HL 9: Focus Session: Exceptional Points and Non-Hermitian Physics in Semiconductor Systems

The strong recent interest into nonconservative/non-Hermitian systems and their exotic degeneracies - so-called exceptional points - is driven by the occurrence of rather unconventional and fascinating physics and by potential applications such as ultrasensitive sensing, orbital angular momentum lasers, and topological energy transfer for mode and polarization conversion. This Focus Session aims at discussing the latest experimental and theoretical results in the rapidly developing field with special focus on semiconductor systems, where engineering the interplay of coupling, dissipation and amplification mechanisms offers novel opportunities. Moreover, we give an overview to young scientists of the exciting possibilities of interdisciplinary research in this field.

Organized by Sebastian Klembt and Jan Wiersig

Time: Monday 15:00–17:30 Location: H33

Invited Talk HL 9.1 Mon 15:00 H33
Exceptional points in optics: From bulk materials to one-dimensional confined systems — •Chris Sturm — Felix Bloch Institute for Solid State Physics, Universität Leipzig, Leipzig, Germany

The research of exceptional points (EP) was initiated by W. Voigt in 1902 when he discovered that for certain directions in orthorhombic crystals only one circular polarized eigenstate exists, as soon as absorption sets in [1]. These directions corresponds to EPs in the momentum space. The presence of such EP is not limited to orthorhombic crystals only and appears in many optical systems. Here we present an overview of the appearance and the properties of these EPs in bulk crystal and optically one-dimensional confined systems. We show that the properties of the EPs in bulk crystals are determined by the dielectric function and the symmetry of the crystal, which allows to distinguish between optically biaxial materials having triclinic, monoclinic or orthorhombic crystal symmetry. In the presence of an optical confinement, like in thin films or microresonators, EPs can even appear in systems consisting of optically uniaxial materials, which was recently observed experimentally (e.g. Ref. [2]). Furthermore, in contrast to bulk crystals, the properties of the EPs are determined not only by the dielectric function of the materials but depends also on the design of the system, e.g., film thickness and confinement properties.

[1] W. Voigt, Ann. Phys. **314**, 367 (1902).

[2] S. Richter, Phys. Rev. Lett. **123**, 227401 (2019).

Invited Talk HL 9.2 Mon 15:30 H33
Complex Skin Modes in Non-Hermitian Coupled Laser Arrays — •Mercedeh Khajavikhan and Yuzhou Liu — 1002 Childs Way, Los Angeles, CA 90089

In the realm of non-Hermitian physics, the possibility of complex and asymmetric exchange interactions between a network of oscillators has been theoretically shown to lead to novel behaviors like delocalization, skin effect, and bulk-boundary correspondence. While the ramifications of these theoretical works in optics have been recently pursued in synthetic dimensions, the Hatano-Nelson model has yet to be realized in real space. In this work, by using active optical oscillators featuring non-Hermiticity and nonlinearity, we introduce an anisotropic exchange between the resonant elements in a lattice, an aspect that enables us to observe the non-Hermitian skin effect, phase locking, and near-field beam steering in a Hatano-Nelson laser array. This work can open up new regimes of phase-locking in lasers while shedding light on the fundamental physics of non-Hermitian systems.

15 min. break

Invited Talk HL 9.3 Mon 16:15 H33
Non-Hermitian effects in exciton polaritons — •Eliezer Estrecho — ARC Centre of Excellence in Future Low-Energy Electronics Technologies and Department of Quantum Science and Technology, Research School of Physics, The Australian National University, Canberra, ACT 2601, Australia

I will present our experimental results highlighting non-Hermitian effects in exciton-polariton systems—quasiparticles arising from the strong coupling of excitons in semiconductors and photons in a cavity. This hybrid system is naturally non-Hermitian due to inherent loss and gain. The former arises from photon leakage through the cavity mirrors and the short lifetime of excitons, while the latter arises from an external pump used to maintain the density, for example, in the creation of Bose-Einstein condensates.

Using exciton-polariton condensates, we demonstrate exceptional points in the deformation parameter space of a quantum billiard. In particular, we are able to trace the energy levels close to the exceptional point, observe the topological Berry phase, and demonstrate the chirality of the state.

We also observe exceptional points in momentum space. By studying the energy and pseudospin structure, we directly measured a novel non-Hermitian topological invariant and differentiated it from its Hermitian counterparts. Furthermore, we also observe an anomalous dispersion resulting from the dissipative coupling of excitons and photons. The resulting inverted dispersion leads to a negative-mass propagation where the particles move in the opposite direction to their momentum.

Invited Talk HL 9.4 Mon 16:45 H33
Nonlinear dynamics and exceptional points in exciton-polariton condensates — •Stefan Schumacher — Physics Department & CeOPP, Paderborn University, Germany

Non-Hermitian physics and exceptional points have attracted significant attention in the past two decades. Enormous progress has been made for example in non-Hermitian optics. Non-Hermitian degeneracies and exceptional points have also been demonstrated for exciton polaritons in semiconductor microcavities [1]. For non-resonant excitation, polaritons can spontaneously exhibit macroscopic coherence, known as polariton condensation. The non-equilibrium nature of polariton condensates makes them perfect for studies of non-Hermitian physics. The gain can be tailored by varying the spatial optical pump profile, for example allowing realization of PT-symmetric lattices [2]. The polariton-polariton interaction gives rise to inherently nonlinear phenomena such as vortex formation [3]. Recently, we reported the observation of an exceptional point in a double-well potential [4]. There, the polariton condensate can be localized in one well and switched off by an additional optical excitation in the other well that surprisingly induces additional loss [4]. The nonlinearity and related energy blueshift also allows to approach the exceptional point. This work paves the way to explore non-Hermitian physics in a system with strong nonlinearity and in tailored potential energy landscapes. [1] T. Gao et al., Nature 526, 554-558 (2015). [2] X. Ma et al., New Journal of Physics 21, 123008 (2019). [3] X. Ma et al., Nature Communications 11, 897 (2020). [4] Y. Li et al., arXiv:2101.09478 (2021).

HL 9.5 Mon 17:15 H33
Exceptional points in anisotropic ZnO thin films — •Sebastian Henn, Evgeny Krüger, Chris Sturm, and Marius Grundmann — 1 Universität Leipzig, Faculty of Physics and Earth Sciences, Felix Bloch Institute for Solid State Physics, Linnéstr. 5, 04103 Leipzig, Germany

In this talk we present findings regarding the existence of exceptional points in anisotropic thin films. Analogous to degeneracies of optic axes in absorptive biaxial materials, so-called singular optic axes [1], anisotropic transparent structures contain exceptional points in momentum space, where two orientation- and polarization-dependent modes are equal in resonance energy and lifetime. The latter is determined by dissipative photon loss at the interfaces, which renders the system non-Hermitian. This phenomenon has been observed in dielectric optical microcavities [2] and principally exists also in anisotropic thin films, where resonances correspond to well-known Fabry-Pérot modes. We show results of rigorous calculations for m-ZnO thin films, based on scattering matrices whose complex poles correspond to the resonance energies. This allows to find exceptional points in two-dimensional momentum space and we confirm important characteristics, such as a square-root topology and circularity.

[1] Grundmann et al., Phys. Status Solidi RRL 11.1 1600295 (2017)
[2] S. Richter et al., Phys. Rev. Lett. 123 227401 (2019)