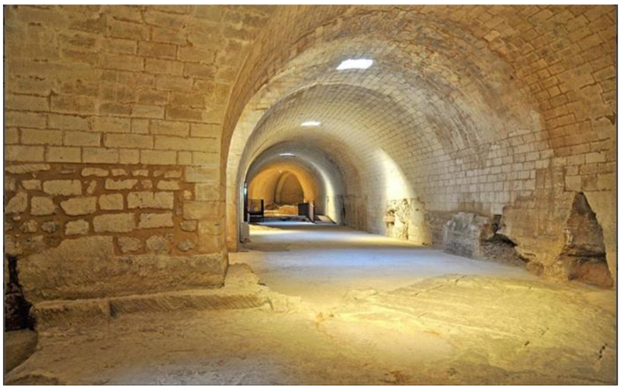
At the end of the conference a premium will be given to the Best Posters attending

TERAMETANANO - 4.

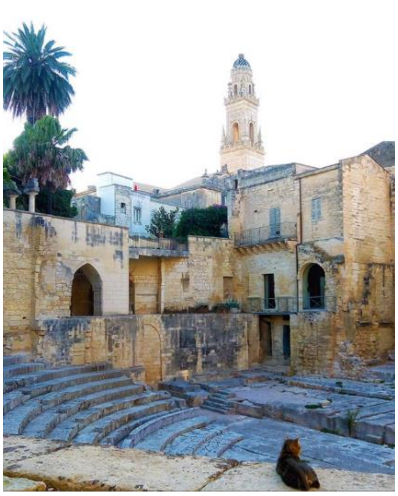
Locations

The IV edition of the TERAMETANANO - 4 conference will be held in the **Castle of Carlo V**, a majestic fortification in the heart of Lecce. It was first built in the Middle Ages, the central structure dates to the 12th century, and was strengthened by Carlo V in 1539. The structure has an original trapezoidal base with four massive arrowhead bastions on each corner and an internal courtyard.





Special evenings will take place, weather permitting, in the **Roman Theatre**, an ancient theatre built by the Romans in the 2nd century AD. It was forgotten for a long time, covered by gardens and palaces and accidentally rediscovered in 1929. Embedded in baroque buildings, it is one of the historical marvels of Lecce, given as an exclusive location for the **TERAMETANANO-4** by the Superintendence of Cultural Heritage.



The **Poster session** will be held in the **Chiostro** of the **Arcivescovado di Lecce** placed in Piazza Duomo. The Chiostro is located inside the Palazzo del Seminario, a historic building built between 1694 and 1709 in the Baroque style of Lecce.


The **Light Dinner** on **May the 27th** will be at Fondazione Palmieri, ex San Sebastiano Church. It is a small deconsecrated Renaissance church in the historic centre of Lecce. It was built in 1520 on the site of an existing rock church. The small façade in Lecce stone with a simple sloping profile is softened by a series of hanging arches under which the portal opens, surmounted by an architrave resting on two fluted columns. Portal and architrave are decorated with floral and symbolic motifs. The building, deconsecrated in 1967, has a simple planimetric layout with a single nave.


Positions of the different locations

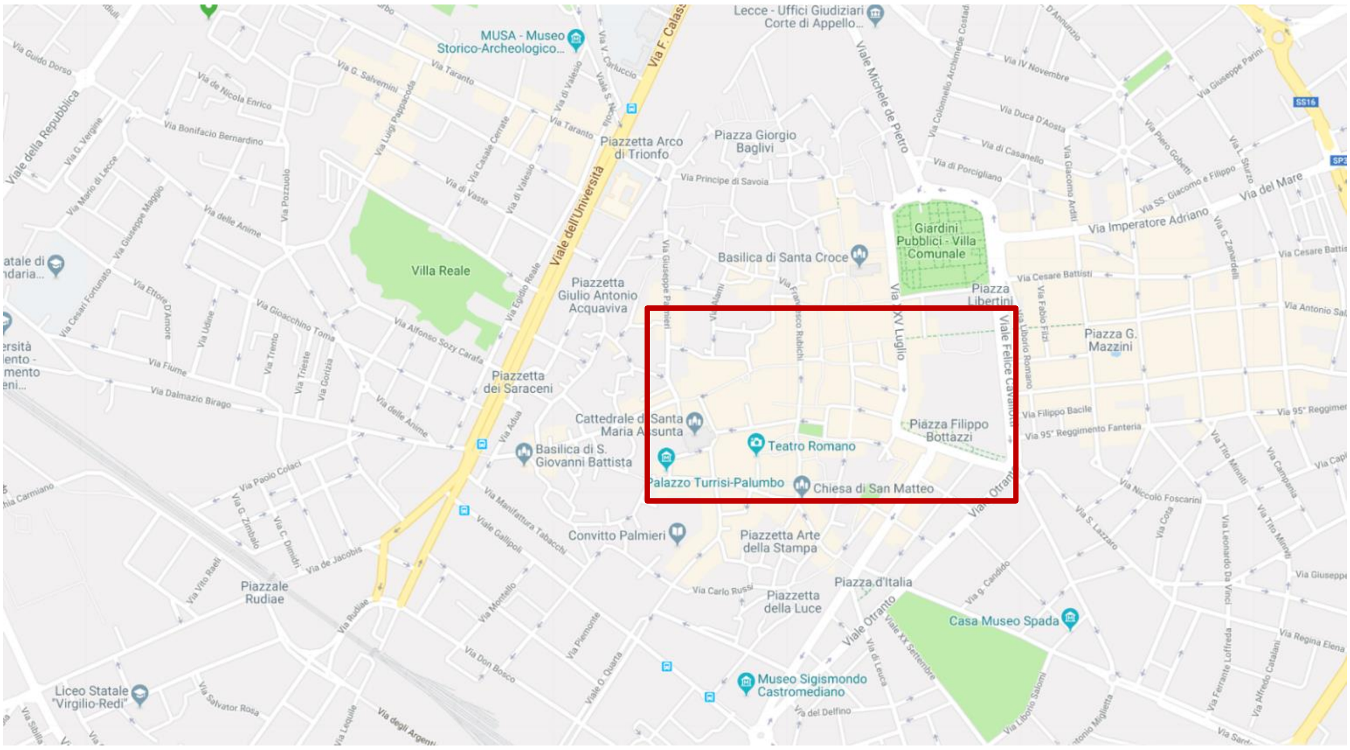
- **Castello Carlo V**
  Via XXV Luglio, 73100, Lecce, Italy

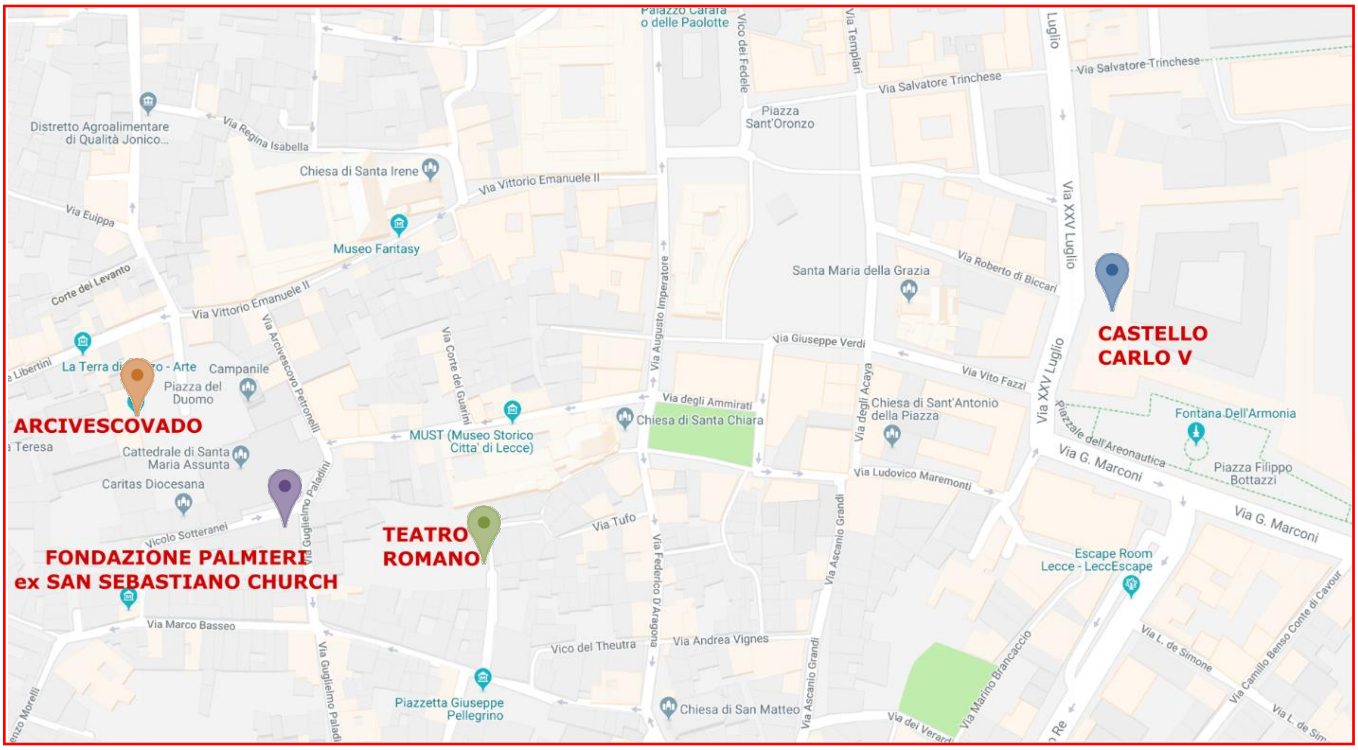
- **Roman Theatre**
  Via Arte della Cartapesta, 10, 73100, Lecce, Italy

- **Arcivescovado di Lecce**
  Piazza Duomo, 73100, Lecce, Italy

- **Fondazione Palmieri, ex San Sebastiano Church**
  Vicolo Sotteranei, 73100, Lecce, Italy

Maps of Lecce





Castello Carlo V

Teatro Romano

Arcivescovado di Lecce

Fondazione Palmieri, ex San Sebastiano Church

Social dinner

The social dinner will be held at the "**Masseria Melcarne**" on **Monday 27th at 20:00**. A bus will collect people at 19:30 from outside the castle Carlo V. Melcarne is an old fortification built between the end of the 16th century and the beginning of the 17th century to defend the house from sea raids, standing just a few kilometres from Lecce. The "Masseria Melcarne" was with time converted into an elegant noble residence.

In the course of the 18th century the complex has undergone important reconstruction works like the two elegant balconies supported by robust corbels.

Position

Strada Provinciale 93, km 5,

73010, Torre Rinalda

Lecce, Italy

Excursion

The Excursion will take place on the afternoon of May 29th. We will visit Otranto, a town set on a rocky spur on the east coast of the Salento peninsula.


Otranto's ancient city centre ("Borgo antico di Otranto") has been recognized by UNESCO as a "Culture of Peace Messenger Site".

A tourist guide will show the Lungomare degli Eroi (Heroes' Promenade), at the foot of the ancient city centre, the Castello Aragonese (Aragon Castle), a mighty construction which forms part of the tough defences of Otranto, and the Cathedral, with its precious mosaic floor and the relics of 800 martyrs killed by the Turks in 1480.



The beaches near the town are very small but pleasant on a sunny May weekday. We recommend to carry a small towel and a swimming suit.

Scientific conference program

Sunday, 26 May

Venue: Castello Carlo V

18:00 – 20:00		**WELCOME COCKTAIL**

Monday, 27 May

Venue: Castello Carlo V

8:30 – 8:45		**Registration**
8:45 – 9:00		**Welcome**
9:00 – 11:00		**Quantum states and cavity QED** **Chair: A. Kavokin**
Keynote	9:00 – 9:45	**P. Rabl** Non-perturbative Cavity QED
Invited	9:45 – 10:15	**C. Sanchez Munoz** Multi-mode Quantum Rabi Model and Superluminal Signaling
	10:15 – 10:30	**J. C. Lopez Carreno** Watching Photons
	10:30 – 10:45	**O. S. Ojambati** Quantum electrodynamics at room temperature: coupling a single vibrating molecule with a plasmonic nanocavity
	10:45 – 11:00	**E. Zubizarreta Casalengua** Conventional and unconventional photon statistics
11:00 – 11:30		**COFFEE BREAK**
11:30 – 13:00		**Polariton Quantum fluids I** **Chair: N. Berloff**
Invited	11:30 – 12:00	**M. Richard** Dispersion relation of the collective excitations in a resonantly driven quantum fluid of polaritons
	12:00 – 12:15	**M. Pieczarka** Quantum depletion of a nonequilibrium exciton-polariton condensate

	12:15 – 12:30	**H. Sigurdsson** Tuning light-matter lasers of microscopically coupled exciton polariton condensates
	12:30 – 12:45	**N. Voronova** Photonic engineering paves the way to direct exciton Bose-Einstein condensation
	12:45 – 13:00	**D. Suarez Forero** Wave-particle duality of single polaritons
13:00 – 14:15		**LUNCH**
14:15 – 15:45		**Interactions in polariton fluids and cuprate excitons** **Chair: F. Laussy**
Invited	14:15 – 14:45	**R. Rapaport** Strong repulsive and attractive interactions in correlated quantum fluids of dipolar excitons and polaritons
	14:45 – 15:00	**T. Chervy** Electron-polariton interactions in the fractional quantum Hall regime
	15:00 – 15:15	**I. Chestnov** Pseudo-drag of a polariton superfluid by an electric current
	15:15 – 15:30	**D. Ziemkiewicz** High power, Q-switching maser based on Rydberg excitons in Cu2O
	15:30 – 15:45	**S. Zielinska** Magneto-optical properties of excitons in Cu2O for weak and intermediate magnetic fields
15:45 – 16:15		**COFFEE BREAK**
16:15 – 18:00		**Optical Control in nanostructures** **Chair: M. Abbarchi**
Invited	16:15 – 16:45	**K. Kavokin** Optical cooling of nuclear spins in semiconductor microcavities
	16:45 – 17:15	**A. Poddubny** Optomechanical Kerker effect for trembling nanoparticles and membranes
	17:15 – 17:30	**S. Gavrilov** Spin networks and supersolid states of cavity polaritons under resonant driving
	17:30 – 17:45	**K. Lekenta** Liquid crystal microcavity as a new building block for the next-generation of spin Hall based devices
	17:45 – 18:00	**N. Karpowicz** Electro-optic imaging in the near infrared
19:45 – 23:30		**BANQUET at Masseria Melcarne (BUS at 19:45 in front of the Castello Carlo V)**

Tuesday, 28 May

Venue: Castello Carlo V

9:00 – 11:00		**2D and novel materials I** **Chair: M. Portnoi**
Keynote	9:00 – 9:45	**J. Finley** Trapping excitons in monolayers and heterostructures of atomically-thin semiconductors
Invited	9:45 – 10:15	**V. Menon** Control of light-matter interaction in 2D materials
	10:15 – 10:30	**T. Smolenski** Shubnikov-de Haas oscillations in optical conductivity of monolayer MoSe2
	10:30 – 10:45	**S. Borghardt** Radially polarized light beams from spin-forbidden dark excitons in monolayer WSe2
	10:45 – 11:00	**A. A. Mitioglu** Magneto-optical investigation of valley coherence in monolayer dichalcogenides
11:00 – 11:30		**COFFEE BREAK**
11:30 – 13:15		**2D and novel materials II** **Chair: Q. Xiong**
Invited	11:30 – 12:00	**M. Lorenzon** Long-range FRET-mediated exciton diffusion in cesium lead halide perovskite nanostructures
	12:00 – 12:15	**D. Reiter** Dynamical theory for controlled optical nonlinearities of monolayers of transition metal dichalcogenides
	12:15 – 12:30	**C. Kastl** Effects of Defects on Band Structure and Excitons in WS2 revealed by Nanoscale Photoemission Spectroscopy
	12:30 – 12:45	**A. Genco** Moving from momentum-indirect to interlayer excitons in van der Waals heterobilayers based on transition metal dichalcogenide alloys
	12:45 – 13:00	**M. Portnoi** Momentum alignment of photoexcited carriers in low-dimensional Dirac materials
	13:00 – 13:15	**L. Maserati** Theoretical and Experimental Observation of Anisotropic 2D Excitons in Self- Assembled Hybrid Quantum Wells

Venue: Fondazione Palmieri, ex San Sebastiano Church

18:30 – 19:30		**Light Dinner**

Venue: Roman Theatre

	19:00 – 20:00	**M. Inguscio, C. Vozzi** General pubblic talks (in italian)
		Chair: J. Finley
Keynote	20:00 – 20:45	**A. Imamoglu** Many-body optical excitations in solid-state systems
Invited	20:45 – 21:15	**A. Tredicucci** Optomechanics in active and chiral systems
Invited	21:15 – 21:45	**Q. Xiong** Room-temperature strong light-matter coupling and polariton condensation in perovskite materials
Invited	21:45 – 22:15	**T. Liew** Cellular automata and quantum neural networks based on exciton-polariton lattices

Wednesday, 29 May

Venue: Castello Carlo V

9:00 – 11:00		**THz and Intersubband transitions** **Chair: A. Imamoglu**
Keynote	9:00 – 9:45	**C. Lange** Subcycle control of spins and photons by nanoresonator near-fields
Invited	9:45 – 10:15	**S. De Liberato** Cavity-mediated bound excitons
	10:15 – 10:30	**G. Scalari** Broadband operation and RF control of Impact THz QCL frequency combs
	10:30 – 10:45	**M. Montanari** n-type Ge/SiGe Multi Quantum-Wells for a THz Quantum Cascade Laser
	10:45 – 11:00	**M. Jeannin** Ultra-Small Mode Volume Three- Dimensional THz LC Circuits for Intersubband Polaritons
11:00 – 11:30		**COFFEE BREAK**
11:30 – 13:00		**Polariton Quantum fluids II** **Chair: S. Kéna-Cohen**
Invited	11:30– 12:00	**P. Walker** Nonlinear Optics with Exciton-Polaritons in High Velocity Waveguides
	12:00 – 12:15	**G. Lerario** Hydrodynamics of vortices, breathing dark solitons and Ising domain walls in a polariton condensate
	12:15 – 12:30	**M. Gromovyl** Polariton condensates in ZnO waveguides: towards integrated polaritonics
	12:30 – 12:45	**A. Maitre** Imprinting solitons on a polariton superfluid
	12:45 – 13:00	**M. Matuszewski** Neuromorphic computing in Ginzburg-Landau polariton lattice systems
13:00 – 14:30		**LUNCH**
14:30 – 19:00		**EXCURSION to Otranto**

Thursday, 30 May

Venue: Castello Carlo V

9:00 – 11:00		**THz and plasmonic systems** **Chair: A. Tredicucci**
Keynote	9:00 – 9:45	**J. Faist** Engineering vacuum fields with metamaterials
Invited	9:45 – 10:15	**A. Fernandez-Dominguez** Plasmon-Exciton Coupling: Light- forbidden Transitions and Quasichiral Interactions
	10:15 – 10:30	**C. Ciraci'** Impact of electron spill-out on Rabi splitting in plasmonic systems
	10:30 – 10:45	**S. D. Ganichev** Terahertz ratchet effects in graphene and semiconductor nanostructures with a lateral superlattice
	10:45 – 11:00	**M. Otteneder** Sign-alternating photoconductivity and magnetoresistance oscillations (MIRO) induced by terahertz radiation in HgTe quantum wells
11:00 – 11:30		**COFFEE BREAK**
11:30 – 13:00		**Metamaterials** **Chair: M. Atature**
Invited	11:30 – 12:00	**S. Nguyen** Tailoring on-demand dispersion with symmetry breaking: from flatband to Dirac cones and multivalley dispersions
	12:00 – 12:15	**V. Caligiuri** A semi-classic description of Epsilon-Near-Zero resonances in Metal/Insulator states nano-cavities
	12:15 – 12:30	**A. Calabrese** THz detectors based on optomechanical metamaterials
	12:30 – 13:00	**Elevator Pitch**

Venue: Arcivescovado di Lecce at Piazza del Duomo

17:00 – 18:30		**Poster session**
18:30 – 19:00		**Light Dinner**

Venue: Roman Theatre

	19:00 – 20:00	**A.Kavokin, C. Toninelli** General pubblic talks (in italian)
		Chair: S. Höfling
Keynote	20:00 – 20:45	**N. Berloff** Polaritonic network as a paradigm for dynamics of coupled oscillators
Invited	20:45 – 21:15	**M. Atature** Optical control of nuclear spins: from nuisance to resource
Invited	21:15 – 21:45	**R. J. Warburton** A quantum dot exciton deep in the strong coupling regime of cavity-QED
Invited	21:45 – 22:15	**S. Kéna-Cohen** Dynamics of carriers, excitons and polaritons in novel materials

Friday, 31 May

Venue: Castello Carlo V

9:00 – 11:00		**Topological polaritons** **Chair: T. Liew**
Keynote	9:00 – 9:45	**S. Höfling** Topological polaritonics
Invited	9:45 – 10:15	**P. St Jean** Topological photonics with exciton-polaritons
	10:15 – 10:30	**L. Pickup** Probing polariton band structures in optically imprinted potential landscapes
	10:30 – 10:45	**O. Jamadi** Observation of photonic Landau levels in strained honeycomb lattices
	10:45 – 11:00	**A. Gianfrate** Direct measurement of the quantum geometric tensor in a two-dimensional continuous medium
11:00 – 11:30		**COFFEE BREAK**
11:30 – 13:00		**Plasmonic systems and nanostructures** **Chair: G. Scalari**
Invited	11:30 – 12:00	**B. de Nijs** Light on the Ångström scale
	12:00 – 12:15	**R. Mermet-Lyaudoz** Experimental observations of bound in the continuum at anti-crossing point induced by symmetry breaking
	12:15 – 12:30	**M. Abbarchi** Solid-state dewetting of Si(Ge)-based complex nano-architectures and their applications in photonics
	12:30 – 12:45	**S. Rajabali** The Effect of the Narrow Gap Split Ring Resonators on the Polariton Spectrum in the Ultrastrong Coupling Regime
	12:45 – 13:00	**M. Pilo Pais** DNA Self-Assembled Nanoantennas
13:00 - 13:30		**Best poster award and concluding remarks**
		End of program

Poster

Thursday, 30 May

P01	D. G. Suarez-Forero	Single photon states from non-stoichiometric bulk perovskites
P02	Dang Ha My	Observation of strong coupling regime with hybrid perovskite in photonic crystal
P03	F. Laussy	Polariton Blockades
P04	E. Del Valle	Dynamical Theory of the Hong–Ou–Mandel Effect
P05	I. Buyanova	Near-infrared lasing from GaNAs-based nanowires
P06	W. Chen	Nanodisk-in-nanopillar semiconductor structure: a platform for an efficient room-temperature spin-photon interface
P07	S. Candussio	Terahertz radiation induced edge currents in graphene in the quantum Hall regime
P08	F. De Luca	Hydrodynamic Description of Difference Frequency Generation in a doubly resonant plasmonic nanostructure
P09	A. Opala	Relaxation oscillations and reservoir filling dynamics in an exciton-polariton condensate
P10	S. Hubmann	High frequency impact ionization and nonlinearity of photocurrent induced by intense terahertz radiation in HgTe-based quantum well structures
P11	A. M. Forero	Electronic and optical properties of a conical nanotube in presence electric and magnetic fields
P12	S. Zielinska	Quantum information with Rydberg excitons in Cu2O
P13	P. Mietki	Hybrid regime of stabilization in exciton-polariton condensates
P14	T. Venanzi	Exciton localization in MoSe2 monolayers induced by adsorbed gas
P15	L. Piper	Perfect Material Absorber for Split-Ring Resonators for Reflection within the Terahertz Regime
P16	M. Wiecha	Surface Plasmon Polariton modes on silver nanowires
P17	R. Norkus	Terahertz excitation spectroscopy for semiconductor band structure characterization
P18	M. Salbini	Gold nanorods SPR-based biosensor for mechanotransduction analysis
P19	I. Avdeev	Hyperfine interaction in transitional metal dichalcogenides monolayers
P20	Comaron	Dynamical critical exponent and quench dynamics in driven dissipative condensate
P21	G. Diaz Camacho	Heralded N -photon sources

P22	S. Mandal	Anti-chiral edge states in Graphene exciton-polariton strip
P23	S. Ghosh	Quantum reservoir processors for quantum information processing
P24	R. Krahne	Planar Aperiodic Arrays as Metasurfaces for Optical Near-Field Patterning
P25	S. D'agostino	Hybrid Metal-Molecule Systems: from a Classical to an Atomistic Description
P26	V. Rumyantsev	Polariton spectrum due to the presence of structural defects and elastic deformation in the chain of microcavities containing quantum dots
P27	L. Polimeno	Photonic Crystal Nanocavity in 2D Layered Perovskite
P28	A. Fieramosca	Room Temperature polaritons in 2D hybrid organic-inorganic perovskites
P29	S. Dickmann	Laser-induced super-long-living spin excitations in a purely electronic two-dimensional gas.
P30	B. Fainberg	Electron-vibrational interactions in molecular aggregates: from exciton absorption and luminescence to exciton-polariton dispersion in nanofibers
P31	H. Vinck Posada	Phonon assisted light matter interaction in the cavity quantum electrodynamics
P32	K. Taranets	Express terahertz diagnosis for breast cancer
P33	C. Duque	Electronic properties of an elliptical quantum ring with variations in its height
P34	C. Duque	Self-similarity and its effects on electronic and optical properties in a quasi-periodic graphene-based superlattice
P35	P. Golovin	THz sources for stimulation of the biological reactions.
P36	H. Vinck Posada	Effects of phonon-assisted cavity feeding process on the Dicke superradiance critical phenomena
P37	C. Duque	Effects of the dimensions, magnetic field and intense non-resonant laser on electronic properties in an eccentric quantum ring

Non-perturbative Cavity QED

P.Rabl

Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria

In typical quantum optical systems the coupling between a single dipole and a single cavity mode is always much smaller than the absolute energy scales involved, which allows us to understand and model light-matter interactions in terms of well-defined atomic and photonic excitations on top of a trivial vacuum state. With recent advances in the field of nanophotonics and circuit QED it is now possible to challenge this well-established paradigm and enter a fully non-perturbative regime, where the coupling between a single (artificial) atom and a photon exceeds the energy of the photon itself. Such conditions can be associated with an effective finestructure constant of order unity and in this talk I will give a brief introduction about the basics models [1,2] and novel effects that govern the physics of light-matter interactions in this previously inaccessible regime.

[1] D. De Bernardis, T. Jaako, and P. Rabl, Phys. Rev. A 97, 043820 (2018);

[2] D. De Bernardis, P. Pilar, T. Jaako, S. De Liberato, and P. Rabl, Phys. Rev. A 98, 053819 (2018);

Multi-mode Quantum Rabi Model and Superluminal Signaling

Carlos Sánchez Muñoz[1,2*], Franco Nori[2], Simone De Liberato[4]
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Recent technological developments have made it increasingly easy to access the non-perturbative regimes of cavity-QED known as ultra or deep strong coupling, where the light-matter coupling becomes comparable to the bare modal frequencies [1,2]. In this work, we address the adequacy of the broadly used single-mode Rabi model to describe such regimes [3]. In the non-perturbative light-matter coupling regimes, the Rabi model becomes unphysical, allowing for superluminal signalling. We show that the multi-mode description of the electromagnetic field, necessary to account for light propagation at finite speed, yields physical observables that differ radically from their single-mode counterpart already for moderate values of the coupling. Our multi-mode analysis also reveals phenomena of fundamental interest on the dynamics of the intracavity electric field, where a free photonic wavefront and a bound state of virtual photons are shown to coexist.

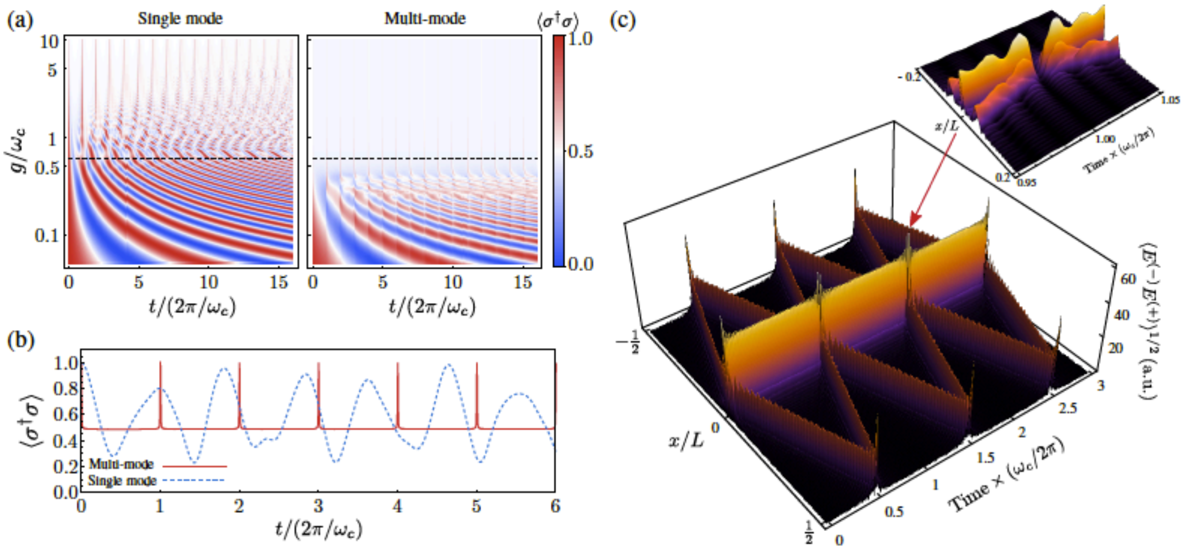

Figure: Dynamics of the intracavity electric field in the ultrastrong coupling regime. (a) Contour plot of the TLS population as a function of time and coupling rate. (b) Evolution of the population of an initially excited TLS for the single-mode (blue, dashed) and multi mode (red, solid) cases (c) Amplitude of the electric field inside the cavity as a function of space and time.

References

[1] C. Ciuti, G. Bastard, and I. Carusotto, Phys. Rev. B 72, 115303 (2005).
[2] J. Casanova, G. Romero, I. Lizuain, J. J. García-Ripoll, and E. Solano, Phys. Rev. Lett. 105, 263603 (2010).
[3] C. Sánchez Muñoz, F. Nori and S. De Liberato, Nature Communications 9, 1924 (2018)

Watching Photons

J. C. López Carreño[a,b], E. Zubizarreta Casalengua[b], E. del Valle[b] and F. P. Laussy[a,c*]

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[b] *Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, E-28049, Madrid, Spain*
[c] *Russian Quantum Center, Novaya 100, 143025 Skolkovo, Moscow Region, Russia*
* Corresponding author: fabrice.laussy@gmail.com

Single photons and the sources that provide them are at the core of the race towards quantum technology [1]. Aiming to obtain the best source of single photons, one is faced with a multitude of desiderata that range from both fundamental (correlations, purity, indistinguishability, etc.) and practical (efficiency, regime of operation, brightness, price, etc.) considerations. Furthermore, recently we have shown that two important properties of a single-photon source (its linewidth and its antibunching) can only be accurately established when measured jointly, rather than by studying them independently [2]. More generally, a realistic and meaningful study of the properties of single-photon sources should consider the way in which their light is observed, rather than merely by the way in which it is emitted.

We use an extended Quantum Monte Carlo method to model the physical detection process of a given quantum source [3]. We tackle the issue of how a single-photon source really behaves when going through the full process of excitation, emission and detection, with a particular focus on the effect of frequency filtering [4]. We will discuss and compare various criteria to characterize their quality as single-photon emitter from this generalized viewpoint and present a conceptual ideal single-photon source that makes a surprising link between quantized and continuous fields [5, 6].

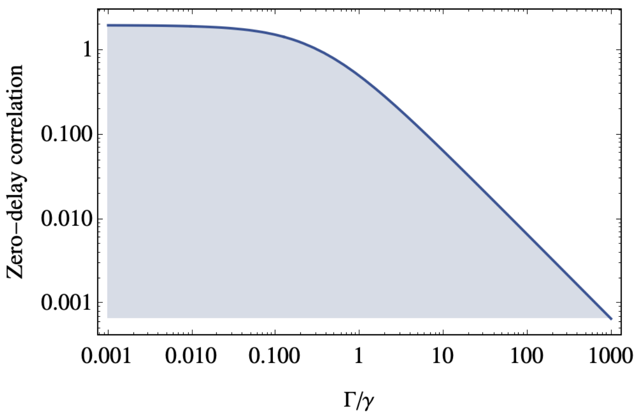

Figure 1. Loss of antibunching due to frequency-filtering. As the linewidth of the system receiving the photons becomes comparable to the linewidth of the emitter, the correlations are completely spoiled.

References

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Quantum electrodynamics at room temperature: coupling a single vibrating molecule with a plasmonic nanocavity

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Interactions between a single emitter and a cavity have been intensely studied as the archetypical system for fundamental quantum electrodynamics. Here we show that precision nano-assembly of single dye molecules into plasmon nanocavities deliver single emitters, but also several novel correlated photon features.

Strongly coupled systems are desirable since the reversible exchange of energy between the emitter and cavity leads to cavity quantum electrodynamical effects such as vacuum Rabi splitting, Rabi oscillations, non-classical photon statistics, and modified Purcell effects. Typically, studies rely on cryogenically-cooled emitters to achieve strong coupling conditions, which brings multiple technical challenges and severely restricts practical implementation, scalability, and the complexity of devices [1].

We demonstrate a novel approach to cavity quantum electrodynamics at room temperature using molecular emitters. Specially-designed DNA origami systems are easy to synthesize, can be produced on a large scale, and single molecules are integrable on-chip through careful self-assembly [2]. Even more intriguing is the capability for strong coupling with these single molecules to open up combinations of chemistry to quantum optics, whilst tailoring the excited state manifold for novel control of chemical reactions [3].

Here we show that a single molecule interacts coherently with a deeply sub-wavelength plasmonic nanocavity, approaching the cooperative regime even at room temperature [4]. Power-dependent pulsed excitation reveals Rabi oscillations, arising from the coupling of the oscillating electric field between the ground and excited states. The observed single-molecule fluorescent emission is split into two modes resulting from anti-crossing with the plasmonic mode, indicating the molecule is strongly coupled to the cavity. The second-order correlation function of the photon emission statistics is found to be pump wavelength dependent, varying from $g^2(0) = 0.4$ to 1.45, highlighting the influence of vibrational relaxation on the Jaynes-Cummings ladder. Our results show that cavity quantum electrodynamic effects can be observed in molecular systems at ambient conditions, opening significant potential for device applications.

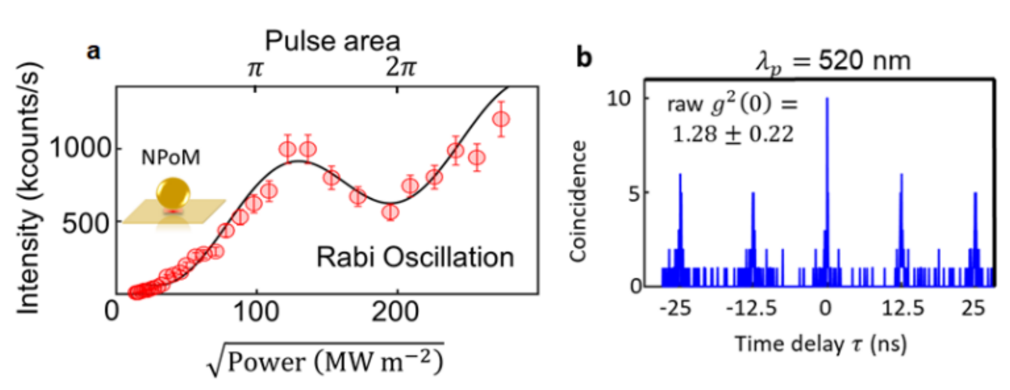

Figure 1: (a) Measured intensity vs power for single molecules in nanoparticle-on-a-mirror (NPoM) plasmonic cavity. (b) Second-order intensity correlation of the emitted light from single Atto647 molecules inside NPoM cavities using (b) 520nm excitation wavelength.

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Conventional and unconventional photon statistics

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We show that the photon-statistics of the light emitted by optical systems under coherent and resonant excitation can be modulated from Sub- to Super-Poissonian due to a self-homodyne interference. This scheme can be further controlled and/or optimized at the *N*-photon level by purposely tuning the coherent excitation. This gives rise to two types of photon correlation emission, that we classify as *conventional* and *unconventional* statistics, after some of the typical mechanisms that give rise to such features [1]. As one application of our theory, we design a perfectly antibunched and subnatural-linewidth (monochromatic) source, based on resonance fluorescence (a qubit weakly excited by a laser, as in the figure) [2,3], which is, in principle, incompatible with the Heisenberg principle. This paradigm is not only interesting for single-mode correlations but can also be extended to multi-mode physics, by exploiting the frequency-resolved two-photon correlation spectrum (2PS), shown in the right-hand side of the figure. When the laser-qubit detuning is large, a perfect circle of antibunching between photons with different frequencies arises (in blue) due to quantum interferences, that reveals exotic squeezing properties of great potential for applications [4].

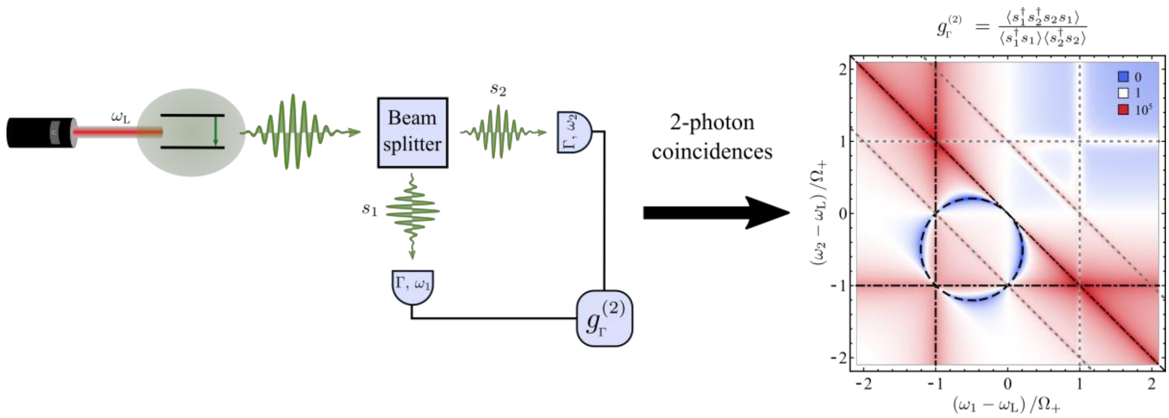

Fig. 1: Typical set-up for the measurement of a 2PS, detected at different frequencies, for a qubit driven by a laser. The 2PS on the right shows a characteristic circle of anticorrelation (blue line), which we have identified as rooted in two-mode squeezing.

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Dispersion relation of the collective excitations in a resonantly driven quantum fluid of polaritons

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Exciton-polaritons in semiconductor microcavities constitute the archetypal realization of a quantum fluid of light [1]. In 2009, the first demonstration of a superfluid state in a polaritons fluid under coherent optical drive [2] has paved the way to a whole new kind of quantum hydrodynamics. Remarkable effects have thus been measured and described such as of quantized vortices [3], solitons [4], and other topological structures involving the spin degree of freedom [5], as well as turbulence effects [6]. A common feature with equilibrium quantum hydrodynamics is that these phenomena can all be understood as a specific manifestation of the collective excitations forming on top of the polariton condensate.

We performed a Brillouin scattering experiment to measure their dispersion relation $\omega(\boldsymbol{k})$ directly, in the regime were two-body interactions are comparable with the loss rate [7]. Typical results are shown in Fig.1 and exhibit surprising features, such as a speed of sound which is apparently twice too low. This observation cannot be explained upon considering the polariton condensate alone. In a combined theoretical and experimental analysis,

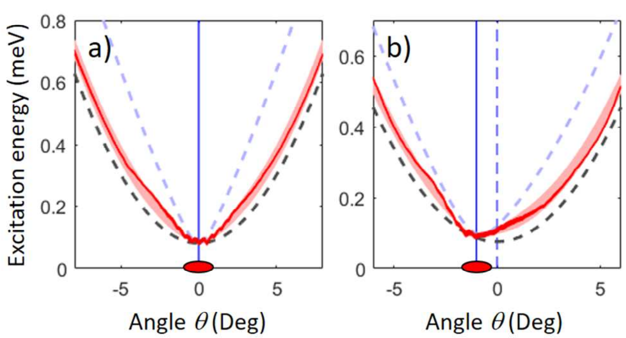

Fig. 1: Measured dispersion relation of the collective excitations (solid red line) for laser excitation at $\boldsymbol{\Delta} = \hbar\boldsymbol{\omega_l} - \hbar\boldsymbol{\omega_0} = \mathbf{0.79}$ meV and $\boldsymbol{\theta} = \mathbf{0}°$ (a), and $\boldsymbol{\Delta} = \mathbf{0.47}$ meV and $\boldsymbol{\theta} = \mathbf{-1}°$ (b), where $\boldsymbol{\omega_0}$ ($\boldsymbol{\omega_l}$) is the polariton ground state (laser) frequency and $\sin\boldsymbol{\theta}$ is proportional to the polaritons in-plane wavevector. The line thickness represents the experimental uncertainty, while the thick pale red line is the theoretical dispersion in the coupled reservoir-condensate model. The dashed curves are the theoretical dispersion relations in two limiting cases: no reservoir (blue) and dominant reservoir (black). The red bullet illustrates the laser spot position in the $(\boldsymbol{\theta}, \boldsymbol{\omega})$ plane (thickness not at scale).

we demonstrate that the presence of a reservoir of long-lived excitons interacting with polaritons from the condensate deeply alters the nature of the collective excitations, and that it explains our measurement quantitatively. This work clarifies the role of such a reservoir in the different polariton hydrodynamics phenomena occurring under resonant optical drive. It also provides an unambiguous tool to determine the condensate-to-reservoir fraction in the quantum fluid, and sets an accurate framework to approach novel ideas for polariton-based quantum-optical applications.

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Quantum depletion of a nonequilibrium exciton-polariton condensate

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Exciton-polariton condensates in semiconductor microcavities form a nonequilibrium bosonic quantum system with a spontaneously appearing macroscopic coherence. The quantum nature of exciton-polariton interactions has been shown recently on a single particle level [1]. In the many-body case, when ground state is macroscopically occupied and the condensate is formed, a consequence of quantum fluctuations and polariton-polariton interactions is the appearance of the ghost excitation branch with negative energies with respect to the condensate. It is occupied by particle-particle scattering, reducing the population of the condensate in the process of so-called quantum depletion [2]. In the case of polariton condensates, this effect is strongly suppressed due to the nonequilibrium processes [3].

In this contribution, we present evidence of quantum depletion of a nonequilibrium, optically trapped exciton-polariton condensate. We create a high density of polaritons reaching the interaction-dominated Thomas-Fermi regime [4] and record signal from both normal (NB) and ghost (GB) excitation branches. This was possible utilising a filtering technique with blocking the strong photoluminescence from the condensate to gain access to very weak signal of the branches, see Fig. 1. Analysis of the occupation in the momentum space reveal the populating mechanisms of the NB and GB, where the GB is populated solely due to quantum depletion. This is manifested in specific power-law decays of the occupation in momentum space [2]. Furthermore, we observe deviations from the equilibrium theory in both branches at high densities. We analyse and discuss the observed phenomena pointing out the importance of the nonequilibrium nature of polariton condensation process.

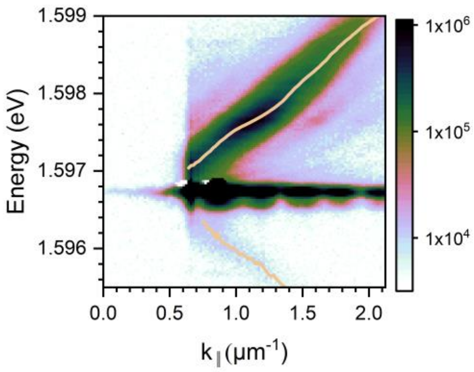

Fig. 1 Example of recorded excitation spectrum in the high density regime. Condensate luminescence is filtered out around **k**=0. Solid lines are the maxima of extracted peaks. The image is saturated and the color scale is logarithmic.

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Tuning light-matter lasers of macroscopically coupled exciton polariton condensates

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Exciton-polaritons undergo a power-driven quantum phase transition to a macroscopically occupied state with long-range phase coherence analogous to the formation of a BEC. One of the advantages of polariton condensates is the easy implementation of nonresonant optical pumping of arbitrary geometries which sustains the condensate indefinitely. Coupled condensate centers [1] have been shown to offer a platform for engineering versatile systems of interacting condensates, such as bosonic Josephson junctions [2, 3], phase and spin-synchronized lattices [4, 5]. It is therefore important to both understand and characterize the features of the simplest coupled condensate system, and the building block of all higher complexity arrays or graphs, which is the *polariton dyad*. A system of two coupled, spatially separated, polariton condensates.

Here, we present an extensive experimental study of phase synchronization and nonlinear dynamics in a polariton condensate dyad. The two condensates become synchronized over ~ 114 μm record distances and display steady oscillating transfer of condensate population between pump spots analogous to Rabi oscillations in a bosonic Josephson junction. We can control the condensate populations belonging to the new eigenmodes of the coupled system (seen in Fig. 1(c,e) as the two separate energy levels) by only changing the distance between the pump spots which dictates the location of the eigenmodes in the gain-region of the dyad. At certain distances only one mode is seen in the gain region (see Fig. 1(d,f)). Furthermore, we also display control over the relative phase between the condensate centers at the pump spots by driving the system asymmetrically (one spot more powerful than the other). Such asymmetric driving of the dyad can thought of as a detuned Josephson system although here the nonequilibrium dyad must be analyzed in the framework of dissipative mean field equations. Our results demonstrate great control over macroscopic two level systems which has potential application in simulation of complex systems, optimizing computationally difficult problems, and superconducting qubits. We reproduce all results qualitatively and semi-quantitatively by both numerical calculation using the generalized Gross-Pitaevskii approach, and analytical derivation of the two-level physics within the dyad. The microcavity sampled used is a strain compensated 2λ GaAs microcavity with three pairs of 6nm InGaAs quantum wells in the cavity spacer.

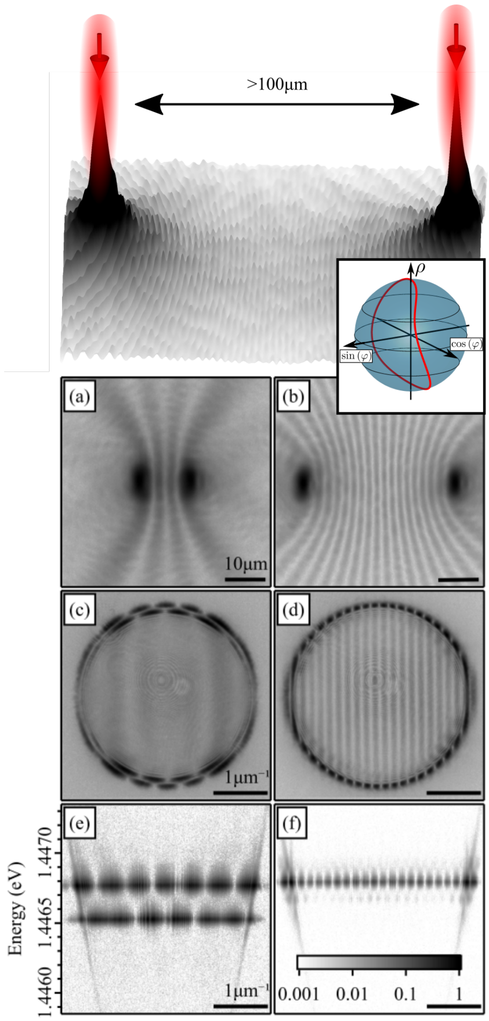

FIG. 1. Measured (a,b) real-space and (c,d) momentum-space photoluminescence. (e,f) Spectrally-resolved momentum-space photoluminescence of the two non-resonantly pumped polariton condensates with separation distances (a,c,e) 12.7 μm and (b,d,f) 37.3 μm, respectively. All images are illustrated in logarithmic scale for better visibility of low-intensity features. Top panel shows a surface plot real space photoluminescence for pump separation of ~ 100 μm. Inset shows a calculated trajectory on the Bloch sphere of the dyad illustrating Rabi oscillations.

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Photonic engineering paves way to direct exciton Bose-Einstein condensation

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In this work, we theoretically predict the possibility to observe superfluid state and Bose-Einstein condensation (BEC) in a gas of two-dimensional direct excitons at elevated temperatures (up to tens of K) in a single quantum well, thanks to the dramatic increase of their lifetime in the off-resonant cavities that strongly suppress exciton radiative decay [1]. We consider single GaAs quantum wells of different thicknesses embedded in a layered medium and show that integral exciton lifetimes in such heterostructures is of the order of 150 ns. We assume a spatially separated c.w. pump at a frequency outside the gap in the density of states produced by the periodicity of the structure (see Fig. 1a), which allows optically generated excitons to readily relax to low-energy states while moving to the central region of the sample. Keeping in mind that in coupled quantum wells, within the indirect exciton lifetimes (~100 ns), BEC occurs on the scales of the order of 12 μm [2], we conclude that for our structures, in the system of the considered size, the achieved lifetime for *direct* excitons is long enough for thermalization.

With the use of quantum hydrodynamic approach combined with the Bogoliubov description, we find the one-body density matrix of the system and, consequently, the superfluid density. Inset of Fig. 1b shows the results of calculations for the normalized densities depending on the temperature, revealing and the critical temperature of the Berezinskii-Kosterlitz-Thouless crossover up to 18.8 K (here shown for one of the considered geometries). We predict that with the appearance of quasi-condensed fraction as the system is cooled below the critical temperature, due to the drastic rise of the coherence length and narrowing of the *k*-distribution of the system, the intensity of luminescence from the structure (along direction normal to the layers) exhibits a manifold increase that can be observed experimentally (see Fig. 1b).

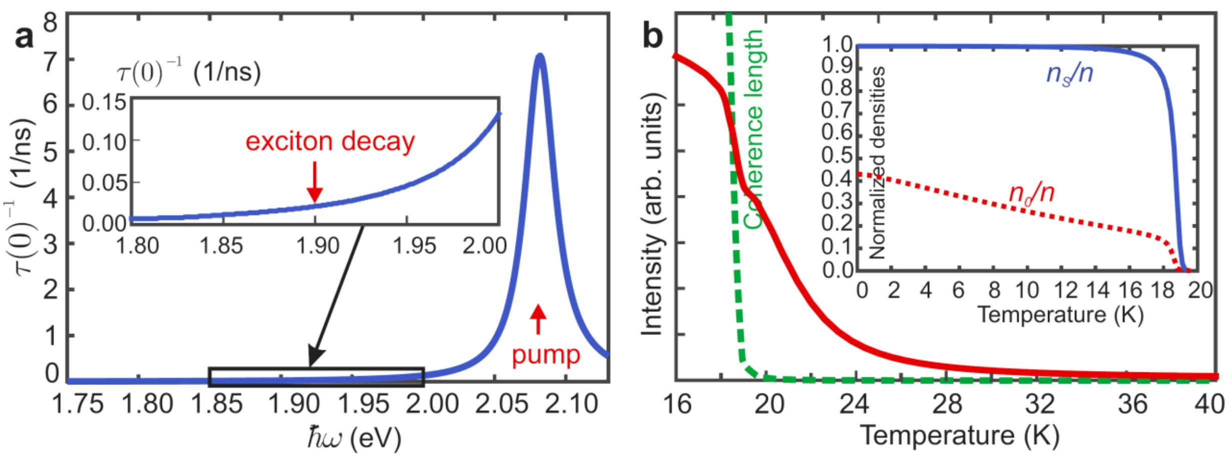

Fig. 1. a Spectral dependence of inverse lifetime of $k = 0$ excitons. Red arrows indicate the pump energy 1.65 eV and exciton optical recombination line 1.57 eV. **b** Photoluminescence intensity in normal direction (solid line) and the coherence length (dashed line, arbitrary units) vs temperature. Inset: normalized superfluid density (solid line) and condensate density (dotted line) vs temperature. The BKT crossover temperature ≈ 19 K.

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Wave-particle duality of single polaritons

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Generation, manipulation and detection of on-chip single photons is key to the development of quantum information-based technologies [1]. Nevertheless, nonlinearities at the single photon level are generally weak, which could limit the implementation of logic operations in current integrated quantum optics circuits.

Thanks to the nonlinearities stemming from their excitonic fraction, microcavity polaritons, the hybrid light-matter quasiparticle emerging from the strong coupling between a cavity mode and an excitonic transition, could represent a promising alternative to perform nonlinear quantum operation in optical circuits [2].

In this work we show that it is possible to use single photons from a semiconductor QD to resonantly excite single polaritons in a semiconductor 2D GaAs-based microcavity. By carefully tuning the injection angle of single photons, we are able to observe single polaritons propagating with a well-defined in-plane momentum.

Interestingly, our setup provides a direct observation of the wave-particle duality for single polaritons. In fact, when single polaritons propagate across a defect in the microcavity, the wave-packet is partially scattered and we observe fringes arising from the time-and-space self-interference of a single polariton wave-packet.

These results prove that microcavity polaritons can offer an alternative way for processing information at the single qubit level, for example by working as single interacting qubits in integrated photonic quantum networks.

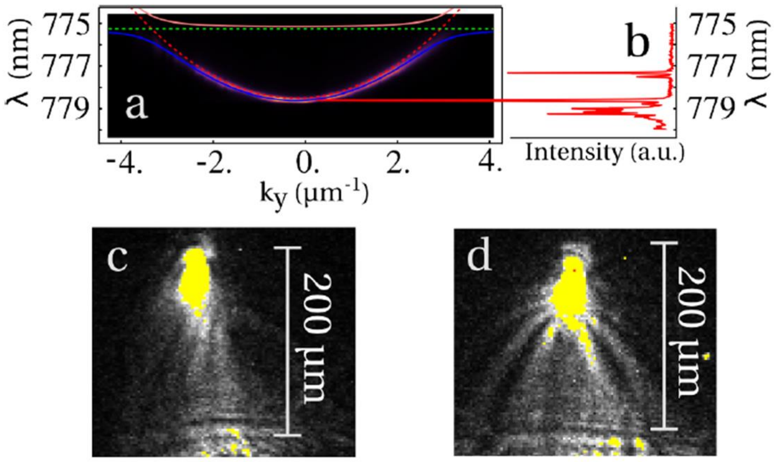

Figure 1: a) Planar Microcavity Dispersion; b) Single QD emission; by carefully tuning the injection angle it is possible to resonantly excite single polaritons; c) Single polariton propagation; d) Single polariton propagation across a defect: self-interference of the wave packet.

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Strong repulsive and attractive interactions in correlated quantum fluids of dipolar excitons and polaritons

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Quantum fluids of matter with long range, anisotropic interactions display rich emergent collective phenomena. A prominent example is the dipole-dipole interaction, which has recently been addressed by a growing community, both from atomic physics as well as from condensed matter physics, with the latter being focused on dipolar quantum fluids of two-dimensional excitons, and very recently, on the introduction of interacting dipolar polaritons. These strongly interacting dipolar exciton and polariton systems offer opportunities to explore new collective phenomena which are currently inaccessible with atomic dipolar gases, and to demonstrate new types of quantum devices on the level of two-particle interaction.

In this talk I will present several recent results in systems of dipolar excitons and polaritons. These include strong experimental evidence for the dynamical formation of a robust dark dense liquid phase of dipolar excitons in a bilayer system, corroborated by a theory predicting a remarkable stabilization of a dense dark-spin exciton Bose-Einstein condensate, driven by particle correlations due to the strong dipolar interactions. Also, I will report on the first observation of a formation of an attractive polaron-like many-body correlated state. This effect, which is due to the anisotropic nature of the dipole-dipole interaction, takes place in a new structure design allowing vertical coupling of dipolar exciton fluids. Finally, I will introduce recent experiments showing formation of flying electrically polarized dipolar-polaritons (‘dipolaritons’) in optical waveguides, resulting in a very large, electrically tunable enhancement of the polariton-polariton interactions, a result promising for future implementations of a dipolar polariton blockade.

Electron-polariton interactions in the fractional quantum Hall regime

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We investigate a two-dimensional electron system (2DES) embedded in an optical cavity. Cavity photons are strongly coupled to Fermi polarons, which leads to the formation of polaron-polaritons [1, 2, 3]. The light-matter coupling strength is sensitive to the electronic ground state. As the magnetic field is varied, we find that not only the energy of the polariton but also their scattering amplitude is changed.

We observe nonlinear energy shifts in the lower and upper polariton lines at certain 2DES filling factors and concomitant enhancements in the electron-polariton scattering amplitude.

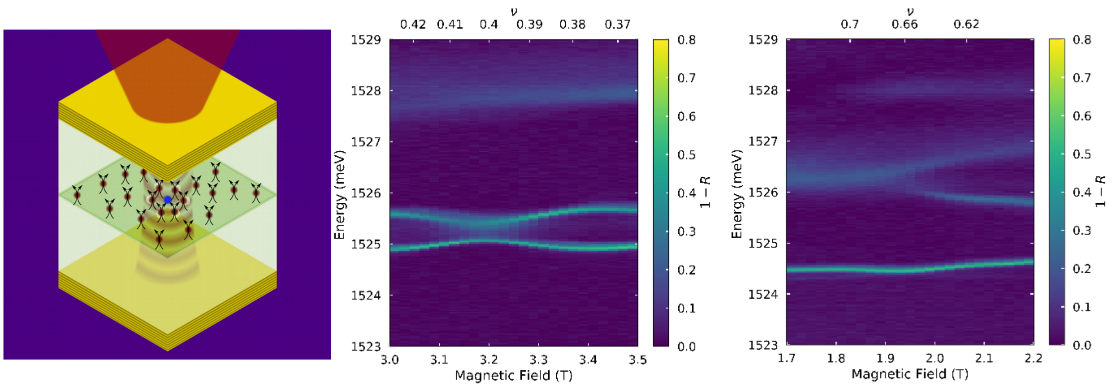

Fig. 1: (a) We embed a 2DES in a semiconductor microcavity. (b,c) The modifications of the lower and upper polariton branches around filling factors 2/5 and 2/3.

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Pseudo-drag of a polariton superfluid by an electric current

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A superfluid state of matter is characterized by zero viscosity, hence it is perfectly protected from being perturbed by a weak external force. This protection constitutes one of the main experimental signatures of a conventional superfluid such as a liquid helium. However, this paradigm is challenged for the out-of-equilibrium systems. However, optically pumped bosonic condensate of exciton-polaritons does demonstrate a dissipationless propagation with a subsonic velocity through a weak defect, that manifests its superfluid behavior [1].

One would naturally expect that in the subsonic regime the polariton superfluid should not be perturbed by an electric current flowing either in the same quantum well or in the neighboring conducting layer. On the other hand, the coupling is possible for non-condensed polaritons which do not belong to the superfluid. Recently, Berman and co-authors [2] predicted the existence of the mutual drag between the normal fraction of a polariton gas and the electric current. Such drag effect is mediated by the long-range interaction between the excitonic component of polaritons and charge carriers. However, the indications of a drag of a polariton superfluid by an electric current have been reported in the recent experimental work [3] demonstrating that the speed of a superfluid polariton flow is sensitive to the magnitude and the direction of the electric current flowing in the same quantum well.

Here we report the mechanism, which allows an electric current to affect the propagation of a polariton superfluid. The proposed mechanism is based on the stimulated relaxation of moving uncondensed excitons dragged by the electric current. We demonstrate that, as the uncondensed fraction is at rest, the condensate most likely forms in the lowest energy state with zero in-plane wave vector. However, if the uncondensed fraction moves, the stimulated relaxation process favors the formation of a moving condensate in a quantum state that is characterized by the lowest condensation threshold.

In particular, if the exciton reservoir is dragged by the electric current, the wave-vector of the forming condensate will depend on the direction and strength of the current. This effect is phenomenologically equivalent to the drag of a superfluid. However, the predicted phenomenon is not a direct drag effect, strictly speaking. It is mediated by the excitonic reservoir. That is why we shall refer to it as a pseudo-drag effect.

We also show that the electron-mediated inelastic scattering of the reservoir excitons to the condensate leads to the transfer of a non-zero mean momentum to the electron gas thus contributing to the electric current. We predict the generation of circular electric currents in a micropillar cavity in the presence of a nonresonant laser pumping at normal incidence.

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High power, Q-switching maser based on Rydberg excitons in Cu_2O

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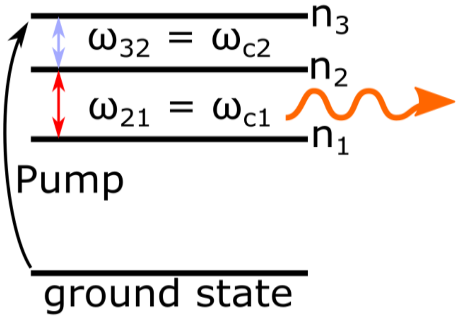
Since many years excitons have played an important role for the optical properties of insulators and semiconductors. As they are composed of an electron and a hole, which are bounded by their Coulomb attraction, they resemble atoms that feature a series of energy levels similar to hydrogen. In 2014 an outstanding experiment realized by Dortmund group [1] has launched the new insight into the field of excitons – it turned out that the yellow series in Cu_2O could be followed up to high principal quantum number n=25. These high-lying excitons in analogy to Rydberg atoms have been called Rydberg excitons. A large spatial extent of RE reaching micrometers, significantly exceeding the wavelength of the wave which has created them, large lifetimes which scale as n^2, the energy spacing of neighbouring states which decreases as n^3 allow for an observation of RE in ranges of external parameters much different from other quantum situations. A small binding energy of RE makes them very sensitive to external electric or magnetic fields, as compared with other systems. Those specific properties od RE in Cu_2O have motivated theoretical and experimental interest in this field.

We aim to investigate the dynamics of such a medium in the situation of population inversion, which leads to possible realization of a solid state maser. Due to the several unique characteristics of this medium, namely exceptionally long lifetimes of excitons and their strong coupling to external field, Cu_2O is a promising candidate for realization of such a device. Recently, a single photon source based on cuprous oxide has been proposed [2]. The wealth of accessible states provides many transitions within milimeter range wavelength while high density of excitons might lead to a significant output power [3]. Recent experimental verification of solid state maser based on diamond [4][5], leads to a renewal of interest in this topic.

One of the common ways of achieving high power pulsed emission in lasers is Q-switching. By dynamically altering Q factor of the cavity, one can delay the stimulated emission until the medium is saturated and maximum allowable population inversion is reached. In the case of maser based on the Rydberg excitons, this can be achieved by simply detuning the masing transition frequency from the cavity frequency. Due to the fact that the excitonic levels exhibit significant Stark shift even for relatively weak electric field, it is possible to create a 3 or 4-level system (Fig. 1a) where the condition of proper match to the cavity frequency occurs due to the microwave field in that cavity, creating a passive, Q-switching system. The result is a highly nonlinear emission characteristic with many high power peaks (Fig. 1b).



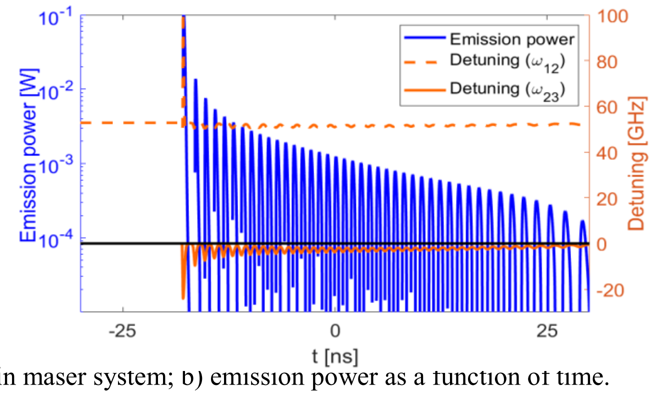


Fig. 1: a) Schematic of Energy levels in maser system; b) emission power as a function of time.

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Magneto-optical properties of excitons in Cu_2O for weak and intermediate magnetic fields

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The behavior of Rydberg Excitons (RE) in external fields (electric and magnetic) has focused more attention just after their detection in a natural crystal of copper oxide (Cu_2O) [1 and 2 for a review of recent works]. Here we present new results concerning the magneto-optical properties of RE. Due to the properties of Cu_2O the critical magnetic field strength, where the magnetic energy equals the Rydberg energy, is quite high (about 600 T). The first studies were devoted to the weak field regime, where the applied field strength was of the order of a few tesla. In the theoretical description the magnetic field is considered as a perturbation [3]. We present experimental results and a theoretical description for the case of the applied field strength up to 150 T. The upper limit corresponds to the intermediate field regime, where the Coulomb interaction and the magnetic field, should be treated on the same footing. Our theoretical approach allows one to calculate spectra for any value of the magnetic field. The results for the field applied in the Faraday configuration are presented. Specifically, in the weak field regime we obtain an excellent fit to the experimental data by of Artyukhin et al. [4]. In the intermediate range, up to B = 150 T, the results of our theoretical calculations show a good agreement with measurements by Kobayashi et al. [5] , see Fig.1.

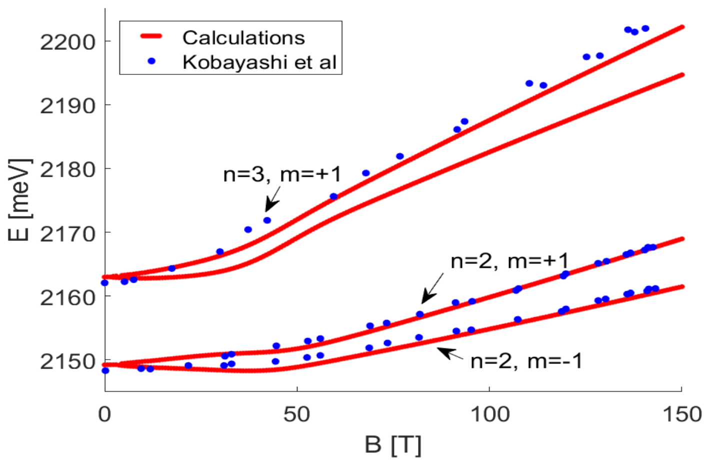

Fig. 1: Comparison of calculated and measured position of excitonic lines.

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Optical cooling of nuclear spins in semiconductor microcavities

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Cooling of different physical systems down to ulralow temperatures often gives an access to new physics or new technological capabilities. Thermodynamics is believed to be universally applicable to many-body systems well isolated from the environment, including, for example, atoms in optical traps; however its validity for specific systems needs experimental verification. Here we explore the possibity of optical cooling of the spin system of lattice nuclei in a semiconductor microcavity, and of real time optical calorimetry directly veryfying the laws of thermal physics at microKelvin temperatures. We show that strains present in such structures do not prevent establishing of the thermal equilibrium in the spin system, which manifests itself in reversible remagnetization across the zero external magnetic field, optically monitored in real time. The heat capacity of the nuclear spin system is shown to be determined by quadrupole interactions, which gives a possibility of its control via strain engineering.

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Optomechanical Kerker effect for trembling nanoparticles and membranes

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The ability to control the direction, frequency, and polarization of the scattered light is essential for operation of antennas, routing of light, and design of topologically protected optical states. For visible light scattered on a particle, the directionality can be provided by the Kerker effect, exploiting the interference of electric and magnetic dipole emission patterns. However, magnetic optical resonances in the particles smaller than the light wavelength in the medium are relativistically weak.

Here, we put forward an optomechanical Kerker effect, where the tunable directional forward or backward inelastic scattering is achieved for a particle lacking magnetic resonances that trembles in space, see panel (a) of the Figure. Our concept is sketched in panel (b). The incident wave excites electric dipole polarization of the particle that oscillates in time. Trembling of the electric dipole in the direction transverse to its polarization induces the loop electric current with non-zero magnetic momentum as well as the electric quadrupole momentum. To describe this multipole conversion, we have developed a novel theoretical framework that incorporates rigorously the effect of the resonant dispersion of the moving medium on the multipolar emission and goes beyond previous approaches restricted to dielectric scatterers with non-resonant permittivity.

We found that the phase difference between electric and magnetic dipoles induced it the trembling particle is governed by the frequency dependence of the particle permittivity. For a particle with resonant permittivity, this enables control of the scattering direction via the detuning of light frequency from resonance. Panel (c) shows by color the forward directivity of the scattered light. The directivity can reach the values up to 5.25 that surpasses the limiting value of 3 for the classical Kerker effect, because the motion-induced electric quadrupole is additionally involved.

Our results apply to a variety of optomechanical systems based on the objects with resonant response, such as quantum dots, membranes of two-dimensional semiconductors, cold atoms, or superconducting qubits. We also put forward an optomechanical spin Hall effect, i.e., directional inelastic scattering of light depending on its circular polarization and discuss the modification of the membrane elastic properties by optical pump.

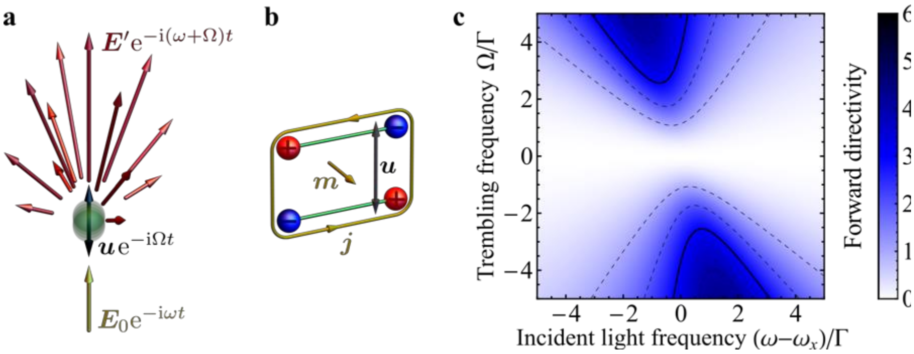

Fig. 1 (a) asymmetric scattering on a trembling particle (b) trembling-induced conversion of electric dipole to the magnetic one (c) directivity calculated depending on the detuning and the tembling frequency.

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Spin networks and supersolid states of cavity polaritons under resonant driving

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Cavity polaritons are composite bosons formed owing to the strong coupling of excitons and cavity photons. They are excited optically and emit light. The lifetimes of polaritons in GaAs-based microcavities lie in the picosecond range, however they form macroscopically coherent (Bose condensate) states under optical driving.

In the case of *resonant* driving, interaction between polaritons results in various collective phenomena, multistability, parametric scattering, etc. Typically, nonequilibrium transitions occur in a threshold manner upon varying external conditions. Apart from a few number of critical points, polaritons were long thought to follow the resonant driving force adiabatically and, for instance, the state of a homogeneous polariton system driven by a constant plane wave was thought to be also constant. However, coupling between spin components has recently been found to result in nonstationary and, in particular, chaotic polariton states whose wave vector is uncertain [1].

Paradoxically, turbulence (chaoticity) goes hand in hand with strong spatial ordering. When the condensate is forbidden to match the symmetry of the external field [2], the system gets rid of strict phase locking and the possibilities open up for both ceaseless variation in a constant environment and the secondary—internal—ordering of the system. In particular, a quasi-one-dimensional (1D) microcavity wire arranges itself into a network of spin-up and spin-down domains alternating each other in a strict order. Furthermore, if a particular spin in such a chain is reversed manually, e.g., by means of an additional properly focused laser beam, under certain conditions all other spins also get reversed with time, no matter how remote they are [3].

Thus, the internally ordered polariton network resembles a crystal rather than a fluid. Similar structures could arise in a periodic potential inducing a lattice of coupled condensates. Today they are often referred to as *supersolid* states [4], implying a non-dissipative ("superfluid") propagation of excitations through such a lattice. We have found that polariton networks also exhibit characteristic "vacancies"—bright or dark solitons—which flow without dissipation and alter their spin states at each node of the network. It is noteworthy, however, that in our case the lattice itself appears out of a perfectly homogeneous Bose gas due to spontaneous symmetry breaking.

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Liquid crystal microcavity as a new building block for the next-generation of spin Hall based devices

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Recently, research on new spintronic and optoelectronic systems has gained great popularity. The devices that would explore the spin state of photons become of special interest as they provide a new degree of possible mechanisms of manipulation of matter by spin-to-orbital momentum conversion of photons.

In this communication we present a novel kind of a tunable microcavity [1] consisting of a nematic liquid crystalline (LC) birefringent optical medium controlled by external voltage enclosed between two distributed Bragg reflectors (DBRs) (Fig.1a). This unique system allows for tunability of TE-TM splitting and shows giant values of this splitting from -15.9 meV to 27.8 meV, an order of magnitude higher to ones reported previously. One of the most interesting phenomena directly dependent on the TE-TM splitting in a cavity is the optical spin Hall effect. We show that thanks to the novel design and the unique possibility to tune the splitting even for zero incidence angle, we are able to observe typical for normal cavities quadrupole spin textures as well as never reported before patterns resembling: dipole, spin doughnuts and whirls (Fig.1b).

Our novel device allows to control the spin state of photon making a new building block for the next-generation of photonic spin Hall devices, and can be easily integrated with light emitters (like various dopants: quantum dots, dyes, thin layers of transition metal dichalcogenides) for room-temperature strong light-matter coupling and lasing.

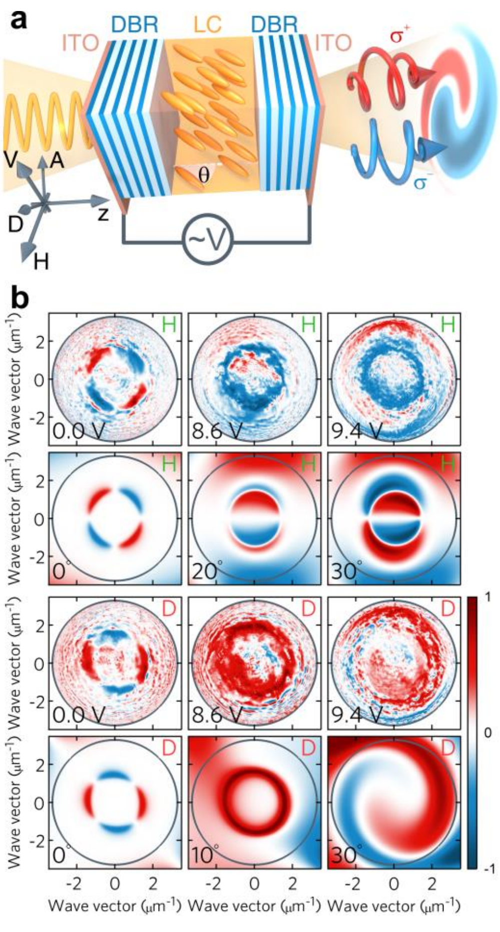

Fig. 1 (a) Scheme of the tunable liquid crystal microcavity. **(b) Degree of circular polarization ρC for liquid crystal microcavity for horizontal (H) and diagonal (D) polarization of incident light.** Experimental results **(first and third panel)** for different voltages applied to the electrodes constituting the outer layers of the structure for H polarization and for D polarization compared with modeled degree of circular polarization **(second and fourth panel)** for different average arrangement of LC molecules angles. Circles mark the areas available experimentally limited by numerical aperture of the objectives.

Acknowledgements

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Electro-optic imaging in the near infrared

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The temporal resolution of electro-optic sampling has recently been improved such that it is now able to directly record the electrical field oscillations of near-infrared[1] and visible light, giving allowing light-matter interaction to be resolved on the sub-cycle scale[2]. This can be extended from a one-dimensional, purely time-domain measurement into a three-dimensional recording of the complete dynamics of the electric field in an image plane. A frame from such an electromagnetic movie is shown in Figure 1.

This allows for imaging of the amplitude and phase of complex light fields in time and space, including those generated by interesting optical systems and even the evolution of the near-field of small objects, with the potential for sub-wavelength spatial resolution without the need for raster scanning.

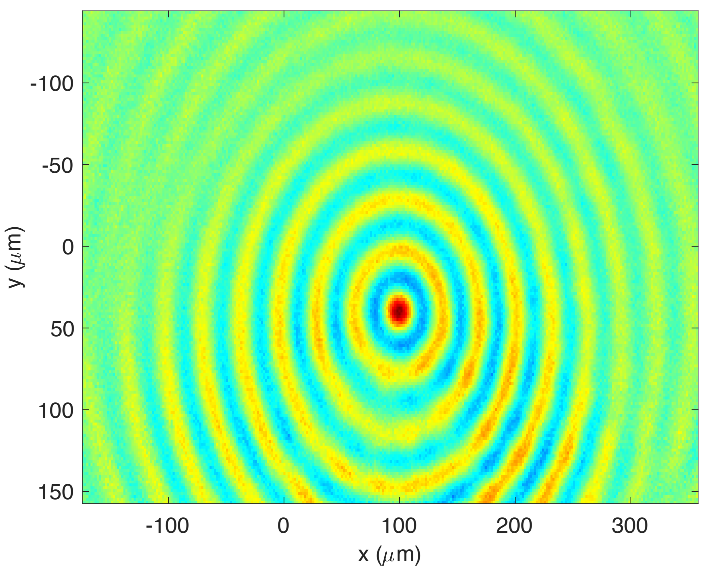

Fig. 1: Captured electromagnetic field distribution of a Bessel beam created by a glass axicon

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Trapping excitons in monolayers and heterostructures of atomically-thin semiconductors

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Quantum light sources in solid-state systems are of major interest as a basic ingredient for integrated quantum photonic technologies. In particular, the ability to site-selectively *create* quantum emitters and *position* them relative to nanophotonic structures (e.g. cavities or waveguides) would be a major step on the road towards integrated technologies. For quantum emitters formed in atomically thin 2D materials, several approaches have been explored to trap excitons including using local-strain, environmental dielectric contrast and the site-selective generation of luminescent point defects. In this talk we will explore each of these approaches and present recent results from our lab. We will begin by exploring the site-selective generation of quantum emitters in hBN encapsulated MoS_2 using **local He-ion irradiation**. Here, upon dosing a ~100x100nm region of the hBN encapsulated MoS_2 with He-ions we observe spectrally narrow emission lines within a narrow energy window ~190±10meV below the neutral 2D exciton. Ab-initio calculations indicate that these emission lines stem from the recombination of highly localized electron-hole complexes at Mo-vacancies created by the He-ion beam. In a second approach, we have explored **trapped dipolar interlayer excitons (IX)** in $MoSe_2$-WSe_2 van-der-Waals heterostructures. Here, we use local strain generated by nanopillars on the substrate surface to localize the IX in a WSe_2-$MoSe_2$-heterobilayer. At the nanopillar sites the IX emission for the lowest excitation levels studied is accompanied by sharp line emission ~50-80meV below the IX. Characteristic exciton, multiexciton like emission emerges and is identified by excitation-power-dependent experiments and our results provide information about exciton-exciton interactions within the strain potential. Finally, we will explore the coupling between localized excitons in TMDs and proximal **nanophotonic plasmonic bowtie antennas**. By performing 3D-FDTD calculations, we tuned the design of the bowtie nanoantennas to match the dipolar resonance with the fundamental exciton transitions in a proximal $MoSe_2$ monolayer. Typical differential reflectance spectra recorded from individual TMD-bowtie nanostructures at room temperature reveal low- and high-energy peaks separated by a dip at the energy of the uncoupled free-exciton. Fitting the spectra as a function of detuning revealed a zero detuning coupling constant of g = 55 meV, in the weak-coupling regime with spectra exhibiting Fano-like behavior. Furthermore, we demonstrate active control of the optical response by varying the polarization of the excitation.

CONTROL OF LIGHT-MATTER INTERACTION IN 2D MATERIALS

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Two-dimensional (2D) van der Waals materials have emerged as a very attractive class of optoelectronic material due to the unprecedented strength in its interaction with light. In this talk I will discuss approaches to enhance and control this interaction by integrating these 2D materials with microcavities, and metamaterials. I will first briefly discuss our previous work on the formation of strongly coupled half-light half-matter quasiparticles (microcavity polaritons) [1] and their spin-optic control [2] in the 2D transition metal dichalcogenide (TMD) systems. Following this I will discuss the formation of polaritons using excited states of excitons (n = 2s) to enhance the nonlinear polariton interaction. Recent results on electrical control [3] and realization of a room temperature polariton LED based on 2D TMDs will also be presented. The possibility to control the valley pseudospin via strong coupling will also be briefly discussed. Finally, I will talk about strain activated room temperature single photon emission from hexagonal boron nitride (hBN) [4] which can be integrated with microresonators on silicon photonic platform.

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Shubnikov-de Haas oscillations in optical conductivity of monolayer $MoSe_2$

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Atomically thin transition metal dichalcogenides (TMD) exhibit a unique combination of extraordinary properties, including valley-contrasting optical response, ultralarge exciton binding energies, and strong exciton-carrier interactions, which make them a promising platform for exploration of condensed matter physics. In parallel, owing to large carrier effective masses, TMD monolayers feature low cyclotron energies, which together with spin-valley locking and finite Berry curvature give rise to a unique structure of spin-valley polarized Landau levels (LLs) that has been recently demonstrated in several transport studies [1-4]. However, to date, the optical signatures of such LLs have been uncovered only for large electron densities [5], where exciton binding is strongly reduced, resulting in the presence of band-to-band inter-LL transitions in the absorption spectrum.

Here we report polarization-resolved resonant reflection of a spin-valley polarized hole system in a charge-tunable $MoSe_2$ monolayer subjected to a strong magnetic field in the opposite limit of low hole densities $p \lesssim 3 \cdot 10^{12}$ cm^{-2}, where the exciton remain tightly bound [6]. We show that the strength of exciton-hole interactions in such a dilute regime is sensitively dependent on the occupation of hole LLs, giving rise to a pronounced, hole-density-dependent Shubnikov-de Haas-like oscillations in the energy and linewidth of the excitonic resonances (see Fig. 1). These oscillations are found to be precisely correlated with LL filling factor, which constitutes a first direct evidence for the influence of integer quantum-Hall states on the excitonic excitations in a TMD monolayer. The interaction-enabled optical access to the quantum-Hall physics that we demonstrate paves the way towards optical investigation of a rich field of strongly correlated phenomena at integer and fractional filling factors in atomically thin semiconductors.

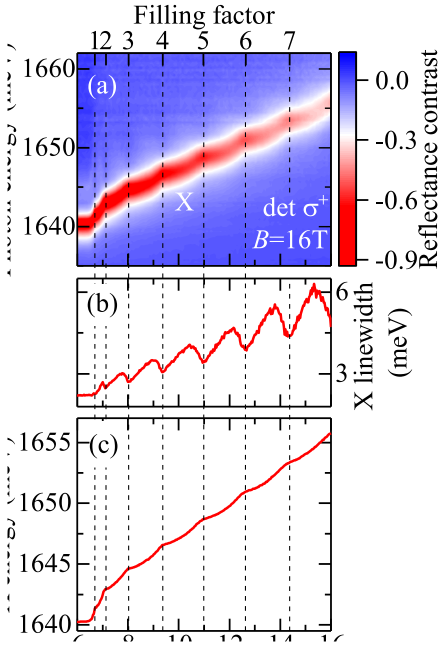

Fig. 1: (a) Reflectance contrast spectra measured at B = 16 T as a function of the gate voltage in σ^+ polarization of detection. (b,c) Gate-voltage dependencies of the linewidth (b) and energy (c) of the exciton resonance, both displaying interaction-induced oscillations that are precisely correlated with LL filling factor.

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Radially polarized light beams from spin-forbidden dark excitons in monolayer WSe_2

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The polarization of light explains many physical phenomena and enables a myriad of optical devices. For a long time, the study of polarization was limited to light with spatially homogeneous states of polarization, such as linear, elliptical and circular polarization. In the last decades, light with spatially variant states of polarization (e.g. radial or azimuthal polarization) has been put in the spot-light of intense experimental and theoretical research. The applications of such light beams include improved focusing, metrology and optical tweezers.

The optical properties of two-dimensional semiconductors hold promise for a new generation of ultra-thin optoelectronic devices and provide unprecedented insight into many-body physics in low-dimensional materials. Especially tungsten-dichalcogenide monolayers, which have a direct but spin-inverted “dark” band gap at the K-points of the Brillouin zone, have been shown to host a variety of exotic excitonic species. While most of these states are optically bright, so-called dark excitons and dark trions, which exclusively couple to light with out-of-plane electric field vector, can be observed only when detecting light in the plane of the monolayer or when using an objective with a high numerical aperture [1].

The two-dimensional geometry of van-der-Waals semiconductors and their atomically well-defined thickness result in a perfect out-of-plane dipole orientation of the dark excitonic states in tungsten-dichalcogenide monolayers which renders these states promising candidates for the on-demand generation of narrow-linewidth radially polarized light.

In our work, we study radially polarized light emitted from dark excitons and dark trions in WSe_2 monolayers. Encapsulation of the monolayers with high refractive index hexagonal boron-nitride is used to shape the dark states’ radiation pattern and achieve emission linewidths near the homogeneous limit. A graphite back gate allows for manipulation of the charge carrier concentration. We employ μ-photoluminescence measurements under normal incidence, as well as spatially and polarization-resolved beam analysis, in order to confirm the polarization distribution in light emitted from these states. While the light emitted through the photoluminescence process is incoherent, we propose strategies to generate coherent radially polarized light beams from dark excitonic states in tungsten-dichalcogenide monolayers.

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MAGNETO-OPTICAL INVESTIGATION OF VALLEY COHERENCE IN MONOLAYER DICHALCOGENIDES

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Monolayer transition metal dichalcogenides (TMDs), such as MoS_2, $MoSe_2$, WS_2 and WSe_2, are novel two dimensional materials with a direct bandgap located at two degenerate valleys (K+ and K-) at the corners of the hexagonal Brillouin zone. The energy bandgap lies in the visible spectral range, which gives rise to efficient light emission and absorption. The optical spectra in monolayer TMDs are dominated by excitonic effects due to strong 2D confinement and electron-hole exchange [1]. Strong spin-orbit interaction and optical selection rules enable the creation of excitons in a specific valley using circularly polarized light. In addition, linearly polarized illumination leads to excitons, whose states are a superposition of those of K+ and K- valleys, which also emit linearly polarized light due to *valley coherence*.

The micro-photoluminescence (PL) spectra of TMDs are dominated by sharp neutral and charged exciton (trion) lines. Recently, we reported the control of the neutral exciton valley coherence in monolayer WS_2 with an out-of-plane magnetic field up to 25 T [2]. The magnetic-field induced valley Zeeman splitting causes a rotation of the exciton linear polarization with respect to the excitation. The effect was found to be due to the rotating polarization in the far-field superposition of the PL. As a result, we extracted a valley decoherence time constant of τ_c=260 fs. Similar effects have been also reported by other groups with a different interpretation, however, in terms of a Hanle effect and attributed to dephasing processes [3,4]. While the control of exciton valley coherence has now been demonstrated, fundamental questions remain about the valley decoherence mechanism.

Our recent linearly polarized-resolved PL experiments on WSe_2 monolayers reveal that up to 25T the neutral exciton linear polarization rotates with respect to the excitation by up to 40° with a reduction of the degree of linear polarization by up to 15%. Thus WSe_2 and WS_2 behave similarly although the precise polarization rotation and depolarization parameters are slightly different. These parameters are the key towards the understanding of the exciton valley coherence. In order to better understand the valley decoherence mechanism, we performed linearly polarized-resolved PL measurements in strained WSe_2 monolayer flakes. We find that the low- and high-energy exciton branch exhibit distinct behaviour of the degree of linear polarization and rotational angle. We attribute these results to complex relaxation channels in-between the bright exciton active levels [5]. Our results elucidate the exciton valley decoherence mechanism, which will lead to a better understanding and control of the exciton valley coherence in 2D dichalcogenides.

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Long-range FRET-mediated exciton diffusion in cesium lead halide perovskite nanostructures

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Colloidal inorganic perovskite nanocrystals (PNCs) are solution-processable functional materials whose emission can be easily tuned via both size and composition.[1] Their exciting optical properties such as the large absorption cross-section and high photoluminescence quantum yield (PLQY) make them ideal candidates for a broad range of photonics and optoelectronics applications.[2] In this work, we present an overview of the exceptionally efficient exciton transport mediated by Förster Resonant Energy Transfer (FRET) in perovskite systems of increasing dimensionality. With a specifically designated optical setup, we directly measure the spatial extent of exciton hopping in a controlled two-dimensional assembly of 0D PNCs, which provides a flat energy landscape with minimal geometric disorder.[3] Steady-state and time-resolved PL microscopy, together with physical modeling of exciton transport, shows an exciton diffusion length of 200 nm and diffusivity as high as 0.5 cm^2/s, which greatly exceed the values reported for FRET-mediated exciton diffusion in chalcogen-based quantum dot solids, and, importantly, matches the optical absorption depth. We further explore the exciton diffusion paradigm in 1D perovskite nanowires and 2D nanosheets, where we image the diffusion across the whole system, with diffusion lengths larger than 1µm. In addition to the exciton diffusion mapping, a significant portion of this work has been dedicated to the optimization of the substrate and the sample passivation. Specifically, we show that with a thermal-based atomic layer deposition process we are able to apply a ~3nm-thick transparent ceramic coating (aluminum oxide) which ensure optical stability over a four month period, thus overcoming the instability issue which often hinders the actual integration of perovskite materials in optoelectronics devices. Our investigation therefore provides the foundation for employing FRET-mediated exciton diffusion in nanostructured perovskites, while also demonstrating practical guidelines to use these bright emitters in optoelectronic devices beyond proof of principle.

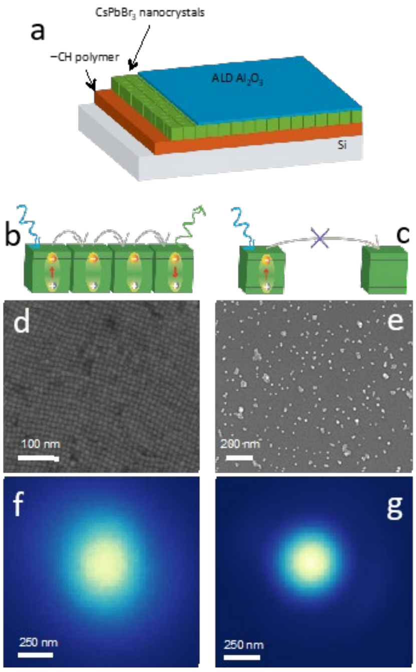

Fig. 1: (a) Schematics of the sample architecture. (b) Efficient and (c) inhibited FRET-mediated exciton diffusion depending on the PNCs distance. SEM micrograph of (d) a close-packed and (e) a sparse monolayer of PNCs. PL intensity profiles emitted by the (f) close-packed and (g) sparse PNCs monolayer, excited at 2.75 eV with a diffraction-limited laser spot.

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Dynamical theory for controlled optical nonlinearities of monolayers of transition metal dichalcogenides

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Semiconducting monolayers of transitionmetaldichalcogenides (TMDCs) promise to revolutionize semiconductor devices used in computer and communication technology. To address these monolayers one can utilize laser light, which induces a strong optical response. To tailor the optical activity of the monolayer, the semiconductor can be embedded into a nano-photonic structure or combined with plasmonic nanoparticles.

We here present a new, versatile method to simulate the electronic and optical properties of TMDCs in such complex structures. Our method self-consistently combines a microscopic description of the carrier and polarization dynamics of a TMDC monolayer with a spatiotemporal full-wave time-domain simulation of Maxwell's equations on the basis of a finite-difference time-domain (FDTD) method beyond the slowly varying amplitude or paraxial approximations [1,2]. Excitonic effects are taken on board by calculating the Coulomb interaction dynamically on the Hartree-Fock level. To describe the second harmonic generation we further introduce a permanent dipole. With this, we calculate the linear and nonlinear optical response of a TMDC monolayer embedded in a nano-cavity formed in the middle between two Bragg mirrors. This allows us to dynamically calculate the spectral shape of the exceptionally strong second-harmonic generation around the exciton lines of TMDC monolayers as shown in Fig. 1. We further show how the second harmonic can be greatly enhanced by the photonic structure [2].

Due to its self-consistency, flexibility, explicit spatio-temporal resolution on the nanoscale and the ready access to light field and electron dynamics, our theory and computational approach is an ideal platform to design and explore spatiotemporal nonlinear and quantum dynamics in complex photonic or plasmonic micro- and nanostructures for optoelectronic, nanophotonic and quantum applications of TMDC monolayers. With this, our simulation method complements the fast-paced experimental development of devices with 2D materials.

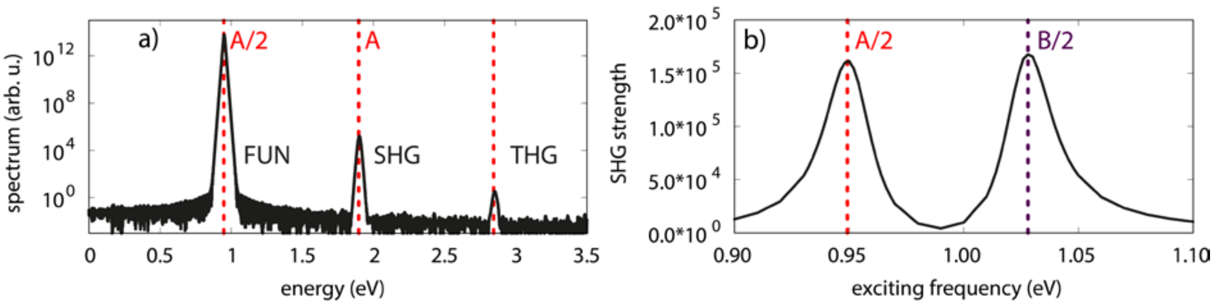

Fig. 1: a) Calculated absorption spectrum of a freestanding MoS_2 monolayer showing pronounced second (SHG) and third (THG) harmonic generation of the incoming laser (FUN).
b) Strength of the signals of the second harmonic (SHG) as function of the exciting laser frequency exhibiting pronounced resonances as half the exciton peaks.

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Effects of Defects on Band Structure and Excitons in WS_2 Revealed by Nanoscale Photoemission Spectroscopy

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Interest in transition metal dichalcogenides (TMDs) has been renewed by the discovery of emergent properties when reduced to single, two-dimensional (2D) layers. Due to electronic confinement and reduced electrostatic screening in two dimensions, the electronic and optical properties of 2D materials are generally more susceptible to strain, surface modifications or structural defects than those of their bulk counterparts. This large tunability of 2D materials provides an effective way to create novel functional properties via defect engineering beyond the conventional concept of doping, such as embedded quantum emitters for nanophotonic applications.

Here, we correlate band structure, chemical state, and optical properties of 2D transition metal dichalcogenides at the nanoscale. In particular, we employ spatially resolved angle resolved photoemission spectroscopy (nano-ARPES) to map variations in band alignment and chemical composition of monolayer WS_2 with an unprecedented spatial resolution down to 150 nm. [1] By correlating the spectroscopic information from nano-ARPES with hyperspectral photoluminescence data, we reveal the interplay between local material properties, such as defect density or chemical composition, and the formation of charged trions, defect-bound excitons and neutral excitons.

Finally, we compare these results to combined atomic force and scanning tunneling microscopy, where we can unambiguously identify the occurring point defects and their electronic structure at the atomic level. [2,3] Surprisingly, we find that in as-grown WS_2 (chemical vapor deposition) sulfur vacancies are initially completely absent, and oxygen atoms at sulfur sites are the dominant defect instead. While the sulfur vacancies exhibit electronic states in the gap, the oxygen substitutions almost recover the band structure of pristine WS_2. Our findings will aid towards understanding defect-related phenomena, such as the – still unknown – nature of single photon emitters in these 2D materials.

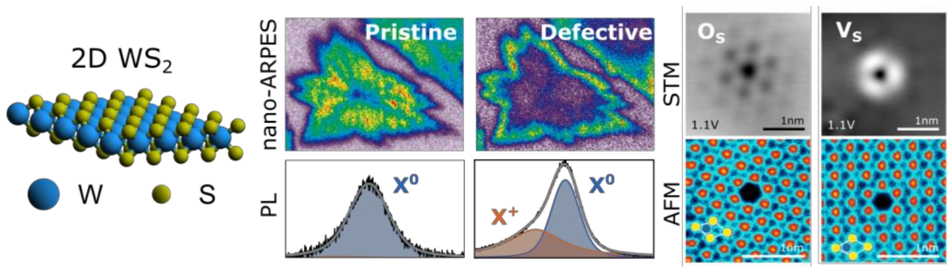

Fig. 1: Nano-ARPES reveals nanoscale variations in the band structure of two dimensional WS_2, which are correlated to the local excitonic properties. High resolution scanning probe microscopy identifies the underlying structure and electronic properties of point defects.

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Moving from momentum-indirect to interlayer excitons in van der Waals heterobilayers based on transition metal dichalcogenide alloys

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Van der Waals heterobilayers (HBs) of vertically stacked atomically thin transition metal dichalcogenides (TMDs) are an exciting platform to develop novel ultra-flexible devices with widely tuneable optoelectronic properties, leading to brand-new materials with unexpected emerging properties.[1] One of the most striking feature is the appearance of indirect excitons (IX), formed by electrons and holes which can be either spatially located in the adjacent materials (interlayer excitons, Fig.1a) or confined in two different valleys of the momentum space (momentum-indirect excitons, Fig.1b). The formers possess long radiative lifetimes and an electric dipole oriented perpendicularly to the plane of the TMDs, which results in enhanced non-linear exciton-exciton interactions.[2] Understanding how to manipulate IX in TMD heterobilayers is crucially important to obtain extreme phenomena such as Bose-Einstein condensation of excitons and polaritons.

In our work, we adopt TMD alloys to continuously tune the heterobilayer properties through modifications of the bandgap, band offset and spin-orbit splitting, by stacking monolayers of WSe_2 and $Mo_xW_{(1-x)}Se_2$ alloys. The IX photoluminescence peak energy at T<10K can be tuned up to 200 meV, spanning through the whole range of alloys composition, with minor variations in the direct exciton energy of the alloy monolayer (Fig.1c). Decreasing the Mo content in the alloy, the indirect excitons energies do not follow a simple linear trend expected in case of pure spatial confinement (pictured in Fig.1a), but they rather bend towards the momentum-indirect transition energy of the WSe_2 homobilayer. A decrease in the band offsets between the two materials changes the nature of IXs from space- to momentum-indirect (Fig.1b), due to the charge carriers tunnelling between the layers and to a strong modification of the band-structure of the entire device. This is confirmed by a significant decrease of the IX lifetimes, by a reduced blue-shift of the IX peak increasing the excitation power or by the appearance of hybridized transitions. This work represents a breakthrough in the design and fabrication of nanoscale devices by adopting TMD alloys, allowing fine and continuous tuning of their electronic band-structure, also shedding light on the nature of the exciton transitions occurring in van der Waals TMD bilayers.

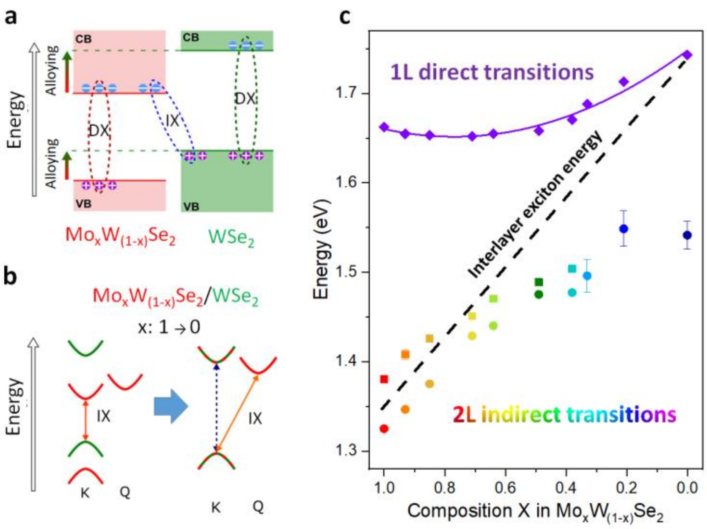

Fig. 1: a) Simple picture of interlayer excitons in the alloys HBs in real space. b) Transition from spatially indirect to momentum-indirect excitons in the HBs pictured in the momentum space. c) Exciton transitions peak energies as a function of the Mo composition x in the alloy. The purple dots and line refers to the alloys monolayers. The rainbow dots are the IX peak energies measured in the HBs, showing two main IX transitions up to x=0.38 and then broadening in multiple peaks depicted by the error bars.

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Momentum alignment of photoexcited carriers in low-dimensional Dirac materials

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Devices made from conventional semiconducting materials manipulate electron flow based on their charge or spin (spintronics), the later offers the promise to revolutionize the way we do computing. In graphene and graphene-like materials, there is an alternative electron property which can be harnessed for device applications: the so-called valley degree of freedom, which could be utilized in an analogous manner to spin in spintronics and has been suggested as a basis for carrying information in graphene-based devices. The ability to control the valley degree of freedom practically is still an outstanding problem. We have proposed a new method of control, using linearly polarized light, to open the door to optovalleytronics.

One of graphene's most widely known optical properties is its universal absorption, defined through the fine-structure constant, which holds true across a broad range of frequencies from the sub-infrared into the visible. A lesser known feature is that linearly polarized light creates a strongly anisotropic distribution of photoexcited carriers with their momenta predominantly aligned normally to the polarization plane. We show how this momentum alignment effect together with graphene's spectrum anisotropy (trigonal warping) at high energies can be utilized for the spatial separation of carriers belonging to different valleys in graphene and gapped graphene-like materials. The optical control of valley polarization in gapped 2D Dirac materials such as phosphorene and single-layer transition metal dichalcogenides can also be achieved via a well-known effect of using circularly polarized light. In gapped materials, the optical selection rules associated with linearly polarized light of near-band-gap energies are valley-independent, in stark contrast to the valley-dependent optical selection rules associated with circularly polarized light. This valley dependence of the circularly-polarized transitions can be utilized to measure the degree of valley polarization induced by linearly polarized light of high (well above the band gap) energies, by analyzing the degree of circularly polarization of the band-edge luminescence at different sides of the light spot.

The momentum alignment phenomenon also explains the hitherto overlooked effect of the giant enhancement of the band gap edge interband optical transition rate in narrow gap carbon nanotubes and graphene nanoribbons which occurs in the terahertz range, thus opening a route for creating novel terahertz radiation emitters.

Theoretical and Experimental Observation of Anisotropic 2D Excitons in Self-Assembled Hybrid Quantum Wells

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Abstract

Self-assembled metal organic materials have great potential for optoelectronic applications due to their atomic and structural tunability. While a vast library of these materials has been studied, understanding optoelectronic properties to drive synthesis has been nearly impossible due to their complex structure. Here we consider the self-assembled layered bulk silver benzeneselenolate, $[AgSePh]_\infty$, as a representative of a class of coordination polymers exhibiting quantum well characteristics. Using state-of-the-art ab initio density functional theory (DFT) and GW and Bethe-Salpeter equation (BSE) approach calculations, we predict and experimentally confirm two-dimensional (2D)-like excitonic and optoelectronic properties in the bulk phase arising from the quantum-confined charge carriers, including large exciton binding energies (~380 meV) and anisotropic absorption and emission. Our study demonstrates how integrating theory and experiment can elucidate general features in hybrid chalcogenide materials scalable *via* supramolecular chemistry with strong excitonic effects in the presence of anisotropic screening and strong confinement.

Many-body optical excitations in solid-state systems

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Two dimensional materials provide new avenues for synthesizing compound quantum systems. Monolayers with vastly different electric, magnetic or optical properties can be combined in van der Waals heterostructures which ensure the emergence of new functionalities; arguably, the most spectacular example to date is the observation of strong correlations and low electron density superconductivity in Moire superlattices obtained by stacking two monolayers with a finite twist angle. Optically active monolayers such as molybdenum diselenide provide a different "twist" as they allow for investigation of nonequilibrium dynamics in van der Waals heterostructures by means of femtosecond pump-probe measurements. Moreover, interactions between electrons and the elementary optical excitations such as excitons or polaritons, provide an ideal platform for investigation of quantum impurity physics, with possibilities to probe both Fermi- and Bose-polaron physics as well as mixtures with tunable density of degenerate fermions and bosons.

After introducing the framework we use to describe many-body optical excitations in van der Waals heterostructures, I will describe two recent developments in the field. The first experiment uses pump-probe measurements to demonstrate how exciton-electron interactions beyond the non-self-consistent T-matrix approximation lead to optical gain by stimulated cooling of exciton-polaron-polaritons. The second experiment shows that a tri-layer system, consisting of two semiconducting monolayers separated by an insulating layer, could lead to hybridization of intra- and inter-layer excitons. The latter has potential applications ranging from strongly interacting polaritons to reaching Feshbach resonance condition in exciton-electron scattering.

Optomechanics in active and chiral systems

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The coupling between electromagnetic fields and mechanical motion has recently produced intriguing fundamental physics, such as the observation of mesoscopic optomechanical phenomena in objects operating in the quantum regime. It is also yielding innovative device applications, for instance in the manipulation of the optical response of photonic elements. These concepts usually involve passive systems in which only the spatial and/or momentum degrees of freedom of the electromagnetic field are affected. Here we will instead discuss two innovative concepts: the first based on active devices, the second considering the polarization degrees of freedom. In the former case, a mechanical element becomes part of a laser cavity, affecting its emission and transport through a self-mixing interference effect. Results are shown both for near-IR laser diodes [1] and THz quantum cascade lasers, discussing non-linear regimes in which optical chaos can be imprinted in the mechanical motion. In the latter case the combinations of a chiral metasurface with a GaAs suspended micromembrane (see Fig. 1) opens new scenarios where the mechanical motion affects the polarization state of a light beam, and vice-versa [2]. Optical characterization of the fabricated samples reveals that the interaction is mediated via moving-boundary and thermoelastic effects, triggered by intracavity photons. This work represents a first example of "Polarization Optomechanics", which could give access to new form of polarization nonlinearities and control, possibly down to the single photon-single phonon quantum level. It could also lead to applications in fast polarimetric devices, polarization modulators and dynamically tunable chiral state generators and detectors.

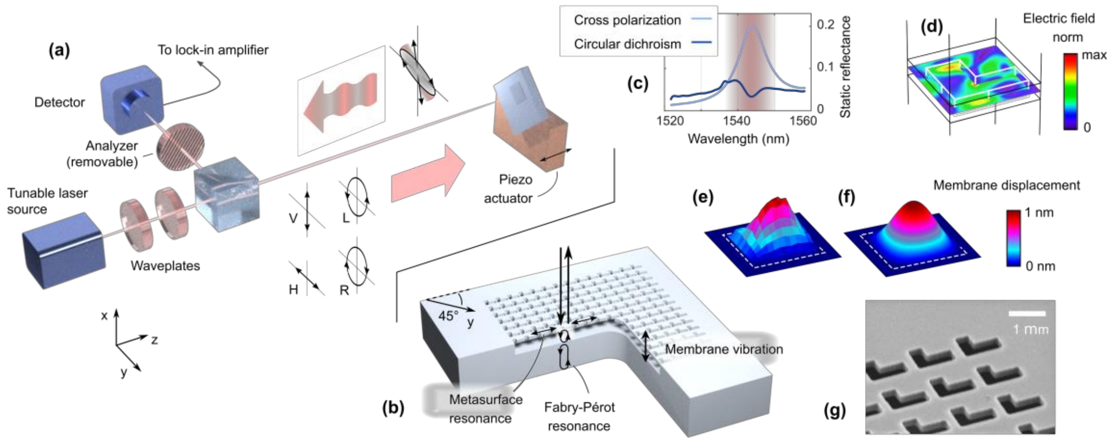

Fig. 1: Optomechanics of a chiral metasurface. (a) Sketch of the setup employed. The device is represented in panel (b): a semiconductor (GaAs) membrane is patterned with L-shaped holes. Chiro-optical effects occur in the wavelength range relevant for telecommunications (c). The field profile of the mode responsible for such effects is plotted in (d). Panels (e) and (f) illustrate the membrane displacement occurring when the fundamental mode is excited, respectively, in an experiment and in a finite-element model. Panel (g) is a scanning electron micrograph of the metasurface.

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Room-temperature strong light-matter coupling and polariton condensation in perovskite materials

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Strong light-matter coupling have been reported in a wide range of organic and inorganic semiconductors, while the demonstrations of the polariton condensation and the subsequent polariton lasing are still limited within a handful of semiconductors at both low and room temperatures. In inorganic materials, polariton condensation significantly relies on sophisticated epitaxial growth, while organic active media usually suffer from large threshold density and weak nonlinearity due to the Frenkel exciton nature. In this respect, strong efforts have been done in hybrid organic-inorganic perovskite materials, as they combine the advantages of both inorganic and organic materials. However, up to now, only the room-temperature strong coupling regime was observed in such materials. The all-inorganic perovskite and more precisely the cesium lead halide perovskites are part of a new class of materials that are currently drawing attention to the photonics community.

In this talk, I will first present our results on synthesis of high quality hybrid perovskite materials and their optical properties, then I will present polariton condensation and polariton lasing at room temperature in $CsPbCl_3$ nanoplatelets embedded in a planar microcavity. These effects are unambiguously evidenced in the blue region of the visible spectrum by superlinear power dependence, macroscopic ground state occupation, blueshift of the ground state emission, narrowing of the linewidth and the build-up of long-range spatial coherence. Finally, I will present our latest results on room-temperature strong light-matter coupling in $CsPbBr_3$ nanowires embedded in a planar microcavity, where a polariton emission characterized by the typical polariton dispersion in laterally confined nanostructures is clearly evidenced in the green region of the visible spectrum. Such successful realization of room-temperature strong light-matter effects at different wavelengths and in different perovskite crystals geometries advocates the considerable promise of perovskite materials for polaritonics applications.

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Cellular automata and quantum neural networks based on exciton-polariton lattices

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Exciton-polaritons are hybrid states of light and matter existing in semiconductor heterostructures. They have been typically studied in planar microcavities containing quantum wells, exhibiting spin-sensitive phenomena such as the optical spin Hall effect and nonlinear effects such as solitons and bistability. More recently, there has been a growing interest in studying exciton-polaritons in patterned lattices, where the interplay of spin-orbit interaction with magnetic field was shown to give rise to topological physics [1]. Furthermore, as we will show, nonlinear interactions in such systems demonstrate complex phenomena, realizing cellular automata [2] and artificial neural networks [3].

Recently, experimental evidence has shown the appearance of quantum correlated polaritons [4,5]. We show that in the quantum regime, exciton-polariton lattices can behave as quantum neural networks and are capable of performing quantum (non-classical) tasks [6].

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Subcycle control of spins and photons by nanoresonator near-fields

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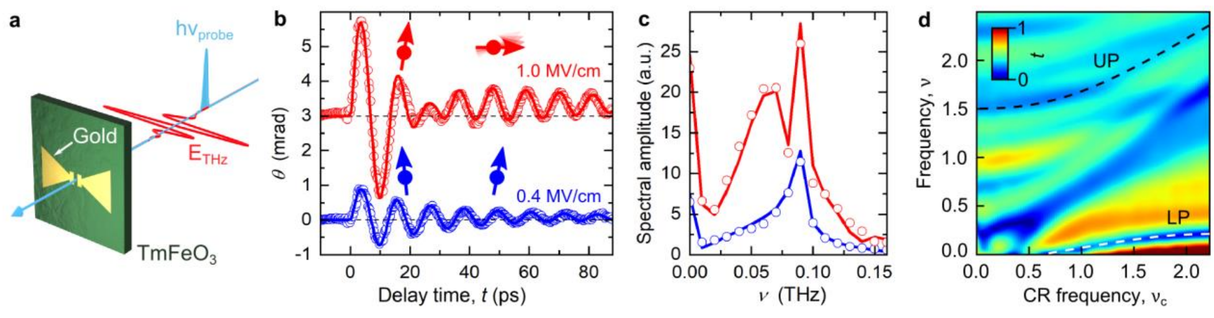
Metallic THz nanoresonators offer precise control over light-matter interaction as their near-fields can be structured and enhanced on sub-wavelength length scales with great flexibility. Here, we exploit custom-cut THz resonators to control non-perturbative dynamics of spins and photons on subcycle time scales.

Strong, resonant THz pulses with photon energies in the meV range have enabled coherent control of spins [1] in solids while introducing only minimal excess energy. Yet, the low efficiency of the Zeeman interaction has limited the attainable spin deflections to a few degrees. Coupling crystal-field split electronic transitions with the magnetic anisotropy field has allowed THz electric fields to drive large-amplitude magnons [2]. Here, custom-cut gold nanoantennas processed on antiferromagnetic $TmFeO_3$ crystals (Fig. 1a) generate THz near-fields in excess of 20 MV/cm, inducing extremely strong spin dynamics (Fig. 1b). A characteristic phase flip, an asymmetric spectral splitting of the magnon resonance (Fig. 1c), and a long-lived offset represent novel fingerprints of all-coherent spin switching, as supported by our numerical simulation [3]. The low dissipation of only a single THz photon per spin and the sub-wavelength spatial definition may facilitate scalable, THz-rate spin devices.

Moreover, THz nano-resonators have explored novel limits of cavity quantum electrodynamics. In the ultrastrong coupling regime, the vacuum Rabi frequency Ω_R becomes comparable to the carrier frequency of light, ω_c, giving rise to quantum phenomena related to anti-resonant light-matter interaction. Most spectacularly, for $\Omega_R/\omega_c \rightarrow 1$, the ground state is theorized to host a virtual photon population, predicted to be released in analogy to Unruh-Hawking radiation of black holes, by modulating Ω_R. Here, we present a parameter-free design approach for extreme coupling strengths $\Omega_R/\omega_c \gtrsim 1$, which treats the electronic and the photonic components as an entity. Specifically, pushing the limits of semiconductor heterostructure growth, we couple THz resonators to the cyclotron resonance (CR) of two-dimensional electron gases of highly n-doped GaAs quantum wells. Using the CR as a mirror-like structure to strongly confine the vacuum mode, we demonstrate coupling strengths of up to $\Omega_R/\omega_c = 1.43$, corresponding to a ground state population of 0.37 virtual photons. Our most advanced structures comprise of a switch which can be photoactivated by near-infrared femtosecond pulses to fully modulate Ω_R.



Antenna-enhanced subcycle dynamics of spins and photons. a, Schematic of $TmFeO_3$ crystal and antenna, THz pulse (red curve) and Faraday probe (blue shade). **b,** Transient Faraday rotation for THz peak far fields of 0.4 and 1.0 MV/cm (circles), and calculation (solid curves), and **c** corresponding Fourier transform. **d,** Transmission spectra of ultrastrongly light-matter coupled structure. ν_c, CR resonance frequency; LP, lower polariton; UP, upper polariton.

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Cavity-mediated bound excitons

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Intersubband transitions in doped quantum wells (QW) do not present bound excitons. In those systems the Coulomb interaction between electron and hole is repulsive and it only leads to a depolarization blue-shift of the single-electron transitions [1].

We have demonstrated that, when the QWs are embedded in a photonic cavity, the exchange of virtual cavity photons can bind electron and hole together, leading to the creation of an intersubband bound exciton [2].

The theory is based on an exact bosonic treatment of the interacting electron gas, and it predicts that above a certain coupling threshold a novel discrete resonance appears below the ionisation edge. In our case, the ionisation edge corresponds to the onset of the *continuum* above the QW barriers. This resonance describes a polaritonic excitation: part-photon and part-bound exciton.

Using a sample consisting of 13 GaAs/AlGaAs n^+-doped semiconductor QWs embedded in a metal / active region / metal grating cavity, we were then able to experimentally observe such a discrete resonance. We thus provided a first demonstration of the existence of a bound state of two charged particles kept together not by Coulomb interaction but by the exchange of virtual cavity photons.

On one hand, our work shows how strong light–matter coupling can be used as a novel gauge to tune both optical and electronic properties of semiconductor heterostructures beyond those permitted by mere crystal properties, with direct applications on mid-IR technology.

On the other hand, the possibility to use cavity photons as mediators of an attractive electromagnetic interaction between charged particles has been recently investigated also in other systems [3], and highlighted as a possible route to increase the critical temperature of superconductors.

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Broadband operation and RF control of THz QCL frequency combs

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Recently, on-chip quantum-cascade-laser-based frequency combs [1] are gaining increasing attention both in the Mid-IR [2] and in the THz [3, 4] spectral regions. THz devices offer the possibility of filling the gap of comb sources in a spectral region were no table-top comb is available. I will discuss direct THz comb generation from both homogeneous and heterogeneous quantum cascade lasers. Octave spanning emission spectra and comb operation on bandwidth larger than 1 THz are reported for heterogeneous cascades [5]. I will also report on a series of new structures with homogeneous cascade design that feature a very low threshold current density (< 100 A/cm^2), a bandwidth of roughly 1 THz in comb operation (Fig.1(a,b)) centered around 3 THz and an extremely wide bandwidth (>1.65 THz) when driven in CW in the NDR region . This extremely broadband emission in the NDR (Fig.1(c,d)) is studied as well with NEGF simulation and is based on an interplay between strong photon assisted transport due to the highly diagonal transition and domain formation. These structures are also showing RF injection [6] locking with extremely reduced microwave powers (see Fig.1(f)). I will discuss as well a method to finely control the repetition rate of the laser based on a piezo-actuated external cavity (Fig.1e).

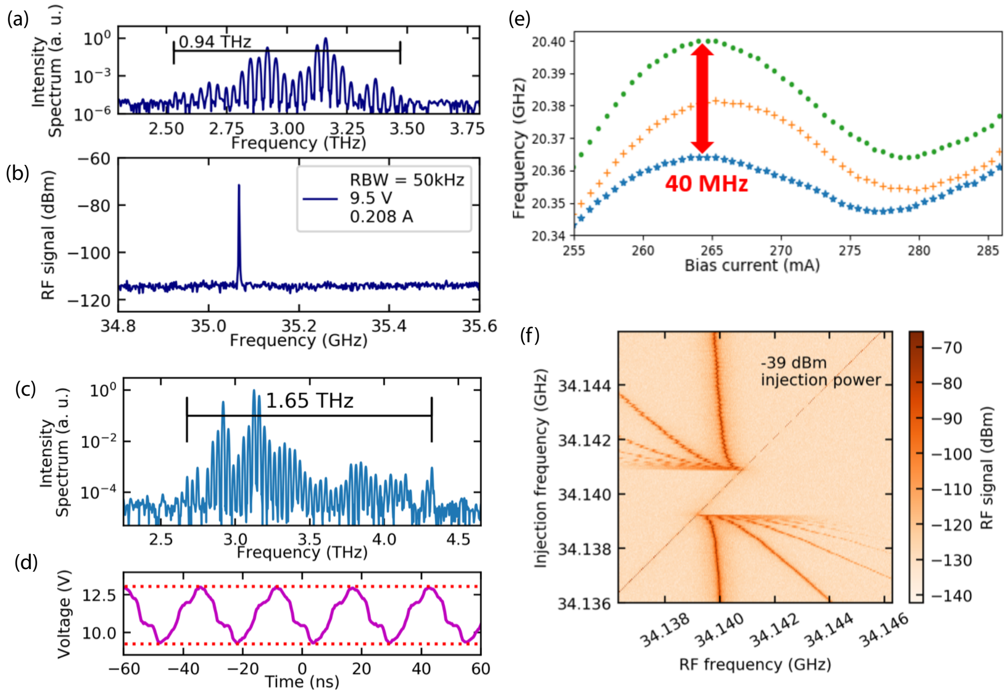

Fig. 1: a) CW spectrum before NDR and b) corresponding beatnote. c) CW emission in the NDR region and voltage oscillations d). e) Beatnote tuning for 3 different positions of the external cavity. f) injection locking for a 1 mm cavity.

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n-type Ge/SiGe Multi Quantum-Wells for a THz Quantum Cascade Laser

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Theoretical predictions indicate that the n-type Ge/SiGe multi quantum-well system is the most promising material for the realization of a Si-compatible THz quantum cascade laser (QCL) operating at room temperature [1, 2]. With the view to realizing a Ge/SiGe QCL, we present the optical and structural properties of n-type strain-symmetrized Ge/SiGe asymmetric coupled quantum wells (ACQWs) grown on Si(001) substrates by means of ultrahigh vacuum chemical vapor deposition [3]. Extensive structural characterization obtained by scanning transmission electron microscopy (STEM), atomic probe tomography (APT) and X-ray diffraction shows the high material quality of strain-symmetrized structures (up to 5-micron active region thickness) and heterointerfaces (featuring interface roughness below 0.2 nm), down to the ultrathin barrier limit (about 1 nm). By performing THz absorption spectroscopy measurements combined to theoretical modeling on different ACQWs (varying well width or barrier thickness), we unambiguously demonstrated control over inter-well coupling and electron tunneling [3]. Motivated by the promising results obtained on ACQWs, which are the basic building block of a cascade structure, we investigate electroluminescence on a Ge/SiGe THz QCL design, optimized through a non-equilibrium Green's function formalism [4]. Simulations show that, due to the non-polar nature of SiGe alloys, the maximum gain of a Ge/SiGe QCL is much more robust against the temperature increase with respect to III-V based devices. Moreover, the interface roughness values measured on our samples are predicted to allow the possibility to achieve gain overcoming the losses of double-metal waveguides at room temperature. The results obtained represent a key step towards the realization of a Si-based QCL.

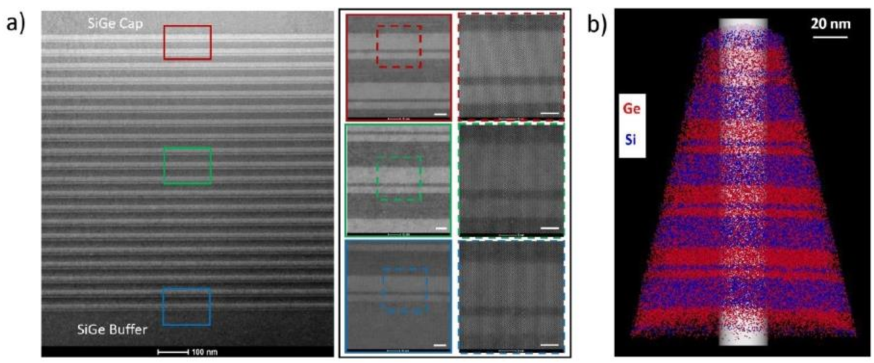

Fig. 1: a) Z-contrast STEM micrographs and b) APT 3D atom-by-atom reconstruction of an ACQWs sample.

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Ultra-Small Mode Volume Three-Dimensional THz LC Circuits for Intersubband Polaritons

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Metamaterials, consisting in the periodic repetition of artificially designed meta-atoms with dimensions much smaller than the wavelength of interest λ_0, are often described as high frequency inductor-capacitor (LC) resonators sustaining a resonance at $\lambda_0=(LC)^{1/2}$. Their peculiar ability to efficiently confine the electromagnetic field on a subwavelength scale is at the heart of their macroscopic behavior, opening new prospects for optoelectronic devices [1]. The LC circuit concentrates the electric field in an extremely small effective volume V_{eff} linked to its capacitive parts. Light-matter interaction occurring in the coupling between an absorber/emitter and the electric field inside the circuit capacitors scales as $1/V_{eff}^{1/2}$, and can thus be strongly enhanced.

Here, we demonstrate a novel, three-dimensional architecture realizing a LC resonator which embeds a semiconductor material in its capacitive elements. This architecture makes use of a newly developed processing technique that permits to define metallic patterns on both sides of the semiconductor layer. The resulting meta-atom, shown if Fig. 1 (a), has a highly subwavelength dimension ($\lambda_0/20$) and confines the electric field in a nanoscale volume $V_{eff}=10^{-7}\lambda_0^3$. The optical properties of our resonator are studied by inserting a two-dimensional electron gas inside the capacitive elements, which sustain an intersubband plasmon at a frequency ω=3.3 THz. The spectroscopic features of the ultra-strong coupling, between the LC mode and the intersubband plasmon, allow us to assert that the electric field in our resonators is totally confined between the capacitor plates [2]. This ultra-compact, three-dimensional architecture allows us to report a relative Rabi frequency of $2\Omega_R/\omega=0.27$ (Fig. 1 (b)) with few thousands electrons only, which represents a record low number for intersubband systems. In the quasi-static limit, there is no fundamental limitation for the effective volume, which can be made arbitrarily small and thus paves the way towards the exploration of the ultra-strong coupling between light and few electrons [3].

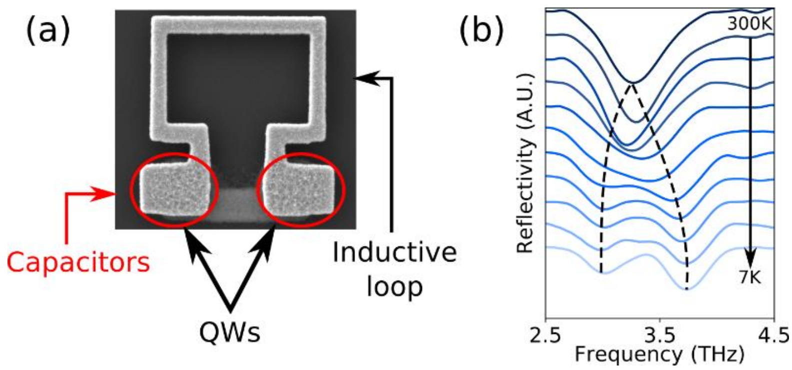

Fig. 1: (a) Electron microscope image of the 3D LC resonator, showing the top metallic part. 5 GaAs QWs are inserted inside the capacitors. The lower metal plate is formed by the two capacitor pads connected by a straight wire. (b) Reflectivity of the metamaterial as a function of temperature, showing a clear polaritonic splitting.

Acknowledgements

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Nonlinear Optics with Exciton-Polaritons in High Velocity Waveguides

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Exciton-polaritons are the hybrid quasi-particles formed by strong coupling of semiconductor excitons and photons. Their excitonic component provides giant optical nonlinearity at least 3 orders of magnitude larger than in weakly coupled semiconductors [1,5], opening up a wide range of technological and scientific applications.

Many such applications have been demonstrated in a Fabry-Perot microcavity geometry [2]. Recently, waveguides have emerged as a complementary platform for applications in polaritonics [3,4]. Compared to microcavites, the polaritons propagate with high wavenumber and are confined by total internal reflection rather than by distributed Bragg reflectors (DBRs). Tighter spatial confinement of the optical field in the vicinity of the quantum wells provides stronger photon-exciton coupling [3] while the high wavenumber naturally leads to an order of magnitude higher group velocity [1]. The spatial coordinate in the propagation direction becomes interchangeable with time so that, for example, the evolution of a continuous-wave beam along the waveguide is analogous to the temporal evolution of a 1-dimensional condensate [5]. The excitons may easily be pumped with a laser since there is no DBR blocking the pump wavelength, which allows simple amplification of propagating pulses [6]. Finally, the simple structure makes growth and fabrication devices much easier.

In this talk I will discuss polariton propagation in waveguides [1,5], especially our recent experimental studies of nonlinear effects such as spatio-temporal optical continuum generation [7], pulse amplification [6] and the route towards nonlinear pulse modulation in Gallium Nitride polariton waveguides [4] which can operate at higher temperatures than in Gallium Arsenide owing to the higher exciton binding energy.

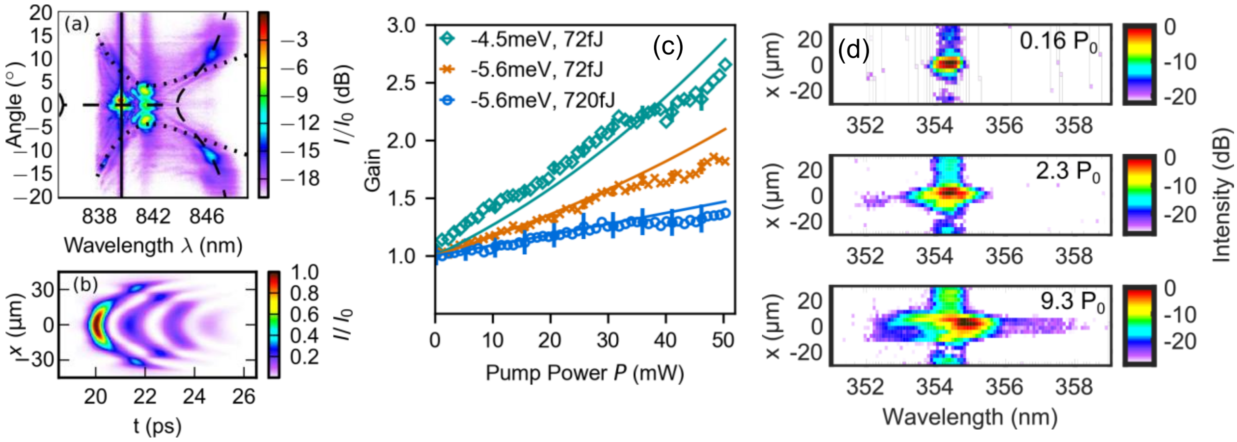

Fig. 1: (a) Spectrum of spatio-temporal optical continuum and (b) simulation of a pulse train, both generated from picosecond pulses in a Gallium-Arsenide based polariton waveguide [7]. (c) Amplification of propagating polariton pulses by an exciton reservoir generated by resonantly pumping the exciton [6]. (d) Spatio-temporal spectral broadening in a Gallium-Nitride quantum-well based waveguide at 200 Kelvin (power increases from top to bottom).

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Hydrodynamics of vortices, breathing dark solitons and Ising domain walls in a polariton condensate

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Topological excitations–such as vortices and dark solitons–have been predicted and experimentally observed in different platforms, spanning from atomic to polariton condensates.[1,2] However, the lifetime and/or the motion of these topological excitations has been always limited by experimental constraints (i.e. phase fixing when using a resonant pump, and polaritons lifetime in the case of transient excitation).

In this study, we have investigated the possibility of generating collective excitations in a polariton fluid when working within the bistable regime. We have observed the spontaneous generation of topological excitations in the wake of a structural defect along the polariton flow. Their propagation is sustained for macroscopic distances by engineering both the spatial density distribution and the in-plane velocity of resonantly-pumped polaritons. Two types of collective excitations are generated depending on the fluid Mach number: on one hand the proliferation of vortices and, on the other hand, dark solitons pairs obtained while increasing the fluid velocity. Furthermore, the bound state of two dark solitons is robust to perturbations (i.e. it does not collapse into vortices due to snake instabilities as in previous works) and it shows two different dynamics: breathing solitons and the formation of two parallel Ising domain walls (Figure a and b).

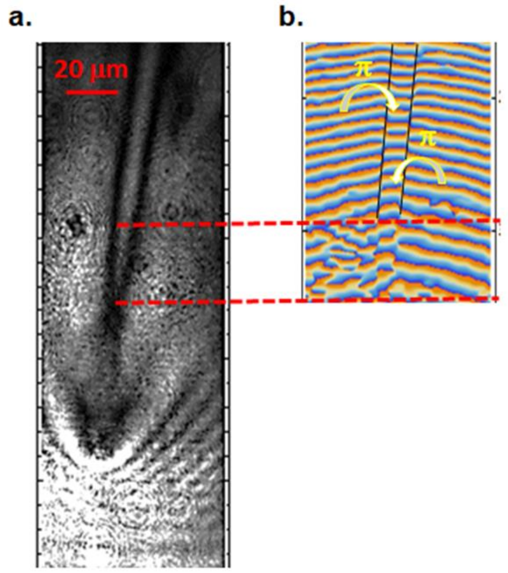

Figure a. Space density distribution and dark soliton generation in the wake of a structural defect. **Figure b.** Phase map showing the formation of Ising walls.

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Polariton condensates in ZnO waveguides: towards integrated polaritonics

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A polariton laser is based on the condensation of polaritons which are quasi-particles resulting from the coupling between a light mode and an excitonic resonance. The laser does not require electron-hole gain and therefore exhibits a very low threshold. The concept was initially developed for semiconductor-based vertical microcavities. However, this approach requires high cavity quality factors (typically 10^3-10^5), which are very difficult to achieve in the case of large-bandgap semiconductors such as GaN and ZnO [1,2]. Meanwhile, these materials provide a promising platform for room-temperature polaritonic devices due to large oscillator strength and exciton stability. In this context, a new geometry for polaritonics based on guided photonic modes strongly coupled to excitonic resonances is an interesting alternative [3,4]. The geometry is very appealing because of its simple technological realization, easy electrical injection, and because it opens the possibility for integrated polaritonic circuits with very limited radiative losses.

Recently, we have reported for the first time polariton lasing based on guided modes from 5 to 300K, using ZnO-based waveguides [5]. Most important, we could also demonstrate amplification of a guided polariton condensate under optical pumping [5]. This initial demonstration was done in planar waveguides.

In the present work we will present new results for the case of rib waveguides, which provide not only vertical but also horizontal confinement, making one step further towards integrated polaritonics. The sample was grown by molecular beam epitaxy on *m*-plane bulk ZnO substrates. The rib waveguides were defined by using optical lithography and reactive ion etching. A sketch of the sample is shown in Fig. 1(a). The depth of the etching is about 30 nm, while the width varies between 0.65µm and 9.5µm, covering various configurations from transversal mono-mode up to highly multi-mode waveguides. An important aspect of the sample is the presence of regular horizontal cracks, perpendicular to the *c*-axis and typically separated by 5-40 µm. The later constitute horizontal cavities for guided modes (see Fig 1(b) and 1(c)) and enable in-plane polariton lasing [6]. In this talk we will discuss the influence of the lateral confinement and the cavity length on polariton lasing under optical pumping.

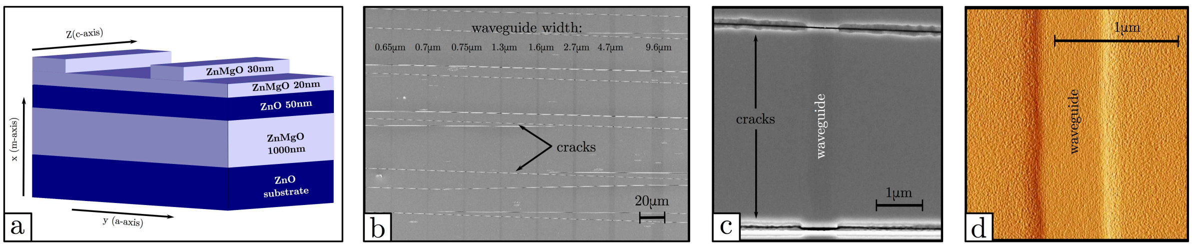

Fig. 1: (a) sketch of the sample. (b), (c) SEM images of rib waveguides. (d) AFM image of a ZnO rib waveguide.

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Imprinting solitons on a polariton superfluid

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Exciton-polaritons are quasi-particules created by a strong coupling between photons and excitons. In planar microcavities, phenomena such as superfluidity [1] or Bose-Einstein condensation [2] can be observed. Those systems have demonstrated to be very efficient in the hydrodynamical generation of topological excitations, such as vortex-antivortex pairs or dark solitons [3, 4]. However, the lifetime and motion of those excitations were limited by the driven dissipative nature of the system.

Inspired by a recent theoretical paper [5], we managed to implement a large and bistable polariton superfluid, in which topological excitations are spontaneously generated in the wake of structural defects. Depending on the hydrodynamic regime of the system, vortices or solitons pairs are observed and sustained for macroscopic distances.

In order to reproduce and control those excitations, we now directly imprint the solitons on the fluid using a Spatial Light Modulator. By tuning the phase profile of the excitation, we can play with the shape of the solitons and study their interactions and behaviour to reach an equilibrium point. The experimental results are in good agreement with the theoretical predictions.

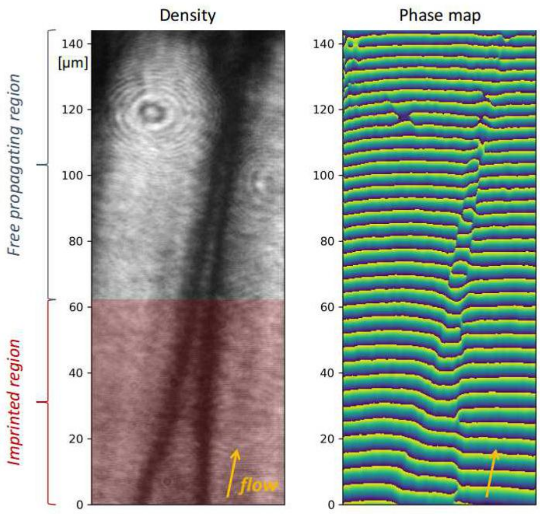

Fig. 1: Imprinting and propagation of a solitons pair on a polariton superfluid. Left, the density image with the solitons imprinted on the lower part and freely propagating on the upper part. Right, the extracting phase map, showing a phase jump of π corresponding to each soliton.

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Neuromorphic computing in Ginzburg-Landau polariton lattice systems

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The availability of large amounts of data and the necessity to process it efficiently have led to rapid development of machine learning techniques. To name a few examples, artificial neural network architectures are commonly used for financial forecasting, speech and image recognition, robotics, medicine, and even research. However, efficient hardware implementation is still lacking, since the most developed computing technologies available have been designed for the von Neumann architecture. Reservoir computing (RC) is a recent and increasingly popular bio-inspired computing scheme which holds promise for an efficient temporal information processing [1]. We demonstrate the applicability and performance of reservoir computing in a general complex Ginzburg-Landau lattice model, which adequately describes dynamics of a wide class of systems, including coherent photonic devices. In particular, we propose that the concept can be readily applied in exciton-polariton lattices, which are characterized by unprecedented photonic nonlinearity, opening the way to signal processing at rates of the order of 1 Tbit s^{-1} [2].

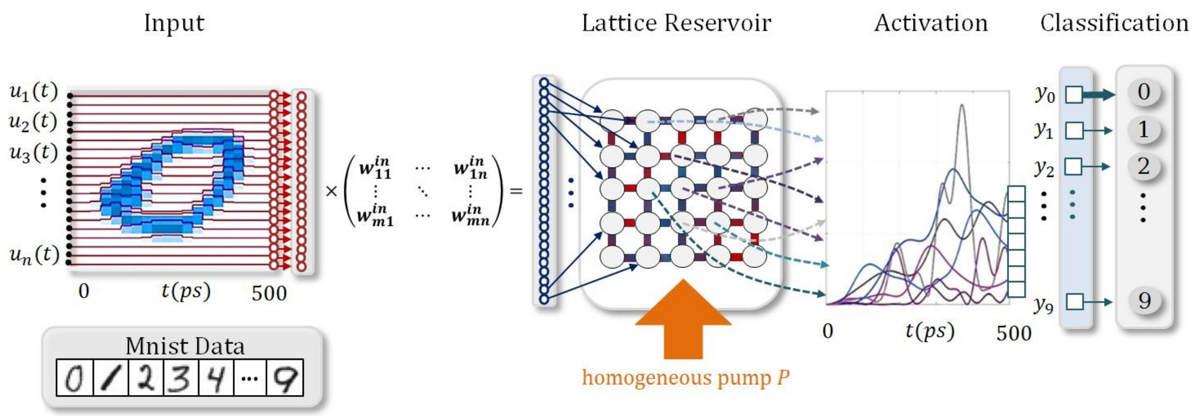

Fig. 1: Scheme for a handwritten digit classification task. Data is convoluted with random weights and imprinted on the lattice by driving each of the lattice sites. At the same time, the system is pumped to maintain a dynamic state close to the stability (or lasing) threshold. The resulting density in each node (activations) is recorded at the end of the sequence and used for classification of the input.

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Engineering vacuum fields with metamaterials

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Keywords: Superconducting, photonic, quantum material

When a collection of electronic excitations are strongly coupled to a single mode cavity, mixed light-matter excitations called polaritons are created. The situation is especially interesting when the strength of the light-matter coupling Ω_R is such that the coupling energy becomes close to the one of the bare matter resonance ω_0. For this value of parameters, the system enters the so-called ultra-strong coupling regime, in which a number of very interesting physical effects were predicted. Using metamaterial coupled to two-dimensional electron gases[1], we have demonstrated that a ratio Ω_R/ω_0 close to[2] or above unity can be reached.

We also demonstrated that such ultra-strong light-matter coupling can be achieved using special geometries where the only less than 100 electrons are effectively coupled to the resonator[3]. Other metamaterial engineering include the inter-meta-atom coupling using a surface plasmon polariton resonance[4]. This feature enables to restore the dispersion to the metamaterial ensemble and to control the linewidth of the latter. One very intriguing feature of the ultra-strong light-matter coupled system is the prediction that photon pairs will be emitted through non-adiabatic modulation of the coupling. To this end, we have realized metamaterials based on high Tc superconductors that retain a high quality factor resonance for magnetic field up to 9T and coupled them to two-dimensional electron gases[5]. Because the resonator is designed to be switchable using the superconducting transition, experiment can now be conducted using very intense terahertz fields.

We have also used transport to probe the ultra-strong light-matter coupling[6]. In these experiments, we have used transport samples engineered with cavities and studied them under very weak THz irradiation and now irradiation at all, showing an influence of the cavity in both cases.

We have constructed a electro-optic based setup[7] that, we demonstrated recently, enables the probing of the vacuum field in free space and retrieve its first order correlation function in both space and time. Such experiment can be used also to probe the unconventional ground state of the ultra-strongly coupled systems[8].

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Plasmon-Exciton Coupling: Light-forbidden Transitions and Quasichiral Interactions

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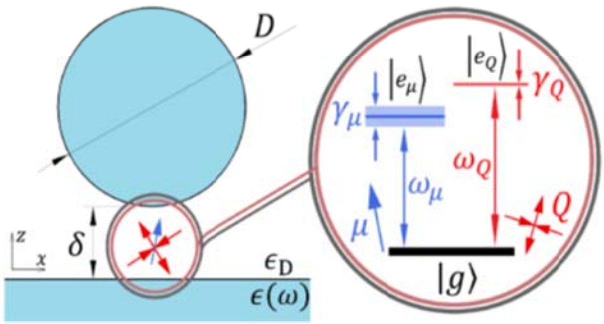
In this talk, we will present two plasmon-exciton-polariton phenomena emerging due to the deeply sub-wavelength nature of surface plasmon (SP) resonances in nanocavities [1]. First, we will investigate the impact that light-forbidden exciton transitions [2] have in the population dynamics and far-field scattering spectrum of hybrid systems comprising nanoparticle-on-a-mirror SPs and three-level quantum emitters (QEs). We will show that the presence of quadrupolar transitions in the QE leads to a strong modification of the usual Purcell enhancement and Rabi splitting phenomenology for dipolar excitons. Second, we will present a combined classical and quantum electrodynamics description of the interactions between two circularly-polarized QEs held above a SP waveguide [3]. We will establish the conditions required to achieve non-reciprocal, chiral, coupling between them. Moreover, by relaxing the stringent requirements for chirality, we will reveal a quasichiral regime, in which the quantum optical properties of the system are governed by its subradiant state, giving rise to extremely sharp spectral features and strong photon correlations.



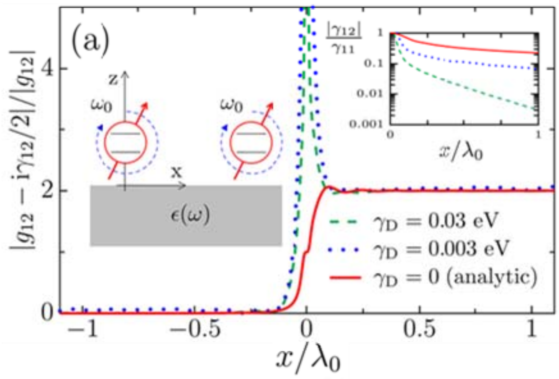


Fig. 1: (a) A three-level QE is placed at the gap of a metallic NPoM cavity. (b) Effective coupling between two circularly-polarized QEs above a metal surface (left inset) versus their relative position.

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Impact of electron spill-out on Rabi splitting in plasmonic systems

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Plasmonic structures are ideal candidates for field enhancement and confinement to extremely small volumes and, thus, offering an excellent environment to support enhanced light-matter interactions [1,2]. Rabi splitting is the manifestation of strong coupling between electromagnetic field such as light and matter, such as metallic particles. At sub-nanometer length-scale, nonlocal and quantum tunneling effects are expected to influence the interaction between quantum emitters and surface plasmons, which unavoidably require to go beyond classical models. Quantum hydrodynamic theory (QHT) has emerged as an efficient tool to probe nonlocal and quantum effects in closely spaced metallic nanostructures [3]. We apply state-of-the-art QHT [4,5] to investigate the quantum effects on strong coupling of a point-dipole emitter placed a fraction of a nanometer away from metallic particles. In order to understand the effects of the quantum hydrodynamic model on the plasmon-emitter coupling, we compare our results with the conventional local response approximation and Thomas-Fermi hydrodynamic theory.

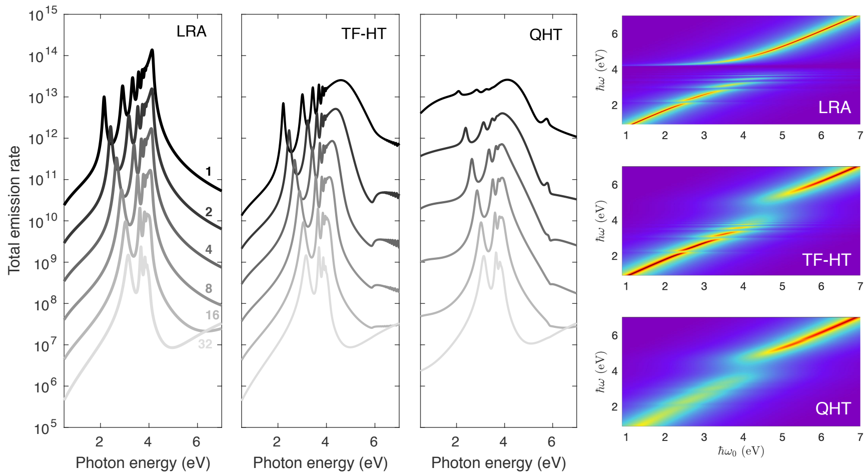

Fig. 1 On the left, decay rates of a dipole between a 40 nm Na sphere dimer for different gap sizes (from 1 to 32 nm). On the right, dipole spectra for the same structure as a function of the emitter frequency ω_0. The results are computed within the local response approximation (LRA), Thomas-Fermi hydrodynamic theory (TF-HT) and quantum hydrodynamic theory (QHT).

Our results show that the impact of nonlocal and quantum effects on the fluorescence properties in configurations where metals are separated by gaps of a few nanometers might be drastic (see Fig. 1). Depending on the specific material properties of the plasmonic system, QHT may show a decrease in the threshold oscillator strength required to observe Rabi splitting with respect to models in which the spill-out is neglected [6].

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Sign-alternating photoconductivity and magnetoresistance oscillations (MIRO) induced by terahertz radiation in HgTe quantum wells

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We report on the observation of an anomalous sign-alternating photoconductivity induced by THz radiation in HgTe quantum wells (QWs) [1]. As illustrated in Fig. 1(a), the increase of the magnetic field B applied perpendicularly to the QW plane results in a double (single) change of the photoconductivity sign in Corbino disc (Hall bar) samples before the conventional Shubnikov-de Haas oscillations set in at higher B. This surprising behaviour is observed in structures with both normal and inverted band ordering, as well as in QWs with critical thickness and linear dispersion. We demonstrate that the sign-alternating photoconductivity is consistently described within a model accounting for electron heating by radiation. Within this mechanism, the first sign inversion, B_{inv}, in Corbino samples takes place at $B = 1/\mu$, providing a direct optoelectronic method to measure the carrier mobility μ, while the inversion at B^*_{inv} (common in both geometries) originates from a different temperature dependence of the transport scattering rate at magnetic fields below and above the inversion point. Such temperature behaviour is consistent with dark transport measurements, but the effect is much more pronounced in the photoresponse, where it qualitatively modifies the magnetic field dependence. We thus demonstrate that photoconductivity can be a very sensitive probe of the temperature variations of the transport characteristics, even those that are hardly visible using conventional methods. Besides the anomalous photoconductivity, we observed THz/microwave induced resistance oscillations (MIRO), which previously have not been observed in HgTe QWs, see Fig. 1(b). It is remarkable that the THz-induced oscillations could be clearly detected in a material with mobility as low as 3×10^5 cm^2/Vs.

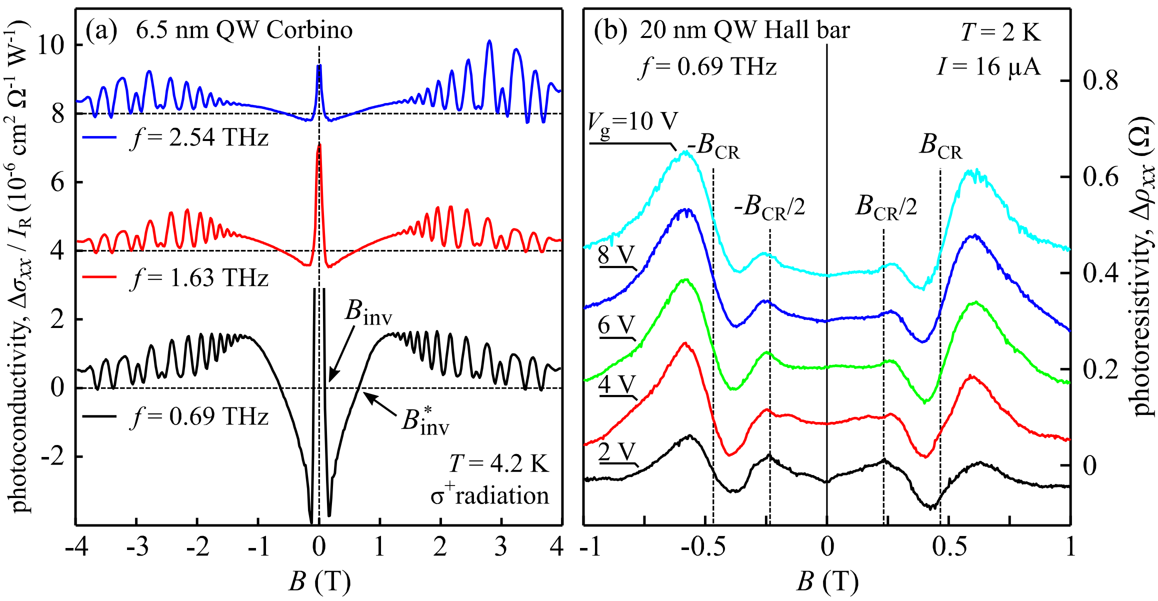

Fig. 1: (a) Magnetic field dependence of the photoconductivity normalized to the incident radiation intensity $\Delta\sigma_{xx}/I_{\text{R}}$ measured in Corbino samples fabricated from a HgTe QW with critical thickness (6.5 nm) described by a linear energy dispersion. B_{inv} and B^*_{inv} indicate the positions of the inversion points. (b) Magnetic field dependence of the photoresistivity measured in a 20 nm HgTe QW illuminated with linearly polarized THz radiation. Vertical dashed lines indicate the position of cyclotron resonance $B_{\text{CR}} = 0.47$ T and its second harmonic $B_{\text{CR}}/2$.

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Terahertz ratchet effects in graphene and semiconductor nanostructures with a lateral superlattice

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The paper overviews experimental and theoretical studies of terahertz radiation induced ratchet effects in graphene and semiconductor nanostructures with a lateral superlattice. First, ee present symmetry arguments allowing a phenomenological analysis of the respective phenomena, then outline the microscopic theory and finally discuss the main experimental findings. We show that an efficient way to generate a dc electric current caused by ratchet effect implies symmetry reduction of the initial material, e. g. semiconductor quantum wells or graphene, accomplished by deposition of a periodic asymmetric lateral metal structure on the top of the two-dimensional structure. We show that the ratchet photocurrent induced in such samples is caused by the combined action of a spatially periodic in-plane potential and the spatially modulated radiation due to near field effects of light diffraction [1,2].

The modulated potential necessary to generate ratchet photocurrent is obtained by fabricating either a sequence of metal stripes on top of 2D structure or inter-digitated comb-like dual-grating-gate structures (DGG), for graphene structures see left panel of Fig. 1. The photocurrent amplitude and direction can be controlled by applying different voltages to the two gratings, as well as by different structure asymmetry, carrier type and density. A typical behavior of the ratchet photocurrents in graphene upon variation of the back gate potential is shown in the right panel of Fig. 1. The data reveal that the ratchet photocurrent reflects the degree of asymmetry induced by different top gate potentials and in fact vanishes for a symmetric profile. Moreover, in graphene the ratchet photocurrent is strongly enhanced in close to the Dirac point. We show that the ratchet photocurrent includes the Seebeck thermo-ratchet effect as well as the effects of ”linear" and ”circular" ratchets, which are sensitive to the corresponding polarization of the driving electromagnetic force. The experimental data are analyzed for both, the electronic and plasmonic ratchets taking into account the calculated potential profile and the near field acting on carriers in two-dimensional electron gas. In the presence of an external magnetic field a dc electric current excited by terahertz laser radiation shows $1/B$-oscillations with amplitudes much larger as compared to the photocurrent at zero magnetic field. These magneto-oscillations result from the Landau quantization and, for (Cd,Mn)Te at low temperatures, from the exchange enhanced Zeeman splitting in diluted magnetic heterostructures. The theoretical analysis, considering the ratchet and magnetic quantum ratchet effects in the framework of a semiclassical approach, describes well the experimental results.

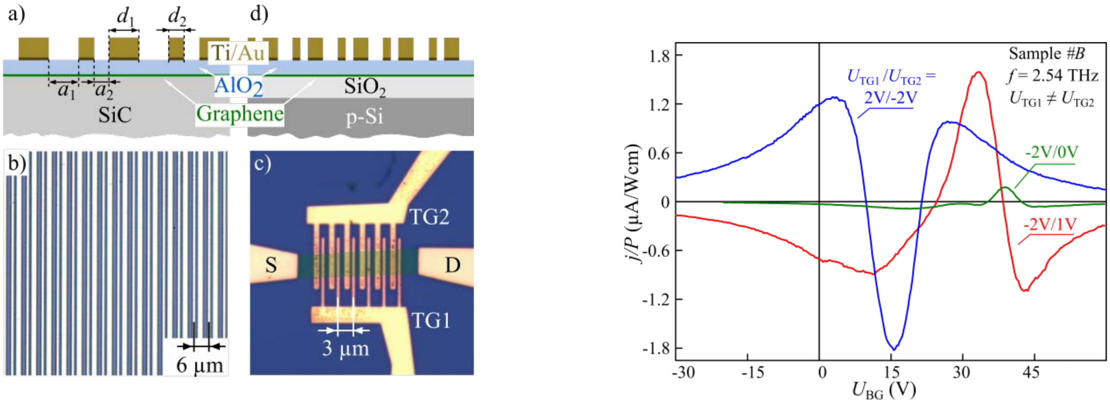

Fig. 1. Left panel: (a), (d) Cross section of the structure. Here, $d_{1,2}$ and $a_{1,2}$ are the width of metal stripes and the spacing in-between, respectively. (b) Sketch of metal finger structure deposited on epitaxial graphene. (c) DGG structure deposited on the exfoliated graphene flake. Right panel: Back gate voltage dependence of the photocurrent normalized on the radiation intensity measured for three sets of unequal potentials at the top gates.

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Tailoring on-demand dispersion with symmetry breaking: from flatband to Dirac cones and multivalley dispersions

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Engineering the energy-momentum dispersion of photonic structures is at the heart of photonic research. In contemporary optics, two types of dispersions have been extensively studied: flatband dispersion and Dirac dispersion. The first one gives rise to localized stationary eigenstates which are extremely sensitive to disorder effects due to an infinite effective mass, thus suggests a new regime of light localization. Being an opposite extreme to flat dispersion, Dirac dispersion corresponds to massless photonic states and enables many exotic physical features such as Klein tunneling, zero-refractive index materials and photonic topological insulator. Other than flatband and Dirac dispersions, most recently, it is also suggested that photonic multi-valley dispersion can provide squeezed light, as well as Josephson oscillation in momentum space.

In this presentation, we show that symmetry breaking can open a new degree of freedom to tailor energy-momentum dispersion in photonic crystal. This enables an on-demand tuning of the local density of states of the same photonic band from zero to infinity, as well as any constant density over an adjustable spectral range. As a proof-of-concept, we demonstrate experimentally the transformation of the very same photonic band from conventional quadratic shape to a Dirac dispersion, a flatband dispersion and a multivalley one (see Fig.1) by finely tuning the vertical symmetry breaking of the photonic structures [1]. This opens up a new way to control the direction of emitted photons, and to enhance the spontaneous emission into desired modes [2]. As application, making use of multivalley dispersion, we demonstrate for the first time a single-mode microlaser emitting at high oblique angle (i.e. 20 degrees) (see Fig.2) [3]. Our results provide an unprecedented degree of freedom for optical dispersion engineering in planar integrated photonic devices.

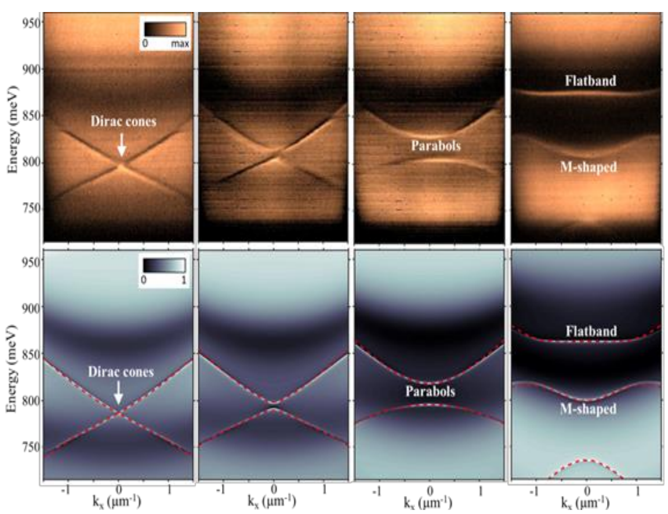

Figure 1: Angular resolved Reflectivity measurements (Upper Panel) and Numerical/Analytical calculations (Lower Panel) of the "comb" grating dispersion for different vertical symmetry breaking. The sample consists of passive "comb" grating of which the vertical symmetry breaking is finely tuned via the filling factor of the design.

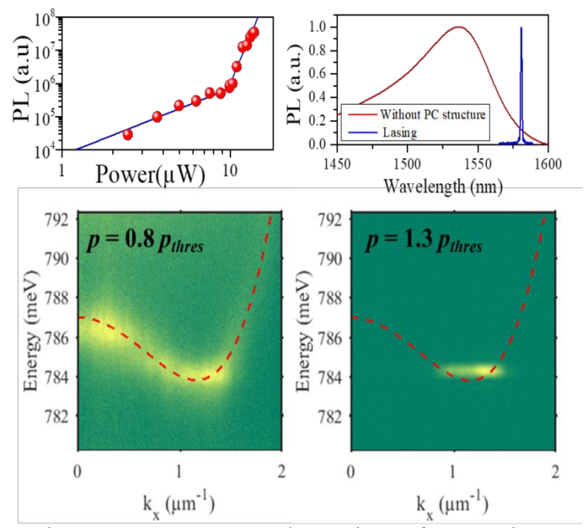

Figure 2: Upper panel: Lasing of an active "comb" grating with W-shaped dispersion. Lower panel: angular resolved photoluminescence measurements below and above threshold. The red-dashed line corresponds the analytical calculation of the photonic dispersion.

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A semi-classic description of Epsilon-Near-Zero resonances in Metal/Insulator nano-cavities

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Renewed interest in the resonant properties of Metal/Insulator nano-structures arose due to their exotic photonic and plasmonic response together with straightforward fabrication and flexibility. [1–4] These structures have been recently used to enhance the photophysical performances (photoluminescence, decay lifetime and quantum yield) of weakly coupled fluorophores via Surface Plasmon Enhanced Absorption (SPEA) and Surface Plasmon Coupled Emission (SPCE), as shown in Figure 1. [5] Here, we demonstrate in a semi-classic framework that such an enhancement is provided by the *epsilon-near-zero* (ENZ) response of suitably dimensioned Metal/Insulator nano-cavities occurring at their resonant frequencies. We demonstrate that the excitation of these ENZ modes in metal/insulator/metal (MIM) nano-cavities occurs via *resonant tunneling* of photons, lifting the need of momentum matching. Our semi-classic approach allows retrieving simple analytical relations for the design of the resonances of these cavities, bringing under the quantum domain systems that are usually though prerogative of the classic electromagnetism. We illustrate theoretically and experimentally the possibility of using our structures as narrowband *superabsorbers* and *refractive-index sensors,* opening to the possibility of engineering complete ENZ bands in the visible range and to the investigation of the strong interaction with fluorophores potentially embedded within the cavity.

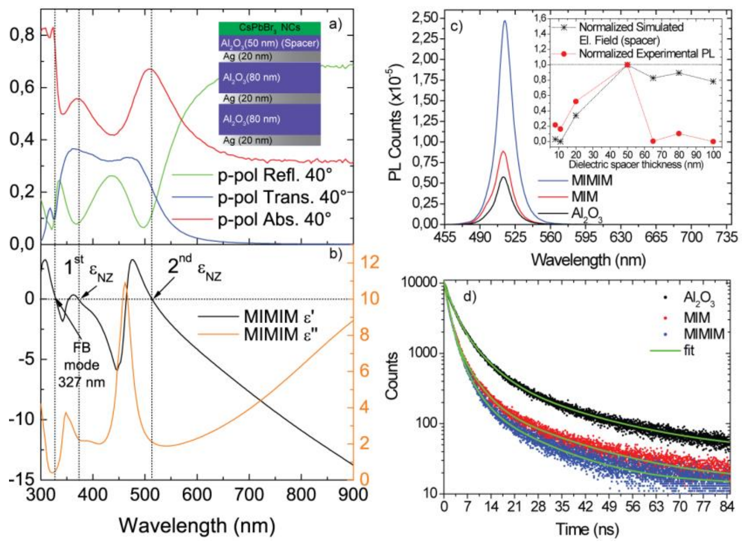

Figure 1: (a) Transmittance (blue), Reflectance (green) and Absorbance (red) of the MIMIM Double-ENZ systems. (b) Ellipsometrically measured real (black) and imaginary (orange) parts of the dielectric permittivity of the MIMIM Double-ENZ structures. (c) Spontaneous emission and (d) decay times of $CsPbBr_3$ nanocubes deposited on a bare Al_2O_3 substrate (black dots), a MIM (Single-ENZ, red dots) and a MIMIM (Double-ENZ, blue dots) structures.

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THz detectors based on optomechanical metamaterials

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The THz spectral domain offers a wide range of applications, from medicine to astronomy, security and imaging. In this context, the quest for a compact, fast and sensitive detector operating at room temperature is still an active research topic. As shown recently [1] nano-optomechanical systems provide a very interesting approach, which naturally combines modulation frequencies in the 10 MHz range with room-temperature operation. In this work, we exploit a THz meta-atom resonator with a flexible part, where forced mechanical vibrations are caused by incident THz radiation and read-out optically. The origin of the THz optomechanical force has been identified as either electric (Coulomb force) or photo-thermal [2], depending on the vibrational mode that is excited. While both mechanisms can be implemented in detection, an inherent limitation of the photothermal force is that the response time is limited by the thermal diffusion constant of the structure, while the Coulomb force is instantaneous.

We recently realized a new design with fully metallic mechanical element, in order to enhance instantaneous over retarded effects (figure 1a). We will report on the experimental results with devices operated under vacuum, where the quality factor is nearly two orders of magnitude larger than in air. Signature of instantaneous electric effects are found in the phase of forced mechanical motion (figure 1b) and demonstrate the presence of a Coulomb force on our cantilevers. This force is generated from excitation of a THz resonant LC mode in our device, while the residual observed thermal effects are due to a broadband absorption of radiation from the substrate and not to metamaterial properties.

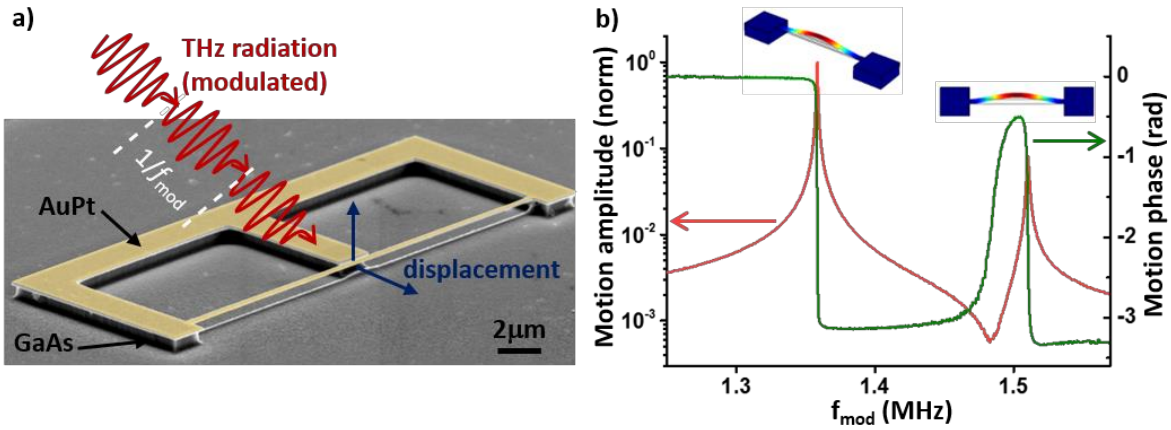

Fig. 1: (a) SEM picture of a fabricated device, with a sketch of the operation principle. THz radiation from a Quantum Cascade Laser source is sent onto the resonator; light intensity is modulated at the frequency of mechanical vibration modes. (b) Amplitude and phase of forced mechanical oscillations of the cantilever, as a function of the THz modulation frequency. The fundamental out-of-plane and in-plane mechanical modes can be seen. The measurement was taken in vacuum, at a pressure of about 10^{-1} mbar.

The concept of optomechanical THz meta-atoms is very versatile and can have many different implementations. Beyond the Coulomb interactions, magnetic forces can also be exploited to make instantaneous optomechanical devices, a field that has been relatively less explored. We have applied this concept to THz patch antennas [3]: we will report on preliminary theoretical studies and will show the first fabricated devices.

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Polaritonic network as a paradigm for dynamics of coupled oscillators

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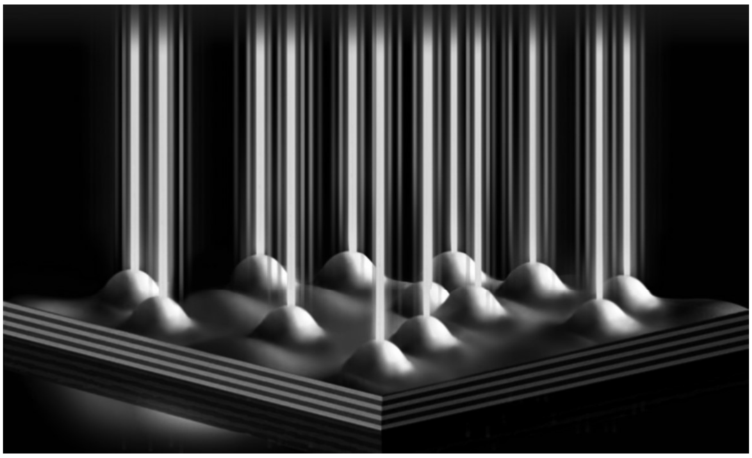
For a long time two pervasive topics of modern science -- dynamics of coupled oscillators and simulations of many-body solid state systems -- have barely crossed their paths.
Complex dynamic behaviour of networks of coupled oscillators arise in various scientific disciplines ranging from biology, physics, and chemistry to social and neural networks as well as established and emerging technological applications. Such networks are paradigmatic models for understanding the mechanism of various different collective phenomena. At the other end of spectrum of nonlinear dynamical studies lies the complex many-body solid-state systems that are often considered as powerful platforms for simulating various elaborate Hamiltonians. A number of systems were realised using neutral atoms, ions, electrons in semiconductors, polar molecules, nuclear spins, superconducting circuits etc. [1]. These are typically equilibrium systems that realise ground or excited states of their structure Hamiltonians. Recently, photonic and polaritonic lattices have emerged as promising platforms for many-body quantum and classical simulations [2,3]. These systems are typically of a gain-dissipative nature, capable of symmetry breaking and spontaneous pattern formation, and have constant nonzero fluxes even at the steady state. Furthermore, as I argue in my talk, when the lattice elements have photonic component and the gain-dissipative nature the wavefunction packets evolve, interact and synchronise in a close resemblance to the coupled oscillators that governed by the universal order parameter equations. As a result, on one hand, many classical phenomena found in such networks can be explained or predicted by the behaviour of the corresponding system of coupled oscillators, one the other hand, strong nonlinearities, spin-orbit coupling, sensitivity to magnetic fields, and individual site control greatly enrich possible states and dynamical regimes that can be generated in such lattices.

In my talk I will propose and theoretically justify the use of networks of exciton-polaritons (polaritonic networks) as a flexible universal platform to realise a vast array of known and extensively studied systems of coupled oscillators such as Kuramoto, Sakaguchi-Kuramoto, Stuart-Landau, Lang-Kobayashi oscillators and beyond. The networks of polariton condensates are therefore capable of implementing various regimes acting as analogue Hamiltonian optimisers [4,5,6], producing Chimera states, exotic spin glasses [7] and large scale secondary synchronization of oscillations, probe new exotic dynamical regimes and to create novel states of matter.



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Optical control of nuclear spins: from nuisance to resource

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Optically active spins in solids offer exciting opportunities as scalable and feasible quantum-optical devices. Numerous material platforms, such as diamond, layered materials and semiconductors, are under investigation, where each platform brings advantages along with challenges. From the photonics perspective, the brightness and the coherence of light from semiconductor quantum dots remain practically unchallenged today, while the electronic spin coherence is modest owing to the magnetic noise generated by the nuclear spins of the quantum dot. In this talk, I will present an overview of the current progress to overcome such challenges for solid-state spin-photon interfaces and highlight opportunities to transform their nuclei from nuisance to resource.

A quantum dot exciton deep in the strong coupling regime of cavity-QED

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The strong-coupling regime of cavity quantum-electrodynamics (cQED) represents a fully quantum light-matter interaction. It results in non-linearities at the level of a single photon. Achieving strong coupling is key to creating coherent atom-photon couplings and photon-photon gates. Three parameters are typically used in its description: the atom-photon coupling rate g, the atom decay-rate γ, and the photon loss-rate κ. True strong-coupling is achieved only when $g >> \gamma$ and $g >> \kappa$.

An exciton in a quantum dot represents, in the best case, a close-to-ideal "atom" [1]. In particular, a quantum dot has a large optical dipole moment. This potentially leads to a large coupling strength g in cQED provided the cavity has a small mode-volume. The conundrum is that a small mode-volume cavity is typically fabricated with nano-fabrication, a process which often leads to a large κ via scattering-induced losses and also an increased γ via additional dephasing-channels. The condition $g >> \kappa$ is particularly difficult to satisfy.

We report here an experiment in which we achieve both $g >> \gamma$ and $g >> \kappa$. We use a quantum dot embedded in a highly-miniaturized, fully-tunable Fabry-Pérot microcavity [2,3]. This gives reasonably large values of g, and, crucially, a way to miniaturize without increasing γ and κ. The quantum dot is embedded in a charge-tunable heterostructure which gives close-to-transform limited optical linewidths, *in situ* tuning via the dc Stark effect, and control of the quantum dot charge via Coulomb blockade. The output mode is a simple Gaussian beam. We achieve $g/2\pi$=3.85 GHz, $\gamma/2\pi$=0.28 GHz and $\kappa/2\pi$=0.72 GHz (Q-factor=500,000), resulting in a cooperativity $C=2g^2/\kappa\gamma=150$.

Resonant laser spectroscopy shows a very clear avoided crossing at the quantum dot exciton-cavity resonance. The splitting between the two peaks, the polaritons, is a factor of 7 larger than the individual polariton linewidths. The intensity correlation function $g^{(2)}(t=0)$ exhibits photon blockade when the laser is tuned to one of the polariton resonances. On detuning the laser slightly, we observe pronounced oscillations in $g^{(2)}(t)$, unambiguous evidence of a coherent exciton-photon exchange. Detuned from the polariton resonances, $g^{(2)}(t=0)$ rises above 100.

This geometry is presented as an ideal platform to explore and exploit both the strong and weak coupling regimes of cQED.

This work was performed with Daniel Najer, Immo Söllner, Matthias Löbl and Daniel Riedel at the University of Basel, Switzerland; and Sascha Valentin, Rüdiger Schott, Andreas Wieck and Arne Ludwig at the Ruhr-University, Bochum, Germany.

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Dynamics of carriers, excitons and polaritons in novel materials

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We will paint an overview of some of our recent work on the spectroscopy of low-lying excitations in molecular, hybrid organic-inorganic and monolayer semiconductors. We will begin by addressing charge carrier diffusion in halide perovskite thin films. Large carrier diffusion constants is known to be an essential requirement for the development of efficient photovoltaic devices, but there is a wide range of values reported in the literature for diffusion constants in perovskite thin films. By using temporally and spatially resolved imaging, we demonstrate that carrier diffusion constants vary significantly amongst various perovskite compositions and that transport is generally non-diffusive in these materials. Most surprisingly, the materials giving the largest solar cell efficiencies are those, which have the smallest effective diffusion constants.

Then we will discuss work on the measurement of exciton-exciton nonlinearities in monolayer transition metal dichalcogenides. These materials are attractive for room-temperature polaritonics due to their ease of integration and large exciton binding energy. By using planar samples supporting high quality-factor Bloch surface wave polaritons, we find that the effective polariton-polariton interaction constant is on the order of $\sim 10^{-3}$ $\mu eV \cdot \mu m^2$, which is much lower than the theoretically predicted value.[1] Further studies demonstrate that phase space filling is the dominant nonlinearity in this system, in contrast to the Coulomb interaction that dominates in group III-V materials.

Finally, we will discuss the possibility for using strong light-matter coupling to invert the energetic ordering of singlet and triplet states and use this to modify the intersystem crossing dynamics of organic molecules. We demonstrate inverted singlet-triplet ordering in a material showing thermally assisted delayed fluorescence. By measuring the quantum yield of the microcavities and the prompt and delayed fluorescence rates, we can extract the reverse intersystem crossing rates. We find that these rates are not modified significantly in the presence of strong coupling and we attribute this principally to $1/N$ scaling of rates involving single-molecule processes collective strong coupling.[2]

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Topological Polaritonics

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Topological insulators constitute a striking example of materials in which topological invariants are manifested in robustness against perturbations. The most striking characteristic is the emergence of topological edge states at the interface between areas with distinct topological invariants. The observable physical effect is unidirectional, robust edge transport, immune to disorder or defects. Topological insulators have at first been observed in the integer quantum Hall effect, and subsequently suggested and observed also in the absence of a magnetic field. These were fermionic systems of correlated electrons. However, during the past decade the concepts of topological physics have been introduced into numerous fields beyond condensed matter, ranging from microwaves and photonic systems to cold atoms, acoustics, mechanics and even classical electric circuits. Recently, topological insulators were proposed in exciton-polariton systems organized as honeycomb (graphene-like) lattices, under the influence of a magnetic field [1,2]. Exciton-polaritons are the new eigenstate quasiparticles resulting from the strong coupling of matter, more precisely quantum well excitons, to light in an optical microcavity mode.

Here, we demonstrate experimentally the first exciton-polariton topological insulator and as such the first symbiotic light-matter topological insulators. In polaritonic honeycomb lattices, we show the existence of a $C = 2$ Chern topological insulator, manifesting in a chiral, topologically protected edge mode [3]. This system leads the way towards new topological polaritonic devices based on nonlinearity, gain, interactions and coherence.

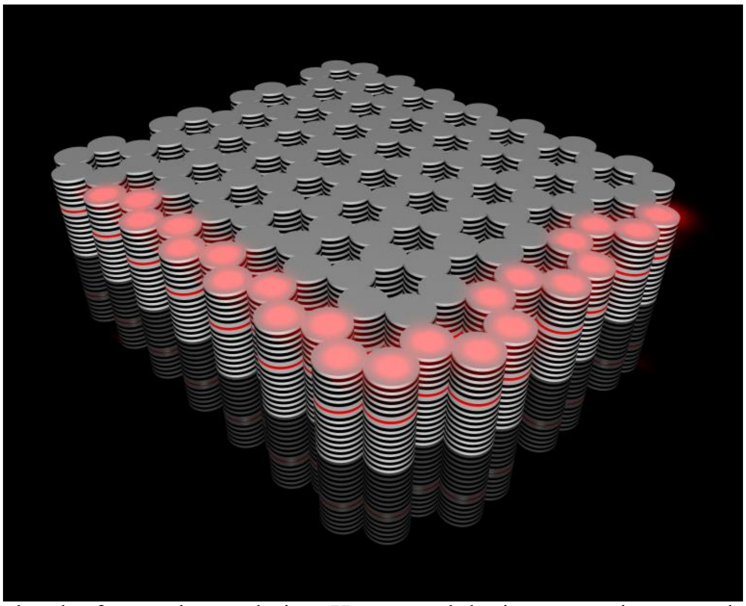

Fig. 1: Schematic sketch of an exciton-polariton Honeycomb lattice supporting a topological edge mode.

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Topological photonics with exciton-polaritons

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Exploring topological physics in photonic systems is a promising avenue for developing novel generation of optical devices that are robust against external perturbations and fabrication defects [1]. It is however still challenging to implement topological lattices in media exhibiting strong optical nonlinearities and/or optical gain. Hence, cavity polaritons formed from the strong coupling between quantum well excitons and cavity photons are particularly appealing: their photonic part allows for engineering topological properties in lattices of coupled micropillars [2], while their excitonic part gives rise to a strong Kerr-like nonlinearity and to lasing [3]. Here I will present two recent experiments that take profit of this dual nature.

In the first one, we used a photonic molecule formed from six coupled micropillars to implement a microlaser where lasing occurs in a mode carrying a well-defined orbital angular momentum with a chirality that can be optically-controlled, i.e. from a clockwise to a counter-clockwise phase twist [4]. Furthermore, we show that nonlinear contributions to the gain can lead to a bistable regime involving modes presenting distinct topological charges and polarization patterns [5]. In the second work, we implemented a one-dimensional array of coupled micropillars that emulates the Su-Shreefer-Heeger Hamiltonian. In this lattice, we implemented topological interface states by introducing a defect in the alternating inter-pillar coupling strengths, and studied how the properties of these states (i.e. their energy, the symmetry of their wave-function and its spatial localization) evolve in the presence of strong polariton-polariton interactions.

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Probing polariton band structures in optically imprinted potential landscapes

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The study of band structures in polariton lattices has previously been restricted to samples with permanent periodic potential landscapes created through lithographic processes such as lattice etching. With etched lattices the full band structures can readily be imaged in the linear regime below threshold [1, 2] due to the periodic potential permanently existing. Using these etched systems has led to the successful demonstration of flat bands [1, 3], Dirac cones [1] and recently topologically protected edge states [2] in polariton systems. Here recent work on the engineering of band structures via optical imprinting of the potential landscape will be presented demonstrating progress towards emulating systems similar to the Su-Schrieffer-Heeger model. Qualitative reproduction of the effects is achieved through numerical modelling by averaging the results of many stochastic initial conditions that are left to evolve under the suitable Schrödinger dynamics in the linear regime. This work holds promise of a highly tunable band structure emulator with potential expansion into the realm of topologically protected states without the need of lithography.

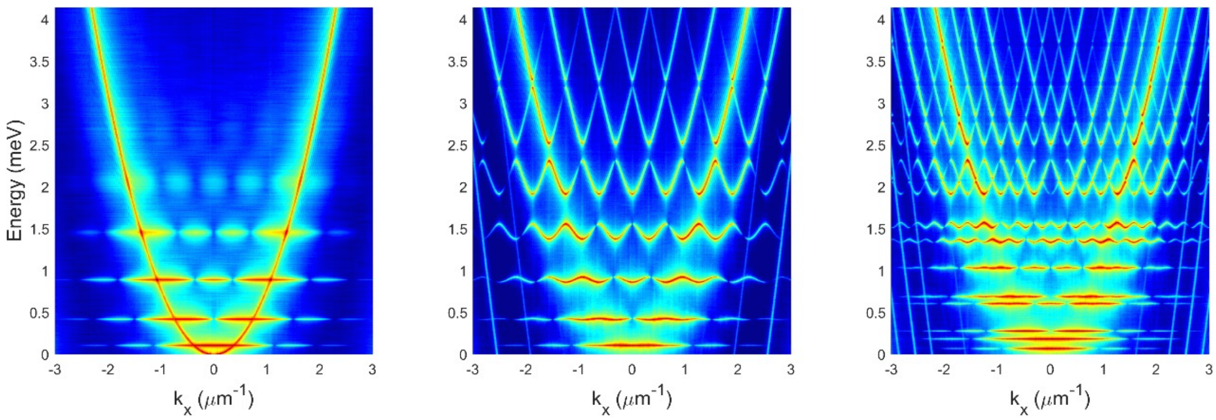

Figure 1 Numerically calculated single particle dispersions in potentials with the spatial profile of a dyad (left) and infinite chains of peaks relating to chains of condensates (middle and right).

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Observation of photonic Landau levels in strained honeycomb lattices

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Photonic resonators consisting of semiconductor coupled micropillars arranged in hexagonal lattices (Fig. 1(a)) provide an excellent platform to study, emulate and control the transport and topological properties of single-layered 2D materials like graphene [1]. The lattices of photonic micropillars allow the control of the onsite energies, nearest-neighbours coupling and direct access to the dispersion and wave functions in simple photoluminescence experiments. Even though photons are barely sensitive to magnetic fields, it has been shown that the engineering of a hopping gradient in a honeycomb lattice creates an artificial valley dependent magnetic field [2]. The intensity of this pseudo-magnetic field is directly proportional to the hopping gradient applied to the lattice.

In this work, we use strained polariton honeycomb lattices to study photonic Landau levels under pseudo-magnetic field. By modulating the hopping amplitudes between micropillars, we have implemented different gauge field intensities. We reveal the emergence of flat photonic Landau levels both in S and P bands by combining real and reciprocal space photoluminescence experiments. As an example, Fig. 1(b) shows the measured spatial distribution of the n=0 Landau level (S bands) at an “effective” magnetic field of 3.000 T. The emission comes mainly from a single sublattice, a specific mark of the action of the pseudo-magnetic field.

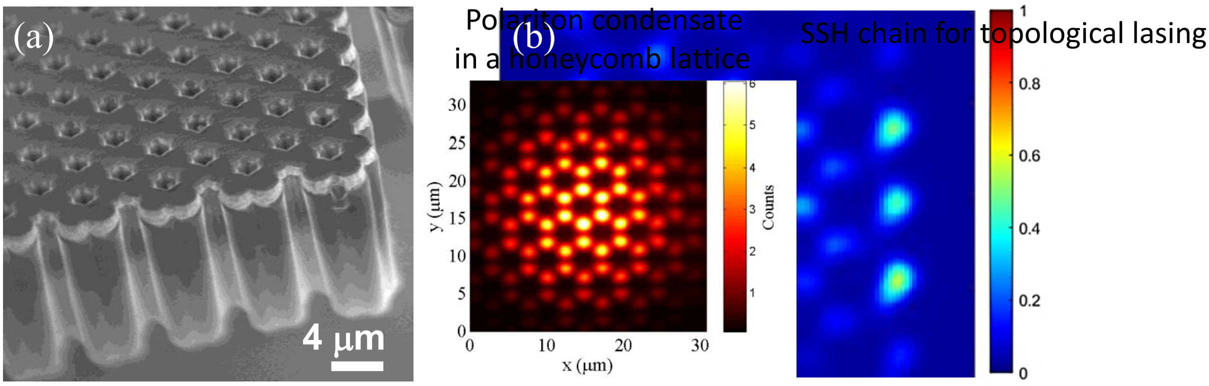

Fig. 1 (a) SEM image of a polariton honeycomb lattice composed by coupled micropillars. (b) Real space photoluminescence of the n=0 Landau level in a strained honeycomb lattice.

The lattices of semiconductor micropillars employed in this work open exciting possibilities to study phenomena at the crossroad of solid-state physics and photonics. Taken advantage of the strong coupling between the confined photons and the quantum well excitons embedded in the micropillars, our platform opens the way to study Landau levels subject to photon-photon interactions and to the observation of lasing in isolated flat bands.

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Direct measurement of the quantum geometric tensor in a two-dimensional continuous medium

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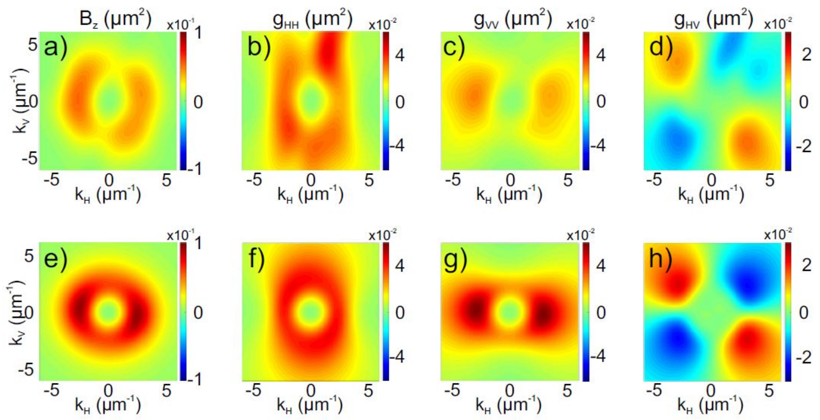

FIG. 1. Experimental and theoretical Fourier space distribution of the four components of the quantum geometric tensor.

In this work [1] we report the first direct measure of the complete geometry of an an energy band. Collecting and analyzing the fluorescence of a radiative photonic mode we are able to reconstruct the reciprocal 2D space distribution of all the four components of the quantum geometric tensor, i.e. the metric tensor and the Berry curvature [2, 3].

This was possible thanks to the investigated system, which is an high quality 2D exciton polariton microcavity with a Q $\approx$ 100000 resulting in a lifetime $>$ 100 ps and consequently a linewidth $<$ 0.1 nm. This kind of planar cavity is naturally subject to an effective SOC (Spin Orbit Coupling) stemming from the TE-TM (Transverse Electric and Transverse Magnetic) energy splitting. This together with a linear polarization splitting, induced by a crystal anisotropy, give rise to a non-Abelian Gauge field that drives the appearance of a couple of Dirac cones and pesudospin-monopoles, also observed here for the very first time, demonstrating the intrinsic chirality of 2D photonic modes. Adding an effective Zeeman splitting to the Hamiltonian by means of an external magnetic field, the time reversal symmetry is broken and the Dirac cones are split. This leads the formation of a chiral photonic band with controlled Berry curvature.

The direct access to the Berry curvature and the quantum metric is of enormous interest for the scientific community in the field of topological physics. This work opens new perspectives allowing the access to topological index beyond the Chern number and, more in the specific, to study the interplay between interactive quantum fluids (polaritons) and topological systems.

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Light on the Ångström scale.

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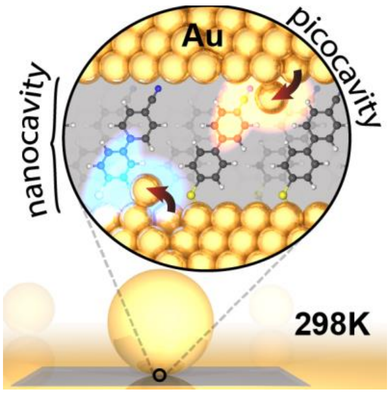
In plasmonic nanogaps, light can be trapped down to the nanometre scale. However, this plasmonic confinement has strong non-linear dependencies on distances and geometries in the nanostructure. This means that top-down fabrication methods are often not precise enough to yield accurate and repeatable nano-optical devices.

By marrying the stiffness and high reproducibility of molecular scaffoldings with the powerful plasmonic properties of noble metal nanostructures, powerful self-assembled nano-architectures can be formed that are able to trap light even on sub-nanometer length scales. Such systems not only form capable sensors for surface enhanced Raman spectroscopy, but the immensely enhanced fields are also extraordinarily sensitive to Ångström and even sub-atomic scale features. This allows single molecule chemistry to be probed in real time inside the plasmonic hot-spots.



Experimental Observations of Bound States in the Continuum at Anti-Crossing Point Induced by Symmetry Breaking

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Bound states in the continuum (BICs) are localized states which exists within a continuum spectrum of propagating waves [1]. Although BIC was first predicted as an exotic anecdote of quantum mechanics [2], this counter-intuitive phenomenon has been observed even in many systems of classical waves.

During the last few years, research on BIC has become a very active topic in the field of nanophotonics [3,4], leading to many fascinating features such as parity-time physics [5], topological charges [6] and new design of micro lasers [7,8]. In photonic structures, BICs correspond to a theoretical infinite quality factor (Q) of radiative modes for a given set of wavelength, polarization and wave-vector. Such peculiar feature is the hallmark of antisymmetric modes at normal incidence, but can also be observed at oblique incidence by tuning the design parameters to obtain destructive interference of radiative channels. Up to now, BICs at oblique angle were only evidenced with photonic crystal exhibiting full vertical symmetry: suspended in the air, or deposited on substrate and immersed in and index matching liquid. Indeed, the “accidentally” destructive interference is based on single polarization design and the BIC disappears as soon as the vertical symmetry is broken.

In this work, we demonstrate a new kind of BIC which is induced by vertical symmetry breaking. Our sample consist of a 2D photonic crystal slab which sit on top of a substrate and not immersed in any index matching liquid. Moreover, the photonic crystal slab is partially etched (~50%), thus the vertical symmetry is strongly broken (***Figure 1***). As consequence, TE-like (i.e. odd) and TM-like (i.e. even) modes will hybrid via TE-TM coupling, thus exhibiting anti-crossing effect in the energy-momentum diagram (***Figure 2***). Via hybridization, the two modes can exchange losses and when the phase matching condition is fulfilled: one would takes all the losses while the other one becomes BIC (i.e. lossless) as suggested in Friederich-Wintgen’s seminal work [9]. Such BIC is experimentally demonstrated with the observation of a vanishing Fano resonance – signature of interactions with the continuum – in the vicinity of the anti-crossing point. The experimental results are perfectly reproduced by numerical simulations. Our BIC is very robust and can be tuned along a broad range of angle by modifying the symmetry breaking (i.e. etching depth). Our results opens the way to study BICs, their topological nature and devices based on BIC (lasers, sensors) in photonic crystal exhibiting a vertical symmetry breaking as a new degree of freedom.

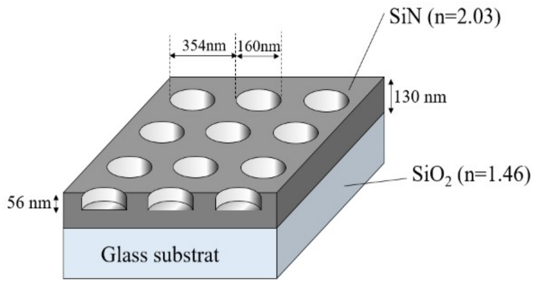

Figure 1: Studied design

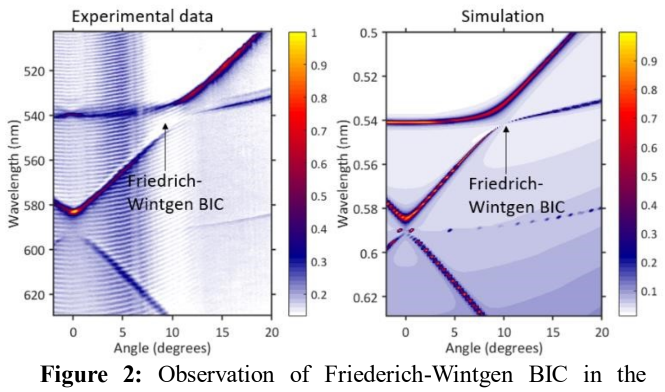

Figure 2: Observation of Friederich-Wintgen BIC in the studied design through (a) Experiment and (b) Simulation

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Solid-state dewetting of Si(Ge)-based complex nano-architectures and their applications in photonics

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Dewetting is a ubiquitous phenomenon in nature: many different thin films of organic and inorganic substances share this shape instability driven by surface tension and mass transport. This spontaneous phenomenon leads a thin film to break and drip in isolated islands. Here, I will address two distinct cases of solid-state dewetting: 1) templated wetting of silicon and 2) spontaneous dewetting of silicon-germanium.

Templated solid-state dewetting can be used to frame complex nanoarchitectures, nanowires (up to 0.75 mm long) and connected circuits of monocrystalline silicon on insulator with unprecedented precision and reproducibility
over large scales [1]. Phase-field simulations quantitatively benchmark the experimental results revealing the dominant role of surface diffusion as a driving force for dewetting and the role of faceting in stabilizing the nanostructures.I will discuss the use of these ordered structures as dielectric Mie resonators for visible and NIR light manipulation [2,3].

Spontaneous dewetting of thick SiGe layers leads to the onset of spinodallike structures as accounted for by the features of Minkowski-functionals and evolution of Betti numbers [4]. The formation of these disordered structures is interpreted in the framework of the Cahn-Hilliard-Cook theory of phase separation in analogy with spinodal dewetting of polymers and liquid-metals.
I will discuss the possibility to exploit this bottom-up, self-assembly method to form hyper-uniform, dielectric metasurfaces at visible and near-infrared frequencies [5] over ultra-large scales.

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The Effect of the Narrow Gap Split Ring Resonators on the Polariton Spectrum in the Ultrastrong Coupling Regime

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Ultrastrong coupling (USC) regime has been raised as an intriguing research topic in cavity quantum electrodynamics experiments due to its capability to modify the ground and the excited states of a coupled system [1-3]. In our study, the Landau level (LL) transitions in a two dimensional electron gas ultrastrongly couple to complementary terahertz (THz) split ring resonator (cSRR) arrays as metasurfaces. Reducing the capacitive gap of cSRRs leads to an enhanced electric field due to a smaller mode volume (V), which increases the coupling ratio as it scales with $1/\sqrt{V}$. According to our results, an inhomogeneous broadening of the upper polariton branch below a threshold gap width is introduced by this reduction.

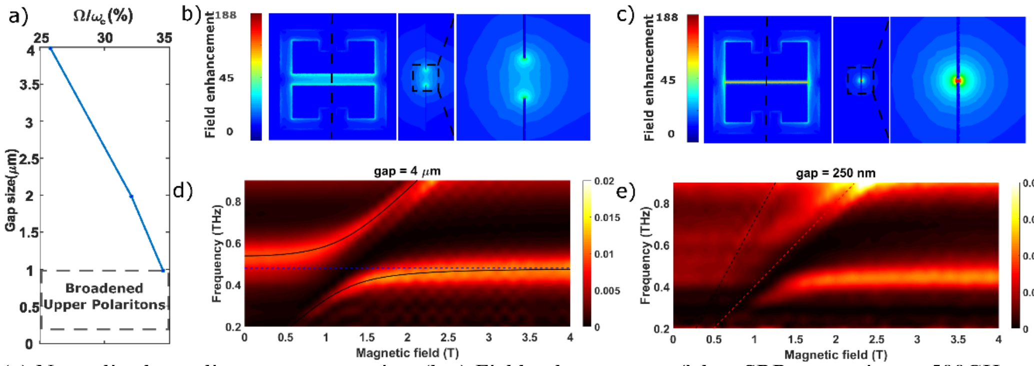

Fig. 1: (a) Normalized coupling rate vs. gap size. (b,c) Field enhancement of the cSRR resonating at 500GHz and 50 nm below the surface (left) and the side view of the field enhancement distribution inside the substrate (middle and the magnified figure on the right), simulated by CST Microwave Studio for the gap size of (b) 4 mm and (c) 250 nm. (d,e) Transmission measurements as a function of magnetic field are shown for gap size of 4 mm and 250 nm, respectively. Extracted transmission maxima fitted with Hopfield model to determine the upper and lower polariton branches (solid lines) and the cavity frequency (dotted line) are marked in (d). The dotted lines in (e) show the first order cyclotron transition corresponds to $f = \omega_c/2\pi$ (red line) and a higher order cyclotron transition corresponds to $f = 1.78\times\omega_c/2\pi$ (black line).

Our system consists of cSRRs coupled to LL transitions of GaAs/AlGaAs quantum wells (QWs). To increase the coupling rate of the system, quantified by vacuum Rabi frequency (Ω), the gap size of the resonators is systematically reduced from 4 mm to 250 nm. To keep the resonant frequency constant, the cavities have been carefully designed to resonate at 500GHz. The normalized coupling ratio to the cyclotron transition frequency, Ω/ω_c, has a 50% increase by reducing the gap size from 4 μm to 1μm (Fig. 1a). Below 1μm, the upper polariton starts to broaden inhomogeneously. The tangential component of the electric field at 50 nm below the surface (where the QW is located) and its distribution as moving away from the surface are shown in Fig. 1b and 1d for 4 μm and 250 nm gap size, respectively. At 250 nm gap size, the confined and enhanced electric field can lead to an inhomogeneous change in the electron density and broadening the transition energies. An additionally observed feature is highlighted by a dotted line in Fig. 1e which corresponds to $f = 1.78\times\omega_c/2\pi$. This indicates the strong modification of the measured spectrum due to the narrow resonator gap which needs further investigation. Furthermore, the lower polariton energy deviates from the empty cavity resonant frequency at high magnetic fields which cannot be fully described by the Hopfield model. Similar observations have been recently reported in metasurfaces ultrastrongly coupled to LL transitions in strained-Ge QWs[4]. For future works, the broadening of the upper polariton may be retrieved by an embedded gate to modify the electron density below the gap.

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DNA Self-Assembled Nanoantennas

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DNA can be used as a tool to rationally assemble metallic nanoparticles (NPs) and single photon emitters (e.g. organic fluorophores and quantum dots) with a defined arrangement, nanometer spacing, and tunable plasmon resonance. These structures can be tailored to have unique optical properties such as custom-tuned hot spots for surface enhanced Raman and fluorescence spectroscopies [1], and small mode volumes able to promote strong-coupling between plasmons and molecular excitons [2]. In this talk, I will discuss our assembly strategies to use DNA as a self-assembly tool to fabricate optical antennas that include a variety of hybrid nanocomponents. For example, using DNA complementarity along stoichiometry and spatial-exclusion, we position an individual QD at exactly the center between two metallic NPs [3]. The resulting structures display high emission enhancement compared to individual emitters. The flexibility of using DNA as an assembly methodology is an ideal approach to study plasmon-single emitters interactions and to integrate nanocomponents for optical applications.

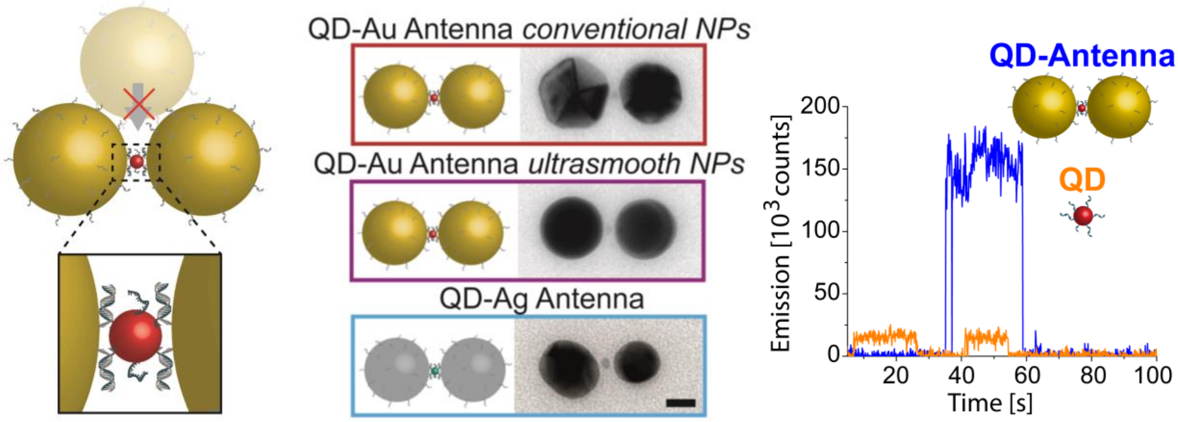

Fig. 1: Example of DNA self-assembled nanoantenna. Here, an individual QD is positioned between two metallic NPs. The large molar excess of the larger species and their disproportionate size difference prevents more than two NPs to be attached to an individual QD. The antennas display enhanced fluorescence in respect with individual QDs.

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Single photon states from non-stoichiometric bulk perovskites

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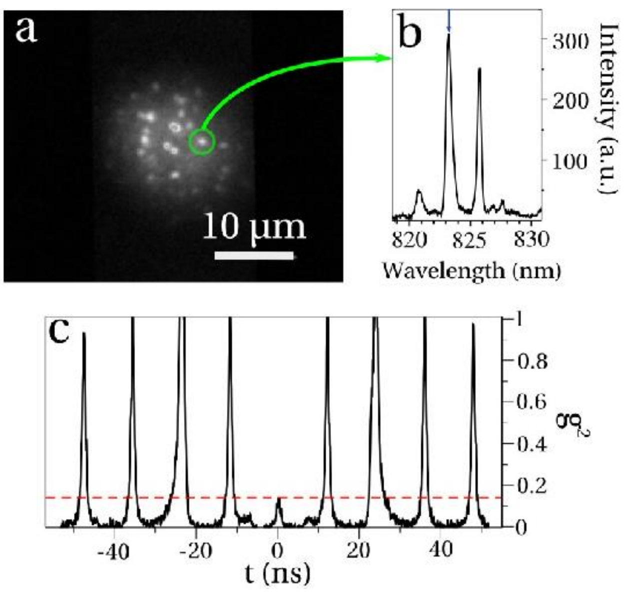
The evolution of quantum information processing has rendered the qubits sources a fundamental research area. In recent years, deterministic sources made of semiconductor quantum dots have shown high efficiency, indistinguishability and narrow bandwidth. However, their expensive growth procedures and limited operation wavelengths, leave open the door for alternative single photons sources.

In this work, we demonstrate single photons emission from hybrid organic-inorganic bulk perovskites when breaking the stoichiometry of their precursors, with a simpler and more economic process compared with most diffused single photons sources. We attribute this effect to the formation of inorganic nanometric domains able to confine the exciton in sub-wavelength volumes. Their narrow emission, saturation behavior and antibunching (second order correlation value of 0.14 at zero delay), confirm a zero dimensional confinement of the exciton in the material. Since the domains are formed in a bulk material, they have advantages in terms of scalability and integrability. Additionally, their operation range (820-850 nm) opens interesting possibilities for quantum information processing technologies in the near infrared domain.



a) Real space image of sample's photoluminescence. b) Spectrum of an emitting center. c) Second order correlation function of an emission peak isolated in energy and space. The value of 0.14±0.05 confirms the presence of zero dimensional emitters in the sample.

Observation of strong coupling regime with hybrid perovskite in photonic crystal

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Cavity polaritons are quasi-particles arising from the strong coupling regime between excitons of quantum wells and photons of micro-cavities. The hybrid light/matter nature of polaritons makes the quasi-particles behave like ultra-nonlinear photons – which are particularly attractive for optical switching and logic elements. Indeed, thanks to the photonic component, such platform exhibits naturally all advantages of photonic integrated circuits towards traditional electronic counter-parts. Additionally, the giant nonlinearity of polaritons – inherited from the excitonic component – makes it possible to greatly reduce the energy consumption required for switching or amplifying photonic information.

Since the first demonstration of cavity polariton, a number of experiments have been performed in GaAs and CdTe-based systems, which, due to their comparatively low binding energy (~5 meV), require cryogenic temperatures to operate. The quest for polaritonic devices operating at room temperature is orienting current research trends towards materials with higher binding energies GaN, ZnO, organic semiconductors and, more recently, monolayers of transition metal dichalcogenides (TMDCs). One class of materials that shows particular promise for room temperature polaritonic devices are hybrid organic-inorganic perovskites (HOP). In the last 20 years, the emerging of HOP raised a tremendous attention for optoelectronic application, thanks to their unique properties combining bandgap tunability, high luminescence quantum yield, narrow emission line-width, and facile synthesis. Thin two dimensional (2D) HOPs composed of alternating inorganic/organic monolayers are crystalline multi-quantum well structures presenting presenting robust excitons, with binding energies in the hundreds of meV range. 2D HOPs give rise to delocalized Wannier excitons, and thus present much higher nonlinearity than Frenkel excitons in organic materials, exhibiting a behavior similar to exciton nonlinearity in GaAs quantum wells.

In this work we report on demonstration of perovskite-based polaritons at room temperature in photonic crystal structures. 2D HOP is deposited via spin-coating onto photonic crystal backbone composed of 1D or 2D periodic structures of hole and forms a pillar-lattice of high refractive index. The strong coupling regime between HOP excitons and Bloch photons is evidenced by the observation of anti-crossing effect in photoluminescence and reflectivity measurements. Compared to conventional designs with Fabry Perrot cavities, our approach makes it possible to optimize separately the active material and the photonic backbone. Indeed, we show that it would be possible to engineer the polaritonic dispersion from Dirac cones to flatband by simply depositing 2D HOP onto well-designed photonic crystal structures. Our results open the way for polaritonic devices at room temperature with new class of materials such as HOP and TMDCs.

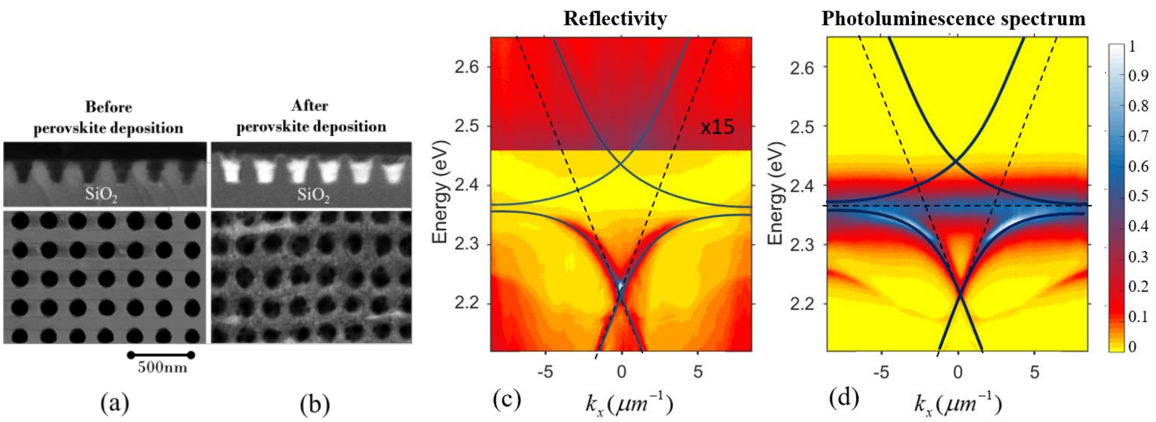

Fig. 1: Scanning electron microscope images of the sample before (a) and after (b) the deposition of HOP. Angular resolved reflectivity (c) and photoluminescence spectrum (d) – polarization S at room temperature.

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Polariton Blockades

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Recently, the long awaited *polariton blockade* [1] has been reported by two independent groups [3, 4]. This passes a milestone which took a long detour through another *unconventional* route to likewise evidence polariton correlations (in the form of antibunching) despite weak polariton interactions as compared to their dissipation. Note that in the meantime, unconventional photon blockade, whose interested had been rekindled by the polariton scenario, had been discovered [4, 5] again [6].

In this talk, we will provide a unified picture of conventional and unconventional polariton blockade [7]. We show how they sit side by side in the same system, along with other interesting photon-statistics resonances, but that they indeed to correspond to distinct mechanisms, with marked differences. We discuss, in particular, how they pertain to different types of quantum correlations [8] as evidenced by the Gaussian, or not, character of the state which is formed in the system. Finally, keeping in mind the very small values of antibunching reported in the pioneering reports, we provide the theoretical optimum values within reach of current systems and where to look for them (a treasure-map in terms of detuning, driving configuration, etc.) [8].

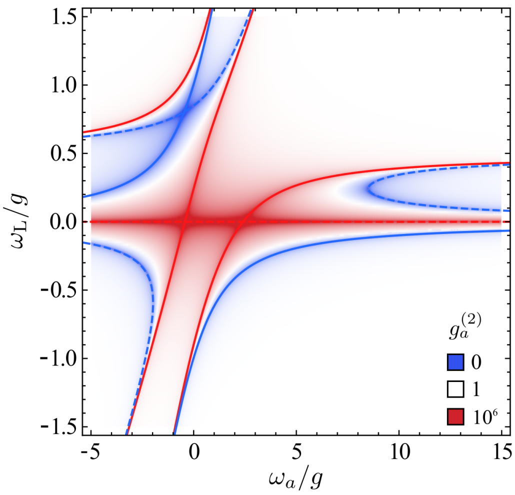

Fig. 1: A map of conventional and unconventional polariton blockade in a microcavity. Dashed lines correspond to the unconventional mechanism and solid to the conventional one. Red is for bunching and blue for antibunching. This figure exhausts the two-photon correlations provided by this system.

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Dynamical Theory of the Hong–Ou–Mandel Effect

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We develop a full dynamical theory of the Hong–Ou–Mandel (HOM) effect [1], taking into account the fundamental time uncertainty of the photon detection events [2]. We focus on the HOM configuration where the input arms of the beam splitter are two independent two-level emitters, that is, single photon sources. We compare spontaneous emission with the steady state under both incoherent and coherent pumping. We use a master equation formalism including the detectors in the dynamics, in order to correctly reproduce the HOM dip (the suppression of the crossed correlation function at zero delay between detected photons) and to be able to extract from it in each case all the relevant information: indistinguishability, purity of the sources or coalescence of the photons in the beam splitter.

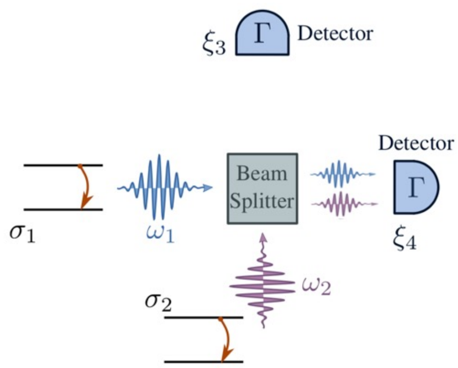

Fig. 1: HOM set-up: photons emitted by two 2-level systems enter the two input beam splitter arms. Two detectors at the output arms capture the photons that result from their interference.

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Near-infrared lasing from GaNAs-based nanowires

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Semiconductor nanowires (NWs) are currently regarded among the most promising systems for constructing nanolasers, as a nanowire represents a naturally formed cavity and also provides gain medium. The flexibility in engineering the gain material and laser cavity can be extended by employing dilute nitride GaNAs alloys. The giant bowing in the bandgap energy characteristic for dilute nitrides allows easy tuning of lasing wavelengths, whereas an increase in electron effective masses upon N incorporation reduces carrier spill-out from GaNAs quantum wells, improving laser thermal stability.

In this work we demonstrate lasing from the GaNAs region of GaAs/GaNAs core/shell and GaAs/GaNAs/GaAs core/shell/shell NWs grown by molecular beam epitaxy. In both structures, the 5K photoluminescence (PL) spectra measured at low pump fluences (P_{exc}) are found to originate from localized exciton emission, coupled to the fundamental $HE_{11a/b}$ Fabry-Perot cavity modes. With increasing P_{exc}, sharp lasing emission was observed from the GaNAs band-to-band transitions, which exhibits an 'S'-shape dependence on P_{exc} accompanied by line narrowing (Fig.1). By using rate equation analysis, a threshold gain, g_{th}, of 3300 cm^{-1} and a spontaneous emission coupling factor, β, of 0.045 are derived for the GaAs/GaNAs structure [1], whereas g_{th} = 4100–4800 cm^{-1} and β up to 0.8 are deduced for the core/shell/shell NW. The performed simulations identify the HE_{21b} cavity mode as the lowest threshold mode for lasing at 0.87 μm. The lasing mode changes to HE_{11a} in the GaAs/GaNAs/GaAs core/shell/shell NWs with [N]~2.5% that lase at 1 μm [2]. This conclusion is supported by the polarization of the lasing line. From temperature dependence of the lasing emission, a high characteristic temperature, T_0, increases in the structures that have the outer passivating shell reaching 160(±10) K. Our results demonstrate a promising alternative route to achieve room-temperature NIR NW lasers thanks to the excellent alloy tunability and superior optical performance of dilute nitride materials.

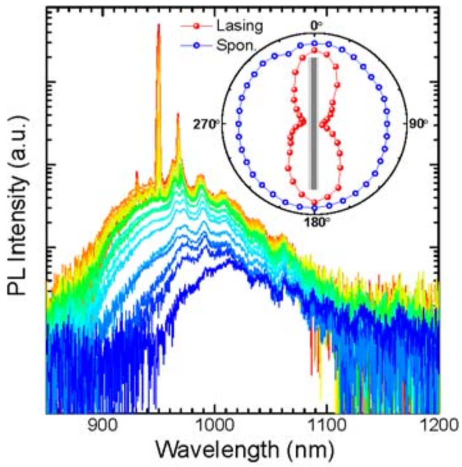

Fig.1: Power-dependent PL spectra at 5 K. The inset in shows PL polarization in spontaneous (open circles) and lasing (dots) regimes.

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Nanodisk-in-nanopillar semiconductor structure: a platform for an efficient room-temperature spin-photon interface

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Owing to their superior optical properties regarding optimized light management, semiconductor nanopillars/nanowires in one dimensional (1D) geometry are building blocks for nano-photonics. They also hold potential for efficient polarized spin-light conversion in future spin nano-photonics. Unfortunately, so far spin generation in 1D systems remains inefficient at room temperature and there exists generally a limit to simultaneously achieve the required strong spin polarization and high radiative efficiency. Here, we propose a conceptually new approach that can effectively overcome the limit by significantly enhancing the radiative efficiency of the electrons with the desired spin while suppressing that with the unwanted spin, which simultaneously ensures strong spin polarization. We demonstrate generation of record-high electron spin polarization up to 60% at room temperature in a GaNAs nanodisk-in-GaAs nanopillar structure, facilitated by spin-dependent recombination via merely 2-3 defects in each nanodisk [1]. Our approach paves the way for realization of an interface for efficient spin-photon quantum information transfer at room temperature - a key element for future spin-photonic applications.

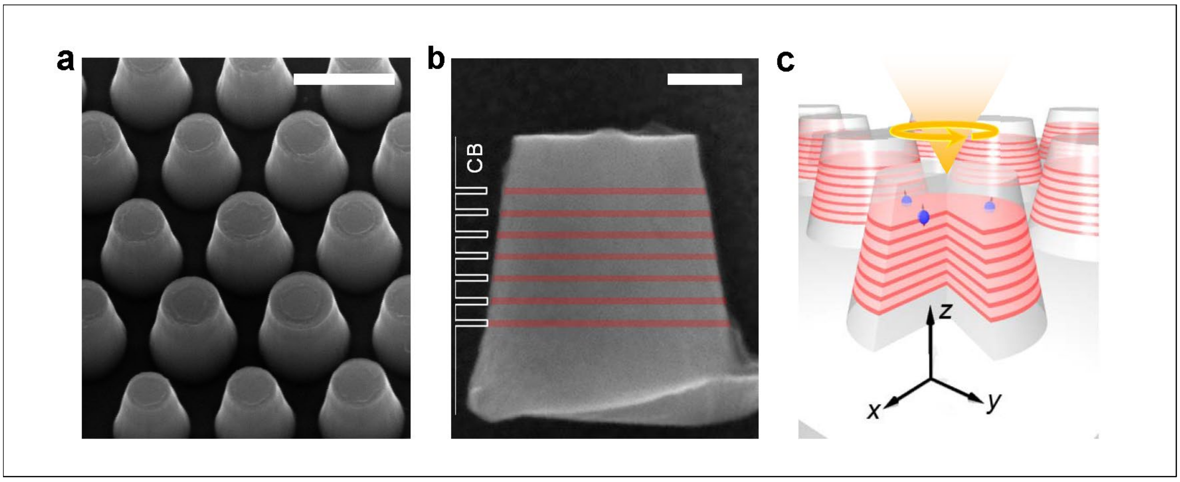

Fig. 1. a) Scanning electron microscopy (SEM) image of the arrayed GaNAs nanodisk-in-GaAs nanopillars (DiP). b) Side-view SEM image of an individual DiP, where the seven GaNAs nanodisks are shown in red color. The energy profile of the conduction band (CB) edge along the nanopillar axis is indicated on the left side. The scale bars in a) and b) denote 400 nm and 100 nm, respectively. c) Schematic illustration of the experimental configuration. (From Ref.1)

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Terahertz radiation induced edge currents in graphene in the quantum Hall regime

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We reported on the observation and study of THz radiation induced edge currents in two-dimensional (2D) structures in the quantum Hall effect regime [1]. On example of high mobility exfoliated graphene, we show that a direct electric current in chiral edge channels is generated due to Drude-like absorption of THz photons with energies smaller than the cyclotron gap resulting in a net velocity of the charge carriers. The direction of the edge photocurrent is determined by the polarity of the external magnetic field while the radiation polarization affects only its amplitude, see Fig. 1 (a). Furthermore, the data for different gate voltages demonstrate that the photocurrent direction does not depend on the type of carriers. The microscopic theory and model developed, see Fig. 1 (b), describe well the experimental data. We demonstrate that the photocurrent is caused by unbalancing persistent edge currents when driving the system out of thermal equilibrium. Analysing the magnitude of the chiral edge currents observed in the present work, we found that the relaxation time of non-equilibrium carriers in chiral edge channels is two orders of magnitude longer than the momentum relaxation time of bulk carriers at zero magnetic field. We emphasize that the mechanism of the photocurrent generation is strikingly different from the previously reported magnetic-field-induced photoelectric effects as well as zero-magnetic field photocurrents in 2D systems, which all rely on the 2D motion of free carriers, for review see [2].
Experiments were performed on Hall bar structures prepared from exfoliated graphene / hexagonal boron nitride stacks. Mobilities, obtained at liquid helium temperature, are about $7\text{x}10^4$ cm^2/Vs and the carrier density was varied in a wide range by a back gate. Experiments were performed with a pulsed NH_3 molecular laser operating at $f = 3.3$ THz. An external magnetic field was applied normal to the sample surface and parallel to the radiation (Faraday geometry). All measurement were done at $T = 4.2$ K.

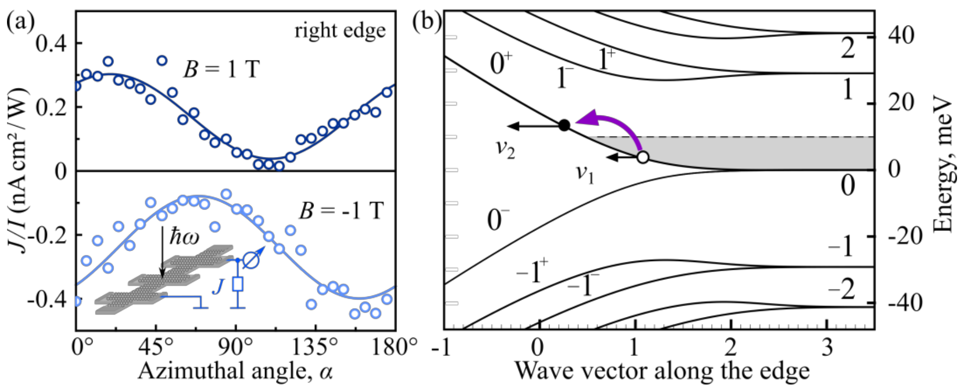

Fig. 1. (a) Dependence of the edge photocurrent on the orientation of THz electric field for magnetic fields of ± 1 T. Inset shows the measurements geometry. (b) Schematic illustration of the photocurrent generation. Spectrum of Landau levels in graphene with an armchair edge. The energy is given in absolute units corresponding to $B_z = 1$ T, the grey line illustrates the position of the Fermi level.

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Hydrodynamic Description of Difference Frequency Generation in a doubly resonant plasmonic nanostructure

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The efficiency enhancement of nonlinear optical processes in extremely confined volumes (~100 nm^3) is a great challenge in the field of nanophotonics, however it could lead to new applications in different areas, including for instance optical parametric amplification, holography and parametric down-conversion for quantum cryptography and computing applications [1]. Due to their opacity and large absorption, metals are usually considered a hindrance for high efficiency in traditional photonic systems. However, light interaction with metal nanoparticles, i.e. plasmonics, gives unmatched possibilities of both confinement and electromagnetic field enhancement. These properties, together with the large intrinsic nonlinear susceptibilities of metallic systems, make plasmonic systems ideal candidates for nonlinear optic applications, as already demonstrated, for example, for second-harmonic generation (SHG) [2]. Here, we present the design of a plasmonic system for efficient difference frequency generation (DFG). We perform a theoretical and numerical analysis of linear and nonlinear properties of the structure. In particular, we model the system using a hydrodynamic theory for electron dynamics inside the metal [1]. The hydrodynamic equations for the nonlinear polarization in the case of DFG have been derived in the undepleted pump approximation. A key element for the efficient implementation of these equation is to write the nonlocal contributions as purely surface current terms [3]. This can be done by exploiting the particular mathematical form of the nonlinear surface terms, which, it turns out, can be approximated as a function of the bulk and external values of the electric field. As a result, we obtained a free-parameter model for DFG in plasmonic system. As an example of application of our method, we have designed a doubly resonant gold structure, whose linear properties have been optimized for DFG as shown in Fig. 1. We have then estimated the DGF conversion efficiency to be ~10^{-8} for a 50 MW/cm^2 pump and 1 kW/cm^2 seed for the frequencies highlighted in Fig. 1.

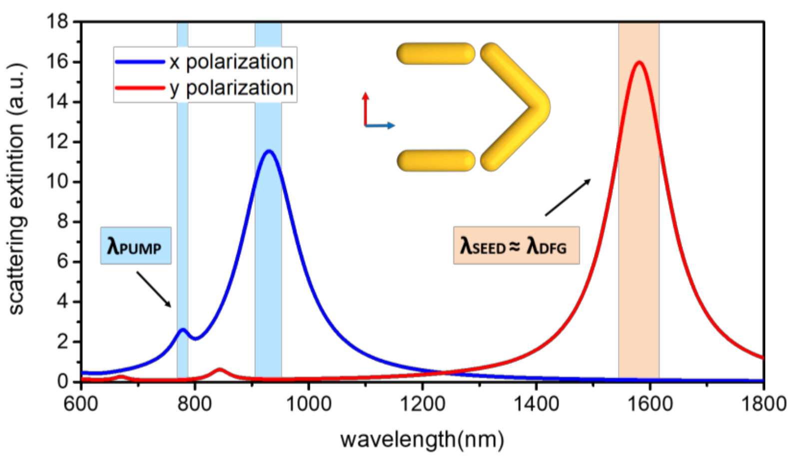

Fig. 1: Scattering spectra of the plasmonic nanostructure: blue and red lines represent the linear scattering spectra of the coupled antenna, calculated using FEM method, when illuminated with light polarization parallel and orthogonal to the long axis of the nanorod, respectively. Inset: gold nanostructure studied.

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Relaxation oscillations and reservoir filling dynamics in an exciton-polariton condensate

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Exciton-polaritons enabled the creation of a novel class of bosonic condensates characterized by dissipative nonlinear dynamics. As demonstrated in recent experimental works, exciton polariton condensates under non-resonant optical pulsed excitation can exhibit oscillatory behaviour in time [1],[2]. The manifestation of polariton condensate complex dynamics takes place when the density of incoherent exciton reservoir is rapidly depleted while increasing condensate density [3]. By analogy to the well know semi-classical nonlinear physical systems (eg. B-class semiconductor lasers), this type of dynamic behaviour is called relaxation oscillations. In this work, we performed numerical and analytical investigation of relaxation oscillations in the nonresonantly pumped polariton condensate [4]. The presented considerations are based on the analysis of the open dissipative Gross-Pitaevskii equation with multistep free carrier exciton-polariton relaxation process. The experimentally observed time-evolution of condensate density can be explained by studying the topology of phase space trajectory in the physical system. We used bifurcation analysis for the classification different regimes of condensate dynamics, e.g. fast stabilization, slow oscillations and ultrashort pulse emission (Fig.1). Next, we defined the analytical condition for the observation of relaxation oscillations. Additionally, we used the simple nonlinear oscillator model for the description of condensate time-evolution and oscillations. The analytical solution is in excellent agreement with both the results of numerical simulations and experimental observations [1],[2].

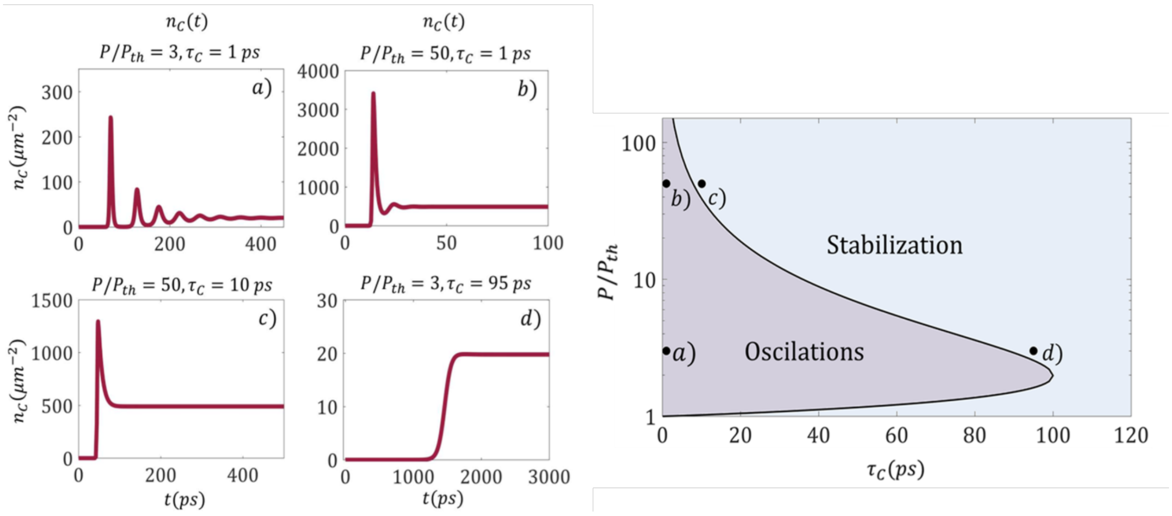

Fig. 1: Examples of evolutions of condensate density corresponding to the points marked in the diagram, showing region in parameter space which exhibits oscillations in the case of continuous wave excitation.

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High frequency impact ionization and nonlinearity of photocurrent induced by intense terahertz radiation in HgTe-based quantum well structures

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We report on the observation of the band-to-band *light* impact ionization under conditions of a photon energy much smaller than the forbidden gap [1]. The signature of *light* impact ionization is that the angular radiation frequency is much higher than the reciprocal momentum relaxation time. Thus, the impact ionization takes place solely because of collisions in the presence of a high-frequency electric field. Studying photogalvanic current and photoconductivity we observed that at high power both effects show a highly superlinear dependence on the radiation intensity. Fig. 1(a)-(c) shows that the photocurrent dynamically inverses its sign with rising intensity. The intensity dependence of the photoconductivity is shown in Fig. 1(d) demonstrating that the nonlinearity drastically increases with the frequency decrease. We show that at high intensity the nonlinear behavior of both photoresponses can be well fitted by the exponential function, $\exp(-E_0^2/E^2)$, of the radiation electric field amplitude E and the characteristic field parameter $E_0 \sim \omega^2$. Our study shows that this behavior is caused by the generation of electron hole pairs due to light impact ionization. The observed dynamical sign inversion of the photogalvanic current is explained by the interplay of the photocurrent excited in the conduction band and that caused by the photoexcited holes. The nonlinearity has been detected for linearly and circularly polarized THz radiation with laser lines of different frequencies ranging from 0.6 to 1.07 THz and intensities up to hundreds of kWcm^{-2}. The effect has been measured in a wide range of temperatures (4.2-90 K) on narrow HgTe/CdTe QWs of 5.7 nm width. Such QWs have been previously suggested theoretically as a system well suited to convert a HgTe QW from topologically trivial state into a nontrivial 2D Floquet topological insulator applying intense terahertz radiation [2]. Our experiments show that the observation of this process in real systems is hindered by the light impact ionization. To overcome this obstacle measurements with semitransparent gate are required. This will allow to reduce substantially free carrier density and, consequently, to suppress the impact ionization.

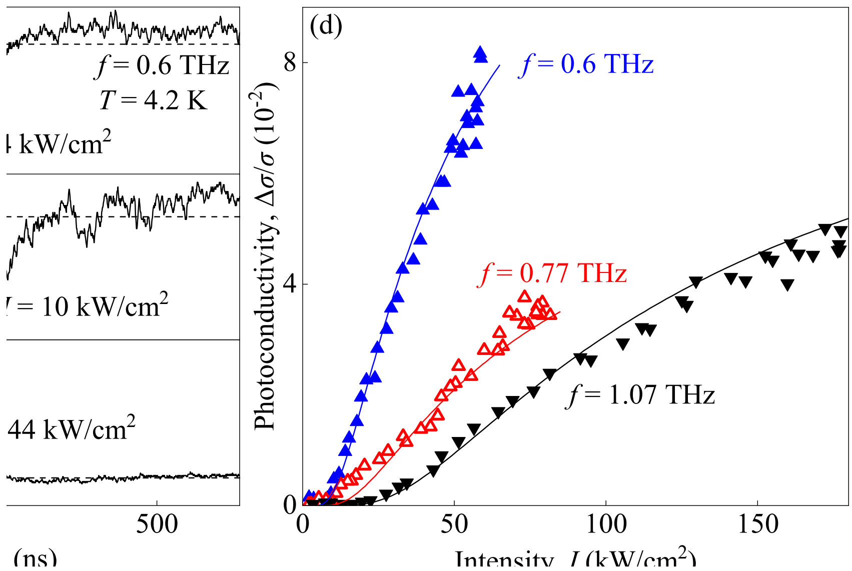

Fig. 1: Panels (a-c): Time variation of the photocurrent at different intensities with a frequency of f = 0.6 THz. Panel (d): Dependence of the photoconductivity on the radiation intensity for different radiation frequencies.

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Electronic and optical properties of a conical nanotube in presence of electric and magnetic fields

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Semiconductor Nanotubes SNTs are structures with promising applications in optoelectronics devices e.g. Light emitting diodes, photodetectors, solar cells and solid-state sources of single-photons [1, 2]. A variety of experimental techniques can be used to grown 1D nanostructures as nanowire superlattices, conical nanowires and conical nanotubes [3, 4]. Furthermore, the technical ability to control the growth of SNTs regarding their composition and morphology allows modifying the electronic configurations and optical properties of SNTs. In this work, we calculate the energies of an electron confined in a thin conical nanotube as functions of electric and magnetic fields applied along the symmetry axis for different degrees of conicity (Fig.1), by solving the Schrödinger equation under the effective mass approximation using the finite element method FEM. In the other hand, linear intersubband optical absorption coefficient and refractive index change are investigated as a function of the incident optical intensity and structure parameters such as opening angle. Our results reveal that interplay between the diamagnetic and centrifugal forces produces different effects in structures with different conicity degree. In relation to this, important changes occur in the energy spectrum, the magnetization and optical properties for different structural configurations. Finally, we also show how the magnetization of a SNT can be modified significantly by the application of an external electric field, resulting in the appearance of the so-called magnetoelectric effect.

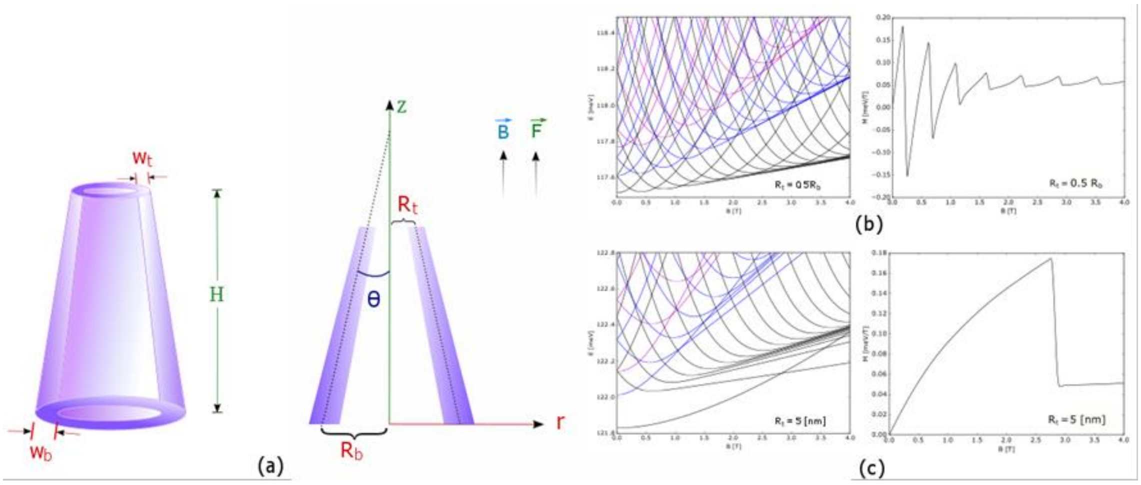

Fig. 1: (a) Truncated cone shaped nanotube and its cross-section showing the structural parameters. On the other hand, its energy spectrum on the left and magnetic dipole moment on the right in function of the magnetic field intensity B for (b) R_t= 0.5 R_b and (c) R_t = 5nm.

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Quantum information with Rydberg excitons in Cu_2O

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Photons are the best information carriers, but they are very difficult to manipulate with. Electromagnetically induced transparency (EIT) is a quantum optical effect which leads to a significant reduction of absorption and group velocity of a resonant probe laser beam (or even single photon) of frequency which matches to a so-called transparency window. The modification of medium properties is done by a stronger control field. Recently, a lot of attention has been directed to the Rydberg excitons, the new structures observed in Cu_2O as yellow exciton series up to a large principal quantum number of n = 25 [1]. The unique combination of their huge size, long radiative lifetimes, possible strong dipole-dipole interaction and miniaturization of samples can be exploited to perform robust light-exciton quantum interfaces for quantum information processing purposes [2,3]. Under normal circumstances optical nonlinearities are too small to enhance the photon-photon interaction so the optical quantum gate operation cannot be effectively implemented. The optical nonlinearity in Rydberg excitons media can be greatly enhanced in the presence of o quantum interference in EIT systems. Cross-phase modulation can occur in multilevel EIT systems, which are accessible in Cu_2O, when propagating pulses are allowed to interact for a considerably longer time by reducing their group velocities and also by making them of the same orders. The importance of cross-phase modulation is in implementing two-qubit all-optical quantum phase gate (where one qubit gets a phase shift dependent on the state of the other qubit) due to considerable values of nonlinear (Kerr) phase shifts conditions of EIT.

We investigate the inverted Y system for Rydberg excitons in Cu_2O (Fig. 1 a), where two separate, weak probe fields (or photons) share a common transparency window, propagating at almost identical group velocities. By choosing appropriate excitonic states, a considerable slowdown of light (single photons) can be achieved and therefore it is possible to achieve a resonant enhancement of nonlinear interaction leading to a cross phase modulation (Fig. 1 b). Combination of EIT and RE opens up new prospect for their applications in nonlinear quantum optics and in quantum information.

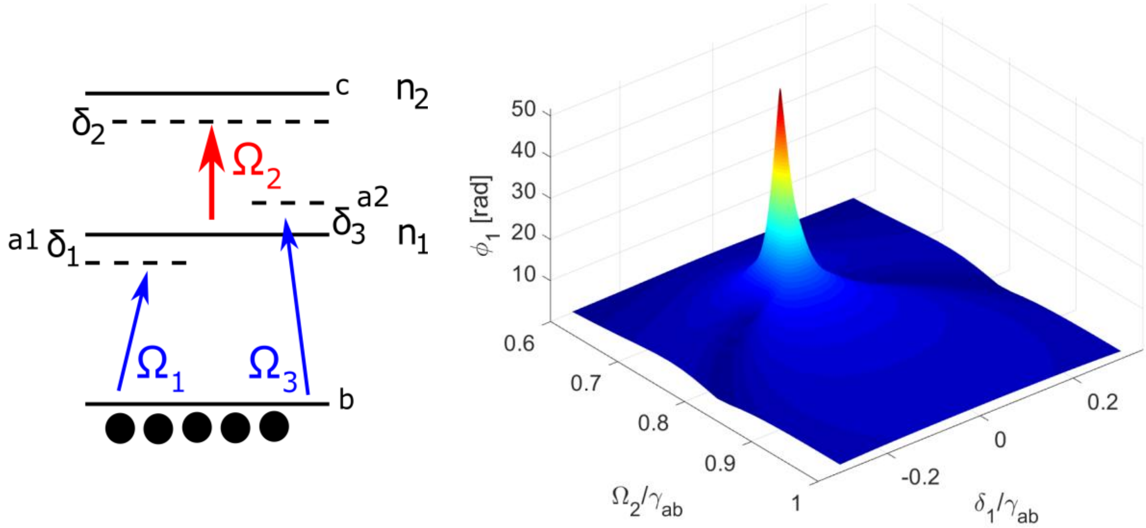

Fig. 1: a) Schematics of the energy levels in the considered system;

b) cross phase modulation for probe field Ω_1 as a function of detuning and

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Hybrid regime of stabilization in exciton-polariton condensates

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Exciton-polariton condensates modeled with open-dissipative Gross-Pitaevskii and exciton reservoir density equations are characterized by strong instability, especially for short living polariton particles. We inspect the influence of the energy relaxation β on the stability in such systems [1].

$$i\hbar\frac{\partial\psi(\boldsymbol{r},t)}{\partial t} = \left[-(1-i\beta)\frac{\hbar^2}{2m^*}\Delta + \frac{i\hbar}{2}(Rn_R(\boldsymbol{r},t)-\gamma_C) + g_C|\psi(\boldsymbol{r},t)|^2 + g_R n_R\right]\psi(\boldsymbol{r},t),$$

$$\frac{\partial n_R(\boldsymbol{r},t)}{\partial t} = P(\boldsymbol{r},t) - (\gamma_R + R|\psi(\boldsymbol{r},t)|^2)n_R(\boldsymbol{r},t).$$

Including the mechanism of relaxation is necessary since in many experiments there are no observations of instabilities in contrast to the theoretical predictions.

Using the Bogoliubov-de Gennes method, we derive the condition for the stability in the case of uniform pumping that depends on the relaxation parameter β. The analytical results that agree with numerical simulations are shown in Fig. 1. For sufficiently large β factor it is possible to achieve stabilization in entire parameter space, where γ_C^{-1}, γ_R^{-1} are the polaritons and reservoir excitons lifetimes, respectively and P/P_{th} is the ratio of the pumping rate to the threshold value when condensation occurs.

Moreover, we analyze the behavior of the condensate in the case of perturbation by a short optical pulse under stationary uniform pumping. Despite being in the stable regime according to the Bogoliubov analysis, the condensate reveals intermittent instabilities in the case of a strong perturbation. Surprisingly, this hybrid regime occurs only for non-zero energy relaxation parameter values. Examples of the condensate evolutions in the cases where relaxation is absent or present are shown in Fig. 2.

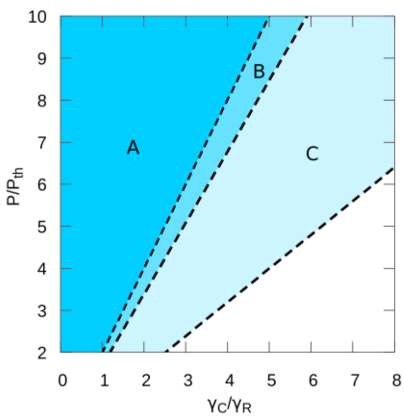

Fig. 1: Diagram of stability for different values of energy relaxation factor β. Stable regimes are marked with colors, where A: β=0, B: β=0.4, C: β=1.6

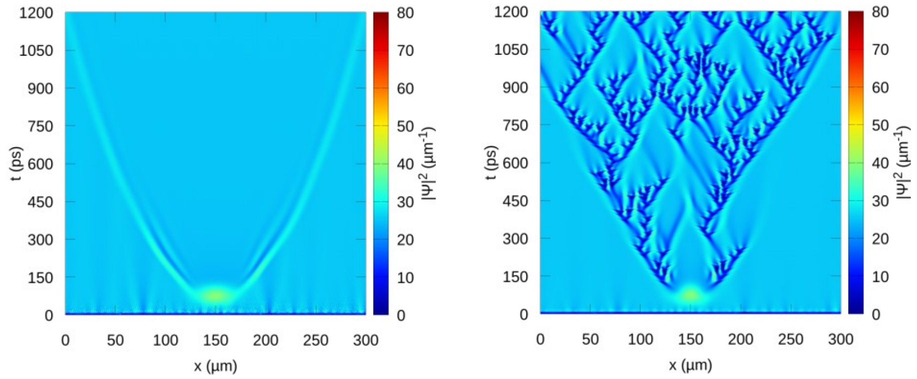

Fig. 2: The evolution resulting from a strong pulsed perturbation in a stable regime. (a) relaxation factor β = 0: the condensate proceeds to a stationary state. (b) β = 0.4: while the steady state is stable, perturbed condensate ends up in a spatiotemporal intermittent regime [2].

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Exciton localization in $MoSe_2$ monolayers induced by adsorbed gas

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Lattice defects and dielectric environment play a crucial role for 2D materials. In particular an effect related to the extreme surface-to-volume ratio is the extremely strong influence of physisorption and chemisorption of gas molecules on the optical and electronic properties [1,2]. In this work we investigate the impact of physisorbed gas molecules in ambient conditions on the optical properties of $MoSe_2$ monolayers by means of low-temperature photoluminescence (PL). More specifically, we focus on the physics of excitons localized by gas molecules studying the effects of laser irradiation and temperature.

Laser irradiation causes a release of previously physisorbed gas molecules from the monolayer. This results pronounced photo-gating. The effect is completely reversible in air (figure 1a).

The localized exciton PL peak shows a systematic and large red-shift with temperature (figure 1b). This energy shift cannot be explained only in terms of bandgap renormalization. Instead, we explain the shift in terms of thermal instability of the localized excitons in combination with hopping effects between localization centers.

Furthermore we have performed a careful lineshape fitting of the PL spectra. A key point of the fitting model is that we introduce an effective temperature in the form $T_{eff}^2 = \alpha T^2 + T_0^2$ in order to take into account the inhomogeneous disorder potential induced by defects and physisorbed gas molecules (figure 1c). In the above formula, T is the lattice temperature, T_0 is an induced temperature at zero Kelvin, and α is a fitting parameter. With this model we are able to reproduce the experimental data with excellent agreement.

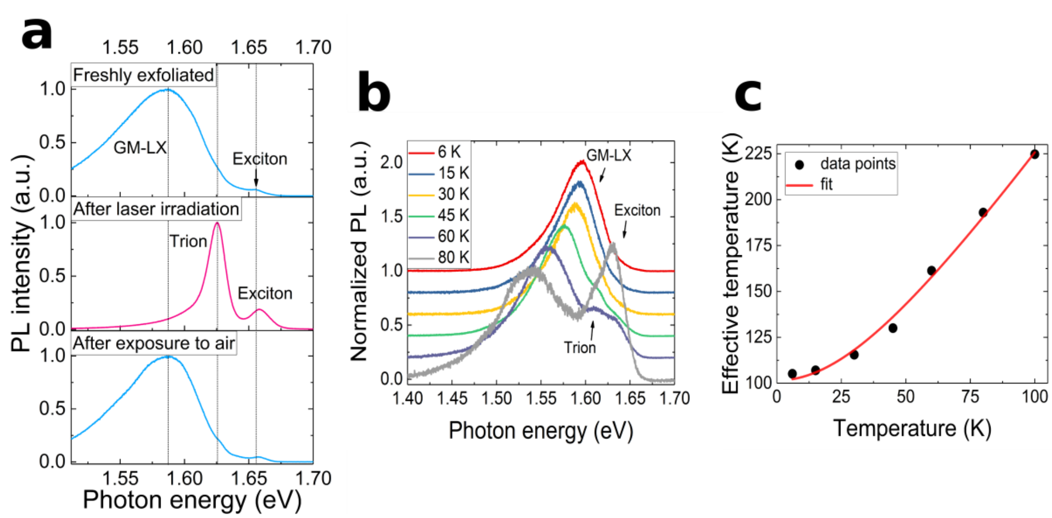

Fig 1: (a) PL spectra at 5 K of $MoSe_2$ monolayer before and after laser irradiation. (b) Temperature dependence of the air gas molecules localized exciton (GM-LX) peak. (c) Effective temperature extracted from the model vs. the actual lattice temperature.

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Perfect Material Absorber for Split-Ring Resonators for Reflection within the Terahertz Regime

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It is known that perfect absorbers can be created using a ground plane to enhance the response of metamaterials [1]. We demonstrate such enhancement of split ring resonators (SRRs) through the coupling of the resonators to a gold layer cavity. At resonance, a dipole is induced within the SRR, in response to this the gold layer mirrors the dipoles charge and acts as a layer of SRRs with the reverse dipole to that of the SRRs, the two opposing dipoles couple together due to the close proximity and for an enhanced system [2]. The gold layer and resonators are separated by a layer of air, as shown in figure 1 a), which form a cavity. On one of the internal faces of the cavity there is a 200 nm thick layer of gold and on the opposite face, there is a pattern of split ring resonators with side length 45 µm with a 5 µm spacing between the SRRs as shown in figure 1 b). Figure 1 c) shows the resonance response of the SRRs and the coupled system. The resonance response of the SRRs is shown with the blue line and has a maximum at 0.61 THz. The cavity is shown with the orange line and has a resonance response at 0.55 THz has an extinction of -45.8 dB. The resonance for the SRRs shows an increase in reflection as there is no gold layer to act as a mirror meaning that outside of the resonance the THz passes through the resonators. In contrast, the cavity shows a decrease in the reflection because the gold layer acts as a mirror reflecting the THz, this reflection is suppressed by the resonance of the SRRs and the THz is absorbed. By comparing the resonances shown in figure 1 it is seen that the addition of the gold layer increases the strength of the resonance response significantly.

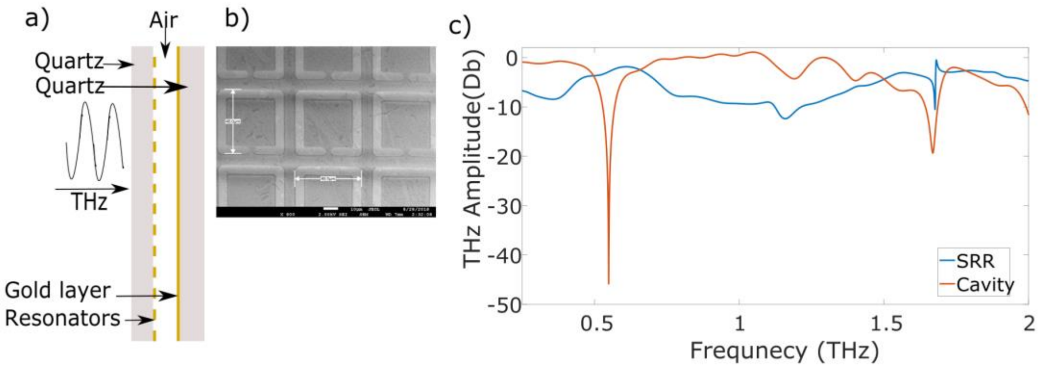

Figure 1: a) A diagram showing the layers for the cavity used to enhance split ring resonators. The thickness of the gold and resonator layers is 200 nm and the cavity thickness is 12 µm. The resonator size is 45 µm. b) The reflected spectrum of the cavity (Orange) enhanced split ring resonators of a side length of 45 µm and a peak at 0.55 THz. The reflection of the split ring resonators (Blue) without the gold layer with a peak at 0.61 THz.

Due to the addition of the gold, the transmission of THz through the cavity is effectively zero. Meaning that any THz that is not reflected is absorbed by the cavity. The resonance has very high extinction of -45.8 dB, typical values for the THz absorption in reflection systems are 99-99.8 % [3,4]. The advantage of using the air gap in the cavity is that the cavity can be filled with other materials easily to study the response of those materials on the resonance response of the cavity.

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Surface Plasmon Polariton modes on silver nanowires

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Scattering-type Scanning Near-Field Optical Microscopy (s-SNOM) enables subwavelength imaging independent of the incident wavelength from GHz to the visible range[1]. It is based on a conventional Atomic Force Microscope (AFM) with a laser (with the wavelength of interest) focused onto the nanometer sized cantilever tip. With this technique, we are able to measure propagating surface waves as a static interference pattern that can be imaged[2]. To suppress the background radiation, the recorded signal is demodulated at higher harmonics of the cantilever oscillation and the so-called pseudo-heterodyne detection scheme is applied.

In this work, we excite Surface Plasmon Polaritons (SPPs) on silver nanowires (Ag NW) placed on a GaAs substrate with a near-infrared laser at λ=853 nm (sketch Fig. 1a, AFM topography Fig. 1b) and measure the SPPs with our s-SNOM device. By employing different excitation geometries and polarizations, different interference patterns arise (Fig. 1c and 1d). In Fig. 1c (blue arrow for incident light direction) the SPP wavelength appears as a much longer wavelength due to a phase retardation geometry. The striking tilted pattern for an incident beam perpendicular to the NW (Fig. 1d) is reminiscent of a beating pattern of different modes. We developed suitable models and fit both data sets. For measurement 1d) we considered two different modes.

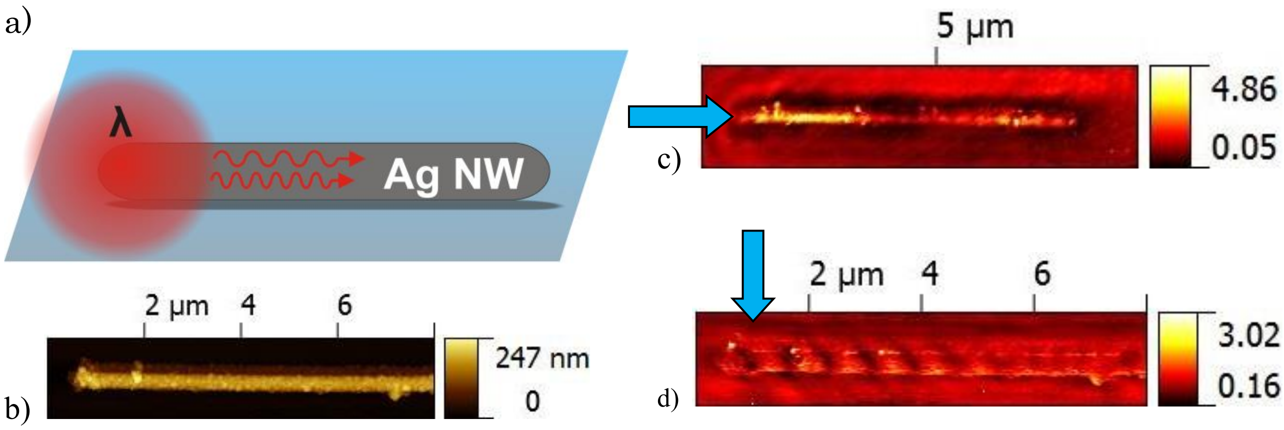

Fig. 1: a) Sketch of an Ag NW on a substrate excited by a laser spot b) topographical AFM picture of an Ag NW (diameter ~200 nm) on a GaAs substrate c) + d) the corresponding s-SNOM images reveal static wave patterns formed by the interference of different wave contributions which depend strongly on the geometry of the incident laser beam.

Our results shed light on a recent report[3], showing an enhanced THz emission for THz photomixers using Ag NWs in their active region.

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Terahertz excitation spectroscopy for semiconductor band structure characterization

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Micro- and opto- electronic device performance is affected by barriers in heterojunctions. Barrier for holes and electrons are established by conduction and valence band offsets. They are determined by various theoretical and experimental techniques. Terahertz emission spectroscopy (TES) is novel technique for conduction band offset determination.

Terahertz (THz) emission from the surface of a semiconductor was demonstrated by Auston group [1]. Since the surface THz emission is a universal phenomenon in semiconductors, THz time domain spectroscopy can be also used as a characterization tool of these materials. Two main mechanisms of THz emission from femtosecond laser excited semiconductor surfaces are the photocurrent surge in the surface electric field and the spatial separation of more mobile photoexcited electrons and slower holes at the surface (the photo-Dember effect). The photocurrent surge effect provides the information on the energy band-bending at the crystal surface, whereas nearly monoenergetic electron bunches excited by femtosecond laser pulse and ballistically propagating towards the bulk can be exploited for studying the details of the electron energy band structure. Intrinsic field may be seen as efficient generation near bandgap of a material. In Fig. 1(a) there is onset in different semiconductor materials. Which are explained due to surface depletion layer or piezoelectric field in InGaN/GaN heterojunction. Peaks in InGaAs and InP denotes scattering to subsidiary valley which lowers THz radiation efficiency [2].

The TES technique assumes ballistic propagation of photoexcited carriers in a thin enough layer of a narrower-gap semiconductor. The layer width should be smaller either than the optical penetration length, for photocarriers to be uniformly distributed, or than the distance the carriers travel while THz-pulse emission takes place. Conduction band offset in GaAsBi/GaAs heterojunction was determined by measuring THz excitation form thin GaAsBi layers [3]. Due to barrier arising in conduction band for electrons, there is no THz generation above GaAsBi band gap. After reaching needed excess energy electrons transfer to GaAs substrate. This leads to efficient THz generation Fig 1 (b).

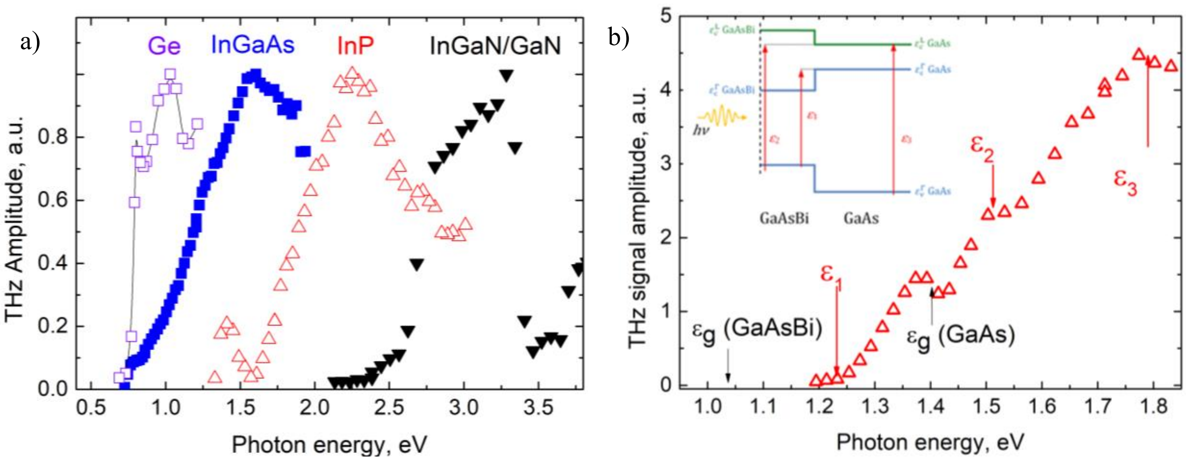

Fig. 1 TES spectra of (a) bulk Ge, 1 μm layer InGaAs, bulk InP, 76 nm layer InGaN on GaN; (b) 100 nm layer of GaAsBi on GaAs substrate (Inset: corresponding energy band structure)

Main advantage of this technique is a direct relation between measured parameters and its spectral feature. Disadvantage is spectral resolution limited by laser pulse width.

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Gold nanorods SPR-based biosensor for mechanotransduction analysis

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Sensing of force and movement in biology involves the conversion of an external mechanical stimulus into a biochemical signal, a process termed mechanotransduction. It plays an important role in embryogenesis[1], vascular physiology[2] and in a variety of sensory systems including those that respond to sound, acceleration, and touch[3], such as microvilli, stereocilia and cilia. In this work, we present an innovative biomechanical biosensor based on plasmonic nanostructures for investigating force generation by mechanosensory cells.
Confinement and enhancement of light by plasmonics allows a high density of independent subwavelength sensor elements to be constructed in submicrometre-sized arrays. The integration of plasmonic structures into devices is enhancing the sensor sensitivity and signal/noise ratio, enabling a new class of ultrasensitive biosensors. Plasmonic materials typically consist of metallic structures that support electromagnetic oscillations. When light hits the nanostructures, free electron oscillations produce the so-called surface plasmon resonances (SPRs). The structure under study is composed by a gold layer deposited on silicon substrate, a polyelectrolyte (PE) dielectric layer with thickness in the range 1÷9 nm, which acts as a spacer layer between the top gold nanorods and the gold layer. Gold nanorods have unique SPR properties that strongly depend on their size and shape[4], but they are also strongly linked to the dielectric layer thickness. We focused our study on the swelling properties of the PE layer in order to be able to control in a dynamic way its thickness. Indeed, pH-induced swelling of a PE layer can be exploited to change the coupling between nanorods and gold film, which results in a resonance shift in SPR spectroscopy. Spectra show a shift of the coupled NR-film SPR during incubation in PBS, suggesting that the gold nanorods are being pushed away from the gold film because of the swelling of the PE layer. After drying, the shift disappears because of the deswelling of the PE layer, showing that no appreciable memory effect is present. The immersion in PBS for 30' of a 7 nm thick PE layer leads to an SPR resonance corresponding to that of a 9 nm thick unswollen PE sample, which shows that the amount of thickness increase in the swelling process is of about 2nm.
These results show that a shift of SPR can be exploited for measuring changes in dielectric layer thickness, which can be applied to produce sensors for estimating forces in cellular mechanotransduction.

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Hyperfine interaction in transitional metal dichalcogenides monolayers

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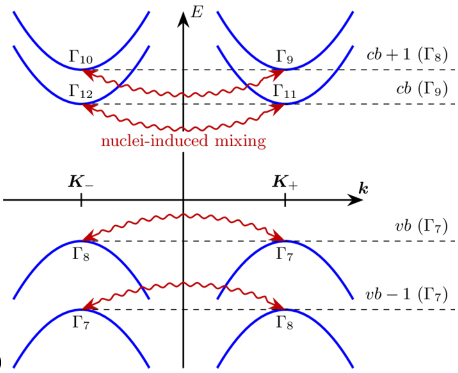
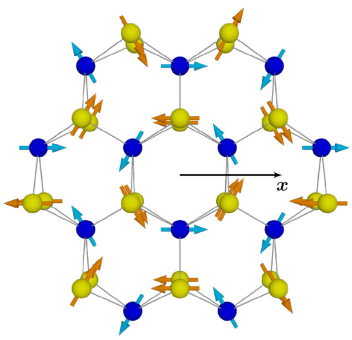
Transition metal dichalcogenides monolayers (TMD MLs) are unique two dimensional semiconductors with direct band gap and strong spin-orbit interaction, which leads to the locking of the spin and valley degrees of freedom [1]. Nowadays quantum dots (QDs) made of single-layer TMD flakes are very promising systems for applications in optoelectronics and quantum information processing systems. The spin-valley relaxation in these structures can be very long, in particular for resident holes [2]. The main mechanism of spin-valley relaxation in small magnetic fields is the hyperfine interaction with the host lattice nuclei, which is assumed to be strong in TMD MLs due to the same relativistic nature as of the spin-orbit interaction.

In this work we present a comprehensive theory of the hyperfine interaction in TMD MLs [3]. Effective Hamiltonian of the hyperfine interaction is derived from the symmetry analysis in the bases of electron and hole states at the $\boldsymbol{K}_{+}$, $\boldsymbol{K}_{-}$ valleys, related by time inversion. The hyperfine interaction with nuclei is much weaker than the spin-orbit splitting and therefore it mixes only pairs of energy degenerate states in the two valleys, as shown in Fig. 1a). For each pair of the closest to the band gap subbands (cb+1, cb, vb, vb-1) we derive effective Hamiltonian of the hyperfine interaction with metal and chalcogens sublattices. Using the explicit orbital composition from the 22-bands tight-binding model [4] we find relations between the independent constants of the hyperfine interaction tensors and estimate their absolute values.

The spin-valley locking leads to the "helical" structure of the hyperfine interaction. As a result, the nuclear spin polarization, created by dynamic nuclear spin polarization (nuclear spin polaron) "rotates" in real space. The lowest energy nuclei spin configuration for the valley pseudospin polarized along $\boldsymbol{x}$ is shown in Fig. 1b). We demonstrate that the hyperfine interaction in TMD MLs is strongly anisotropic, and can contain non-collinear terms at the chalcogens sublattice. In the conduction bands (cb+1, cb) the constants of the out-of-plane hyperfine interaction are two times larger, than the in-plane ones. As a result, initial out-of-plane valley pseudospin polarization decreases approximately 2 times in a few nanoseconds due to precession in the random nuclear field. In the upper valence subband (vb) the hyperfine interaction is purely of the Ising type. This explains the observed long hole spin relaxation times and makes p-type QDs made of TMD MLs particularly promising for the optoelectronic applications.



a)



b)

Fig. 1: a) The band diagram of Mo-based TMD ML with the indication of the representations of the states. The wavy arrows show, that the hyperfine interaction mixes only the energy degenerate states. b) "Helical" dynamic nuclear spin polarization created by linearly polarized light along $\boldsymbol{x}$ direction.

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Dynamical critical exponent and quench dynamics in driven-dissipative condensates

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We investigate universal features of both incoherently-driven and parametrically-pumped exciton-polariton condensates, for experimentally-relevant parameters, when quenching the systems from a disordered to an ordered configuration. First, we evaluate the dynamical critical exponent from the long-time scaling behavior of the dynamics of spontaneously-generated topological defects (vortices) and the characteristic lengths of the systems. We report strong numerical evidence that both polariton systems show the same critical behavior, characterized by the dynamical critical exponent $z \approx 2$ with logarithmic correction to the diffusive dynamics [1]. We find that the universal properties of the system, also in the dynamical case, are dominated by BKT-type of physics in analogy to the static case considered recently theoretically [2] and experimentally [3], ruling out possible contributions of the KPZ ($z = 1.61$) nonlinear terms, for the realistic system sizes considered in this work. Secondly, we study the vortex dynamics, we consider finite-duration linear quenches across the critical point [4]. We demonstrate explicitly that our findings agree with the general Kibble-Zurek mechanism scenario [5], which provides a characterization of the relation of topological defect density to quench rate, through the critical exponents of the system [6]. A detailed investigation of the steady-state system of an incoherently-driven condensate is also performed in order to facilitate our studies. Our results, based on a phenomenological stochastic model for the lower-polariton branch of an incoherently-driven condensate [7], shows analogous critical behavior to earlier work based on coupled exciton-photon equations for the parametrically-pumped condensates [2].

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Heralded *N*-photon sources

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We proposed in 2014 a scheme to produce light that consists exclusively of *N*-photon bundles (packets of *N* photons), for a tuneable integer *N* [1]. This is achieved by Purcell-enhancing a class of processes in the emission of a quantum source, the so-called *leapfrog processes*, that involve virtual photons which are strongly quantum correlated [2]. Following our exhaustive mapping of such leapfrog processes in resonance fluorescence [3], we show how one can similarly Purcell enhance more sophisticated configurations with the aim of realizing a universal quantum emitter, with, as an illustrative and important particular case, an **heralded N-photon sources**, that is, with one photon signaling the arrival of a *N*-photon bundle [4]. Such a source would be considerably more useful for technology as it would operate in a regime more compatible with pulsed operation, rather than suffering from the uncertainty in the time of emission under CW excitation. This would allow, for instance, the development of scalable *kN* photon sources (with prospects of high-purity 20-photon sources or higher with today's parameters [5], useful for boson sampling applications among other immediate uses). At a fundamental level, such sources also bring new questions on the nature and robustness of high-photon number correlations [6], which we will discuss alongside with other prospective applications.

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Anti-chiral edge states in Graphene exciton-polariton strip

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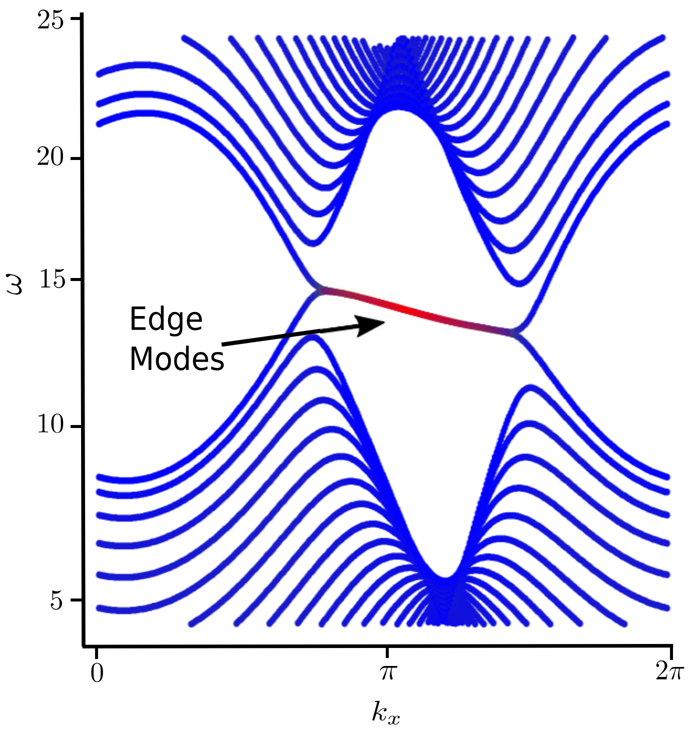
Nontrivial topology ensures the existence of chiral edge states, which propagate in opposite directions and eliminate backscattering [1]. Even though the field of topological physics has advanced significantly, due to the presence of counter-propagating edge states the control over the flow of information (charge/spin) from one side to the other side of a device has remained a challenge. This problem can be overcome if both the edge states propagate in the same direction.

We present a scheme to obtain antichiral edge states in an exciton-polariton honeycomb lattice with strip geometry, where the modes corresponding to both edges propagate in the same direction. Under resonant pumping the effect of a polariton condensate with nonzero velocity in one linear polarization is predicted to tilt the dispersion of polaritons in the other, which results in an energy shift between two Dirac cones and the otherwise flat edge states become tilted. Our simulations show that due to the spatial separation from the bulk modes the edge modes are robust against disorder [2].



Dispersion spectrum where both the edge states have the same nonzero velocity.

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Quantum reservoir processors for quantum information processing

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We introduce quantum reservoir processing as a platform for quantum information processing developed on the principle of reservoir computing that is a form of artificial neural network. A quantum reservoir processor can efficiently perform qualitative tasks like recognising entangled states or quantitative tasks like estimating entropy, purity and negativity. This architecture can be implemented as both softwares and hardwares. For hardware implementation, quantum reservoir processors can be realized in a variety of systems, e.g., arrays of semiconductor quantum dots, superconducting qubits, exciton-polaritons in semiconducting microcavities, cold atoms and NV centres in diamond.

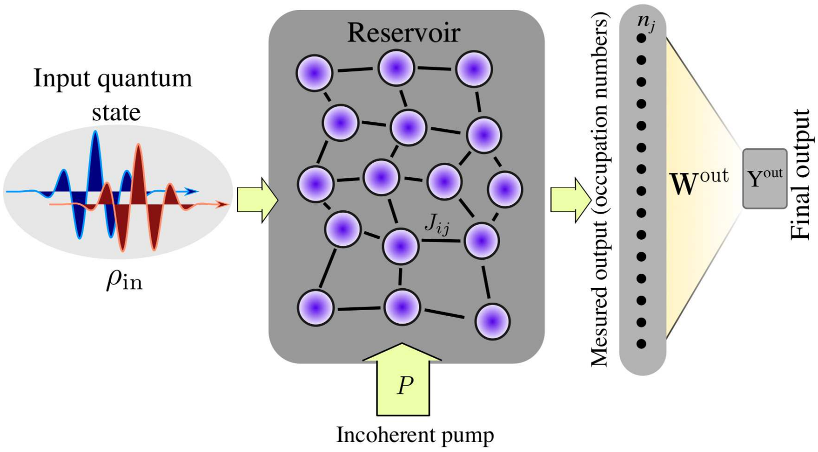

Figure 1: Schematic representation of a quantum reservoir processor. A quantum state in the form of an optical field excites a fermionic lattice with random coupling J_{ij} in an effective Fermi-Hubbard model. The occupation numbers of the fermionic sites are extracted and combined to give a final output. This generic architecture can perform various tasks, such as identifying a quantum state and simultaneously estimating its various properties.

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Planar Aperiodic Arrays as Metasurfaces for Optical Near-Field Patterning

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In flat optics, the modulation of phase, amplitude, polarization of light with subwavelength metal and dielectric antennas has been employed with great success to shape the properties of the reflected and refracted beams, which proved a versatile approach to replace or even enhance the performance of far-field optical elements. [1,2]

In our work, we explore a fundamentally new perspective for flat optics by designing planar metallic metasurfaces for functionality in the optical near-field. This concept provides the possibility to engineer entirely new optical elements that act in the plane or vicinity of the metasurface. We demonstrate this functionality of near-field modulation and control by fabricating a set of aperiodic arrays of nanoresonators (Figure 1) that are able to achieve light concentration at the centre of the pattern, generation of optical vortices, and switching of the near-field intensity pattern via changing the wavelength or linear polarization angle of the illumination. The obtained near field modulation is evaluated by two-photon-photoluminescence that probes the intensity of the near-field under widefield illumination, which is essential to capture the collective effects induced by our metasurfaces.

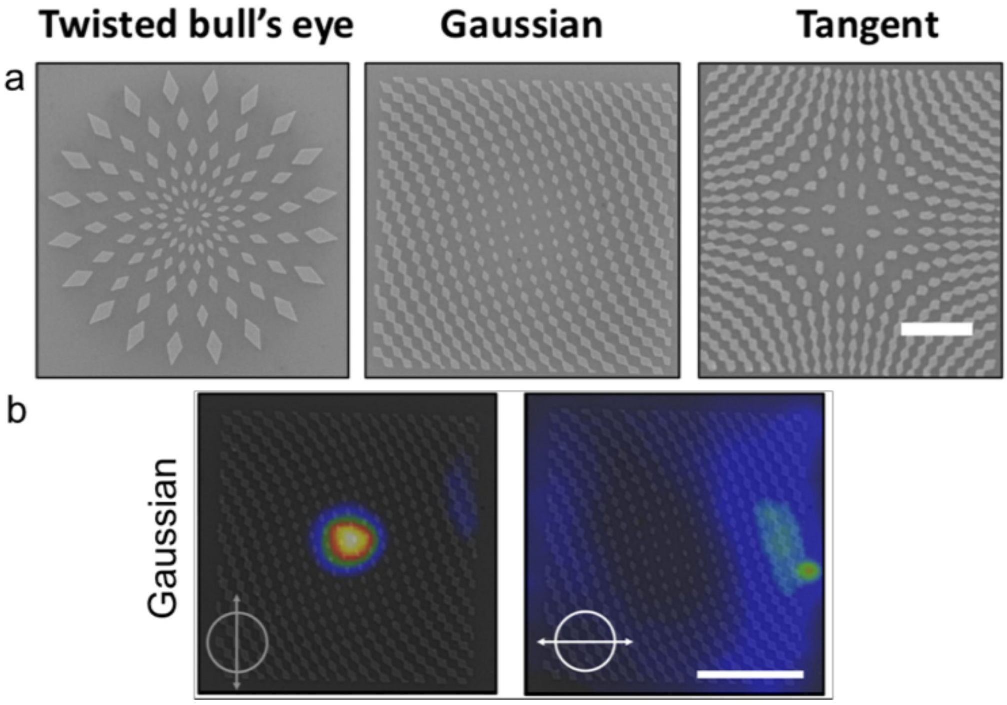

Fig. 1 (a) Scanning electron images of three different aperiodic metasurface structures. (b), Optical near-field intensity measured by two-photon photoluminescence of the Gaussian pattern under illumination with different linear polarization.

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Hybrid Metal-Molecule Systems: from a Classical to an Atomistic Description

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In the last few years, the development of fabrication and characterization techniques and their capabilities to manage light-matter interaction at the sub-nanometer scale have spreaded the interest toward the quantum nature of matter among the scientific communities dealing with nanophotonics and plasmonics.

In this work the absorption properties of an hybrid system consisting of a molecular emitter, i.e. *trans,trans-1,4-diphenyl-1,3-butadiene* (t,t-DPB), interacting with a tetrahedral cluster of Ag20 are investigated by considering several levels of approximations: (i) the *Time-Dependent Density Functional Theory* (TD-DFT) [1], (ii) the *Finite Element Method* (FEM) [2] and (iii) the *Dipole-Dipole Model*.

For metal-molecule distances smaller than 0.45 nm, each absorption spectrum is characterized by the presence of two peaks. Reasoning in terms of two-coupled dipoles model, these two peaks are explained as the *bonding* dipole due to the hybridization of the z- components of the surface charge of the two oscillators, i.e. molecule and cluster, and the uncoupled x- and y- modes of the three-fold degenerate plasmon. In more details, the molecule transition dipole moment oriented along the z-direction interacts only with the z component of the cluster transition dipole and creates two hybrid states, one of which is not visible or dark. In Fig.1 the effects of the metal-molecule distance on the spectral position of the lower-energy peak are reported. Even if the *dipole-dipole* interaction model seems to work well in terms of trend for distance larger that 0.5 nm, the effects of the quantum electron density distribution appear to be crucial in order to faithfully describe the electro-optical interaction among the two nanosystems in close contact (almost touching). Classical models seem, thus, to fail in reproducing TD-DFT results for the ultra-nearfield regime of interaction.

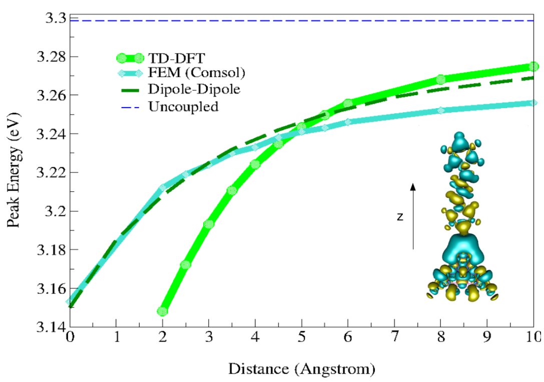

Fig. 1: Bonding mode energy *vs* metal-molecule distance. Inset: transition density at the resonance for d = 2 Å.

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Polariton spectrum due to the presence of structural defects and elastic deformation in the chain of microcavities containing quantum dots

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The theoretical study of the photonic band structure of binary one-dimensional arrays of tunnel-coupled microcavities shows that subjecting the system to the controllable elastic strain is an effective tool for altering its eigen mode structure and optical properties. This applies both for the cases of microcavity arrays with embedded quantum dots and for quantum-dot-free lattices. Similarly to our previous works [1,2], the numerical calculations were carried out for the following modeling values of parameters corresponding to real resonator systems (see e.g. Ref. [3]) and leading to polariton effect. The frequency of cavity-localized resonance photonic modes lies in the terahertz range The strain and the photonic disorder lead to an increase of the effective mass of the propagating photon modes in the structure and hence to a decrease of their group velocity. This results in formation of slow light modes that can be efficiently controlled by the externally applied strain. These results pave the way to applications of irregular microcavity chains in optical integrated circuits and as classical or quantum optical switches [4]. The considered arrays of coupled optical cavities open promising vistas for fabrication of optical circuits, where the light propagation would be controlled by variable contents of structural "defects" (composition and positions of microcavities) as well as by the alterable magnitude and character of applied strains.

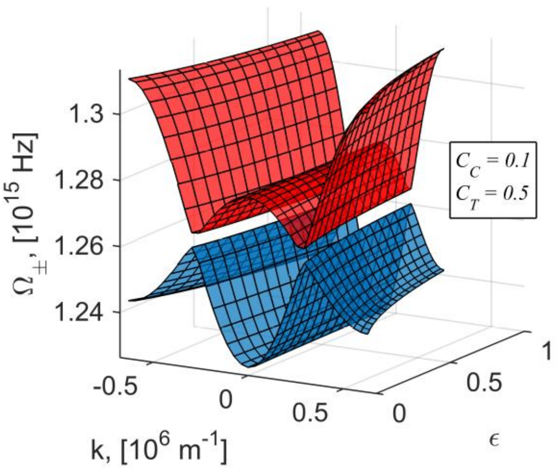

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Fig. 1:The dependence of dispersion frequencies $\Omega_\pm\ k,C_C,C_T,\varepsilon$ of electromagnetic excitations in a nonideal 1D chain of microcavities on defect concentration and elastic deformation caption. This chain of cavities has a randomly located defects in composition (with concentration of C_C) and distances between the pores (with a concentration of C_T), ε is a corresponding component of strain tensor.

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Photonic Crystal Nanocavity in 2D Layered Perovskite

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Organic-inorganic two-dimensional (2D) perovskites are considered very intriguing materials thanks to their stunning optoelectronic properties and easy manipulation. These semiconductors have a quantum-well structure consisting of sub-nanometric inorganic layers (metal halides) confined between organic layers (long chain ammonium cations). The last ones acting as a potential barrier [1].
Exploitation of 2D perovskites in scalable, on-chip nanophotonic circuits and cavity quantum electrodynamics (QED) experiments requires robust techniques for the fabrication of high-quality optical resonators. In particular, monolithic systems, in which the photonic resonator hosts the quantum emitter is required for ideal on-chip devices overcoming problems such as the spatial matching between emitter and the optical mode, scattering losses, etc. [2].
In this context, for the first time, a photonic crystal nanocavity in a 2D single crystal perovskite has been designed and successfully realised (Figure 1a).

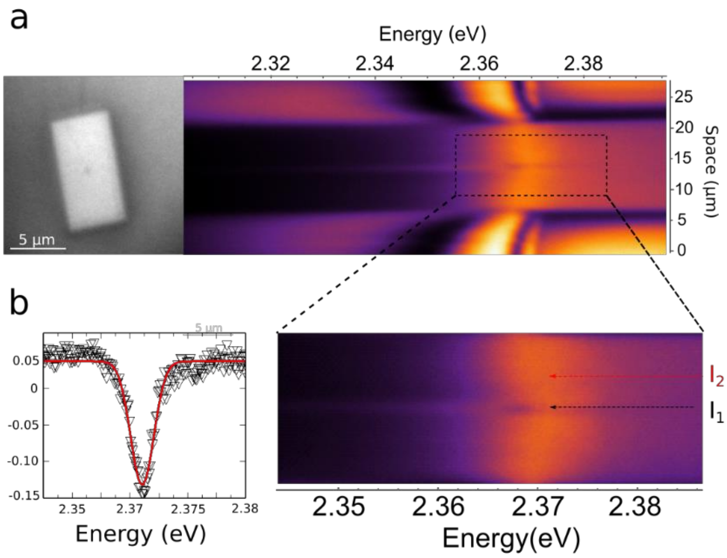

Figure 1. a) Left Panel. Image of photonic crystal with L_3 optical cavity at the center (dark spot) measured at low temperature (T=4K); Right Panel. Reflection spectrum of the photonic crystal with white light in which is visible an optical mode in correspondence of the nanocavity. b) Optical cavity mode obtained by the difference I_2-I_1, highlighted in the zoomed spectrum in the right.

High quality 2D perovskites have been synthesized by an antisolvent vapour assisted crystallization method that allows to obtain extremely smooth and uniform flakes extended hundreds of square micrometers. Photonic crystal nanocavities have been patterned on single crystal by Focused Ion Beam (FIB) milling. The properties of the cavity modes have been controlled by modifying the lattice parameters. In particular, a L_3 photonic nanocavity has been obtained with a quality factor, Q, of 500. Note that this is done directly in the active material where the exciton emission is preserved, marking a first step toward monolithic integration of a perovskite emitter–cavity system.

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Room Temperature polaritons in 2D hybrid organic-inorganic perovskites

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Hybrid organic-inorganic perovskites, a natural realization of a self-assembled multiple QWs structure, have emerged as very promising materials for photonic applications. They offer a great synthetic versatility, showing stable excitonic resonances up to room temperature. We investigated the strong light-matter coupling and the excitonic properties of 2D perovskite by using single-crystal flakes. In strong light-matter coupling regime, polarization-resolved photoluminescence measurements show new excitonic features that can be tuned by changing the organic counterpart of the 2D perovskite. We also exploited the natural optical birefringence of the single crystal to completely rotate the linear polarization degree.

Furthermore, embedding the 2D perovskite single crystal in a planar microcavity, a spin dependence of the exciton-exciton interaction energies is measured, similar to the ones known for inorganic quantum wells at cryogenic temperatures. From our experimental evidences the interaction constant value results more than one order of magnitude larger than alternative room temperature polariton devices reported so far.

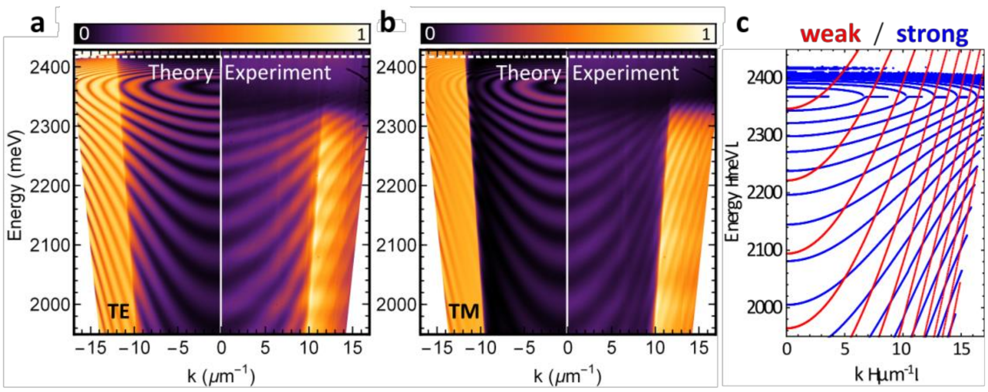

Figure 1: (a, b) Energy vs in-plane momentum reflectivity spectra for TE, (a), and TM, (b), polarization, collected under white light illumination on single perovskite crystal. $k = \frac{2\pi}{\lambda}\sin\theta$, where λ is the wavelength and θ the incidence angle. Multiple resonances are due to the Fabry-Perot modes. In the right/left part of Fig. (a,b), the experimental/simulated reflectivity maps are reported. (c) Reflection minima calculated with (blue lines) and without (red lines) the excitonic resonance. The white dashed lines indicate the exciton energy position.

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Laser-induced super-long-living spin excitations in a purely electronic two-dimensional gas.

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The lowest-energy excitation in a $\nu = 2$ quantum Hall system is a purely electronic cyclotron spin-flip exciton (CSFE) [1] where electron is promoted from the upper spin sublevel (with 'spin-down') of the zero Landau level to the next Landau level with 'spin-up'. The CSFE energy is well smaller than the cyclotron one: it is separated from upper magnetoplasma mode by a negative Coulomb shift (1mV) and from the ground state by a gap of $\approx 5-7\,$mV. The q-momentum dispersion of the CSFE energy is rather weak and has a smooth minimum at $q = q_0 \approx 1/l_B$ (l_B is the magnetic length [1]). The considerable Coulomb shift consists of two negative contributions: the first one is the zero-momentum $q = 0$ shift determined only by the second-order Coulomb correction [2]; and the second part is the first-order correction at a finite momentum [1]. Both contributions at $q \approx q_0$ are approximately equal. At low temperature (actually at $T < 0.1\,$mK) the CSFE can only relax with the emission of hard acoustic phonons [3]. An extremely long life of the state is determined by the following reasons: (i) the studied relaxation is simultaneously the energy and spin relaxation process – the CSFE is a 'dark' exciton, radiative relaxation is suppressed; (ii) the state is energetically far from the ground state, so emitted phonons possessing a very short wavelength are only weakly coupling to the state. A theoretical estimate yields the characteristic CSFE relaxation time expected to reach several milliseconds. At higher temperatures a radiative mechanism of the relaxation is switched on via thermal-activation transition to the upper magnetoplasma state fast-relaxing radiatively. As a result, experimentally even at $T > 0.4\,$mK the CSFE relaxation (actually the spin relaxation) can occur with the characteristic time of 100 mcs [4] — still super long for unconfined systems consisting of free conduction-band electrons. In the works [4-5] the CSFE relaxation and kinetics are studied both experimentally and theoretically. The dense CSFE ensemble (with the CSFE number N_x reaching ten percents of the number of magnetic flux quanta N_ϕ) is created by means of the resonant photoexcitation pumping. To monitor the CSFE ensemble state, an additional time-resolved technique of the photoinduced resonant absorption/reflection (PRA/R) is employed. Experimentally, at a given CSFE concentration $n = N_x/N_\phi$ above 5 percents a threshold enhancement of the PIRA/R signal is observed when the temperature is dropping below some value $T_0 = T(n)$ within the $0.4\,$K$< T < 1\,$K range. This effect can be explained in the framework of a CSFE-ensemble phase transition to a coherent state — Bose-Einstein condensate. Theory describes both incoherent and coherent states in terms of the so-called excitonic representation (see Refs. [2,3] and the Supplementary Note 1 in Ref. [5]) and gives a tenfold increase in the PIRA/R signal during the CSFE-ensemble transition to the condensate state (i.e. to a Bose-condensate formed in a purely electronic system). The theory estimation agrees with the experimental data.

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Electron-vibrational interactions in molecular aggregates: from exciton absorption and luminescence to exciton-polariton dispersion in nanofibers

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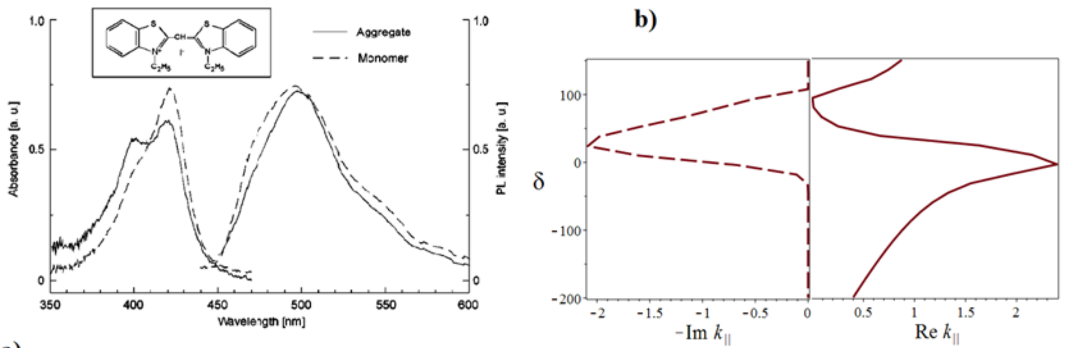
Recently organic dye nanofibers demonstrated long-range Frenkel exciton polariton (FEP) propagation at room temperature [1] owing to a considerably larger oscillator strength compared to inorganic semiconductors. To realize such long-range propagation, the FEPs should be stable. Their stability is governed by splitting between two branches of the polariton dispersion, the correct calculation of which is of decisive importance. The latter necessitates the proper description of the Frenkel exciton line shape that is impossible without taking the electron-vibrational interaction into account. In general, taking the effect of strong electron-vibrational interactions on the FEPs into account is a non-trivial problem. The point is that in this case both the interaction with radiation field and electron-vibrational interaction should be considered as strong.

In this work we have developed a model that enables us to account for electron-vibrational effects on absorption, luminescence of molecular aggregates and FEPs in nanofibers using a mean-field theory [2,3]. The exciton luminescence and absorption spectra in our mean-field theory obey Stepanov's law. Among other things, our theory describes both narrowing the J-aggregate absorption and luminescence spectra, and diminishing the Stokes shift between them with respect to that of a monomer. The model also generalizes the mean-field electron-vibrational theory [2] to the systems with spatial symmetry, exciton luminescence and the FEPs with spatial dispersion. The correspondence between manifestation of electron-vibrational interaction in monomers, molecular aggregates and exciton-polariton dispersion in nanofibers is obtained by introducing the aggregate line-shape functions in terms of the monomer line-shape functions. With the same description of material parameters we have calculated both the absorption and luminescence of molecular aggregates (Fig.a) and the FEP dispersion in nanofibers (Fig.b). We apply the theory to experiment on fraction of a millimeter propagation of FEPs in photoexcited organic nanofibers made of thiacyanine (TC) dye [1].



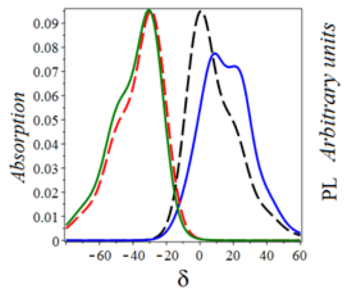


Fig.a). Experimental absorption and photoluminescence spectra of TC aggregates and monomers (top), and theoretical description of aggregate absorption and photoluminescence (bottom). In the top solid curve represents spectra of the aqueous solution containing TC aggregates; dashed curve, spectra of a monomer solution prepared by dissolving TC dye in methanol. In the bottom solid curves represent the aggregate spectra; dashed curves - spectra of a monomer. Dimensionless detuning δ increases when the wavelength decreases.

Fig.b). FEP dispersion for real (solid line) and imaginary (dashed line) part of the wave number corresponding to the wave vector parallel to the fiber calculated with parameters that are identical to those of the bottom of Fig.a).

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Phonon assisted ligth matter interaction in the cavity quantum electrodynamics

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It is studied the influence of the phonon-assisted cavity feeding mechanism on the optical and quantum properties of the main systems in the cavity quantum electrodynamics; which are the vertically stacked quantum dots, a quantum dot-cavity system, and a photonic molecule coupled to a quantum dot. It is found that the phonon-assisted cavity feeding is a selective decoherence mechanism, that makes the coherences constant from short times and affects the structure of the associated Hilbert space. Its effects over the system observables are deeply studied and allow to introduce the intermediate quantum coupling regime. This new regime is responsible for many effects that have been considered as anomalous in the literature. The existence of this regime open a new research scenario in the cavity quantum electrodynamics, and it is corroborated by experimental measurements of a photonic molecule coupled to a quantum dot, which was realized in cooperation with an experimental research.

Express terahertz diagnosis for breast cancer.

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In 2018 cancer was the cause of death for approximately 9.6 million people in the world what makes it second most deadliest disease [1]. For the women, the most common type of cancer is breast cancer. When diagnosed at early stages it can be cured in almost 90-100% cases but here is where the problems start. Methods which are used for the diagnosis such as cytology, ultrasound and X-ray studies struggle to identify neoplasia. In most of the cases women find out that they got cancer when it is already on the 2-3 stage. Thus, the issue of prevention and diagnosis of breast cancer becomes especially relevant. Recent studies in the field of THz diagnosis showed that there is a difference between spectral characteristics of normal and cancerous cells [2]. Therefore, promising is to use sources and recorders of the THz radiation for an early diagnosis of breast disease.

Here we used the spectrometer based on a silicon nanosandwich structure (SNS) prepared in the Hall geometry, which simultaneously can act as an THz emitter and as a detector. The SNS itself is an ultra-narrow p-type quantum well (Si-QW) confined by the δ-barriers heavily doped with boron on the n-Si (100) surface. These structures have been shown to demonstrate high mobility of charge carriers [3]. Another fine point is that boron atoms inside the δ-barriers form trigonal dipole centers (B^+ - B^-) due to the negative-U reaction: $2B^o \rightarrow B^+ + B^-$. These dipole centers create crystallographically oriented sequences that confine the edge channels in p-Si-QW [3]. In addition, it was shown that by varying the drain-source current the p-Si-QW edge channels perform as effective sources and recorders of the THz and GHz radiation due to the presence of negative-*U* dipole centers of boron, with the microcavities embedded that allow the control of THz and GHz spectra.

During experiments device was aimed to the point of neoplasm localization while measuring current-voltage characteristics of reflection and/or emission radiation from bio-tissue. In other words, device operates as a balance recorder. I.e., current-voltage characteristics of the device allow the information about bio-tissue properties. Figure 1 shows the dependence U_{xx} on the frequency value determined by varying the stabilized drain-source current value for three different cases that correspond to different stages of oncology of the female breast. Particular attention was paid to the relation between power enhancement of the signal with the development of cancer as well as the features in the 2.5-3.3 THz range that is frequency characteristic of the DNA oligonucleotides, with the process of developing oncology. Other features appear to indicate deterioration of the lymphatic system (160 GHz). The proposed method is quite promising for the more detailed early stage THz diagnostics of the breast diseases.

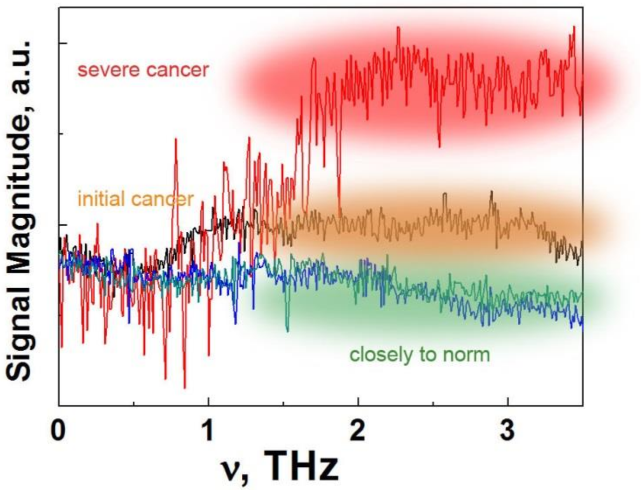

Fig. 1. The THz spectra that result from the balance of the radiation of a biological tissue and the silicon nanosandwich emitter. These spectral characteristics allow the classification of different pathological states of tissue

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Electronic properties of an elliptical quantum ring with variations in its height

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The quantum dots and quantum rings are interesting low dimensional structures due to the facility for controlling their electronic and optical properties with size and shape changes [1]. In the experimental works, in most of cases, there are difficulties to reach a perfect symmetry for the system. Hence, it is necessary taking into account the shape and size of the structure with asymmetries.

In this work, the energies and wave functions of an electron confined in an elliptical quantum ring with variable height and modulated by trigonometric functions for three different shapes of the cross section were calculated: square, triangular and parabolic. In addition, the number of hills on the ring was varied as can be seen in Fig. 1. The 3D Schrödinger equation is solved by the finite element method in the software COMSOL Multiphysics [2] using a coefficient form for a partial differential equation. The edges of a parallelepiped were used as a boundary on which the wave function becomes zero. In order to take the different masses in the system, the program was built with two domains assigning the parameters depending on the material (GaAs embedding in Al_xGa_{1-x}). Related to the cross-section shape, the energies are in general from highest to lowest in the following order: triangular, parabolic and square. The degenerations or not of the states are explained by the isolation or not of the quantum dots formed on the ring.

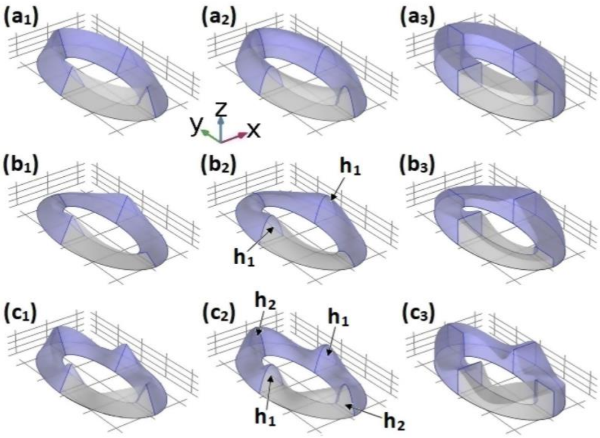

Fig. 1: Schematic representation of the studied quantum ring for triangular, parabolic, and square cross-sections, corresponding to the first, second and third columns, respectively. The number of quantum dots has taken as zero, two and four. The h_1 and h_2 labels represent the quantum dots.

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Self-similarity and its effects on electronic and optical properties in a quasi-periodic graphene-based superlattice

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The outstanding behavior of graphene-based systems under magnetic field has promoted its study by several authors [1-3]. Additionally, when a graphene periodic superlattice is used the energies have strong changes in comparison with graphene in bulk. In particular, the presence of self-similarity or self-anti-similarity in the superlattice has important influence on energy spectra and the optical properties.

In order to calculate eigenvalues and eigenfunctions has been taken a one-dimensional Dirac-like equation to model the quasiperiodic graphene-based Fibonacci superlattice. The system is under perpendicular magnetic field. Energy spectra for three magnetic fields are depicted in Fig. 1, the first one taken as B =2.92 T and (b, c) integer powers of golden mean τ. In these two last values is evidenced the self-similar ($2.92\tau^4$) and self-anti-similar ($2.92\tau^2$). Note the presence of oscillations and comparing with graphene in bulk, a red-shift of the subbands is observed. The energy spectra as well as strength transitions and magneto-optical absorption are discussed in detail in this work.

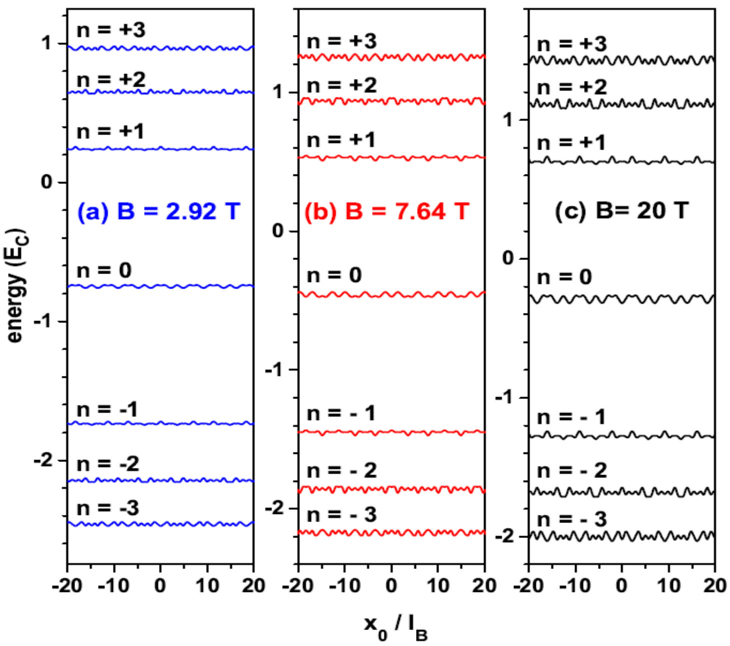

Fig. 1: Subbands of Fibonacci superlattice graphene as a function of the wave function center (l_B units) for three magnetic fields and $V_0/E_F = 2\pi$.

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THz sources for stimulation of the biological reactions.

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In today's world, even with the high development of medicine and technology is still a problem associated with the fact that there are diseases, therapeutics which still meets many obstacles associated with insufficient level of technological progress. However, in recent years, there have been THz emitters made within frameworks of the silicon planar technology, the THz radiation of which is able to affect both the lymphatic system and the work of biological processes at the cellular level, will radically change the view of solving the problems of Alzheimer's and diabetes.

The technology of devices production described by the silicon nanostructures heavily doped with boron. The presence of edge channels with the different topology of microcavities inserted allows you to control the radiation spectrum as seen in Fig. 1. Specifically the interplay between quantum quantization phenomena and spectral dependences is observed.

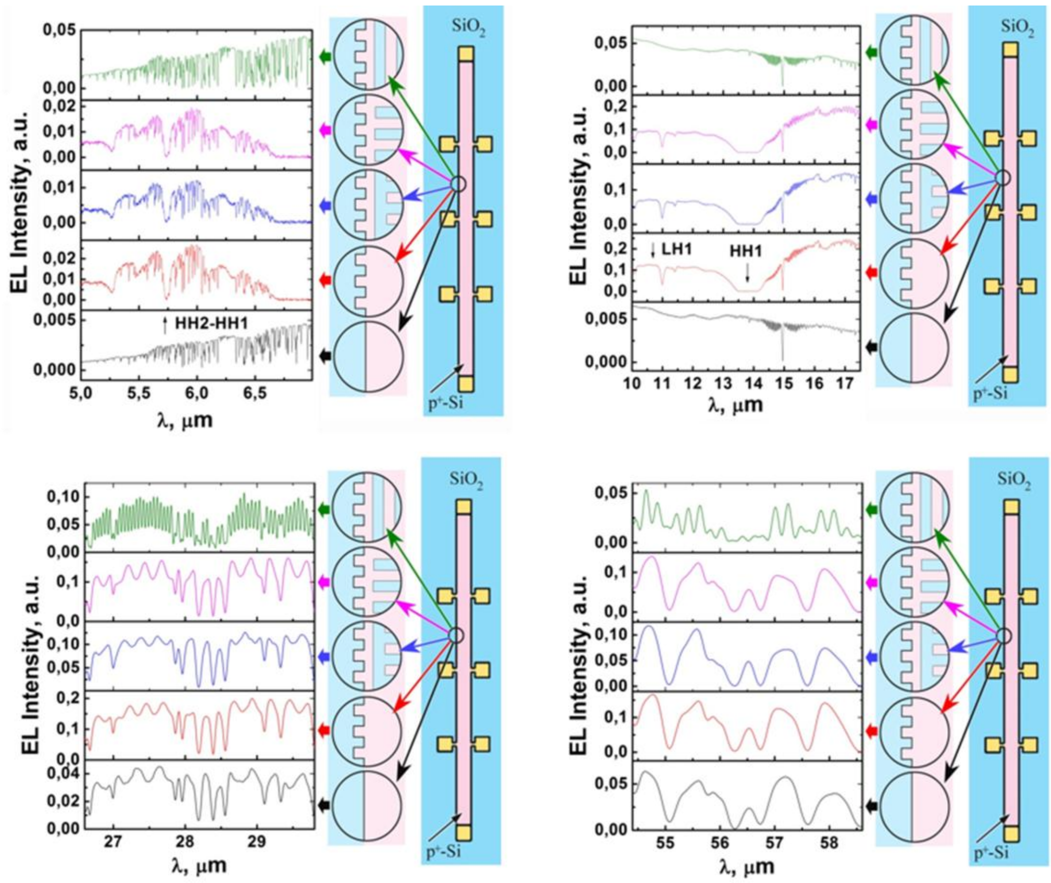

Figure 1. Spectral dependence of the GHz and THz modulated radiation vs the sample architecture. Different type microcavities are demonstrated which give rise the variations in the luminescence spectra.

All samples show coherent phenomena at room temperature and are easily reproducible. These THz emitters are included in the therapy of coronary heart disease in the Almazov national medical research centre. It should be noted that the picture of the lymphatic network is consistent well enough with the known network of acupuncture, as well as with the established schemes of transmission of nerve impulse. The potassium-sodium pump works in the same way. The propagation of IR radiation described by the Hodgkin-Huxley mechanism as the propagation of an asymmetric soliton along DNA oligonucleotides. Most of the body's reactions occur at a frequency of 2.8 GHz, corresponding to the excitation of hydrogen bonds in guanine. Terahertz radiation can stimulate the lymphatic system in the brain and body, which contributes to the fight against ischemic heart attack and should contribute to the fight against Alzheimer's.

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Effects of phonon-assisted cavity feeding process on the Dicke superradiance critical phenomena

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Single-photon superradiance, the cooperative spontaneous emission of one photon from an assembly of identical quantum emitters, exhibits all the good properties of quantum many body systems in atomic physics and quantum optics. In this contribution, we present a theoretical proposal where the effects of the phonon-assisted cavity feeding (PACF) on an assembly of emitters in a cavity, i.e., the Dicke model, are analyzed. The cavity feeding assisted by phonons is based on a combined effect of exciton-cavity and exciton-phonon couplings, and accounts for a process where the exciton decays into a cavity photon and the energy discrepancy is compensated by the emission or absorption of a phonon. First, the power photoluminescence spectra are calculated in order to characterize the main features of the emission. In the next stage, we assess the collective effects of the strong coupling regime related to Dicke superradiance (focusing at phonon-assisted features) as it has been reported experimentally. On the other hand, a sharp analysis of the correlations in the system is carried out, mainly the quantum correlations like entanglement; the statistics of the emission is characterized by the higher-order correlation functions.

Effects of the dimensions, magnetic field and intense non-resonant laser on electronic properties in an eccentric quantum ring

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The possibility of controlling electronic and optical properties in low dimensionality systems, in particular quantum rings, as well as their promising multiple applications become interesting systems to be studied [1].

In the present work, calculations of electronic properties were made in an eccentric GaAs quantum ring embedded in a $Al_{0.3}Ga_{0.7}As$ matrix, with variations in the dimensions of the structure and combined effects of magnetic field and non-resonant intense laser field (ILF). Additionally, dipole matrix elements were calculated for different eccentricity values of the quantum ring and linear polarization directions of the ILF. The numerical finite element method was used to solve the Schrödinger equation with Dirichlet boundary conditions. The temporal dependence of the equation disappears with Kramers-Henneberger unitary transformations [2]. Taking into account the different effective masses in the system, the dressed potential is calculated both numerically and analytically for linear polarization of the ILF. The appearance of oscillations in the energy spectra as a function of the magnetic field are evidenced. Also, the importance of the polarization of the resonant laser that excites the transitions is demonstrated by the activation of different transitions depending on the polarization-direction. A comparison of the energies with the limiting case of a quantum disk, which can solve analytically, validates our results.

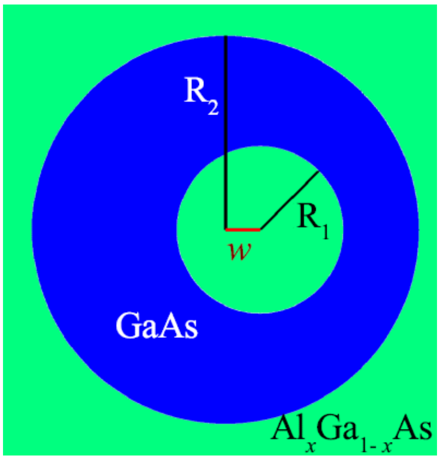

Fig. 1: Eccentric quantum ring with inner and outer radii R_1 and R_2, respectively. The eccentric parameter is represented by w.

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