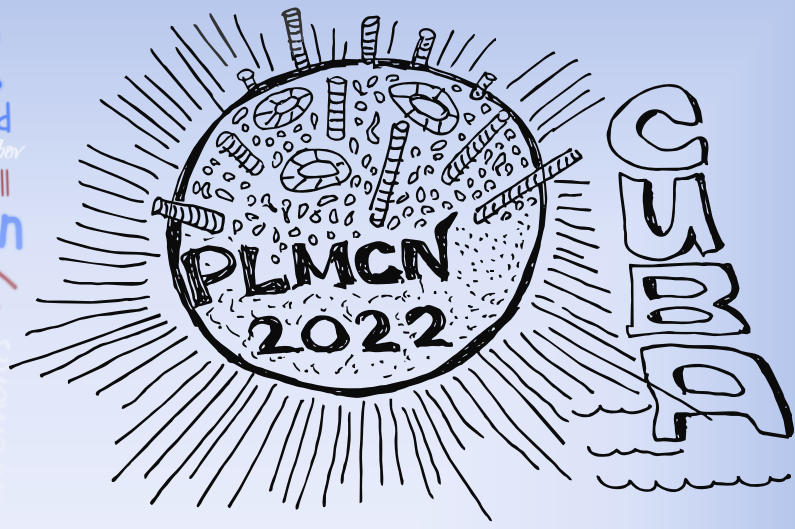


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movements



22nd International Conference on

Physics of Light-Matter Coupling in Nanostructures

Varadero - Cuba
April 10-16, 2022

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topology modeling
allotted diffusion
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Welcome to PLMCN22!

The **International Conference on Physics of Light-Matter Coupling** has a long and, I would modestly say, a glorious story. Started in St. Nectaire (France) in 2000, this conference visited already 12 countries in Europe, Asia and America. It has grown from a small workshop to a significant international event attended by over 300 delegates in its peak years before the pandemic. As many other scientific conferences, the PLMCN has been forced to go on-line in 2020, and we decided to skip the edition of 2021 hoping that the traditional on-site format will be restored by 2022. The organisation of the conference in 2022 was quite challenging, but after all it worked out. I am very happy to welcome the participants of PLMCN 2022 in the beautiful Varadero resort. My feeling is that it is crucially important for this community to get together again after the two-year break that costed so dearly to many of us. I wish everyone to enjoy not only the talks and posters but also, and mostly, informal discussions during coffee breaks and lunches, at the free time in the evenings. This is why we are here. The experience shows that whatever we talk about, some interesting physics comes out of this eventually. I would like to express my sincere gratitude to Nina and Pino who made this event possible. Please blame them for any practical issues if any (joke!). Don't miss our welcome mojito!

Happy PLMCN!

Alexey Kavokin

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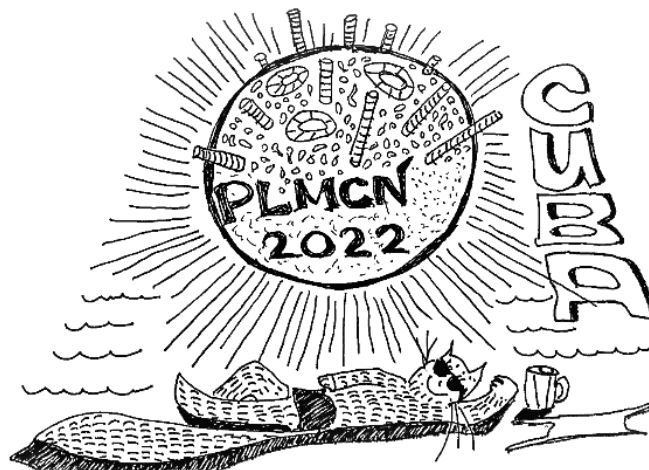
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BOOK OF ABSTRACTS



PLMCN22 SCIENTIFIC PROGRAM

Topical sections:

	–	Excitons and Polaritons 2D Materials
	–	Optics of 1D structures and Quantum Dots
	–	Physics of exciton-polaritons
	–	Non-Hermitian and Topological physics
	–	Plasmonic, Metamaterials, Novel optical devices
	–	Indirect excitons and spin-related phenomena

* – talk will be presented by a co-author

T.B.C. – talk not confirmed

MONDAY, April 11, 2022

10:45-11:05	Welcome Coffee and On-site Registration
11:05-11:15	Opening
11:15-12:00	Andreas Stier
12:00-12:15	Jonas Kiemle
12:15-12:30	Manuel Katzer
12:30-12:45	Aidan Campbell
12:45-13:00	Bilal Tanatar T.B.C.
13:00-15:00	Lunch
15:00-15:30	Stella Kutrovskaya
15:30-16:00	Mikhail Portnoi
16:00-16:15	Svetlana Vitusevich
16:15-16:45	Coffee Break

TUESDAY, April 12, 2022

09:15-10:00	Daniele Sanvitto
10:00-10:15	Sergey Alyatkin*
10:15-10:30	Yago del Valle Inclan Redondo
10:30-10:45	Hassen Souissi

10:45-11:15	Coffee Break
11:15-11:45	Martin Weitz
11:45-12:15	Elizier Estrecho
12:15-12:30	Dąbrowka Biegańska
12:30-12:45	Ismaël Septembre
12:45-13:00	Charly Leblanc
13:00-15:00	Lunch
15:00-15:30	Javier Cuerda
15:30-15:45	Robert Salzwedel
15:45-16:00	Francesco Rinaldo Talenti
16:00-16:30	Coffee Break

WEDNESDAY, April 13, 2022

09:15-09:45	Sebastian Klembt*
09:45-10:00	Sevak Demirchyan
10:00-10:15	Pavel Kokhanchik
10:15-10:45	Erik Kirstein
10:45-11:15	Coffee Break
11:15-11:30	Katharina Nisi
11:30-11:45	Maanwinder Partap Singh
11:45-12:00	Katja Barthelmi
12:00-12:15	Alexander Hötger
12:15-12:30	Matthias Wurdack
12:30-12:45	Chenjiang Qian
12:45-13:00	Andrew Wild
13:00-15:00	Lunch

THURSDAY, April 14, 2022

09:15-10:00	Pavlos Lagoudakis
10:00-10:15	Davide Nigro
10:15-10:30	Carolin Lüders
10:30-10:45	Dror Liran
10:45-11:15	Coffee Break
11:15-11:45	Sven Höfling
11:45-12:00	Katarina Boos
12:00-12:15	Frederik Bopp
12:15-12:30	Artur Trifonov
12:30-12:45	Michał Zieliński
12:45-13:00	Santiago Ríos-Álvarez T.B.C.
13:00-15:00	Lunch
15:00-15:30	Alexey Kavokin
15:30-15:45	Helgi Sigurðsson
15:45-16:00	Dąbrowka Biegańska
16:00-16:30	Coffee Break

FRIDAY, April 15, 2022

09:15-09:45	Masha Vladimirova
09:45-10:00	Sergiu Anghel
10:00-10:15	Michal Zimmerman
10:15-10:30	Nedelea Vitalie
10:30-10:45	Rémi Aristégui*
10:45-11:15	Coffee Break
11:15-11:45	Dario Ballarini
11:45-12:00	Tamsin Cookson*
12:00-12:15	Elena Rozas Jimenez
12:15-12:30	Anna Grudinina*
12:30-12:45	Nina Voronova
12:45-13:00	Best Student Talk Award + Closing

MONDAY April 11, 2022 | 11:15 – 12:00**Manybody enhanced spin-valley physics in 2D semiconductors**

Andreas V. Stier
Walter Schottky Institut, TU München

In bulk and quantum-confined semiconductors, optical spectroscopy in high magnetic fields has historically played an essential role in determining the fundamental properties of excitons such as their mass, size, binding energy, dimensionality, and spin. In conventional semiconductors such as GaAs, or CuO₂, which have light carrier masses and small exciton binding energies (E_B), magnetic fields of order 10T are typically sufficient to achieve the regime where magnetic (cyclotron) energies exceed E_B . In marked contrast, in the family of monolayer semiconductors such as MoS₂, WSe₂ or 2D Ruddlesden-Popper perovskites, carrier masses are heavier and E_B is huge (hundreds of meV), requiring much larger magnetic fields of order 100 T to approach a similar regime [1,2,3].

In this talk, I will review our recent progress on magneto-optical spectroscopy of laterally small ($\sim \mu\text{m}$) and atomically thin semiconductors in extremely large magnetic fields up to 91 Tesla with a special emphasis on the spin-valley physics of neutral and charged excitons.

At charge neutrality, high field magneto-spectroscopy revealed the diamagnetic shifts of the exciton Rydberg states in the typical TMD monolayer semiconductors encapsulated in hBN [2,3], which allowed the unambiguous identification of those states, a quantitative and detailed comparison with leading theoretical models (Keldysh potential) and the first direct experimental measure of the exciton's reduced mass for a monolayer semiconductor.

These studies aided our understanding of Coulomb interactions in 2D semiconductors and provided design principles for future devices.

In gated structures, at excess electron-or hole doping, we examine the interaction of the exciton with the surrounding Fermi sea [4]. We observe spontaneous valley polarization of interacting Landau levels, reminiscent of a magnetic phase transition, in hole doped WSe₂ that is due to an enhanced Zeeman energy of carriers in interacting LLs.

Finally I will highlight our recent results on electron doped MoS₂, where we find that it is indeed the electron spin of the resident electron bath that defines the exciton spin and ground state of the dressed exciton [5,6].

These results cannot be understood within a single-particle picture, highlighting the importance of exchange interactions and intervalley correlations in determining the ground state of 2D excitons in monolayer semiconductors.

- [1] A.V. Stier et al., Nature Comm. **7**, 10643 (2016)
- [2] A.V. Stier et al., Phys. Rev. Lett. **120**, 057405 (2018)
- [3] M Goryca et al., Nature Comm. **10**, 1 (2019)
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MONDAY April 11, 2022 | 12:00 – 12:15

Berry curvature-induced local spin polarisation in gated graphene/WTe₂ heterostructures

Jonas Kiemle,^{1,2,*} Lukas Powalla,^{3,4} Elio J. König,³ Andreas P. Schnyder,³ Johannes Knolle,^{2,5} Klaus Kern,^{3,4} Alexander W. Holleitner,^{1,2} Marko Burghard,³ and Christoph Kastl^{1,2}

¹Walter Schottky Institut and Physics Department, Technical University of Munich, Am Coulombwall 4a, Garching, Germany

²MCQST, Schellingstrasse 4, München, Germany

³Max-Planck-Institut für Festkörperforschung, Heisenbergstrasse 1, Stuttgart, Germany

⁴Institut de Physique, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland

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*Corresponding author: jonas.kiemle@wsi.tum.de

Experimental control of local spin-charge interconversion is of primary interest for spintronics. Van der Waals heterostructures combining graphene with a strongly spin-orbit coupled two-dimensional (2D) material enable such functionality by design. Electric spin valve experiments have thus far provided global information on such devices, while leaving the local interplay between symmetry breaking, charge flow across the heterointerface and aspects of topology unexplored. Here, we probe the gate-tunable local spin polarisation in current-driven graphene/WTe₂ heterostructures through magneto-optical Kerr microscopy. Even for a nominal in-plane transport, substantial out-of-plane spin accumulation is induced by a corresponding out-of-plane current flow. We present a theoretical model which explains the gate- and bias-dependent onset and spatial distribution of the Kerr signal as a result of a non-linear anomalous Hall effect in the heterostructure, which is enabled by its reduced point group symmetry. Our findings unravel the potential of 2D heterostructure engineering for harnessing topological phenomena for spintronics, and constitute an important step toward nanoscale, electrical spin control.[1]

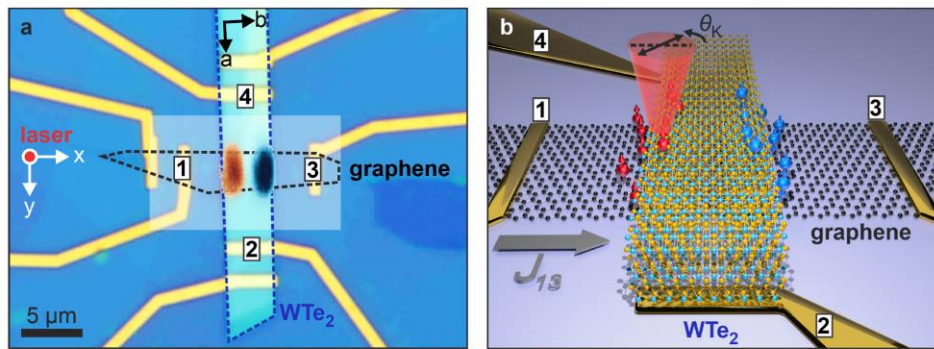


Figure 1: a) Optical microscope image and b) sketch of a graphene/WTe₂ heterostructure. The overlay in a) shows the current-induced Kerr rotation signal at the junction. An oscillating current j_{13} at frequency ω is applied along the graphene stripe. At the heterojunction, the current-induced out-of-plane spin component (red and blue arrows) is locally read-out by a polar Kerr rotation measurement at frequency ω .

References

- [1] L. Powalla, J. Kiemle, *et al.*, arXiv:2106.15509 (2021).

MONDAY April 11, 2022 | 12:15 – 12:30

Impact of optically pumped non-equilibrium steady states on luminescence emission of atomically-thin semiconductor excitons

Malte Selig, Dominik Christiansen, Manuel Katzer*, and Andreas Knorr

Nichtlineare Optik und Quantenelektronik, Institut für Theoretische Physik,

Technische Universität Berlin, 10623 Berlin, Germany

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The interplay of the non-equivalent corners in the Brillouin zone of transition metal dichalcogenides have been investigated extensively. While experimental and theoretical works contributed to a detailed understanding of the relaxation of selective optical excitations and the related relaxation rates, only limited microscopic descriptions of stationary experiments [1] are available so far. In this work we present microscopic calculations for the non-equilibrium steady state properties of excitons during continuous wave pumping. In good agreement with recent experimental work [2-4], we find sharp features in photoluminescence excitation spectra and degree of polarization which result from phonon assisted excitonic transitions dominating over exciton recombination and intervalley exchange coupling [5].

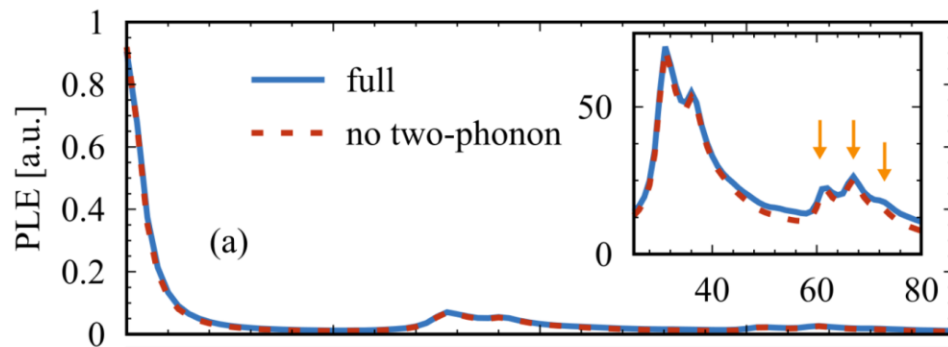


Figure 1: Photoluminescence Excitation Spectrum (PLE) at 7 K. Contributions to the PLE for an exciton lifetime of 5 ps. For detunings larger than 26 meV, we report a sharp increase of the PLE which can be traced back to efficient emission via excitonic relaxation pathways which are assisted by the emission of optical intravalley Γ and optical and acoustic intervalley phonons.

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- [2] Chow, C. M. et al. npj 2D Materials and Applications **1**, 1–6 (2017)
- [3] Chow, C. M. et al. Nano letters **17**, 1194–1199 (2017)
- [4] Shree, S. et al. Physical Review B **98**, 035302 (2018)

Strongly correlated electronic states in MoSe₂/WSe₂ moiré heterostructures

A. J. Campbell,^{1,*} M. Brotons-Gisbert,¹ S. Feng,¹ H. Baek,¹ V. Vitale,² J. Lischner,² K. Watanabe,³ T. Taniguchi,³ and B. D. Gerardot¹

¹ IPaQS, Heriot-Watt University, Edinburgh, Scotland

² Thomas Young Centre, Imperial University, London, England

³ National Institute for Materials Science, Tsukuba, Japan

*Corresponding author: ac174@hw.ac.uk

Moiré heterostructures formed from twisted layers of transition metal dichalcogenides (TMDs) have been shown to host strongly correlated states including Mott insulators and Wigner crystals [1-3]. However, experimental investigations have been mostly limited to two stacked monolayers. Here we use white light reflection spectroscopy to investigate the intralayer excitons in a unique device of stacked WSe₂/MoSe₂ where there are 1L/1L, 2L/1L, 1L/2L and 2L/2L regions with the same twist angle (~ 57 degrees). By changing the carrier concentration we compare correlated electron and hole states formed in each region. We observe, relative to the 1L/1L heterobilayer, correlations are suppressed in heterostructures using 2L MoSe₂, while they are enhanced using 2L WSe₂.

Due to different dielectric environments, we also observe a splitting of the intralayer excitons localised in each layer of the bilayers. In 2L WSe₂/1L MoSe₂ we probe the effects of the correlated electronic insulating phases on each layer-localised exciton individually and find larger changes to the peak position and linewidth in the layer adjacent to the heterostructure interface. Our results introduce layer thickness as a new tuning knob for the formation of correlated electronic states in TMD moiré heterostructures, as well as dielectric engineering in the use of excitons as a sensitive probe of correlated states.

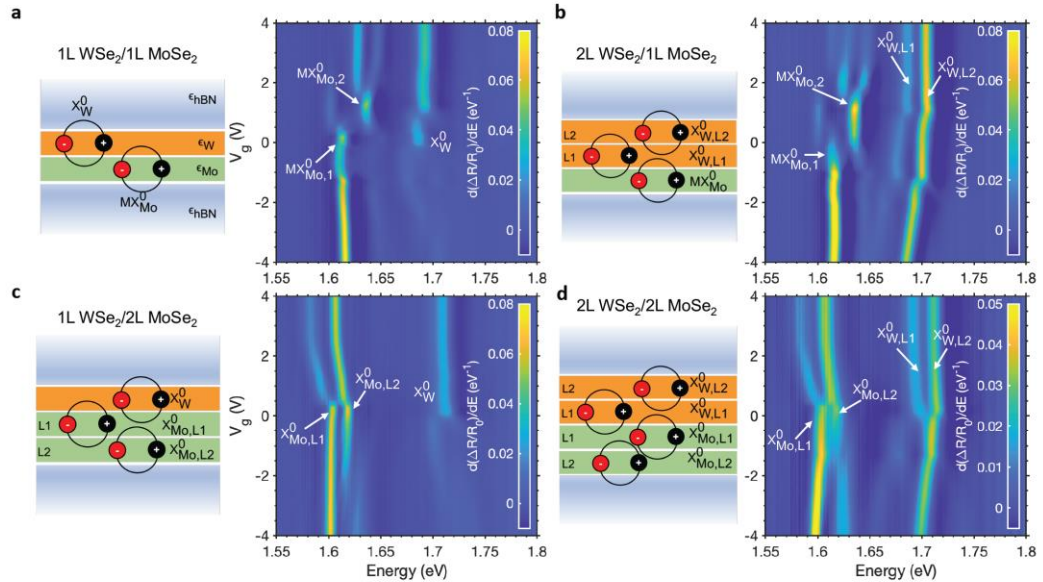


Figure 1: **a-d** Density plot of the V_g dependence of the derivative of the reflection contrast with respect to energy $d(\Delta R/R_0)/dE$ in the 1L WSe₂/1L MoSe₂ (a) 2L WSe₂/1L MoSe₂ (b) 1L WSe₂/2L MoSe₂ (c) and 2L WSe₂/2L MoSe₂ (d) heterostructure regions.

References

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- [2] E. C. Regan et al. Nature **579**, 359 (2020)
- [3] Y. Shimazaki et al. Nature **580**, 472 (2020)

MONDAY April 11, 2022 | 12:45 – 13:00**Metal insulator transitions in bilayer electron-hole systems in transition metal dichalcogenides****B. Tanatar,^{1,*} S. T. Chui,² and Ning Wang³**¹*Department of Physics, Bilkent University, 06800 Ankara, Turkey*²*Bartol Research Institute and Department of Physics and Astronomy, University of Delaware, Newark DE 19716 USA*³*Department of Physics, Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong**Corresponding author: tanatar@fen.bilkent.edu.tr

We investigate metal-insulator transitions for double-layer two-dimensional electron-hole systems in transition metal dichalcogenides stacked on opposite sides of thin layers of boron nitride. The interparticle interaction is calculated by including the screening due to the polarization charges at different interfaces, including that at the encapsulation and at the substrate of experimental structures. We compute and compare the energies of the metallic electron-hole plasma and the proposed insulating exciton solid with fixed-node diffusion Monte Carlo simulation including the high valley degeneracy of the electron bands. We found that for some examples of current experimental structures, the transition electron/hole density is in an experimentally accessible range between $4.1 \times 10^{12} \text{ cm}^{-2}$ and $14.5 \times 10^{12} \text{ cm}^{-2}$ for spacer thicknesses between 2.5 and 7.5 nm. Our result raises the possibility of exploiting this effect for logic device applications. [1]

References

- [1] S. T. Chui, N. Wang, and B. Tanatar, Phys. Rev B **104**, 195432 (2021).

Exciton observation in Linear Carbon Chains

S.Kutrovs kaya^{1,2,*}, A.Osipov², V.Samyshkin², S.Demirchyan³, A.Kucherik², A.Kavokin^{1,3}

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²Stoletovs' Vladimir State University, Gor'kogo str.87, Vladimir, Russia

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The hybridization of s – and p-orbitals of carbon carbon atoms gives rise to the formation of a rich variety of allotropic forms of carbon. The great interest of scientific community has being especially attracted to the long linear carbon chains (LLCC) for its unique properties and hard complexity of synthesis. The recent observation of excitons and trions in LLCCs has a fundamental importance as it presents the first experimental evidence of bright exciton states in monoatomic chains. It crowns an effort of many groups who provided the excitonic gaps calculation in one-dimensional carbon chains [1, 2] and predicted the excitonic features in carbon chains.

The triplet fine structure observed in low-temperature photoluminescence spectra that has repeatedly been observed in polyyne chains of different lengths (from 8 to 24 atoms in a straight part) is to be due to the spatially direct neutral exciton, position and negative trion peaks [3]. The non-radiative exciton decay channel observed in the time-resolved PL spectra at the room temperature is most probably associated with the thermal hopping of one of the carriers forming the exciton between parallel polyyne chains[4]. Excitons are not destroyed by this hopping process but they become radiatively inactive or dark. Moreover, the time-resolved optical response of excitons in carbon chains is found to be dependent on the band-gap of the chain and the lengths of straight parts of the chains that provides a control tool for fine tuning of the radiative properties of carbon chains for applications in carbon lasers and light-emitting diodes.

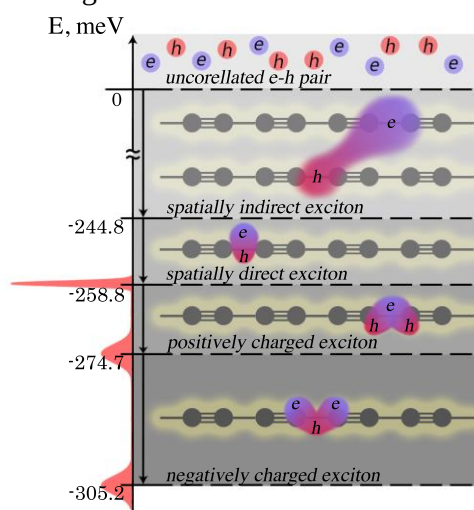


Figure 1: The schematic energy diagram explaining the fine structure of the excitonic triplet in polyyne chains. Photoexcited electrons and holes may form spatially indirect excitons that do not emit light, as well as charged and neutral spatially direct excitons. The calculated transition energies of direct and indirect excitons as well as X⁺ and X⁻ trions are indicated with respect to the transition energy between uncorrelated electron and hole states.

References

- [1] Mostaani E., et al., Lambert. Phys. Chem. Chem. Phys. **18**, (2016).
- [2] Deretzis I., La Magna A. The European Phys. J. B **81**, 1 (2011).
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- [4] S. Kutrovs kaya, et al, Phys.Rev.Research **3**, 013071 (2021).

MONDAY April 11, 2022 | 15:30 – 16:00**Optics of quasi-one-dimensional carbon nanostructures****M. E. Portnoi^{1,*} and R. R. Hartmann²**¹*Physics and Astronomy, University of Exeter, Exeter, United Kingdom*²*Physics Department, De La Salle University, Manila, Philippines**Corresponding author: m.e.portnoi@exeter.ac.uk

This invited presentation covers a range of our mostly analytical results on dipole transitions in various quasi-one-dimensional carbon-based nanostructures with the focus on THz emission from optically-excited nanocarbons.

We show that the curvature effects in quasi-metallic single-walled carbon nanotubes and edge effects in narrow-gap graphene nanoribbons not only open band gaps, which are typically in the THz range, but also result in giant enhancement of the probability of optical transitions across these gaps with a sharp decrease in transition probability away from the band gap edge. The dipole transition matrix element practically vanishes in the mid-infrared range and then increases again at optical frequencies leading to a proposal of using these nanostructures as active elements of coherent THz emitters with inversion of population achieved by either photoexcitation or injection of non-equilibrium carriers [1].

We present a general theory of bipolar graphene waveguides supported by numerical modelling, and confirmed by simple analytic estimates for exactly solvable potentials [2]. By using the amazing property of Dirac materials, that a potential barrier can localize an electron, we show that unlike the trivial guided modes existing for both massive and massless 2D electrons, we deal with purely Dirac/graphene physics opening the door to new optoelectronics applications based on gate-tunable THz pseudo-gap.

The technology of synthesizing carbynes (also known as linear acetylenic or polyyne carbons) has evolved rapidly over the last few years, with stable long chains deposited on substrates now being a reality. A prominent feature of long polyyne chains (chains with two alternating non-equal bonds) is the presence of topologically protected mid-gap edge states. For a finite-length chain the two edge states form an even and odd combination with the energy gap proportional to the edge-state overlap due to tunneling. These split states of different parity support strong dipole transitions. We have shown [3] that for long enough (over 18 atoms) carbyne chains, the energy separation between the HOMO and LUMO molecular orbitals formed by the edge states corresponds to the THz frequency range. There are several other allowed optical transitions in this system which can be used to maintain inversion of population required for THz lasing.

Another recent achievement in nanocarbon technology is a demonstration of controlled synthesis of cyclocarbons, in particular cyclo[18]carbon allotrope [4]. The properties of cyclocarbons in an external electric field differ drastically depending on the parity of the number of dimers in a polyyne ring. For an odd-dimer cyclocarbon, as a result of the inversion symmetry absence, an experimentally attainable electric field should open a tunable gap between otherwise degenerate states leading to two states with allowed dipole transitions between them in the THz range [5]. A population inversion can be achieved again using optical pumping.

This work was supported by the EU H2020-MSCA-RISE projects TERASSE (H2020-823878) and DiSeTCom (H2020-823728) and by the NATO Science for Peace and Security project NATO.SPS.MYP.G5860s.

References

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- [3] R.R.Hartmann, S.Kutrovskaya, A.Kucherik, A.V.Kavokin, and M.E.Portnoi, *Phys. Rev. Research* **3**, 033202 (2021).
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- [5] R.A.Ng, M.E.Portnoi, R.R.Hartmann, *arXiv:2202.01568* (2022).

Nanowire structures: optics and biosensing

S.Vitusevich,^{1,*} and D.Pustovyi¹

¹*Forschungszentrum Jülich, IBI-3, 52425 Jülich, Germany*

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Nanowire (NW) structures represent the key materials for the development of information technologies, including quantum computing, optoelectronics, and bioelectronics [1]. Despite exciting progress in developing NW-based device structures, there are still a lot of open questions, especially for liquid-gated nanowire field-effect transistor (FET) biosensors. In this work, we studied the properties of NW FET transducers fabricated for biosensing applications using low-energy light scattering spectroscopy. Ar-Kr laser ($\lambda_{\text{ex}} = 488.0$ nm) laser beam was focused on the sample. Spatial lateral mapping of the phonon Raman spectra of the structure was provided by moving a piezoelectrically controlled stage. The accuracy of determining the frequency of the phonon line was 0.15 cm^{-1} . To avoid heating the sample, the power of the exciting laser radiation was $\sim 0.1 \text{ mW}$, which corresponded to the radiation power density on the sample surface of $\sim 10 \text{ kW/cm}^2$. The shape of the Si phonon line in the Raman spectrum is analyzed by fitting the experimental data with a Lorentzian function. The intensities, frequencies, and half-widths of the Si Raman phonon lines are determined. The intensity distribution map of the Si phonon lines obtained by scanning in the active region with quantum wires (Fig. 1a) perfectly correlates with the optical image.

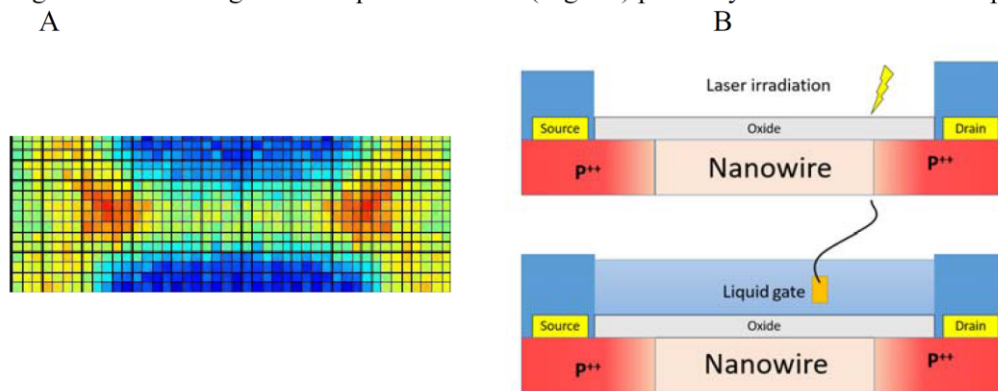


Figure 1: (A) A map of the distribution of Raman line intensities over the NW structure under study, (B) schematic presentation of strain scanning experiment (top) and liquid-gated NW FET biosensor (bottom).

We found that strain along the nanowire is redistributed nonuniformly. In the case of unstressed silicon, the LO-TO frequency of the Si line is $\approx 521 \text{ cm}^{-1}$. Under the action of elastic deformations, the frequency of this phonon line is shifted. Elastic deformations are calculated. It is found that the entire structure under study is under compressive strains along the nanowire. In the middle of NW the elastic compressive strains are smaller due to partial relaxation of deformations. The strain map shows that the magnitude of strains is larger near the contact regions. The fact may reflect that vacancy of oxygen forms in the middle of the nanowire. This is very promising for biosensing applications, including single trap phenomena approach [2]. Moreover, we have performed a study of C-reactive protein solutions using liquid-gated NW FET structures (Fig.1b, bottom). High sensitivity is demonstrated. The results are important for the prediction of cardiac disease stages.

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TUESDAY April 12, 2022 | 09:15 – 10:00

Waveguide polariton condensates via bound states in the continuum

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In this work we will review the recent progress of polaritons in 2D planar waveguides which offer interesting advantages in terms of long lifetimes, ease of manipulation, tailoring of the band topologies and increase of their interaction via dipolar effects [1,2].

Amongst the features obtained in these devices we will discuss the realization of polariton-based photonic lasing [3] and the actual role played by dipolar polaritons in the realization of highly interacting polariton modes [4].

Emphasis will be given to the interesting possibility of patterning such structures via shallow or deep etching, not only allowing to inject and collect light to/from radiation-uncoupled polariton modes, but also to form new polariton dispersions. In particular, playing with the periodic patterning and fill factor, symmetry mismatched resonant polariton modes can be fold within the light cone, behaving as topologically protected bound states in the continuum (BICs). These can give rise to polariton states with theoretically infinite lifetime, despite lying in the radiating far field. We exploit these unique features by showing polariton Bose-Einstein condensation at a saddle point surrounding the BIC in the 2D lower polariton dispersion [5], thus demonstrating an ultra-low threshold for condensation and manipulation of the dipolar character via electric field.

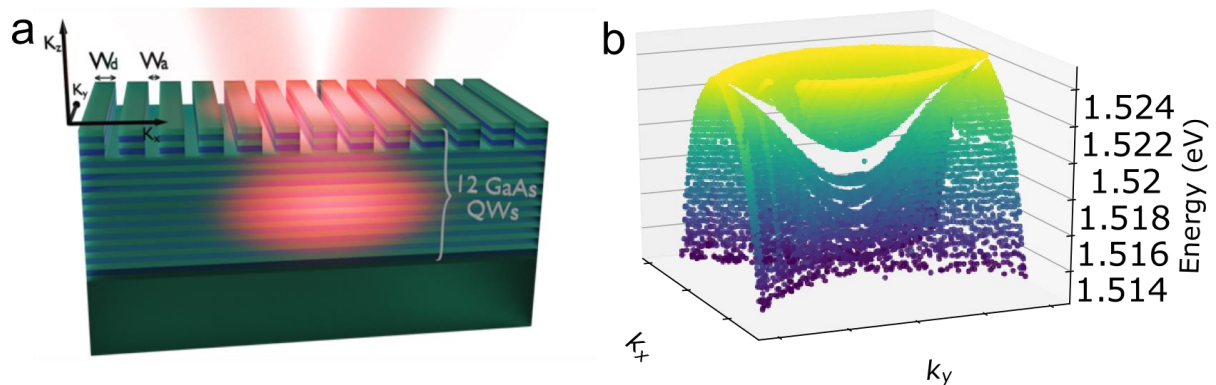


Figure 1: (a) Scheme of a polariton waveguide, patterned for BEC condensation into a BIC. (b) Experimental 2D dispersion around the BIC point

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Microcavity polaritons in optical Lieb lattice: transition from ballistically expanding to trapped polaritons

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Artificial lattices are of great appeal for fundamental investigations in condensed matter physics [1]. Unlike crystalline structures existing in nature, artificially created ones enable to reach exotic physical settings in the laboratory, for example, giant artificial magnetic fields [2]. Therefore, these systems are a promising platform to simulate and study quantum phenomena emerging across many desirable periodic potentials.

In this work, we implement and study two-dimensional optically imprinted Lieb lattices in a semiconductor microcavity [3]. By tuning the lattice geometry, we demonstrate a transition from ballistically propagating polariton condensates, scattering from non-resonant excitation areas and synchronizing across the lattice, to confined polariton states, trapped in between the pumped areas around zero momentum, as shown in Figure 1. Moreover, we reveal that in the intermediate regime polaritons exhibit multimodal condensation accompanied by mode competition over the gain, which results in a complex photoluminescence intensity distribution. The optically realized polariton system is a flexible testbed for investigation of non-Hermitian physics in two-dimensional arrays of interacting coherent nodes.

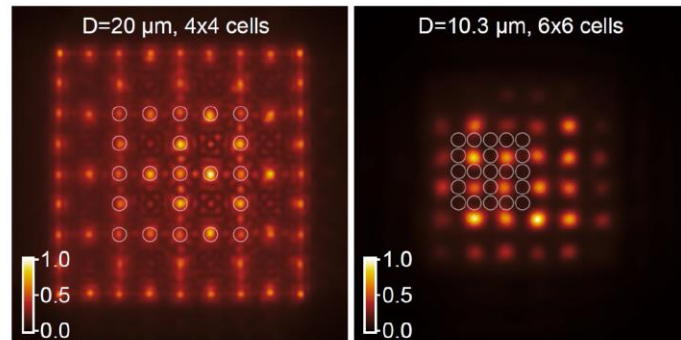


Figure 1: Real space polariton photoluminescence above condensation threshold under non-resonant continuous wave excitation arranged in Lieb geometry. For lattice constant of $D=20\ \mu\text{m}$ (left) polaritons synchronize across cells and condense on top of the lattice nodes, while for smaller period $D=10.3\ \mu\text{m}$ (right) polaritons localize in potential minima in between pumping spots (shown with white circles).

This work was supported by the Russian Science Foundation (RSF) grant no. 21-72-00088.

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TUESDAY April 12, 2022 | 10:15 – 10:30

Fast dynamic optical lattices of exciton-polaritons

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Static optical potentials have been a fruitful tool in the study of exciton-polariton condensates, from spin weak-lasing and non-Hermitian degeneracies to Ising machines and new measurements of the polariton-polariton interaction strength. By using two separate lasers with a fixed frequency offset between them, we demonstrate the creation of the first dynamic optical potential for exciton polariton condensates: a one-dimensional conveyor belt. In contrast with previous dynamical potentials created by SAWs, optical modulation timescales comparable to the condensate lifetime are easily achievable, bringing exciton-polariton studies into the regime of continuous-time Floquet systems.

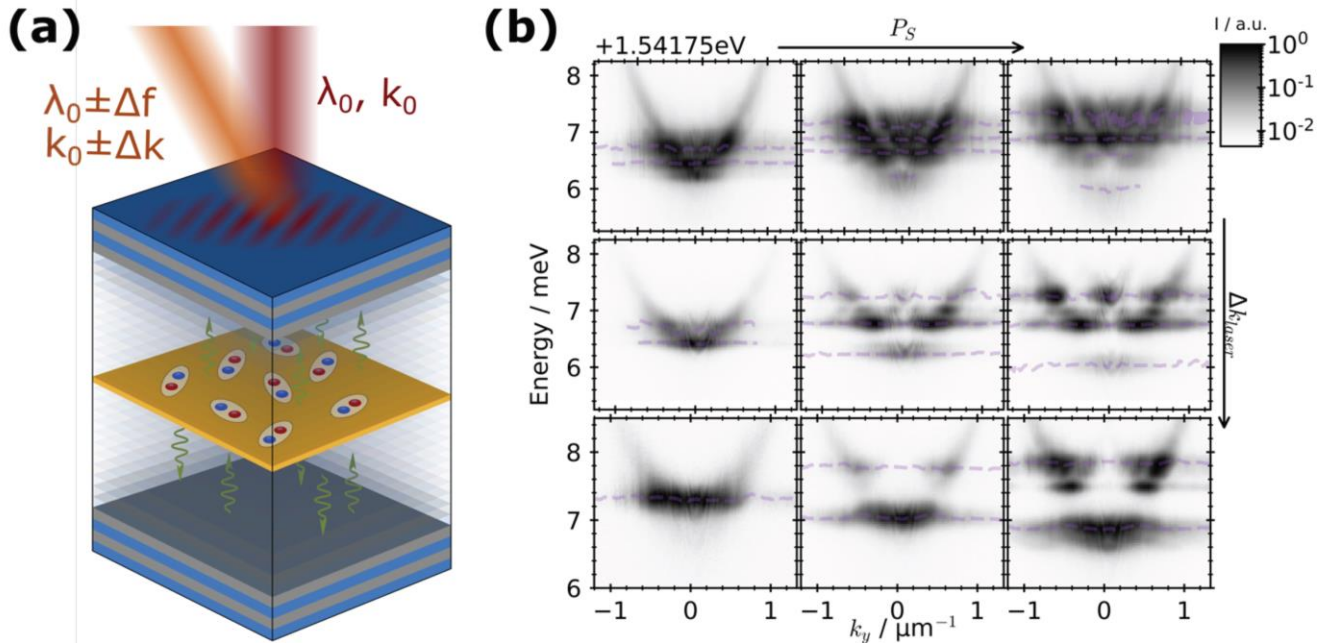


Figure 1: (a) Diagram of the conveyor belt potential creation. (b) Example bandstructures for a static lattice, varying the potential depth and periodicity.

TUESDAY April 12, 2022 | 10:30 – 10:45

Analysis and modeling of polaritonic gain in GaN ridge polariton lasers

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Following the demonstration of polariton lasing in GaN ridge polariton lasers [1,2], the polaritonic analog to conventional semiconductor diode lasers, we here analyse and model the laser dynamics in the interesting case of waveguide polaritons. The laser cavities are GaN etched ridge structures with DBRs operating under strong coupling [3] up to 300K with a 66 ± 10 meV Rabi splitting (Fig. 1(a,b)). They are optically pumped with a line-shaped spot, resonantly pumping the exciton reservoir.

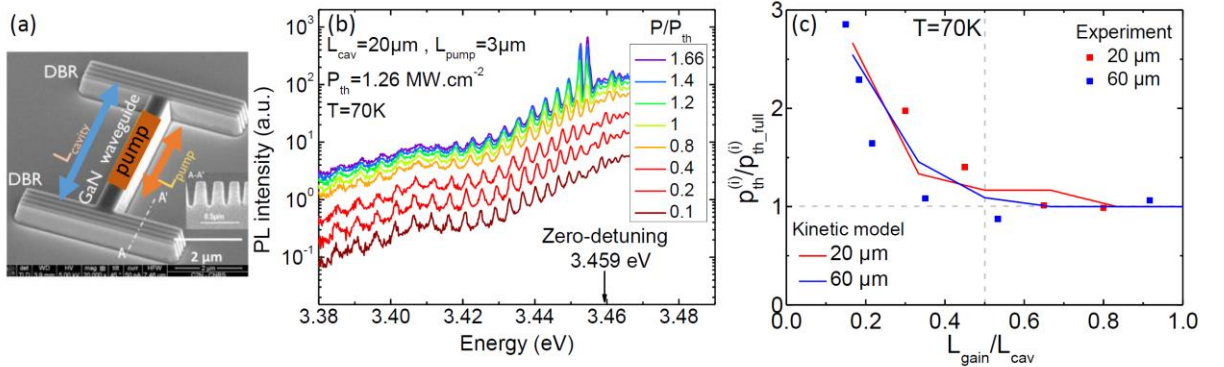


Figure 1: (a) SEM image of a 5 – μm long polariton ridge waveguide; (b) PL spectra across the lasing threshold, for a 20 μm -long ridge; (c) Laser power at threshold $p_{th}^{(i)}$, integrated along the whole excitation length, vs gain length, normalized to its value $p_{th,full}^{(i)}$ for $L_{pump} = L_{cav}$.

We study the effect of a varying optically-pumped length. The polariton laser is operated for an exciton reservoir length of just 15% of the cavity length [2]. It is worth noting that this would not be possible in a conventional ridge laser with population inversion. This experimental observation agrees quantitatively with simulations based on semiclassical Boltzmann equations for polaritons (Fig. 1(c)) [4,5].

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TUESDAY April 12, 2022 | 11:15 – 11:45**Observation of a non-Hermitian phase transition in an optical quantum gas**

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Quantum gases of light, as photons or polariton condensates in optical microcavities, are collective quantum systems enabling a tailoring of dissipation from e.g. cavity loss. This makes them a tool to study dissipative phases, an emerging subject in quantum manybody physics. Here the demonstration of a non-Hermitian phase transition of a photon Bose-Einstein condensate to a new dissipative phase, characterized by a biexponential decay of the condensate's second-order coherence, is reported [1]. The experiment is performed in a dye microcavity where the photo-excitable dye molecules provide both a heat and a particle reservoir. The dissipative phase transition occurs at an exceptional point which resides well inside the condensed regime of the optical quantum gas, at loss rates a thousand times smaller than the crossover to lasing. While usually Bose-Einstein condensation is connected to ordinary lasing by a smooth crossover, the observed phase transition separates the novel, bi-exponential phase from both lasing and a first, oscillatory condensate regime. The demonstrated principles pave the way for a wide class of dissipative quantum phases, for instance in topological or lattice systems.

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Non-Hermitian effects on exciton-polariton dispersion

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Losses are inherent to exciton polaritons but are often deliberately neglected in the theoretical treatment of this system since the effects are weak, or reduced in the experimental samples to increase the polariton lifetime. However, recent progress in non-Hermitian physics [1] has shown that losses can be exploited to enable strong effects, which are not possible in conservative systems. Until recently, non-Hermitian effects in exciton-polariton systems were experimentally explored in parameter space [2]. In this talk, I will provide two examples of loss-induced effects on the dispersion of exciton-polariton systems.

The first is the emergence of non-Hermitian momentum-space topology in a perovskite-based microcavity [3]. The nontrivial topology arises from the polarisation-dependent losses in the system. This enabled us to directly measure the novel non-Hermitian topological invariant [4] in momentum space in this hybrid light-matter system. Our work is an important step towards realising nontrivial dynamics due to non-Hermitian topology.

The second effect is the anomalous dispersion of exciton polaritons based on monolayer WS₂ [5]. The anomalous dispersion is a direct consequence of level attraction arising from the dissipative coupling of excitons and photons. We used this effect to experimentally demonstrate the propagation of negative-mass exciton polaritons, where the particle's displacement is opposite to its momentum. The anomalous dispersion can be used to eliminate instabilities [6] in large polariton condensates or demonstrate negative-mass superfluid dynamics [7] without the complications introduced by periodic nanostructures.

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TUESDAY April 12, 2022 | 12:15 – 12:30

Elementary excitations of exciton-polariton condensates in a synthetic gauge field

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In Bose-Einstein condensates of weakly interacting bosons, including exciton polaritons, dispersive branches of collective elementary excitations are present, populated via interparticle interactions. As particles are excited from the ground state condensate into higher energies and higher momenta, their dispersions can serve as a sensitive probe of the strength of these interactions. Due to the presence of TE-TM splitting of the optical modes in the optical microcavity, the polariton condensate excitation spectrum exhibit two branches, similarly to the low-density polariton states. However, the collective Bogoliubov excitation dispersions are predicted to be strongly anisotropic due to the difference in the interaction strengths for polaritons in singlet and triplet spin configurations [1]. This difference breaks the cylindrical symmetry and affects the dispersions, causing clear anisotropy in directions parallel and perpendicular to the condensate polarization vector axis. Furthermore, when the additional cavity anisotropy (birefringence) is present, the collective excitation eigenstates arise as the interplay between the synthetic magnetic gauge field of the microcavity and the interaction anisotropy [2].

In this work, we study experimentally the elementary excitations of an optically trapped high-density exciton-polariton condensate [3]. By measuring polarization- and angle-resolved photoluminescence, we directly observe the anisotropy of the branches and investigate their pseudospin textures in the momentum space, which corresponds to the effective magnetic field distribution. The measurement allows us to extract the inter- and intra-spin polariton interaction constants. This experiment is a direct realization of a non-Abelian gauge field in an interacting quantum liquid, with the presence of diabolical points and the associated spin structure characteristic of a monopole-like magnetic field. It signifies the possibility of using polariton systems in the high-density (non-linear) regime in future studies of synthetic gauge fields and topological physics.

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TUESDAY April 12, 2022 | 12:30 – 12:45

Annihilation of exceptional points from different Dirac valleys

I. Septembre,^{1,*} Mateusz Król,^{2,3} P. Oliwa², M. Kędziora²,
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P. Kula⁴, W. Bardyszewski⁵, P. G. Lagoudakis^{6,7}, B. Piętka², J. Szczytko²,
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Exceptional points (EPs) are non-Hermitian singularities where both eigenvalues and their eigenvectors coalesce. They arise from a Hermitian singularity, such as a Dirac point, and appear in pairs linked by a Fermi arc. The annihilation of exceptional points stemming from different Dirac points (valleys) has never been reported so far.

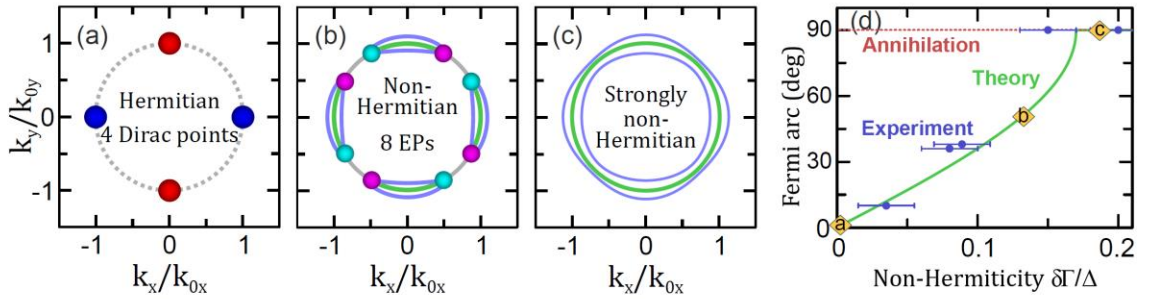


Figure 1: (a-c) Difference of the real part of the energies for an increasing non-Hermiticity. (a) Hermitian case with 4 Dirac points. (b) Non-Hermitian case with 8 EPs. (c) Strongly non-Hermitian case where the EPs have annihilate. (d) Length of the Fermi arc as a function of non-Hermiticity. The rhombus denote the position of panels (a-c) on this figure.

In our work [1], we use a liquid-crystal microcavity [2] where the controlled birefringence brings in resonance the X-polarised cavity mode N and the Y-polarised cavity mode $N + 2$, both having different effective masses. The interplay between the mass difference and TE-TM spin-orbit-coupling leads to the formation of four tilted Dirac cones. Non-Hermiticity in the system splits each Dirac point in a pair of EPs. We show that the EPs can be continuously moved in reciprocal space by varying the non-Hermiticity degree, (controlled by the detuning). At a critical non-Hermiticity, EPs issued from different Dirac valleys and carrying opposite topological charges annihilate. The experiments are perfectly modelled by an effective 2×2 Hamiltonian whose results are shown on Fig. 1.

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TUESDAY April 12, 2022 | 12:45 – 13:00**Universal semiclassical equations based on the quantum metric****C. Leblanc,^{1,*} G. Malpuech,¹ and D. D. Solnyshkov^{1,2}**¹*Institut Pascal, Université Clermont Auvergne, CNRS, Clermont-Ferrand, France*²*Institut Universitaire de France (IUF), Paris, France**Corresponding author: *charly.leblanc@uca.fr*

The geometrical information about the eigenstates of a Hamiltonian is contained in the gauge-invariant quantum geometric tensor, whose symmetric real part defines the quantum metric (QM) characterizing distances between states in a parameter space. Its antisymmetric imaginary part determines the Berry curvature. The QM is now explicitly accounted for in the design and engineering of topological systems, and its integral is linked with the Chern number. Experimental measurements of the QM in different systems also start to appear [1].

In this work [2], we derive semiclassical equations of motion in a two-band system using only the static band geometry encoded in the QM. The solutions of these new equations are in complete agreement with the direct numerical solutions of the Schrödinger equations for all the cases we considered. They describe the anomalous Hall effect (AHE), traditionally attributed to Berry curvature. They also describe the opposite limit, when the wavepacket is coherently distributed over the two bands, and in particular the zitterbewegung (ZBW) motion induced by an emergent non-Abelian gauge field. We show that a wavepacket centered at $k = 0$ exhibits a circular trajectory in real space, with its radius given by the square root of the quantum metric. This quantity appears as a universal length scale, determining the uncertainty of the position of a particle involving several bands. It provides a geometrical origin of the Compton wavelength.

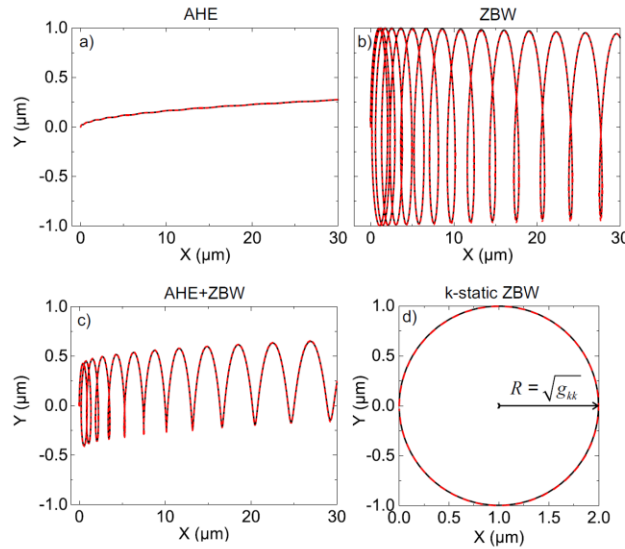


Figure 1: Rashba+Zeeman Hamiltonian. Wavepacket dynamics from Schrödinger (black solid lines) and semiclassical (red dashed lines) equations: a) AHE (single-band initial excitation); b) ZBW (equal fractions of both bands); c) both effects together; d) cyclotron-like orbits at constant k (no potential gradient) with a radius determined by the metric.

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TUESDAY April 12, 2022 | 15:00 – 15:30

Magnetic on-off switching of a plasmonic laser

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Plasmonic nanoparticles arranged in two-dimensional lattices enable strong light-matter coupling, lasing, and Bose-Einstein condensation [1, 2], and hold intriguing prospects for topological photonics and related applications, such as extremely robust signal processing through topological protection against imperfections, or unidirectional propagation of optical modes [3, 4]. While previous studies on plasmonic lasers combine different lattice geometries with metallic nanoelements, magnetic nanoparticles or multiparticle unit cell structures [5] have recently been introduced as novel promising routes towards achieving topologically protected lasers at the nanoscale.

In this contribution, I will discuss on our recent experimental results on plasmonic lasing from lattices of magnetic Co/Pt multilayer nanoparticles immersed in an IR-140 dye solution [6]. We show that circularly polarized excitation leads to a transition between the lasing action and non-lasing emission as the nanoparticle magnetization is reversed, due to the helicity-dependent modification of the optical mode structure of the system. We exploit this effect and its implications on the lasing threshold, to achieve active magnetic field control and on-off switching over lasing. Our results introduce magnetization as a novel mechanism to externally control plasmonic lasers. In addition, the enhancement of local electromagnetic fields due to plasmons provides potential for designing new topological photonic structures where the inherently weak magnetization effects are dramatically amplified in the lasing regime.

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TUESDAY April 12, 2022 | 15:30 – 15:45**Theory of radial oscillations in metal nanoparticles driven by optically induced electron density gradients****Robert Salzwedel,^{1,*} Andreas Knorr,¹ Dominik Hoeing,² Holger Lange² and Malte Selig¹**¹*Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Berlin, Germany*²*Institut für Physikalische Chemie, Universität Hamburg, Hamburg, Germany**Corresponding author: r.salzwedel@tu-berlin.de

Upon optical excitation, metal nanoparticles oscillate in radial breathing modes. These oscillations are assumed to be driven mainly by the thermalization of hot electrons impulsively heating the lattice, which can be described classically [1,2]. Based on a combined approach of quantum hydrodynamics and Heisenberg equations of motion for the optical excitation of electron gas in metal nanoparticles and the associated electron-phonon interaction, we discuss the contribution of additional coherent sources to the radial breathing oscillations.

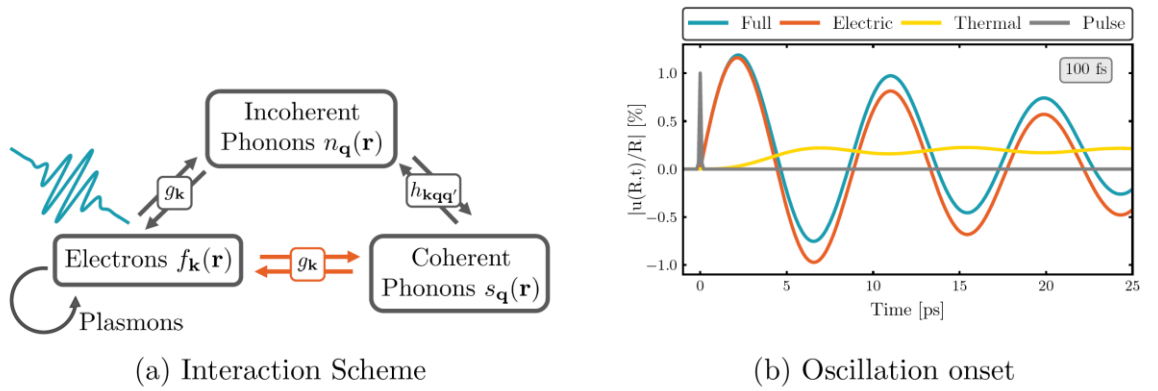


Figure 1: Direct interaction of electrons and coherent phonons. Fig. (a) illustrates the interaction mechanism. The gray arrows indicate the current model whereas the interaction illustrated by the orange arrows is introduced by our quantum mechanical calculations. Fig. (b) provides the calculated relative lattice displacement $\mathbf{u}(\mathbf{R}, t)/R$ of the nanoparticle. Numerically, one can switch on and off the individual interaction mechanisms (electric vs. thermal) which allows to study their respective effect separately.

Our results reveal a more direct coupling mechanism between the field and phonons compared to the established interpretation of experiments [3,4]: the optical pulse induces spatial gradients in the electron density that drive phonon oscillations coherently and directly on the time scale of the optical excitation. Therefore, thermal and coherent contributions must be considered in the early times of the oscillation.

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TUESDAY April 12, 2022 | 15:45 – 16:00**Reduced Model of Nanoscale Photonic Resonators for Inverse Design****Francesco Rinaldo Talenti¹, Stefan Wabnitz¹, Inès Ghorbel², Sylvain Combrié², Luca Aimone-Giggi², and Alfredo De Rossi²**¹DIET, Sapienza University of Rome, 00184 Rome, Italy.²Thales Research and Technology, Campus Polytechnique, 91767 Palaiseau, France.

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In optics, the purpose of Inverse Design (ID) is to create a structure corresponding to a prescribed response to an excitation, a difficult and computing-intensive task. Yet, ID is extremely promising in harnessing modern nanofabrication technologies to achieve original functionalities or to maximize figures of merit[1,2,3]. The bottleneck is the calculation of the response of the structure, needed to compute the error to be minimized. For complex 3D structures such as photonic crystals (PhC), approximated physical models[3] are used in place of standard Finite Differences in Time Domain (FDTD) or Finite Element Method (FEM) solvers, which are computationally expensive hence useless for optimization algorithms. Here we consider the case of a photonic crystal cavity to be engineered such that eigenmodes are strictly equi-spaced in frequency, starting from the fundamental. This enables optical parametric oscillations[4] and possibly mode-locking[5] in the smallest possible resonator. The task is difficult because the relative spacing of the modes need to be computed with accuracy. The main idea here is to use a reduced model of the photonic crystal which describes it as an equivalent Distributed Feedback (DFB) mirror, with parameters adjusted to reproduce the dispersion of a strictly periodic PhC within a spectral range of interest. We consider a class of nanoscale resonators which are obtained by adiabatic modification of a periodic structure and, as an example, the 1D parabolic beam PhC[6] shown in Fig.1(a), where the width $w(x)$ of the beam follows a parabolic rule. Our model describes the structure as a tapered DFB with

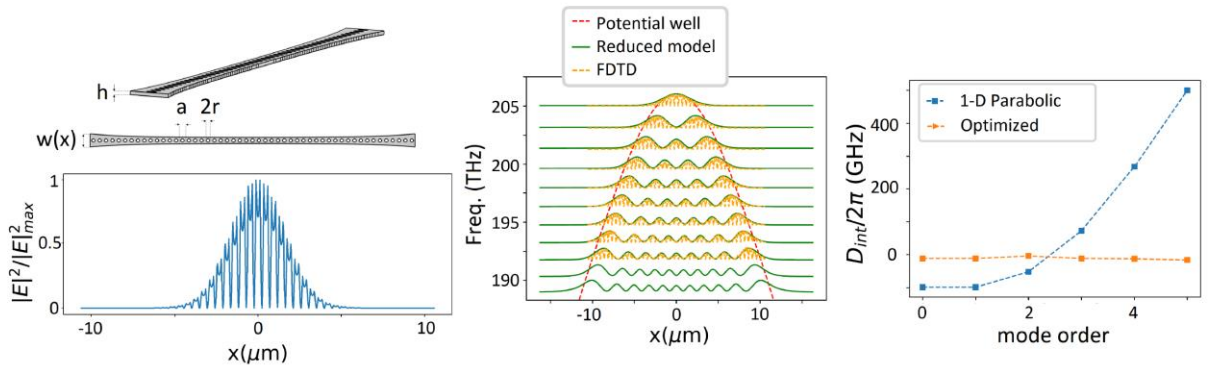


Figure 1: (a) parabolic-beam PhC and field intensity $|E_y|^2$ of the fundamental order mode; (b) eigenmodes calculated by the model (green, envelopes) and FDTD (orange, normalized field $|E_y|^2$) with vertical offset corresponding to the eigenfrequency. (c) Integrated dispersion of the parabolic beam and of the optimized structure (FDTD).

parameters extracted by assuming each section of the width-modulated beam to be periodic and invoking the adiabatic approximation. A posteriori justification is given by the comparison of the predicted eigenmodes with the FDTD calculation (Fig. 1(b)), with deviation within the estimated accuracy of the FDTD (about 30 GHz). Finally, the steepest gradient optimization is used to adjust the profile $w(x)$ such that the integrated dispersion is flattened, as verified by FDTD (Fig. 1(c)).

In conclusion, we have shown that a reduced model can be used for the modal engineering of a certain class of PhC cavities, with applications in the context of nanolasers and parametric sources for quantum-technologies. This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under the Marie Skłodowska-Curie grant agreement No 814147.

References

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WEDNESDAY April 13, 2022 | 09:15 – 09:45**Topological insulator vertical-cavity laser array****A. Dikopoltsev¹, T. H. Harder², E. Lustig¹, O. A. Egorov³, J. Beierlein², A. Wolf², Y. Lumer¹, M. Emmerling², C. Schneider⁴, S. Höfling², M. Segev¹, and S. Klemmt²**¹*Physics Department, Technion, 32000 Haifa, Israel*²*Chair for Applied Physics, Wilhelm-Conrad-Röntgen-Research Center for Complex Material Systems, and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany*³*ITFO, Abbe Center of Photonics, Friedrich-Schiller-Universität Jena, D-07743 Jena, Germany.*⁴*Institute of Physics, University of Oldenburg, D-26129 Oldenburg, Germany.**Corresponding author: sebastian.klemmt@physik.uni-wuerzburg.de

Topological Photonics is an emerging and novel field of research, adapting concepts from condensed matter physics to photonic systems adding new degrees of freedom. After the first demonstrations of topological photonic insulators, the field has moved on to study and exploit the inherent non-hermiticity of photonic systems and the interplay with their topological nature. With the envisaging [1] and realization [2] of topological insulator lasers it became possible to exploit topological effects to facilitate injection locking of arrays of semiconductor lasers. Topological insulator lasers have now been realized using a variety of platforms and designs as a means to efficiently couple and phase-lock extended arrays of lasers to behave like one single coherent laser. The major drawback so far is that the emission appears in the plane of the topologically protected light propagation, thus hindering light extraction. By designing a topological system which employs out-of-plane emitters such as evanescently coupled Vertical Cavity Surface Emitting Lasers (VCSELs), we can successfully separate the emission direction of the individual lasers from the propagation direction of the topologically protected mode in-plane ensuring the topological protection.

In this work, we present the first experimental demonstration of a topological insulator VCSEL array [3]. Using the crystalline topological insulator model and ensure topological mode protection at the interface of a compressed and stretched hexagonal lattice. In contrast to a range of topological photonic systems, here the topological protection is virtually independent of the wavelength or direction of lasing. The individual emitters are arranged in a lattice array measuring a few tens of microns, with each site emitting vertically, allowing for an efficient light collection and resulting in a powerful coherent laser beam. Spatial interference measurements of the topological mode using an inverted Michelson interferometer confirm coherent laser emission of the array, spectrally within the topological bandgap. This highlights that the full array of 30 emitters displays an extended coherent mode emitting at a single wavelength. Our experiments demonstrate that the topologically protected in-plane transport can force the predominantly vertically oscillating emitters to act as one single coherent laser.

References

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WEDNESDAY April 13, 2022 | 09:45 – 10:00

Edge currents and charge density wave in a conducting Möbius stripes

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Magnetic field induced edge currents play an important role in Hall conductivity and a variety of other magneto-transport effect [1]. The direction of currents must be opposite at the opposite edges of a Hall bar.

We have considered a conducting Möbius strip subjected to a strong quantizing magnetic field that has just one edge by definition. We show analytically that this system is characterized either by persistent edge currents or by a stationary charge density wave along the edge. In the first regime, two edge currents propagating clockwise and anticlockwise must jump across the stripe at the point where the external magnetic field is parallel to the plane of the stripe. Such jumps would be possible in an idealized system, where the mean free path of carriers exceeds the width of the stripe. This regime may be achieved in the low temperature limit.

In contrast, in a collision dominated regime, ballistic jumps would be impossible, which is why the circuits of edge currents must be broken. In this latter regime, edge currents are suppressed all together, and a stationary charge density wave (CDW) along the edge of the stripe appears instead. CDW arises as a result of a redistribution of the electron density in real space, which is determined by the interaction between the dependence of the chemical potential on the projection of the magnetic field perpendicular to the plane and the screened Coulomb repulsion of carriers. The predicted change in charge density is macroscopic and can be significant at low temperatures. The density of electronic states in the material forming the band can be reconstructed from the experimentally measured profile of the electron density distribution. That's why Möbius strip topology offers a powerful tool for studying one-dimensional fermionic systems. Freezing of edge currents and formation of the CDW may be triggered e.g. by a local temperature increase introduced by a laser beam.

References

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WEDNESDAY April 13, 2022 | 10:00 – 10:15**Control of SSH chain topology by Rashba-Dresselhaus spin-orbit coupling****P. Kokhanchik,^{1,*} D. Solnyshkov,^{1,2} and G. Malpuech¹**¹*Institut Pascal, Université Clermont Auvergne, CNRS, Clermont INP, F-63000 Clermont–Ferrand, France*²*Institut Universitaire de France (IUF), 75231 Paris, France**Corresponding author: pavel.kokhanchik@uca.fr

The photonic spin-orbit coupling (SOC) has already been shown to be the key ingredient in some realizations of topologically nontrivial photonic systems. While photonic microcavity systems are usually associated with TE-TM SOC, the recently shown [1] ability to engineer a synthetic photonic SOC of Rashba-Dresselhaus (RD) type opens a new perspective to study a new class of topologically nontrivial photonic systems.

Several works [2,3] have attempted to study the influence of Rashba SOC on the topology of electronic states in SSH lattice. Due to the restriction implied on the SOC magnitude and spatial distribution by the material, they only considered the Rashba SOC as a small uniform perturbation to the conventional SSH lattice in the external magnetic field and have not managed to observe any impressive effects on the topology.

In contrast, we investigated the combined effect of spatially modulated RD SOC and a uniform XY polarization splitting in a photonic system. Using the tight-binding approximation, we showed that by varying the amplitude of the RD SOC modulation, we can transform a 1D SSH chain from a trivial to a nontrivial topological state, with the appearance of edge states inside the energy gap (Fig. 1). XY splitting does not affect the topology of a state; however, it does affect the size of the gap and the energy of the edge state, therefore being the essential parameter allowing tunability of the system (Fig. 1).

We emphasize that the proposed system is experimentally feasible in photonic liquid crystal microcavities. To prove that, we solved a 2D Shrödinger equation for a zigzag SSH (Fig. 1), showing the existence of edge states. Furthermore, the strong coupling regime and the topological lasing at ambient conditions could be realized by hybridizing a photonic mode possessing RD SOC with an excitonic resonance.

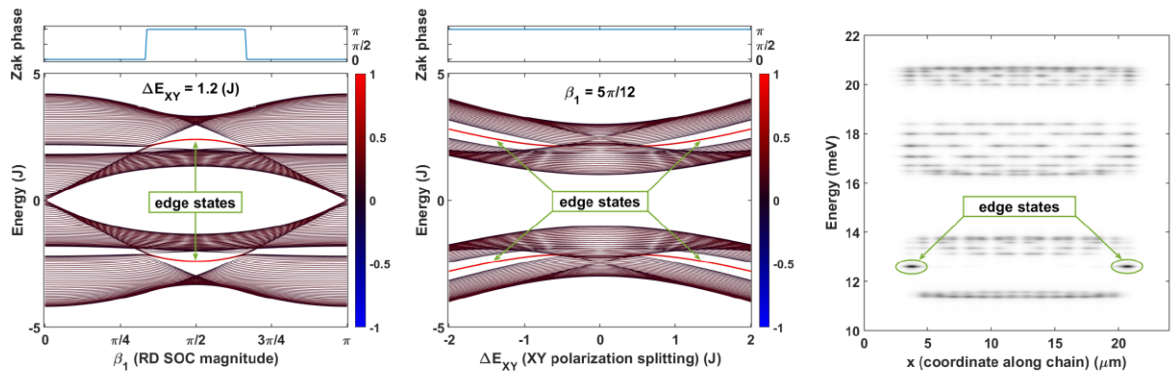


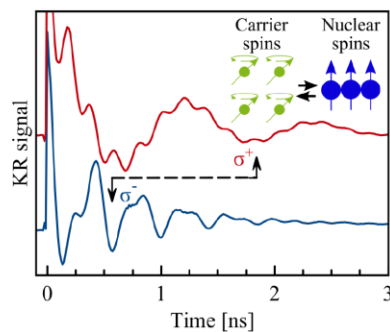
Figure 1: Finite SSH chain spectrum depending on RD SOC magnitude β_1 (left), XY splitting ΔE_{XY} (middle) and spatial coordinate along chain x (right).

References

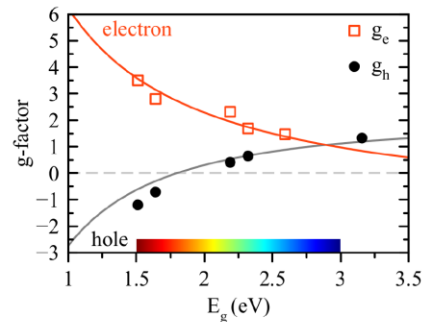
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WEDNESDAY April 13, 2022 | 10:15 – 10:45**Coherent spin dynamics and carrier-nuclei interaction in lead halide perovskite crystals****E. Kirstein,^{1,*} D. R. Yakovlev,^{1,2,3} M. M. Glazov,² E. Evers,¹ E. A. Zhukov,^{1,2}, V. V. Belykh,³ N. E. Kopteva,¹ D. Kudlacik,¹ O. Nazarenko,⁴ D. N. Dirin,⁴ M. V. Kovalenko,⁵ and M. Bayer,^{1,2}**¹*Experimentelle Physik 2, TU Dortmund, 44227 Dortmund, Germany*²*Ioffe Institute, Russian Academy of Sciences, St. Petersburg 194021, Russia*³*P. N. Lebedev Physical Institute, Russian Academy of Sciences, Moscow 119991, Russia*⁴*Laboratory of Inorganic Chemistry, Department of Chemistry and Applied Biosciences, ETH Zürich, Zürich CH-8093, Switzerland*⁵*Laboratory for Thin Films and Photovoltaics, Empa-Swiss Federal Laboratories for Materials Science and Technology, Dübendorf CH-8600, Switzerland**Corresponding author: erik.kirstein@tu-dortmund.de

The class of lead halide perovskites showed a great potential for efficient light matter coupling. In particular a high quantum efficiency of solar cells (25%) and for light emitting diodes (90% of QY) were found. Also for fundamental research of light matter interaction the lead halide perovskite offers a interesting basis as the bandstructure with a s-type valence band and p-type conduction band is kind of inverted as compared to III-V or II-VI semiconductors.



(a) Dynamic nuclear polarization influencing carrier spin precession in $\text{FA}_{0.9}\text{Cs}_{0.1}\text{PbBr}_{0.2}\text{I}_{2.8}$



(b) Universal carrier g -factor dependence for APbX_3 lead halide perovskites, $X=\{\text{I}, \text{Br}, \text{Cl}\}$, $A=\{\text{MA}, \text{FA}, \text{Cs}\}$.

We use the pump-probe Kerr rotation and spin-flip Raman scattering experimental technique and show that they work well for the lead halide perovskite materials. It allows us to measure key parameters responsible for the spin-dependent properties: T_2^* , T_1 , g -factors and their anisotropy, hyperfine interaction with nuclear spins. We found experimentally and confirmed theoretically a universal dependence of the electron and hole g -factors on the band gap (Fig. (b)). We realize optically detected magnetic resonance and highlight the dominating role of ^{207}Pb isotopes in the carrier-nuclei interaction.

References

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WEDNESDAY April 13, 2022 | 11:15 – 11:30

Defect-engineered magnetic field dependent optoelectronics of vanadium doped tungsten diselenide monolayers

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In this work, we investigate semiconducting WSe₂ monolayers, substitutionally doped with vanadium atoms, using low temperature luminescence and optoelectronic spectroscopy. V-dopants lead to a p-type doping character and an impurity-related emission ~160 meV below the neutral exciton, both of which scale with the nominal percentage of vanadium dopants. Measurements using field-effect devices of 0.3% V-doped WSe₂ demonstrate bipolar carrier tunability. The doped monolayers display a clear magnetic hysteresis in photocurrent measurements for the studied range of carrier densities, whereas the valley polarization of the excitons reveals a nonlinear g-factor without a magnetic hysteresis within the experimental uncertainty. [1]

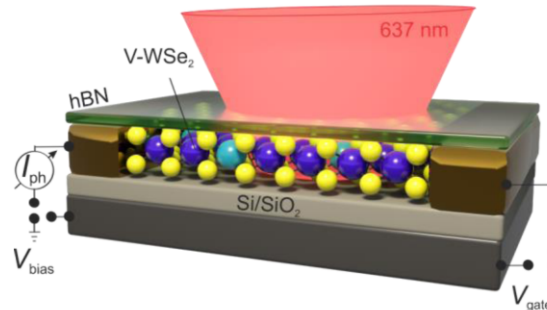


Figure 1: Device scheme of a gated V-doped WSe₂ monolayer.

References

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WEDNESDAY April 13, 2022 | 11:30 – 11:45

Impact of domain disorder on optoelectronic properties of layered semimetal MoTe₂

Maanwinder Partap Singh,^{1,2*} Jonas Kiemle,^{1,2} Ilkay Ozdemir,³ Philipp Zimmermann,^{1,2} Marko Burghard,⁴ Olkay Üzengi Aktürk,^{1,5} Alexander Holleitner,^{1,2} and Christoph Kastl^{1,2}

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We address the impact of crystal phase disorder on the generation of helicity-dependent photocurrents in layered MoTe₂, which is one of the van der Waals materials to realize the topological type-II Weyl semimetal phase. Using scanning photocurrent microscopy, we spatially probe the phase transition and its hysteresis between the centrosymmetric, monoclinic 1T' phase to the symmetry-broken, orthorhombic T_d phase as a function of temperature. We find a highly disordered photocurrent response in the intermediate temperature regime. Moreover, we demonstrate that helicity-dependent and ultrafast photocurrents in MoTe₂ arise most likely from a local breaking of the electronic symmetries. Our results highlight the prospects of local domain morphologies and ultrafast relaxation dynamics on the optoelectronic properties of low-dimensional van der Waals circuits [1].

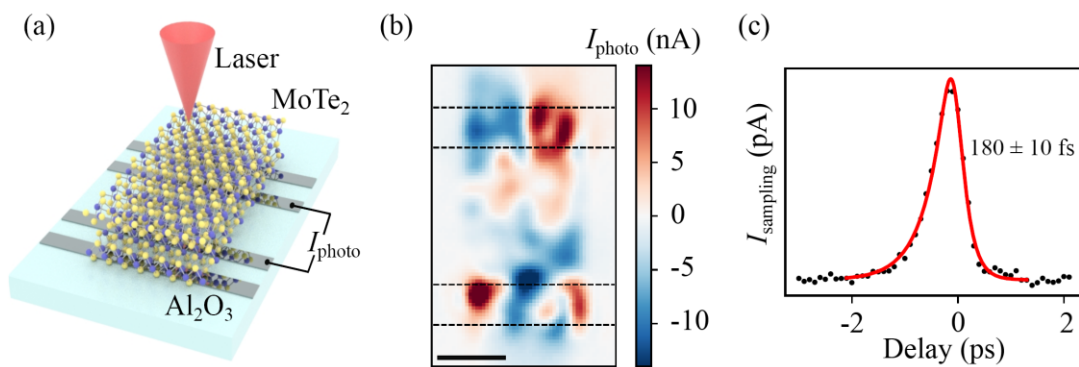


Figure 1: (a) Schematic of scanning photocurrent microscopy. (b) Disordered photocurrent response at 100 K. Dashed lines indicate the position of the metal contacts. Scale bar = 5 μm . (c) Decay dynamics of the ultrafast photogalvanic current at 77 K.

References

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WEDNESDAY April 13, 2022 | 11:45 – 12:00

Exciton-phonon interaction in precisely positioned single photon emitters in monolayer MoS₂

Katja Barthelmi,^{1,*} Alexander Hötger,¹ Julian Klein,¹ Lukas Sigl,¹ Florian Sigger,¹ Samuel Gyger,² Michael Lorke,³ Matthias Florian,³ Frank Jahnke,³ Val Zwiller,² Klaus D. Jöns,⁴ Christoph Kastl,¹ Kai Müller,¹ Jonathan J. Finley,¹ and Alexander W. Holleitner¹

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We demonstrate the site-selective generation of single photon emitters in a monolayer MoS₂ van der Waals heterostack. By irradiating Helium ions on in hBN encapsulated MoS₂ we can position single photon emitters with a lateral accuracy of below 10 nm. The irradiation gives rise to narrow emission lines (FWHM $\sim$ 1-6 meV) within a narrow energy window ($\sim$ 28 meV) around 1.75 eV. Through several cooldown cycles, the energy window can be reduced, while the emitters stay active at the treated sites and therefore show temporal stability [1]. We elaborate the exciton-phonon interaction for such defect bound excitons by discussing the temperature dependence of their luminescence. Our results pave the way towards controlled and deterministic generation of single photon emitters in monolayer TMDC van der Waals heterostacks and quantum photonic devices.

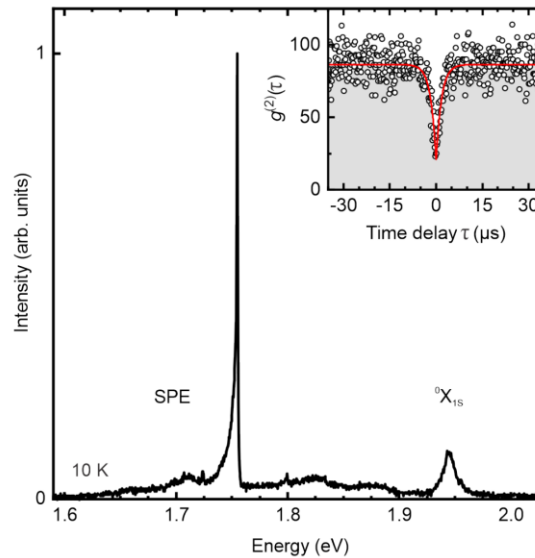


Figure 1: Typical photoluminescence spectrum and $g^{(2)}$ measurement of a single photon emitter (SPE) [1].

References

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WEDNESDAY April 13, 2022 | 12:00 – 12:15**High magnetic field measurements on defect luminescence in monolayer MoS₂ locally irradiated by He-ions**

Alexander Hötger,^{1,*} Julian Klein,^{1,2} Christoph Kastl,¹ Katja Barthelmi,¹
 Thomas Pelini,³ Alex Delhomme,³ Clément Faugeras,³ Marek Potemski,³
 Tomer Amit,⁴ Galit Cohen,⁴ Daniel Hernangómez-Pérez,⁴
 Sivan Refaely-Abramson,⁴ Takashi Taniguchi,⁵ Kenji Watanabe,⁵
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Point defects in monolayer TMDs have been identified as sources for localized quantum emission. We generate sulfur vacancies by rastering a focused He-ion beam across monolayer MoS₂ (cf. Figure 1a). Photoluminescence measurements reveal localized defect luminescence (cf. Figure 1b). At zero magnetic field, three distinct emission bands are observed, [1,2] each with a distinct asymmetric line shape that can be associated with the coupling of a localized emission state to phonons in MoS₂ (cf. Figure 1c). Through magneto-optical spectroscopy of the defect emission, we shed light on the nature of the optical transitions. High-field diamagnetic shift and simulations with an independent boson model yield a consistent picture of a localized state with $\langle r \rangle \sim 2$ nm. We discuss the distinct spin-valley physics of each emission band by comparing the observed high-field valley Zeeman splitting to state-of-the-art DFT and GW-BSE calculations and identify the possible optical transitions throughout the Brillouin zone. [3]

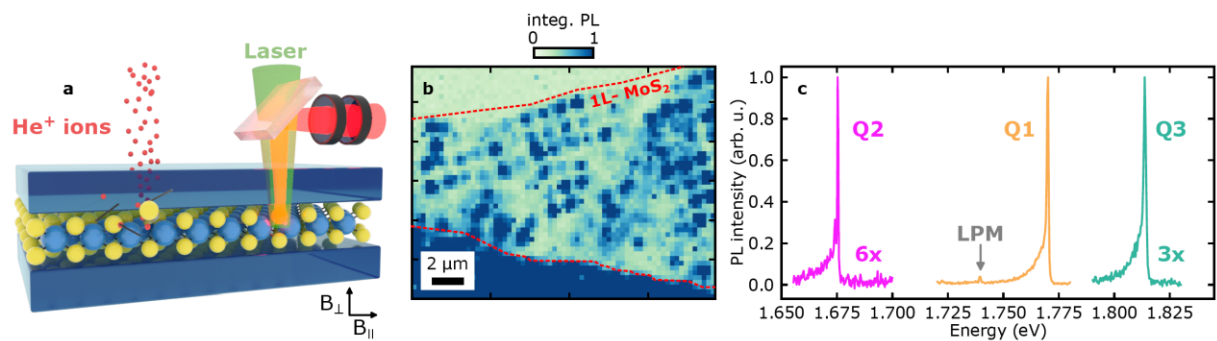


Figure 1: a) Sketch of the He-ion irradiation and the magneto-optical measurement on the generated defect center. b) False color map of the defect luminescence showing the irradiated array pattern. c) Typical photoluminescence spectra of three different emission bands showing similar asymmetric line shapes.

References

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WEDNESDAY April 13, 2022 | 12:15 – 12:30**Room-temperature exciton polaritons in an atomically-thin WS₂ crystal****Matthias Wurdack,^{1,2,*} Eliezer Estrecho,^{1,2} Christian Schneider,³ A.G. Truscott², and Elena A. Ostrovskaya^{1,2}**¹ ARC Centre of Excellence in Future Low-Energy Technologies² DQST, RSPHys, ANU, Canberra ACT 2601, Australia³ Institut für Physik, Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany*Corresponding author: matthias.wurdack@anu.edu.au

Monolayer transition metal dichalcogenide crystals (TMDCs) hold great promise for semiconductor optoelectronics because their bound electron-hole pairs (excitons) are stable at room temperature and interact strongly with light [1]. When TMDCs are embedded in an optical microcavity, their excitons can hybridise with cavity photons to form exciton polaritons (polaritons herein) [2], which inherit useful properties from their constituents.

Here, we show that WS₂ polaritons in a high-quality all-dielectric microcavity (see Fig. 1a) experience strong motional narrowing at room temperature [3], which suppresses the usually dramatic effects of dielectric disorder on the optical response of the atomically-thin crystal. This leads to increased macroscopic phase coherence and enables the polaritons to propagate ballistically over tens of micrometers in the “thermal” regime (see Fig. 1b) paving the path towards dissipationless information technologies based on TMDCs.

We also demonstrate a new approach for engineering an effective trapping potential for WS₂ polaritons by placing a WS₂/Ga₂O₃/WS₂ heterostructure [4] with a small top layer inside the microcavity [5]. By comparing the properties of the free and trapped polaritons in this structure, we find significant enhancement of the ground state emission (see Fig. 1c) and macroscopic coherence in the trap due to increased energy relaxation from the bottleneck into the ground state, strongly reduced inhomogeneous dephasing, and long radiative lifetimes of the cavity photons. This sample design also enables us to indirectly inject the partially coherent trapped polaritons with the free polaritons in the single-layer region (see Fig. 1d), which marks an important step towards realising electrically-injected coherent light sources based on TMDCs, e.g. with ring-contacts [6].

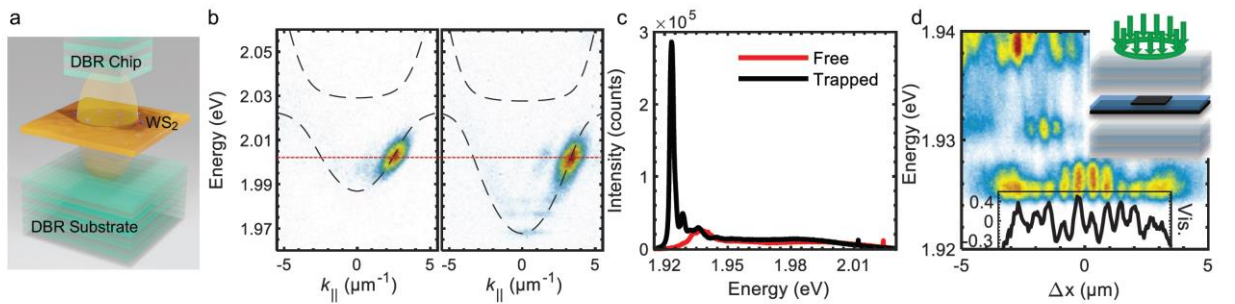


Figure 1: **a** Schematics of the microcavity. **b** Angle-resolved PL spectra of propagating WS₂ polaritons along a potential energy gradient at RT. **c** PL spectra of polaritons inside (black) and outside (red) of a polariton trap at RT. **d** Interference map and (inset) normalized interference fringes of the trapped polariton PL when excited outside of its periphery (see schematics).

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WEDNESDAY April 13, 2022 | 12:30 – 12:45

Fully hBN encapsulated MoS₂ Monolayers attached to Si₃N₄-Nanobeam Cavities with Q>10000

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Monolayer transition metal dichalcogenides (TMDs) are ideally suited as active materials for solid-state cQED due to their large exciton binding energies ≥ 100 meV and emission linewidths close to the homogeneous limit when suitably encapsulated by hexagonal boron nitride (hBN) [1]. However, the direct coupling of 2D semiconductors to 0D nanocavities whilst preserving excitonic properties and high cavity Q-factor remains a challenge. Most commonly, nonencapsulated monolayers are stacked directly on top of prefabricated photonic structures using pick-and place assembly. In this case, the disorder in dielectric environment can perturb the excitonic properties of 2D semiconductors due to spatial modulation of dielectric screening. Whilst dielectric disorder can be mitigated by full hBN encapsulation, this approach moves the TMD monolayer away from the antinode of the cavity field, thereby, trading spatial coupling for homogeneous linewidth. Here, we attach hBN/MoS₂/hBN heterostructures to freestanding Si₃N₄ nanobeam as hybrid cavities (Fig 1a). Our approach solves the trade-off problem by making the unpatterned heterostructure a functional part of the cavity. Therefore, the high excitonic quality and the strong cavity mode-MoS₂ overlap are achieved simultaneously. As shown in fig 1b, our approaches routinely provide cavity mode Q-factors $\geq 10^4$ [2]. We study the coupling between excitons-cavity photons and vibrational modes of the system using a confocal luminescence and Raman spectroscopy. For the cavity optical mode, we find that free trions (X⁻) operate in the non-local regime of light-matter coupling [3]. The detuning dependent emitter-cavity coupling parameter g is shown to be consistent with the shrinking X⁻ diffusion length as lattice temperature increases. In contrast, the interaction between cavity optical mode and free neutral excitons (X⁰) is suppressed due to absorption. The cavity vibrational mode shows the opposite behavior, where selective interaction with X⁰ is observed, whilst X⁻ does not couple strongly. We interpret this behavior as being due to the deformation potential of the two electrons in the trion being offset by the hole. Our results reveal the delicate interplay between coupling between excitons, photons and phonons in hybrid 2D-material cQED nanosystems.

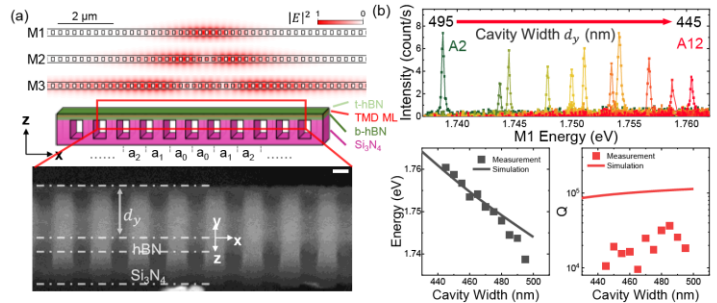


Figure 1(a) Schematic of hybrid nanocavities fabricated with fundamental cavity modes (top) and SEM image of device. (b) Spectra of cavity modes as a function of nanobeam widths. The lower panel compares measured (points) and simulated (lines) cavity mode frequency and Q-factors.

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WEDNESDAY April 13, 2022 | 12:45 – 13:00

Optovalleytronics of two-dimensional materials with tilted Dirac cones

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We analyse the interband optical absorption of linearly polarised light by 2D Dirac semimetals hosting tilted Dirac cones in the band structure[1]. Super-critically tilted (type-II) Dirac cones are characterised by an absorption that is highly dependent on incident photon polarization and tuneable by changing the Fermi level with a back-gate voltage. Unlike their sub-critically tilted (type-I) counterparts, type-II Dirac cones have open Fermi surfaces meaning that there exists large regions of the Brillouin zone where both bands sit either above or below the Fermi level causing many states that would otherwise contribute to absorption to be Pauli blocked. We analyse Dirac cones featuring tilt as well as anisotropy in the Fermi velocity, yielding a wide range of qualitatively unique absorption spectra. Guided by our in-depth discussion we develop an optical recipe to fully characterise the tilt and Fermi velocity anisotropy of any 2D tilted Dirac cone solely from its absorption spectra. We also show that tilted Dirac cones allow spatial separation of carriers belonging to two different valleys under illumination by linearly polarized light, leading to novel optovalleytronic applications. Our results are used to analyse polarisation-dependent light absorption of 8-Pmmn Borophene[2,3].

This work was supported by the EU H2020-MSCA-RISE projects TERASSE (Project No. 823878) and DiSeTCom (Project No. 823728) and by the NATO Science for Peace and Security project NATO.SPS.MYP.G5860.

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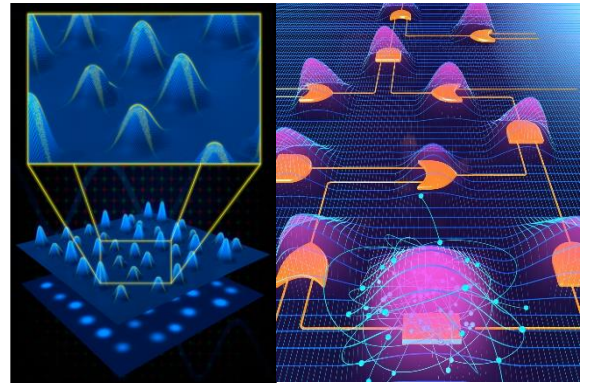
Liquid Light Computing: from logic to analogue simulation

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Modern digital computers have changed our lives in a variety of ways, but the technology on which they are built is rapidly reaching a hard limit due to inherent quantum effects. Two of the main pillars of our modern digital computers are the electronic transistor and the von-Neumann computer architecture. While the von-Neumann architecture established the physical separation of computing tasks like storage and processing, transistors are the fundamental building blocks in digital computers. The drive for faster and more powerful computers can be realised by increasing the number of transistors in a processor and the clock frequency. However, Moore's law will soon come to an end, whilst the breakdown of Dennard's scaling law means that clock frequencies have remain unchanged since 2006. This leads to the pressing quest to develop new kinds of transistors and alternative computing architectures that could one day lead to more efficient computers.

In our labs, we combine state-of-the-art photonic structures and light emitting semiconductor materials in which light and matter fuse to form new types of particles called polaritons. In a sense, polaritons bridge the fields of electronics and photonics by controlling the amount of light vs matter in these hybrid particles. At high densities, polaritons undergo 'condensation' forming micron scale droplets of liquid-light, with all particles within the droplet being coherent and indistinguishable from one another. In this seminar, I will describe the fundamental properties of such liquid-light droplets, aka polariton condensates, and their applications both in analogue (simulators) [1,2] and digital computing (logic) [3,4].



Schematics of (a) a liquid light analogue simulators, (b) liquid light circuit for digital computing

Prof Pavlos Lagoudakis graduated from the University of Athens, Greece. He received his PhD from the University of Southampton, and worked as a postdoctoral researcher at the Ludwig Maximilian University of Munich. In 2006, he joined the faculty of the University of Southampton. In 2016, he joined Skoltech where he setup and heads the Laboratories for Hybrid Photonics. His research spans the fields of photonics, strong light-matter coupling, semiconductor and condensed matter physics.

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THURSDAY April 14, 2022 | 10:00 – 10:15

Integrated quantum polariton interferometry

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In the last two decades, exciton-polariton systems at high excitation density have emerged as a promising platform to explore fundamental physics effects in an analog solid state scenario, ranging from Bose-Einstein condensation [1] to analog gravity [2], as well as to develop, due to their unique and remarkable properties, more application-oriented devices, such as all-optical transistors [3], Mach-Zehnder interferometers [4], couplers [5], just to mention a few.

In parallel, recent experiments have been exploring also the possibility to excite the quantized polariton field in confined geometries at the level of single or few excitation quanta [6,7]. In particular, evidence of quantum correlations at the level of few excitations has been recently reported [8,9], thus suggesting the possibility of using exciton-polariton systems also for quantum information purposes.

Motivated by these recent results and thrilling perspectives, we consider the behavior of integrated circuits fed by single-polariton input states [10], and we show that they can be arranged to build deterministic quantum logic gates in which the intrinsic two-particle nonlinearity plays a crucial role. In addition, we also show that such quantum polariton integrated circuits can be exploited for metrology purposes, as for instance to precisely measure the magnitude of the polariton-polariton interaction at the two-body level, a quantity that has not been directly measured, yet. In general, our results introduce a paradigm for the development of practical quantum polaritonic devices, in which the effective interaction between single polaritonic qubits may provide a unique tool for future quantum technologies.

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THURSDAY April 14, 2022 | 10:15 – 10:30

Quantifying Quantum Coherence in Polariton Condensates

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We theoretically and experimentally investigate quantum features of an interacting light-matter system from a multidisciplinary perspective, unifying approaches from semiconductor physics, quantum optics, and quantum information science. As an example of a hybrid light-matter interface, we drive a polariton microcavity across the condensation threshold and observe the transition from an incoherent thermal state to a coherent state in the emission. By analyzing the phase-space distributions of the emitted light, we quantify the amount of quantum coherence that results from the quantum superposition of Fock states, constituting a measure of the resourcefulness of the produced state for modern quantum protocols.[1]

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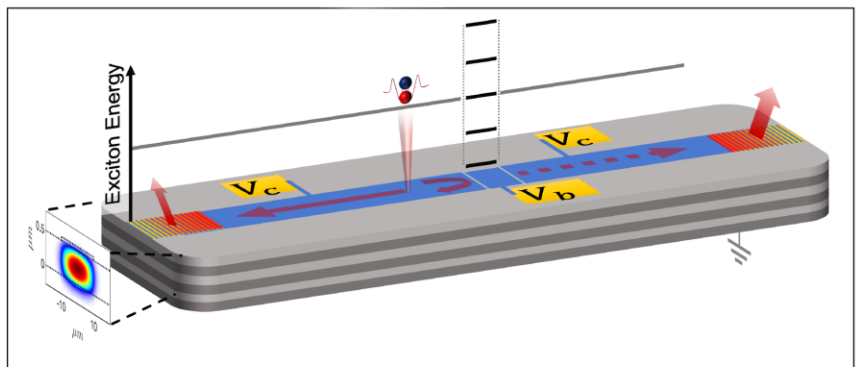
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THURSDAY April 14, 2022 | 10:30 – 10:45**Tunable electro-optical blockade and switching of propagating exciton-polaritons****Dror Liran,^{1,*} Jiaqi Hu,² Nathaniel Lydick,² Hui Deng,² Loren Pfeiffer,³ and Ronen Rapaport¹**¹ *Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 91904, Israel*² *University of Michigan, Ann Arbor, MI 48109, USA*³ *Department of Electrical Engineering, Princeton University, Princeton, NJ, 08544 USA**Corresponding author: dror.liran@mail.huji.ac.il

Electrically biased, low-loss waveguided exciton-polaritons (WGP) are suggested for future highly functional, on-chip quantum-photonic circuits: these high-momentum polaritons can be controlled through their photon part using standard dielectric waveguide technology, and through their excitonic part using quantum confined Stark effect. It was recently demonstrated that electrically biased WGP can be guided to propagate over macroscopic distances in curved waveguide geometries [1], and that their energy and optical non-linearity can be tuned continuously via direct electrical gating [2], that results in enhanced dipolar interactions [3]. These demonstrations make electrically biased WGP promising candidates for observing dipolar quantum blockade of polaritons towards polariton quantum-logic devices.

Here we demonstrate a controlled electrical blockade of WGP, using a potential landscape shaped as a tunable electrical potential barrier for propagating WGP in a channel (see image). WGP are injected into a fixed-biased optical channel and propagate towards the potential barrier. As the bias of the barrier is changed with respect to that of the channel, we observe strong modifications of the transmission and reflection of the WGP into the corresponding waveguide-out couplers. We find that when the electrical bias in the barrier is larger than in the channel, a strong blockade of polaritons occurs, leading to an almost full reflection and to minimal transmission. Energy-resolved transmission and reflection measurements reveal that

the blockade is due to an electrically-induced gap in the WGP density of states inside the barrier, leading to elastic back-scattering of the WGP that acts as an effective mirror [4]. Time-resolved measurements of resonantly injected WGP



reveal the ultrafast dynamics of the WGP in the device. This method of electrical shaping the potential-landscape for propagating polaritons, which can also be dynamically tuned, is an important building block towards a full configurable logical circuitry for polaritons.

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Semiconductor quantum dots for quantum technologies

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S. Klemmt¹, A. Pfenning¹, C. Schneider¹, T. Huber¹, S. Höfling^{1,*}**

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In 1997, Peter Shor presented an algorithm for prime factorization in polynomial time on a quantum computer [1]. Since the security in classical cryptography relies on the mathematical complexity of prime factorization, a possible realization of a quantum computer threatens classical cryptography. To fix this problem there are two possible solutions. One is post-quantum cryptography [2] algorithms, which is still based on mathematical complexity. Here, the encryption is modified such that there is no known attack from a quantum computer. The other solution is quantum key distribution [3], which is solely based on physical principles. The latter solution is preferable, because it is genuinely secure – also in the future.

One concept to overcome the challenge of attenuation to establish long-distance quantum links is the quantum repeater [3] which needs a local memory or a fully connected cluster state [5], which probably needs a local qubit as well to build up the entanglement [6]. Spins in QDs are a promising platform, because their spins can be coherently controlled [7], entangled with emitted photons [8], or entangled with other distant spins [9]. We present our recent experimental developments on highly efficient, tunable self-assembled QDs in photonic structures towards functional quantum systems.

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THURSDAY April 14, 2022 | 11:45 – 12:00

High-resolution spectroscopy of a quantum dot driven bichromatically by two strong coherent fields

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Optically-active excitons in semiconductor quantum dots which can act as two-level systems provide an excellent basis for investigating fundamental light-matter interaction, as well as for the generation of non-classical light. Tailoring the emission spectrum via coherently driving excitonic transitions enables engineered coherent quantum evolution under strong field interactions, which can manifest in experimental observables such as the Mollow triplet, Ramsey interference and Rabi oscillations.

For further control of the system, a second coherent drive can be added to the excitation scheme, with potential applications including suppression of the resonant spontaneous emission or off-resonant excitation, spectral line narrowing, and gain without population inversion.

So far, bichromatic excitation has been studied theoretically as well as experimentally and has revealed an interference-based suppression of the spectral emission line resonant with the exciton frequency, when driven with a strong resonant laser and a second laser detuned to one of the sidebands or its subharmonic of the resultant Mollow triplet.

In this contribution, we expand these previous works by exploring deeper regimes of a bichromatically excited InGaAs quantum dot. In particular, we study the strong field regime where both laser drives are strong enough such that a general non-perturbative analysis is required, resulting in a rich Floquet dressed-state energy structure.

Besides simulated spectra, we provide high resolution spectroscopy measurements which are in good agreement with each other. We observe a reappearance of the central spectral transition at high detuned-laser pump strengths and additional higher order effects, e.g. additional emission triplets at higher harmonics. Furthermore, excitation with an off-resonant primary laser but otherwise similar excitation conditions reveals similar spectral features, but with an enhanced inherent spectral asymmetry [1].

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THURSDAY April 14, 2022 | 12:00 – 12:15

Electric field tunable transition dipole moments and selective optical charging of a single QD molecule

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Coherence, ease of control and scalability lie at the heart of all hardware for distributed quantum information technologies. This is particularly true for spin-photon interfaces based on III-V semiconductor quantum dots (QDs) since they combine properties such as strong interaction with light, robust spin-photon selection rules, nearly pure transform limited emission into the zero-phonon line, and ease of integration into opto-electronic devices. For pairs of vertically stacked QDs, forming a QD-molecule (QD|M), these single dot properties are retained. Additionally, interdot charge tunneling opens the way to enhanced spin coherence times (T_2^*) compared so single dots [1] and to use single QDMs as an interface for the deterministic generation of 2D photonic cluster states [2]. To use single QDMs as flexible spin-photon interfaces, the ability to prepare one and two spin states and electrically gate the spin-spin coupling is desirable.

Here, we realize devices consisting of a single QDM embedded within the intrinsic region of a $\sim 10 \times 25 \mu\text{m}$ micro-photodiode (Figure 1). The efficiency of the spin-photon coupling is enhanced using an annular Bragg grating placed around the QDM. Such approaches enhance the photon extraction efficiency to $>20\%$ over a $>7 \text{ nm}$ bandwidth [3], whilst having capacitance that is small enough ($<200 \text{ fF}$) to facilitate ultrafast ($>500 \text{ MHz}$) electro-optical switching of the orbital tunnel couplings. Our devices demonstrate optical control of the QDM charge status and electronic control of tunnel coupling. Figure 1 shows typical field dependent Rabi oscillations recorded using resonance fluorescence from direct and indirect exciton branches. The exciton optical dipole moment can be electrically tuned from $4.3 \times 10^{-28} - 1.5 \times 10^{-28} \text{ Cm}$, as the orbital state admixtures in the two dots are tuned. Comparison with the detuning dependent exciton decay lifetimes, elucidates the interplay between radiative recombination and phonon induced relaxation between direct and indirect exciton branches as interdot tunnel coupling is tuned. Finally, we demonstrate selective, all optical electron spin preparation in the QDM by resonantly exciting an e-h pair and allowing the hole to tunnel escape, leaving the electron trapped. Optical electron spin preparation and the ability to control interdot orbital couplings provides a perspective to use our devices for the deterministic generation of 2D cluster states.

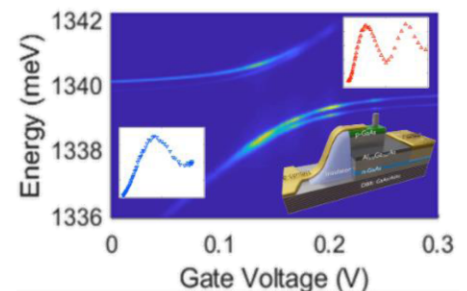


Figure 1 – Avoided crossing of neutral exciton. Insets: Excitonic Rabi oscillations driven on the direct (red) and indirect (blue) exciton branch. Schematic representation of sample structure of fast switching diode (bottom right).

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THURSDAY April 14, 2022 | 12:15 – 12:30**Strong enhancement of heavy-hole Landé factor q in InGaAs symmetric quantum dots revealed by coherent optical spectroscopy**

**A. V. Trifonov,^{1,2,*} I. A. Akimov,^{1,3} , L. E. Golub,³ E. L. Ivchenko,³
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In this work, we experimentally and theoretically demonstrate that in spite of a strong inhomogeneous broadening of the optical transitions in a semiconductor quantum dots (QDs) ensemble, it is possible to achieve uniform magnetic-field-induced optical anisotropy, i.e. orientation of the eigen polarizations of the optical transitions with respect to the direction of an applied magnetic field. We show experimentally using photon echo (PE) spectroscopy, that this scenario is realized in an ensemble of strongly annealed (In,Ga)As/GaAs quantum dots. Fig. 1 shows PE amplitude measured as a function of in-plane magnetic field amplitude, B , and of magnetic field orientation with respect to the axis [100] described by φ . There are B dependent oscillations corresponding to electron and hole spin precession as well as φ dependent oscillations at $B > 0.7$ T reflecting anisotropic properties of hole g tensor. The period of the angular oscillations

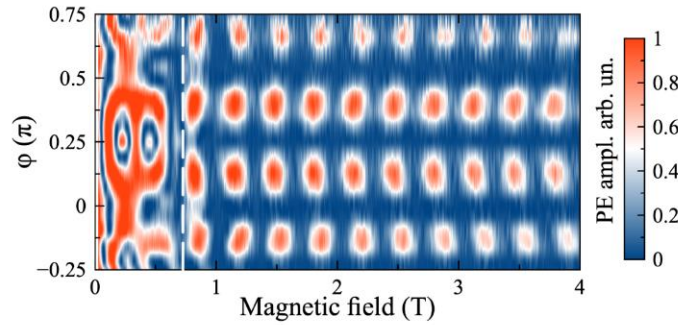


Figure 1: Photon echo amplitude measured as a function of in-plane magnetic field amplitude, B , and magnetic field orientation with respect to axis [100] described by φ , $\tau_{12} = 400$ ps, $T = 1.4$ K.

is explained by a new mechanism related to a strong enhancement of the valence band Landé parameter q which consequently leads to the formation of a large in-plane hole g factor, determined by the D_{2d} symmetry of the QDs. The proposed enhancement appears due to a combination of warping of the heavy hole valence band and strong in-plane localization of the hole wavefunction, which becomes essential in QDs with considerable lateral confinement. Details of the experiment and the proposed mechanism of the factor q enhancement can be found in Ref. [1].

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Dark-bright excitons mixing in alloyed quantum dots

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Despite its name, the dark exciton reveals weak luminescence that can be directly measured. The origins of this optical activity remain largely unexplored. In this work [1], using the atomistic tight-binding method combined with the configuration-interaction approach, we demonstrate that atomic-scale randomness [1-4] strongly affects the oscillator strength of dark excitons confined in quantum dots with no need for faceting or shape-elongation. We show that this process is mediated by two mechanisms: mixing dark and bright configurations by exchange interaction (Fig. 1), and the equally important appearance of nonvanishing optical transition matrix elements that otherwise correspond to nominally forbidden transitions in a nonalloyed case. The alloy randomness has an essential impact on both bright and dark exciton states [1-4], including their energy, emission intensity, and polarization angle. We conclude that, due to the atomic-scale alloy randomness, finding dots with the desired dark exciton properties may require exploration of a large ensemble, similarly to how dots with low bright exciton splitting are selected for entanglement generation.

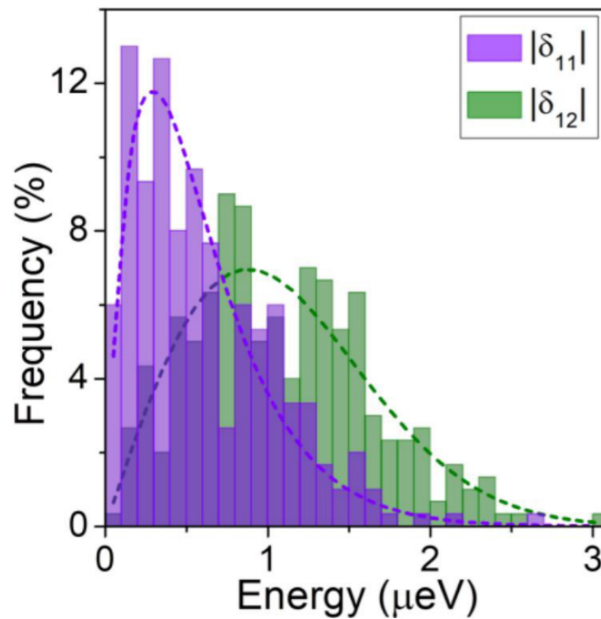


Figure 1: Histogram of absolute values of dark-bright exciton mixing exchange integrals [1] for an ensemble of 300 alloyed quantum dots calculated using atomistic tight-binding method.

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THURSDAY April 14, 2022 | 12:45 – 13:00

Linear and nonlinear optical response in semiconductor diamond-shaped quantum ring under orthogonal electric and magnetic fields

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The improvement in materials growth techniques have made possible practical realization of semiconductor quantum rings having different shapes. In this regard, quantum rings with diamond-shaped an elliptical hole were recently reported [1]. These nanostructures can be used in opto-electronic devices, quantum architecture elements and quantum computation. To carry out these applications with diamond-shaped quantum rings is necessary to have reliable methods to calculate the electron energy spectra. This fact has motivated to consider a single electron confined in a diamond-shaped quantum ring doped with two impurity donors, under threading magnetic field and in-plane electric field. To calculate the optical responses, the corresponding electron energy levels are obtained by solving Schrödinger wave equation within the effective mass approximation and using finite element computational procedure. From these data, we calculate the single electron nonlinear intraband optical absorption coefficient and relative refractive index changes as a function of incident photon energy. These calculations are made within the compact density-matrix formalism under steady state conditions. By considering a centric elliptical hole and a variable height in the quantum ring structure, an anisotropic thickness is obtained which tends to localize the electronic cloud in the valleys of the ring, reason why the electron energy spectrum is formed by vibrational states, rotational states and some constraints caused by the Coulombian interaction between the donors and the electron. In this work, the anisotropic thickness effect on the linear and nonlinear optical responses is analyzed in relation with the position of the impurity donors and the threading magnetic field effect, since these conditions tend to destroy the vibrational states which can lead to redshift and/or a blueshift of the resonant peaks of the intraband optical absorption and relative refractive index change can be observed. Also, these effects are contrasted with the location caused by the electric field, which can reduce the energy separation among the states in the band.

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Features of the dependence of the polaritons dispersion and group velocity in a 1D lattice of micropores with quantum dots on structural defects concentration and homogeneous deformation

V.V. Rumyantsev^{1,2,*}, S.A. Fedorov¹ and A.Ye. Rybalka¹

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The possibility of regulating the propagation of electromagnetic excitations in a polariton structure by controlled external action (elastic deformation) or the presence of structural defects is investigated. A chain of identical micropores randomly containing two types of quantum dots was considered as a model system. Moreover, the chain is in conditions of uniaxial stress (compression or stretching) directed along the axis of the chain. With homogeneous deformation (the corresponding component of the strain tensor is ε) the position of each micropore changes. At the same time, the nearest micropores-resonators are also randomly removed from each other. By diagonalizing the averaged Hamiltonian of such a system, using the theoretical model [1] and the virtual crystal approximation [2], the law of dispersion of polariton excitations $\Omega(k, \{C_C, C_T\}, \varepsilon)$ and the relation for

the group velocity $V(\vec{k}) = \frac{\partial \Omega(\vec{k})}{\partial \vec{k}}$ of polariton excitations propagation in the desired non-ideal system

(see Fig.1) are obtained. Here C_C, C_T are the concentrations of structural defects associated with variations in the composition and positions of the system elements, respectively. Of particular interest is the dependency $k(C_C, C_T)$ that follows from the condition $V_3(k, C_C, C_T) = 0$. This result is important when searching for the possibility of obtaining a Bose-Einstein polariton condensate for the wave vector values $k \neq 0$.

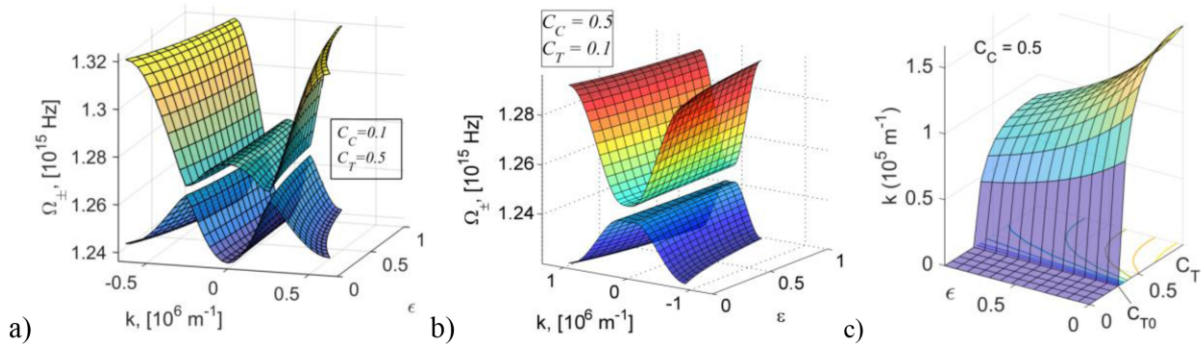


Figure 1: Dependence of the dispersion of polaritons $\Omega(k, \{C_C, C_T\}, \varepsilon)$ and $k(C_C, C_T)$ on the concentration of structural defects and the deformation parameter.

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THURSDAY April 14, 2022 | 15:00 – 15:30**QUBITS BASED ON SPLIT-RING POLARITON CONDENSATES****Alexey Kavokin**

¹Institute of Natural Sciences, Westlake University, No.18, Shilongshan Road, Cloud Town, Xihu District, Hangzhou, China (a.kavokin@westlake.edu.cn) and Russian Quantum Center, Skolkovo, Moscow, 143025, Russia

Superconducting flux qubits are based on a superposition of clock-wise and anti-clockwise currents formed by millions of Cooper pairs. In order to excite the system in a superposition state, the half-quantum flux of magnetic field is passed through the superconducting circuit containing one or several Josephson junctions. The system is forced to generate a circular current to either reduce the magnetic flux to zero or to build it up to a full-quantum flux. We argue that a valuable alternative to superconducting flux qubits may be offered by qubits based on superfluid currents of quasiparticles of *liquid light*: exciton-polaritons, propagating in plane of semiconductor microcavities [1]. Circular currents of exciton-polaritons mimic the superconducting flux qubits being composed by a large number of bosonic quasiparticles that compose a single quantum state of a many-body condensate. The essential difference comes from the fact that polaritons are electrically neutral, and the magnetic field would not have a significant effect on a polariton current. We note however, that the phase of a polariton condensate must change by an integer number of 2π , when going around the ring. If one introduces a π -phase delay line in the ring, the system is obliged to propagate a clockwise or anticlockwise circular current to reduce the total phase gained over one round-trip to zero or to build it up to 2π . We show that such a π -delay line can be provided by a dark-soliton embedded into a ring condensate and pinned to a potential well created by the C-shape non-resonant pump-spot. The physics of resulting split-ring polariton condensates is essentially similar to the physics of flux qubits. In particular, they exhibit pronounced Bloch oscillations passing periodically through clockwise and anticlockwise current states. We argue that qubits based on split-ring polariton condensates may be characterized by a very high figure of merit due to the topological protection of superfluid circular currents. Moreover, as the Bose-Einstein condensation and superfluidity of exciton-polaritons were observed at the room temperature [2], quantum networks based on polariton qubits would not require cryogenic operation temperatures. This makes them a valuable alternative to superconducting qubits [3].

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THURSDAY April 14, 2022 | 15:30 – 15:45

Probing long-time dynamics in optically trapped exciton-polariton condensates

Helgi Sigurðsson,^{1,2*} Ivan Gnusov,³ Stepan Baryshev,³ Stella Harrison,² Kirill Sitnik,³ Sergey Alyaktin,³ Julian Töpfer,^{2,3} Alexis Askitopoulos,³ and Pavlos Lagoudakis^{2,3}

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In this talk I will discuss a series of studies on optically trapped exciton-polariton condensates in semiconductor microcavities which have been shown to possess coherence times exceeding the polariton lifetime by almost three orders of magnitude [1]. This has opened a pathway to drive exciton-polariton condensates into stable states under continuous-wave excitation that exhibit complex long-time dynamics such as the self-induced Larmor precession in the condensate pseudospin with almost $Q \approx 30$ periods resolvable [2], and (similarly) internal Rabi-like oscillations showing spontaneous synchronization between spatially coupled condensate traps [3].

I will discuss how by changing the geometry of the optical traps, squeezing them into anisotropic shapes, can be used to trigger condensation into states of definite linear polarization with perspectives on the role of polaritons as tunable coherent light sources [4]. I will also show how the combination of microcavity birefringence, optical orientation of the incoherent background excitons, and the condensates internal dynamics can dramatically affect the photon statistics of the emitted cavity light, demonstrating a smooth transition from a highly coherent to a super-thermal state of the condensate polarization components [5].

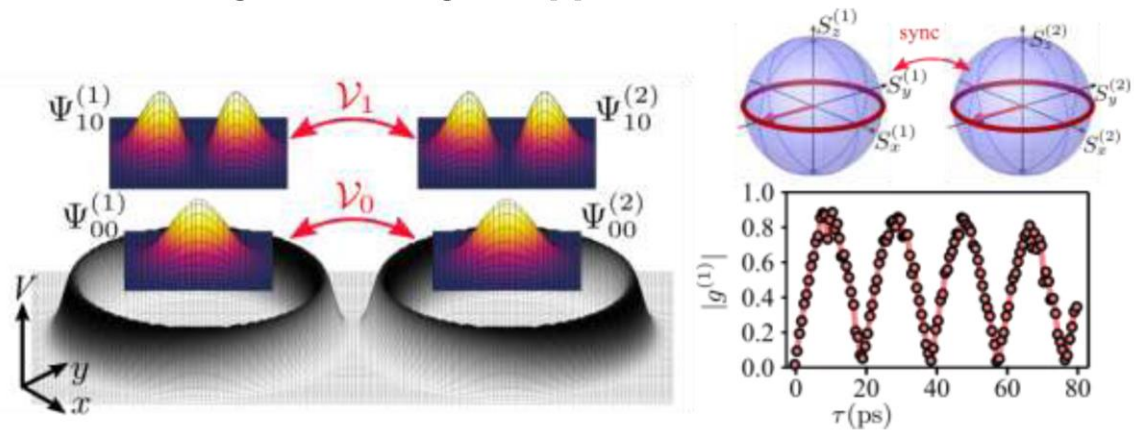


Figure 1: Schematic representation of coupled two-level condensates becoming synchronized.

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THURSDAY April 14, 2022 | 15:45 – 16:00

High-temperature condensation, ballistic propagation and non-hermitian effects of exciton polaritons in AlGaAs-based microcavities

**D. Biegańska,^{1,*} M. Pieczarka,¹ H. Suchomel,² C. Schneider,^{2,3} S. Klemmt,²
S. Höfling,^{2,4} and M. Syperek¹**

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As interacting bosons, exciton polaritons can form a macroscopically coherent state, e.g. a Bose-Einstein Condensate (BEC). With effective masses orders of magnitude lower than that of the free electron, the critical densities (temperatures) required to observe BEC of polaritons are much lower (higher) than that of atoms, making exciton polaritons a perfect platform to achieve condensation at elevated temperatures and even room temperature (RT). RT polariton condensation was currently achieved in various materials, from large bandgap semiconductors to novel materials, such as organic semiconductors, perovskites, and TMDCs. However, in the GaAs-based monolithic microcavities, where the quantum well (QW) excitons binding energy is relatively low, excitons dissociate above cryogenic temperatures. It prevents the formation of the condensate at high temperatures. Here, we employ a strategy to increase the exciton binding energy through band engineering of the $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}/\text{AlAs}$ QWs, exploiting the effect of Γ -X valley mixing [1]. It preserves strong exciton-photon coupling up to 300 K, making it suitable for achieving RT BEC. It would make it a highly advantageous system, with well-established technology, best quality growth and colossal application potential.

In this work, we study the high temperature lasing of polaritons and their ballistic propagation. We employ several excitation schemes, including the pump spot structuring and optical trapping, in order to diminish the influence of incoherent excitonic reservoir on coherent properties of the condensate at high temperatures. We investigate various regimes of polariton lasing, with a careful address of the photon versus the polariton lasing. Most importantly, we observe a propagating polariton condensate, flowing out of the pumping spot at high temperatures (200 K), which is a current record value in this material system.

Additionally, we report on the observation of an anomalous inverted polariton dispersion. It results from the effective non-hermitian coupling to the cavity mode, present due to the complex electronic structure of specially designed AlGaAs/AlAs quantum wells. Such level attraction can be of crucial importance and interest in future research and applications [2] and has not been observed in this material system so far.

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FRIDAY April 15, 2022 | 09:15 – 09:45**Simultaneous measurements of nuclear spin heat capacity, temperature and relaxation in GaAs microstructures.****M. Vladimirova,^{1,*} S. Cronenberger,¹ A. Colombier,¹ D. Scalbert,¹****A. Lemaître² V. M. Litvyak,³ and K. V. Kavokin,³**¹*Laboratoire Charles Coulomb, UMR 5221 Université de Montpellier, CNRS, Montpellier, France*²*Université Paris-Saclay, CNRS, Centre de Nanosciences et de Nanotechnologies, 91120, Palaiseau, France*³*Spin Optics Laboratory, St. Petersburg State University, Ulyanovskaya 1, St. Petersburg 198504, Russia**Corresponding author: maria.vladimirova@umontpellier.fr

Semiconductor microcavities are promising structures for optical studies of deeply cooled nuclear spin system (NSS). However, it has been shown that heat capacity of the NSS in GaAs embedded in a microcavity is much greater than expected from dipolar coupling between nuclei, thus limiting the efficiency of NSS cooling by adiabatic demagnetization [1]. It was suggested that quadrupole interaction induced by some small residual strain could provide this additional reservoir for the heat storage [1, 2]. We check and validate this hypothesis by combining nuclear spin relaxation measurements with adiabatic re-magnetization and nuclear magnetic resonance experiments, using electron spin noise spectroscopy as a unique tool for detection of nuclear magnetization (see Figure). Our results confirm and quantify the role of the quadrupole splitting in the heat storage within NSS and provide additional insight into fundamental, but still actively debated relation between a mechanical strain and the resulting electric field gradients in GaAs [3].

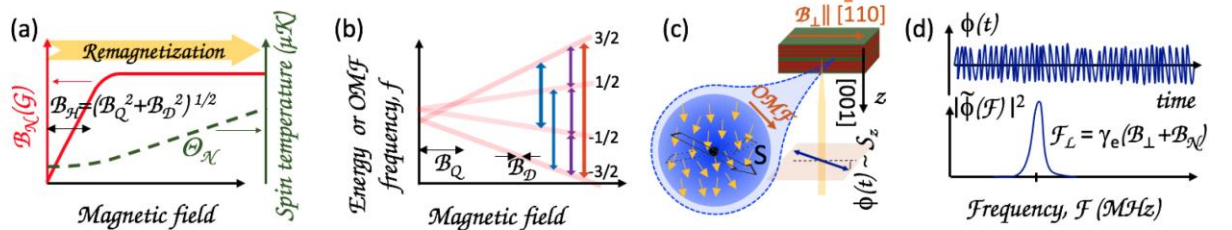


Figure 1: (a) Overhauser field B_N and the corresponding nuclear spin temperature Θ_N as a function of the magnetic field according to spin temperature theory. B_H is a field that characterizes NSS heat capacity. (b) Schematic representation of quadrupole-split nuclear spin levels. Arrows indicate NMR transitions (c) Sketch of the donor-bound electron spin interacting with the underlying nuclear spins. (d) Fluctuations of the electron spin detected via Faraday rotation in time domain within 0.5 GHz frequency band and the corresponding Fourier power spectrum.

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FRIDAY April 15, 2022 | 09:45 – 10:00

Effect of electron density on spin helices in GaAs quantum wells: Interplay of spin-orbit coupling and spin diffusion

S. Anghel,^{1*} A. V. Poshakinskiy,² K. Schiller,¹ G. Yusa,^{3,4} T. Mano,⁵ T. Noda⁵ and M. Betz¹¹Experimentelle Physik 2, Technische Universität Dortmund, Otto-Hahn-Straße 4a, D-44227 Dortmund, Germany²Ioffe Institute, St. Petersburg 194021, Russia³Department of Physics, Tohoku University, Sendai 980-8578, Japan⁴Center for Spintronics Research Network, Tohoku University, Sendai 980-8578, Japan⁵National Institute for Materials Science, Tsukuba, Ibaraki 305-0047, Japan

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Persistent spin helix (PSH) occurs in two-dimensional electron gases (2DEG) when the Dresselhaus and Rashba spin-orbit interactions (SOIs) are equal. The combined SOIs manifest themselves as a real-space spin texture that resembles a one-dimensional spin grating arising due to Larmor precession in a momentum-dependent effective magnetic fields. Under these conditions, suppression of D'yakanov-Perel spin dephasing results in significant enhancement of the spin coherence times. The adjustable Dresselhaus and Rashba SOIs in low-dimensional systems control the PSH spin texture parameters, such as the periodicity of the spin-grating, offering functionality to future spintronic devices. In addition to formation of the PSH through diffusion, general control of the spin transport using external electric fields to provide drift velocities for the electrons in the 2DEG is desirable for some spintronic applications [1,2].

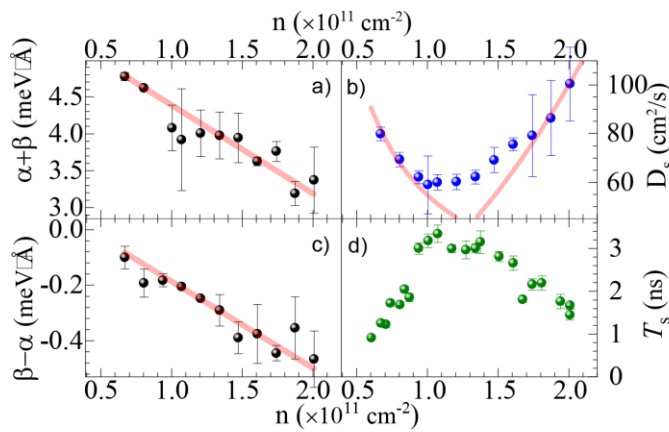


Fig. 1 Low temperature (4K), experimentally measured (a) spin-orbit parameter $\alpha + \beta$, (b) spin diffusion coefficient D_s , (c) spin-orbit parameter $\beta - \alpha$ and (d) PSH lifetime T_s as a function of the electron density. The solid lines in (a) and (c) are linear fits to the data, whereas those in (b) are fits for low- and high-density asymptotics corresponding to Boltzmann to Fermi-Dirac statistics.

In this work we reveal the dependence of the PSH lifetime on spin diffusion coefficient and the electron density, by employing time-resolved magneto-optical Kerr effect microscopy to study the spin polarization evolution in low-dimensional GaAs semiconductors hosting two-dimensional electron gases. It is shown that for the achieving the longest PSH lifetime, the variation of scattering rate with the electron density is of higher importance than the fulfilling of the persistent spin helix condition when the Rashba α and Dresselhaus β parameters are balanced (see Fig.1). More specifically, regardless of the α and β linear dependence on the electron density, the PSH relaxation rate is determined mostly by the spin diffusion coefficient that depends on electron density nonmonotonously. The longest experimentally observed PSH lifetime occurs at an electron density, corresponding to the transition from Boltzmann to Fermi-Dirac statistics, which is several times

higher than that when the persistent spin helix is expected. These facts highlight the role the electron density may play when considering applications for spintronic devices.

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FRIDAY April 15, 2022 | 10:00 – 10:15**Probing Interlayer Pairing Via Density Imbalance in Exciton Bilayers****Michal Zimmerman,^{1,*} Ronen Rapaport,¹ and Snir Gazit^{1,2}**¹*The Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 9190401, Israel*²*The Fritz Haber Research Center for Molecular Dynamics, The Hebrew University of Jerusalem, Jerusalem 9190401, Israel**Michal Zimmerman: michal.zimmerman@mail.huji.ac.il

Motivated by two recent experimental works [1-2], we theoretically study the experimental signatures of collective interlayer pairing in indirect exciton bilayers. To that end, we employ numerically exact quantum Monte Carlo calculations to solve a model Hamiltonian comprising bilayer dipolar bosons at distinct layer densities n_α (with $\alpha = 1, 2$ being the layer index), elucidate its global phase diagram and determine their experimental signatures. We find that IX energy shifts ΔE^{IX} associated with each layer evolve non-trivially as a function of density imbalance $\gamma = \frac{n_2}{n_1} - 1$. In particular, we find that ΔE^{IX} displays a non-monotonous behavior as a function of γ with a finite jump discontinuity precisely at the density balance point, corresponding to the single exciton gap. Considering finite temperature effects at finite density imbalance, we find a cascade of Berezinskii–Kosterlitz–Thouless (BKT) transitions, first into a pair superfluid and only then, at lower temperatures, into independent superfluidity of both layers. Our findings shed light on existing experimental results and serve as a guide for future experiments in light-induced IX excitons in GaAs and transition metal dichalcogenides heterostructures, for which we provide explicit experimental parameters.

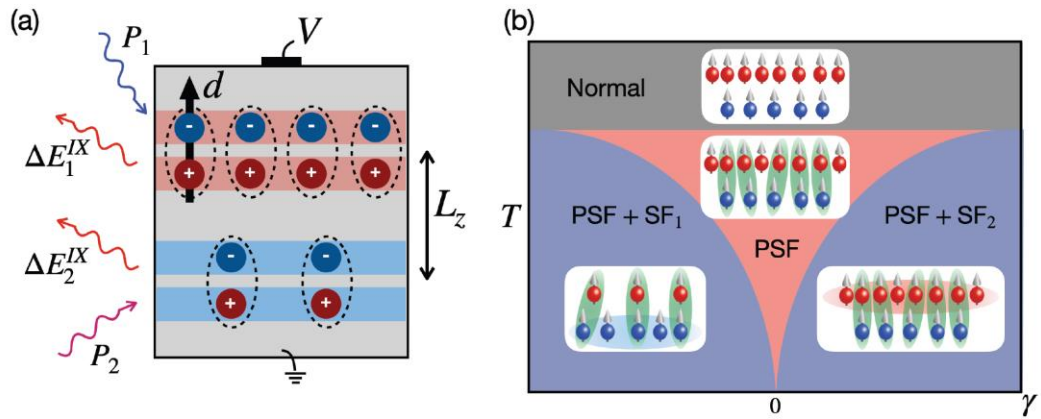


Figure 1: (a) Illustration of the experimental system consisting bilayer dipolar excitons, and (b) schematic finite temperature phase diagram in the regime of strong inter-layer coupling.

References

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FRIDAY April 15, 2022 | 10:15 – 10:30**Q-system with fast optical access for the Zn-vacancy in ZnSe****N. Vitalie,^{1,*} E. Kirstein,¹ E. A. Zhukov,^{1,2} D. S. Smirnov,² P. Greve,¹ I. V. Kalitukha,² V. F. Sapega,² A. Pawlis,³ D. R. Yakovlev,^{1,2} M. Bayer^{1,2} and A. Greilich¹**¹*Experimental Physics 2, TU Dortmund University, Dortmund, Germany*²*Ioffe Institute, Russian Academy of Sciences, St. Petersburg, Russia*³*Peter Grnberg Institute, Forschungszentrum Jlich, Jlich, Germany**Corresponding author: vitalie.nedelea@tu-dortmund.de

DeVincenzo [1] requirements: fast access and long system coherence, imposes certain condition on a qubit. Certain outstanding solid-state devices fulfill these criteria, providing the long-living qubits defined within the crystal structure while being optically accessible through the semiconductor bandgap. Among them, the nitrogen- or silicon-vacancies center, stands out for its robustness: its quantum state could be initialized, manipulated, and measured with remarkable fidelity at temperatures as low as ambient temperature, despite slow initialization, which lies in the range of hundreds of ns.

The technique presented [2] takes advantage of deep defect centers' extended spin coherence time while preserving ultra-fast optical access for spin initiation and readout. Defect centers in ZnSe, the Zn-vacancy center, is selected as a candidate, introduced by ex-situ Fluorine implantation. The primary source of spin relaxation, interaction with nuclear spins, is eliminated by using isotopic purification of ZnSe, ⁶⁴Zn and ⁸⁰Se, so that spin relaxation is dominated by the anisotropic exchange interaction (Dzyaloshinskii-Moriya interaction). In this case, the long spin coherence times up to 100 ns at room temperature with the possibility of fast optical access through an excitonic transition. The spin dephasing time remains almost unchanged in magnetic fields up to 1 T, demonstrating a high homogeneity of the ensemble.

T_2^* is weakly affected by the temperature, Fig. 1. At $T = 300$ K we obtain $T_2^* \approx 0.1 \mu\text{s}$. T-dependence is described using the Arrhenius equation, which gives the T-dependence of the spin dephasing by a term accounting for phonon activation: $1/T_2^*(T) = 1/T_2^*(0) + 1/T_A(T)\exp(-E_A/k_B T)$. Here $T_2^*(T=0) = 0.4 \mu\text{s}$, $T_A(0) = 80$ ns the thermal relaxation coefficient, $E_A(0) = 14$ meV the activation energy, and k_B the Boltzmann constant.

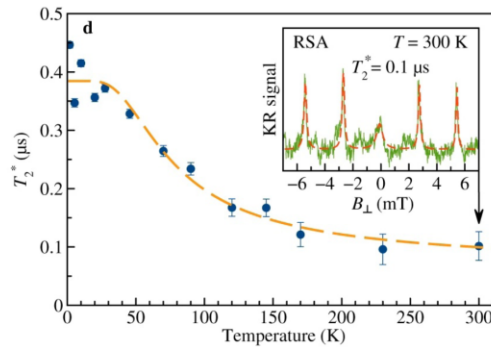


Figure 1: T_2^* as function of bath temperature. Higher temperature leads to reduced suppression of the zero RSA peak, as T_1 approaches T_2^* close to room temperature.

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FRIDAY April 15, 2022 | 10:30 – 10:45**Electrically-controlled exciton transport and trapping in GaN/(Al,Ga)N quantum wells****R. Aristegui,^{1,*} F. Chiaruttini,¹ C. Brimont,¹ T. Guillet,¹ S. Chenot,² Y. Cordier,² B. Damilano,² and M. Vladimirova¹**¹*Laboratoire Charles Coulomb, UMR 5221 Université de Montpellier, CNRS, Montpellier, France*²*CRHEA, Université Côte d'Azur, CNRS, Valbonne, France*

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Giant built-in electric field in the growth direction makes excitons in wide GaN/(Al,Ga)N quantum wells spatially indirect even in the absence of any external bias. The deposition of thin metal layer on top of such heterostructure patterns the in-plane potential experienced by indirect excitons: they get trapped in the plane of the QW under uncovered areas [1].

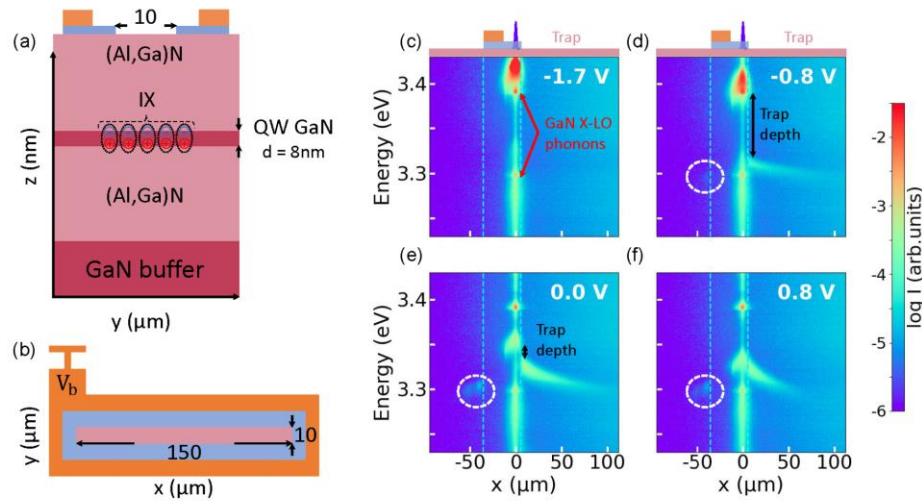


Figure 1: (a) yz- and (b) xy projections of the sample covered by semi-transparent (blue) and opaque (yellow) electrodes. (c-d) Spatially resolved PL spectra (color-encoded in log scale) measured at different values of the applied electric bias. Dashed circles highlight IX emission coming from outside of both the trap and the area covered by the electrodes.

We show that exciton density and spatial distribution in the trap can be controlled by the electric bias that shapes the trapping potential. Exciton accumulation and diffusion efficiency in the trap that we measure via spatially-resolved photoluminescence can be enhanced by application of the negative bias. This enhancement persists until a critical negative bias where the nonradiative losses (measured as strong photocurrent) overcome optical recombination, that we detect as spatially resolved photoluminescence. By contrast, application of positive bias washes out the metal layer-induced in-plane potential, so that excitons can be released from the trap and recover free propagation in the plane. The control of GaN-hosted indirect excitons by electric bias paves the way toward novel optoelectronic devices exploring bosonic features of excitons, including quantum coherence and condensation.

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Novel type of zero-field spin splitting

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In semiconductor structures with broken space inversion symmetry spin-orbit interaction induces spin splitting of electron and hole states even at zero magnetic field. It is commonly considered that there are two contributions to the zero-field spin splitting: the Rashba and Dresselhaus terms.

We uncover that there is an additional term in the Hamiltonian of the zero-field splitting which emerges in quantum wells (QWs) based on cubic crystals, i.e., both zinc-blende and diamond type crystals. This contribution is caused by the interplay of the cubic shape of crystal unit cell and macroscopic structure asymmetry. The effective magnetic field corresponding to this spin splitting is directed along the QW normal (in contrast to the Rashba field which is in the plane) while its magnitude is controlled by the structure inversion asymmetry. The latter allows one to tune the spin splitting by gate voltage.

With the new term included, the effective Hamiltonian of the zero-field splitting, caused by structure inversion asymmetry and linear in the wave vector $\mathbf{k}$, in $(0lh)$ -grown QWs has the form

$$H_{\text{SO}} = \alpha_1 \sigma_y k_x - \alpha_2 \sigma_x k_y + \zeta \sigma_z k_x, \quad (1)$$

where l and h are the Miller indices, σ_j are Pauli matrices, and the first two terms correspond to anisotropic Rashba interaction. We show that the additional term $\sigma_z k_x$ emerges for both electrons and holes and in all QWs except those grown along the high-symmetry axes $\langle 001 \rangle$, $\langle 011 \rangle$, and $\langle 111 \rangle$. Moreover, we find that this term dominates the $\mathbf{k}$ -linear spin splitting of heavy holes in low-symmetry QWs based on III-V semiconductors.

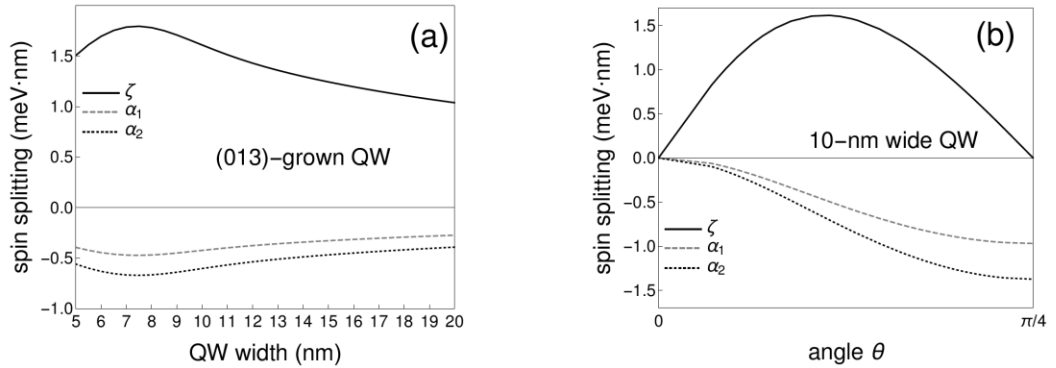


Figure 1: Dependence of spin-orbit coupling parameters on (a) QW width and (b) QW growth direction for electric field $E_z = 100$ kV/cm. θ is the angle between the QW normal and $[001]$.

We calculate the energy spectrum of holes for GaAs/AlAs quantum wells in the framework of the Luttinger model and obtain the spin-orbit coupling parameters of the Hamiltonian (1). We also develop a perturbation theory and derive analytical expressions for the spin-orbit coupling parameters, which are in good agreement with the numerical results. The dependencies of the parameters on the QW and crystallographic orientation are shown in Fig. 1. The spin splitting $\sigma_z k_x$ is dominant in a wide range of QW crystallographic orientations and particularly pronounced in (013)-oriented structures.

G.V.B. acknowledges the support from the Russian Science Foundation (project No.21-72-10035).

FRIDAY April 15, 2022 | 11:15 – 11:45

2D quantum turbulence in exciton-polariton superfluids

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In the last two decades, exciton-polariton emerged as a promising platform for the study of quantum fluids in an optical environment. Here, by tracking on a picosecond time-scale a large number of quantized vortices, we present the experimental attempt to explore turbulent regimes in two-dimensional polariton fluids. We find that the tendency towards vortex clusterization, which is a remarkable feature of 2D quantum turbulence in conservative systems [1,2,3,4], can be measured in a quantum fluid of light despite the short lifetime of polaritons makes these systems strongly dissipative.

We tune the initial kinetic energy of the polariton fluid by resonant injection and observe the formation of vortices and anti-vortices by hydrodynamic nucleation against a ring-shaped potential barrier (Figure 1, left). We measure both density and phase by off-axis holographic technique, which allows us to obtain the vortex distribution and the incompressible kinetic energy of the system at each time frame. We measure an increase in the number of vortices belonging to clusters of the same sign and a decrease of the number of dipoles (vortex-antivortex pairs), resulting in the increase of the correlation function (Figure 1, right). At the same time, the average incompressible kinetic energy per vortex increases, showing the tendency to form high-energy vortex distributions over larger spatial scales.

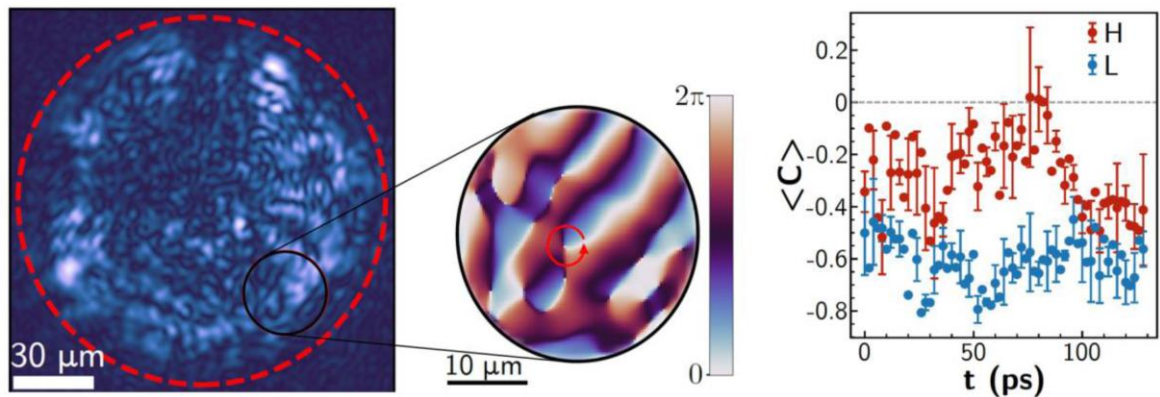


Figure 1: On the left, the density of the polariton fluid 50 ps after the injection. Vortices are visible as a singularity in the polariton phase (in the inset, the phase corresponding to the enlarged spatial region in the circle). On the right, the correlation function is shown for high (red) and low (blue) injection energies.

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FRIDAY April 15, 2022 | 11:45 – 12:00**Giant vorticity in geometrically frustrated polygons of polariton condensates****T. Cookson,^{1,*} K. Kalinin,^{1,2} H. Sigurdsson,^{1,3} J. D. Töpfer,^{1,3} S. Alyatkin,¹ M. Silva,³ W. Langbein,⁴ N. G. Berloff,^{1,2} and P. G. Lagoudakis^{1,3}**¹*Skolkovo Institute of Science and Technology, Skolkovo 121205, Russian Federation.*²*DAMTP, University of Cambridge, Cambridge, UK.*³*Department of Physics and Astronomy, University of Southampton, Southampton, UK.*⁴*School of Physics and Astronomy, Cardiff University, Cardiff, UK.**Corresponding author: *T.Cookson@skoltech.ru*

Vortices of high topological charge have long been investigated due to their inclination to be unstable, even when externally imprinted [1,2] and the challenge remains to find a way to create and stabilise such structures. In this work, we present geometrically frustrated odd-numbered polygons of polariton condensates as a platform for the study of giant vorticity [3]. Geometric frustration occurs when the lattice geometry prevents the formation of a unique groundstate [4]. In magnetic systems, the antiferromagnetic spin arrangement can lead to multiply degenerate ground state configurations [5,6]. This frustration can be engineered into lattices by controlling the coupling between neighbouring lattice sites, as demonstrated recently in coupled laser systems, where optical vortices of alternate chirality formed in triangular lattices [7,8].

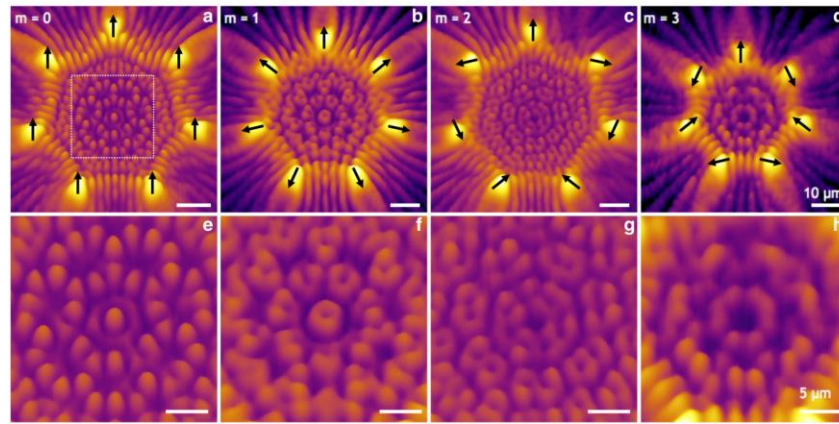


Figure 1: First row: near field density of a heptagon of polariton condensates with in-phase (a), $\pm 2\pi/7$ (b), $\pm 4\pi/7$ (c), and $\pm 6\pi/7$ (d) coupling between neighbouring condensates integrated over hundreds of instances. The black arrows indicate the pseudo-phase of each condensate for the positive phase difference in a clockwise direction. Second row: zoomed in region at the centre of the polygon demonstrating the central vortex appearing and growing with increased multiplicity.

By controlling the coupling between condensates along the circumcircle of the polygon, we engineer geometrically frustrated configurations, as shown for a heptagon in Figure 1. In this system we are able to evaluate the coupling configuration of the polygon through the coherence of the condensates. In Fig. 1(a) all condensates are in-phase and constructively interfering; whereas Figs. 1(b-d) show varying different states of geometric frustration. In Figs. 1(e-h) the centre of the polygons demonstrates a dark notch at the centre increasing in size as the central vortex increases in multiplicity from $m = 1$ in Fig. 1(b), to $m = 2$ in Fig. 1(c), and finally, to $m = 3$ Fig. 1(d) [3], demonstrating the elusive giant vortex. This work opens roads to using polaritonics to simulate systems with complex orbital internal degrees of freedom for 4D analogue simulators.

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FRIDAY April 15, 2022 | 12:00 – 12:15

Polariton-dark exciton interactions in bistable semiconductor microcavities

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In this work, we take advantage of the polariton bistability in microcavities to investigate the interaction strength between lower exciton-polariton and dark exciton states. The study of dark excitons is still challenging due to their inability to interact or recombine with photons, thus resulting in optically inactive particles inaccessible by spectroscopic means. Therefore, to evidence the generation of these states, indirect processes are required. Previous works have reported the use of polaritons to examine dark excitons [1], however, up to date, the determination of the polariton-dark exciton interaction constant remains unexplored. Here, we address this conundrum by combining the quasi-resonant excitation of polaritons and the nominally forbidden two-photon excitation (TPE) of dark excitons in a GaAs-based microcavity. Our results show that for certain conditions, the bistability of the polariton condensate is highly compromised, see Fig 1, which is evidenced by a strong drop in the photoluminescence intensity and the width of the hysteresis cycle. Furthermore, this dramatic drop exposes the presence of a small symmetry breaking such as that created by an effective in-plane magnetic field, allowing us to detect the dark exciton reservoir. This work opens exciting possibilities for optically controlled quantum information processing and the creation of long-lasting potentials.

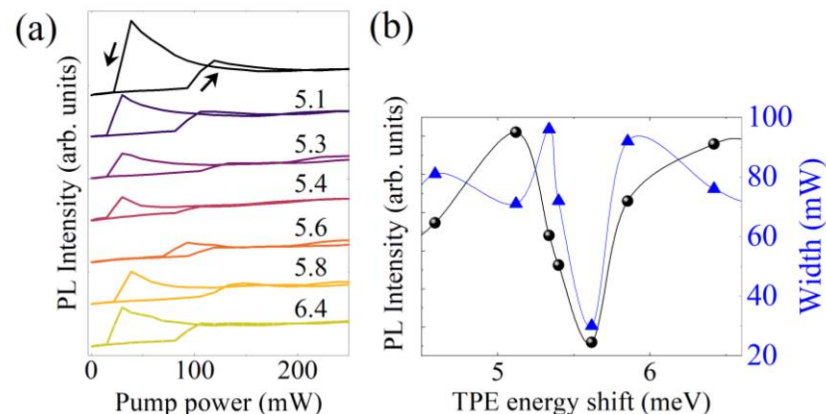


Figure 1: (a) Transmitted intensity versus resonant cw pump power. The hysteresis cycle is scanned for different TPE energies indicated as the shift from the polariton resonance in meV. The top curve displays the control signal without dark excitons in the system. (b) Intensity at 69 mW and width of the bistable region of the curves shown in (a). A clear drop is seen at 5.6 meV in both magnitudes.

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FRIDAY April 15, 2022 | 12:15 – 12:30**Dark excitons effect on the Bogoliubov sound in polariton fluids****Anna Grudinina,^{1,*} Igor Kurbakov,² and Nina Voronova^{1,3}**¹*National Research Nuclear Institute MEPhI, Kashirskoe sh. 31, 115409 Moscow, Russia*²*Institute for Spectroscopy, RAS, 142190 Troitsk, Moscow, Russia*³*Russian Quantum Center, Bolshoy Boulevard 30 Bld. 1, 121205 Moscow, Russia*

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Exciton-polaritons are quasiparticles resulting from strong coupling between quantum well excitons and photons in a microcavity. In the context of polariton superfluidity and elementary excitations, several phenomenological models which take into account the presence of the excitonic reservoir have been developed. In the models [1,2] high-energy excitations are separated in an “active” and an “inactive” reservoirs where only the active part feeds the condensate; in Ref.[3] the model consists of three reservoirs: active, inactive and dark. In the recent work [4], where the equilibrium Hartree-Fock-Bogoliubov description for polaritons was developed, it was shown that the presence of dark excitons considerably affects the Bogoliubov excitations and, in particular, the theoretically expected and experimentally observable speed of sound in a polariton fluid even in the equilibrium regime.

In the present work, we analyze the influence of the bright and dark excitonic reservoirs on the sound velocity for different types of non-resonant excitation (pulsed and continuous-wave) which were shown experimentally [5,6] to lead to essentially different dependence of the condensate-to-reservoir density ratio in the system. We show that while the active reservoir influence on the Bogoliubov sound is dependent on the temperature of the system and can lead either to increase or decrease of c_s , the dark/inactive reservoir contribution is dominant and leads to considerable lowering of c_s compared to the textbook Bogoliubov prediction. The work is funded by the Russian Foundation for Basic Research (RFBR) within the Project No. 21-52-12038 (joint with DFG).

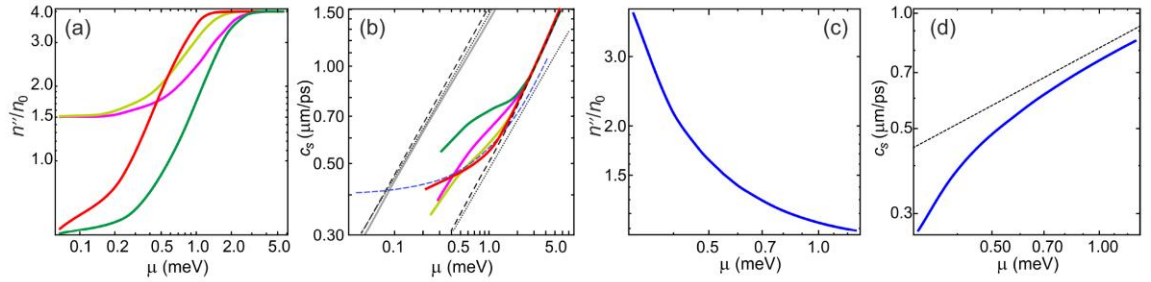


Figure 1: (a,c) The ratio of the dark exciton density n'' to the condensate density n_0 vs. total blueshift μ and (b,d) the speed of sound vs. μ for non-resonant pulsed (a,b) and c.w. (c,d) excitations. The different color lines in (b) correspond to the different fitting of the dark reservoir densities in (a). The blue line in (d) is plotted for the fit from (c) and the black dashed line shows $c_s^B/3$, $c_s^B = \sqrt{\mu/m_{LP}}$.

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FRIDAY April 15, 2022 | 12:30 – 12:45

Anisotropic dispersion of excitations of the BIC polariton condensate**N. Voronova,^{1,2*} A. Grudinina,¹ M. Efthymiou-Tsironi³, V. Ardizzone³, and D. Sanvitto³**¹National Research Nuclear University MEPhI, 115409 Moscow, Russia²Russian Quantum Center, 121205 Skolkovo, Moscow, Russia³CNR Nanotec, Institute of Nanotechnology, via Monteroni, 73100, Lecce, Italy

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In this work, we study the elementary excitation spectrum of planar waveguide exciton-polaritons whose Bose condensation in the quasi-bound-in-the-continuum (BIC) state has been recently reported [1]. Most curiously, due to the band folding effect and the consequent coupling with the quantum well exciton mode, the condensate which is formed on the lowest polariton branch appears in the saddle point of the polariton dispersion rather than in a global energy minimum. We show that as the particles start to accumulate in the quasi-BIC state with an infinite lifetime, a local energy minimum starts to appear around the saddle point $k = 0$ in the Bogoliubov spectrum of excitations, which allows the polaritons to stay in this state and form a long-living Bose condensate. The created condensate does not emit light, making the direct measurement of the peculiar shape of the spectrum of elementary excitations possible without any momentum filtering. The observed photoluminescence profile in (k_x, k_y) domain, which below threshold corresponds to the cross-cut of the dispersion at a given energy, above threshold changes its shape to display two parallel stripes in corresponding to the flat parts of the Bogoliubov spectrum. The energy-momentum dispersion of the lower polaritons acquires positive slopes with essentially anisotropic shape (see Fig. 1). The work is financially supported by the Russian Foundation for Basic Research Project No. 20–52–7816.

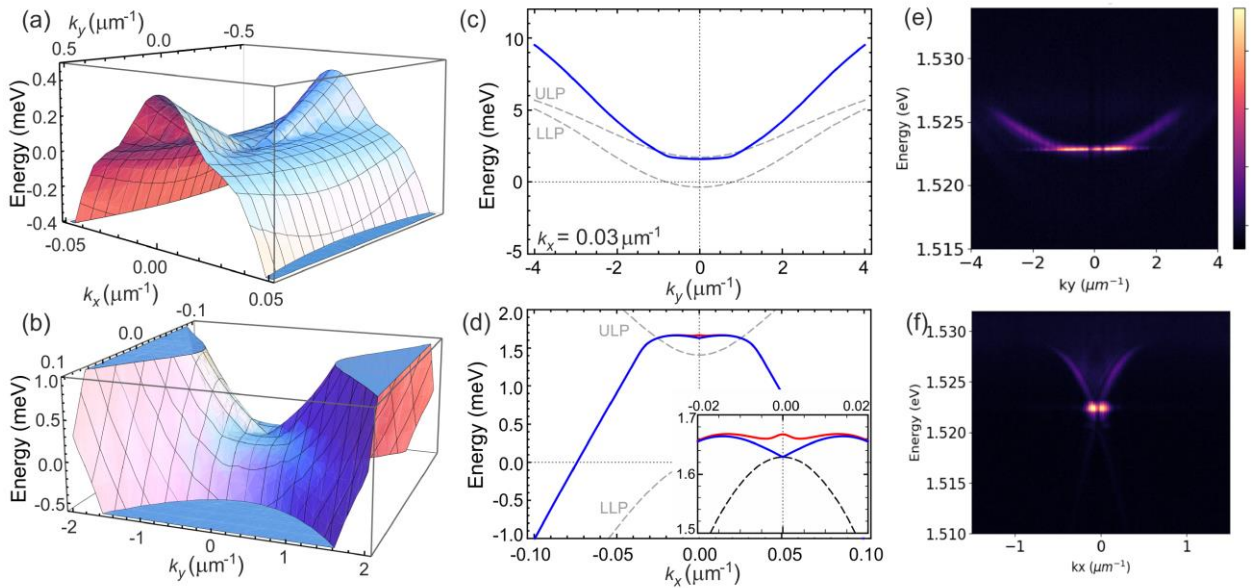


Figure 1: (a) The Bogoliubov dispersion of elementary excitations of the saddle-point when approaching the condensation threshold. (b) Zoom of (a) in the region of small k_x . (c) Cross-cut of (a) close to the BIC state at $k_x = 0$. (d) Cross-cut of (a) at $k_y = 0$, showing the Bogoliubov excitations spectrum for zero non-radiative losses (blue) and $\gamma_x = 0.001 \gamma$ (red). The grey dashed lines show the bare single-particle dispersions. Inset shows a close-up of the local minimum of the excitations spectrum. (e,f) Experimental photoluminescence images above threshold displaying the energy-momentum dispersion of excitations vs. k_y (e) and vs. k_x (f).

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