Q 3: Photonics I

Time: Monday 11:00–13:00 Location: HS Botanik

Invited Talk Q 3.1 Mon 11:00 HS Botanik

3D photonic model systems for topological effects and quantum-optical analogies — •Christina Jörg — Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau

I will present our research on topological photonics and beyond using waveguide arrays and photonic crystals fabricated through 3D microprinting. These photonic structures serve as model systems for fundamental studies, providing a versatile platform to emulate electronic phenomena found in condensed matter. By replicating electronic band structures, topological states, and quantum-optical effects, these systems not only deepen our understanding of established physics but also pave the way for discovering phenomena beyond what has been envisioned in electronic systems.

I will provide an overview of our recent work, which includes the use of higher orbital modes for quantum simulations, employing Kerr-nonlinearity to mimic mean-field interaction effects, and exploring higher-dimensional systems through synthetic dimensions.

Q 3.2 Mon 11:30 HS Botanik

Effect of Disorder on Photonic Density of States — •Florin Hemmann[1,2], Ullrich Steiner[1,2], and Matthias Saba[1,2] — [1]Adolphe Merkle Institute, University of Fribourg, Switzerland — [2]NCCR Bio-inspired Materials, University of Fribourg, Switzerland

Structural color arises from visible light interference in the presence of photonic nanostructures in many animals and plants [1]. As the dielectric contrast increases, such structures can form complete photonic band gaps, where light cannot enter the structure from any angle [2]. This phenomenon is well established for periodic systems, so-called photonic crystals. However, the emergence of a reduced photonic density of states due to the interplay of order and disorder in amorphous structures still needs to be fully understood. Here, we investigate how structural correlations at different length scales affect the photonic density of states. To this end, we generate 4-connected 3D continuous random networks with tunable disorder using a Metropolis Monte Carlo algorithm [3-4]. Utilizing a Monte Carlo bond-switch move, this algorithm simulates structural phase transitions from a crystalline to an amorphous diamond network. The effect of these structural phase transitions on the photonic response is analyzed through a finite-difference time-domain method and a planewave eigensolver method.

[1] V. V. Vogler-Neuling et al. (2024), Adv. Funct. Mater. 2024, 34, 2306528.

[2] J. D. Joannopoulos, et al. (2008), Princeton University Press.

[3] F. Wooten et al. (1985), Phys. Rev. Lett. 54, 1392.

[4] G. Barkema and N. Mousseau (1998), Phys. Rev. Lett. 81, 1865.

Q 3.3 Mon 11:45 HS Botanik

Quantum theory of (fractional) topological transport of lattice solitons — •Julius Bohm, Hugo Gerlitz, and Michael Fleischhauer — Fachbereich Physik und Landesforschungszentrum OPTIMAS, RPTU Kaiserslautern-Landau

Thouless pumps are a well known concept for quantized transport in symmetry protected topological systems. A suitable platform to investigate those systems are ultracold atoms in (time-dependent) lattices. While the experiments show good agreement with the theory they are hard to control and costly.

In recent years experimental groups have been able to investigate lattice solitons in waveguides with nonlinear Kerr media [1]. The time dependency needed for Thouless pumping in such systems is simulated via spatial modulation of the waveguides along the propagation axis.

On the theoretical side these solitons have been considered so far from a semiclassical point of view [2]. In our research we extend this to a full quantum mechanical description and therefore are able to test the low-particle limits in which lattice solitons exist. We are able to simulate integer as well as fractional transport of lattice solitons with the help of exact diagonalization and tensor network based approaches. Furthermore the emergence of integer, fractional and localized phases is explained in terms of an effective soliton bandstructure which also allows to determine topological invariants as effective Chern numbers or Wilson loops.

[1]: Jürgensen et. al., Nature 596, 63-67 (2021)

[2]: Mostaan et. al., Nat Commun 13, 5997 (2022)

Q 3.4 Mon 12:00 HS Botanik

Non-Hermitian geometry and topology induce non-trivial wave packet dynamics — •Ismaël Septembre[1,2], Zhaoyang Zhang[3], Pavel Kokhanchik[2], Guillaume Malpuech[2], and Dmitry Solnyshkov[2,4] — [1]University of Siegen, Germany — [2]Institut Pascal, Clermont-Ferrand, France — [3]Xi'an Jiaotong University, China — [4]Institut Universitaire de France, Paris, France

The geometry of quantum states provides a solid framework for explaining complex phenomena that conventional approaches fail to address. Despite its success in Hermitian systems, quantum geometry remains far less understood in non-Hermitian systems.

In this presentation, I want to show new interesting effects that we predicted and observed experimentally recently using Rubidium vapor cells. First, we study a photonic quasicrystal and demonstrate that combined with non-Hermiticity, it leads to the delocalisation of the wave packet [PRL 132, 263801 (2024)]. This is rather counter-intuitive as both effects (quasicrystal and non-Hermiticity) usually lead to localisation. Then, I will show our latest work where a photonic crystal hosting a ring of exceptional points leads to an anomalous non-Hermitian drift, analogous to but different from the anomalous Hall drift of Hermitian systems [arXiv:2410.14428]. To describe this effect, the biorthogonal quantum metric must be used, which proves the utility of this approach.

Our works represent cutting-edge developments in the field of topological photonics in the broad sense and show how non-Hermiticity can lead to new effects with potential applications in beam steering.

Q 3.5 Mon 12:15 HS Botanik

Topological phase transition in non-Hermitian gauge fields — •Bikashkali Midya — Indian Institute of Science Education and Research Berhampur, India

We will describe the point-gap topological phase transitions and skin-effect in non-Hermitian photonic lattice models. These models incorporate site-dependent nonreciprocal hoppings facilitated by a spatially fluctuating complex gauge field that disrupts translational symmetry. We propose a analytical framework that offers a comprehensive method for analytically predicting spectral topological invariance and associated boundary localization phenomena for bond-disordered nonperiodic lattices, based on imaginary gauge-transformed mean-field periodic lattices. Notably, for a lattice with quasiperiodic gauge-field $g = log|\lambda cos 2\pi\alpha n|$ and an irrational previously unknown topological phase transition is unveiled. It is observed that the topological spectral index W assumes values of -N or +N, leading to all N open-boundary eigenstates localizing either at the right or left edge, solely dependent on the strength of the gauge field, where $\lambda < 2$ or $\lambda > 2$. A phase transition is identified at the critical point undergo delocalization. The theory has been shown to be relevant for long-range hopping models $\lambda = 2$, at which all eigenstates undergo delocalization.

Q 3.6 Mon 12:30 HS Botanik

Exciton-Polariton Artificial Gauge Field Topological Pseudospin Hall Effect — •Simon Widmann, Jonas Bellmann, Johannes Düreth, Siddhartha Dam, Christian G. Mayer, Philipp Gagel, Simon Betzold, Monika Emmerling, Sven Höfling, and Sebastian Klembt — Technische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

We explore the interplay of artificial gauge fields and synthetic dimensions in a chain of coupled elliptical exciton-polariton micropillars, leveraging polariton circular polarization to achieve pseudospin-dependent propagation. The elliptical micropillars, fabricated by etching a GaAs microcavity, exhibit a linear polarization splitting due to their geometry. By carefully engineering the lattice geometry and pillar rotations, we implement an artificial gauge field, inducing complex hopping phases that mimic the effects of a magnetic flux. This design enables pseudospin-dependent propagation: polaritons with opposing circular polarizations travel in opposite directions leading to a Hamiltonian that gives rise to the quantum Hall effect. We introduce an artificial dimension, mapping the effectively 1D chain to a 2D square lattice. Our results highlight the potential of exciton-polaritons as a versatile platform for investigating topological photonics, non-Hermitian physics, and synthetic dimensions in driven-dissipative systems, paving the way for novel approaches to quantum simulation and polaritonic devices.

Q 3.7 Mon 12:45 HS Botanik

Chirped pulses enable robust generation of multiplexed photon states in quantum dots — •Vikas Remesh[1], Moritz Kaiser[1], Gabriela Militani[1], René Schwarz[1], Ria Krämer[2], Stefan Nolte[2], Philip Poole[3], Dan Dalacu[3], and Gregor Weihs[1] — [1]Institute für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria — [2]Institute for Applied Physics, Friedrich Schiller University Jena, Germany — [3]National Research Council of Canada, Ottawa, Ontario K1A 0R6, Canada

To realize a scalable source of frequency-multiplexed single photons, one requires an ensemble of quantum emitters that can be collectively excited with high efficiency. Semiconductor quantum dots hold great potential here. The most efficient scheme is to use chirped laser pulses, due to the robustness against spectral and intensity fluctuations. Here we present a compact, robust, and plug-and-play alternative for chirped pulse excitation of quantum dots, based on chirped fiber Bragg gratings. Using this technique, we demonstrate the collective excitation of vertically stacked, frequency-multiplexed quantum dots in a nanowire, producing high-quality single and entangled photon states. Our experiments set a benchmark towards a simpler yet scalable and resource-efficient approach of producing multiphoton states from quantum dots. APL Photonics 8, 101301 (2023), arxiv.org/abs/2409.13981, Adv Quantum Technol. 2024, 2300352