TT 12: Quantum Transport and Quantum Hall Effects (joint session HL/TT)

Time: Monday 16:45–18:15 Location: H15

TT 12.1 Mon 16:45 H15

kdotpy: A Python application for k·p band structure simulations of zincblende semiconductors — •Wouter Beugeling[1,2], Florian Bayer[1,2], Christian Berger[1,2], Jan Böttcher[3], Leonid Bovkun[1,2], Christopher Fuchs[1,2], Maximilian Hofer[1,2], Saquib Shamim[1,2], Moritz Siebert[1,2], Li-Xian Wang[1,2], Ewelina M. Hankiewicz[3], Tobias Kiessling[1,2], Hartmut Buhmann[1,2], and Laurens W. Molenkamp[1,2] — [1]Physikalisches Institut (EP3), Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Institute for Topological Insulators, Am Hubland, 97074 Würzburg, Germany — [3]Institut für Theoretische Physik und Astrophysik (TP4), Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

The software project kdotpy aims at simulations of electronic band structures of semiconductor devices with k·p theory. The application implements the widely used Kane model, capable of reliable predictions of transport and optical properties for a large variety of topological and non-topological materials with a zincblende crystal structure.

In this presentation, I present the core functionality and features of kdotpy. I will explain how we have implemented principles of modern software engineering and good scientific practice in this project.

TT 12.2 Mon 17:00 H15

End states in zigzag Haldane model nanoribbons — Simone Traverso, Maura Sassetti, and •Niccolò Traverso Ziani — Physics Department, University of Genova, Italy

As topological materials based on the graphene lattice become experimentally realizable in materials such as germanene, the physics of the bound states that characterize them at step edges and in quasi one-dimensional settings becomes relevant.

In this context, the appearance of topological bound states in zigzag Haldane nanoribbons will be addressed [1]. A reentrant topological phase diagram is found. Together with numerical results, a low energy theory extending the Jackiw-Rebbi paradigm will be presented.

[1] S. Traverso, M.Sassetti, N. Traverso Ziani, NPJ Quantum Materials 9, 9 (2024).

TT 12.3 Mon 17:15 H15

Time-reversal invariant Chalker-Coddington model and the real-space renormalisation group — •Syl Shaw and Rudolf A. Römer — Department of Physics, University of Warwick, Coventry, CV4 7AL, UK

The Chalker-Coddington model has been utilised to great success in understanding the plateau transitions in the quantum Hall effect. Since the model's inception, it has been extended to a time-reversal invariant symmetry class to describe the quantum-spin Hall effect. Here we adapt a real-space renormalisation group method[1] to respect time-reversal symmetry and use it investigate the phase diagram of the quantum-spin Hall effect. We aim to find distinct phases as a function of both saddle-point height, z and spin-mixing angle ϕ. At the phase boundary between insulator and metal, we compute the value of the critical exponent of the localisation length, ν, with the same real-space renormalisation technique. [1] S. Shaw, R. A. Römer Physica E 165, 116073 (2025)

TT 12.4 Mon 17:30 H15

Utilizing Silicon Qubit Devices for Quantum Electrical Metrology — •Dustin Wittbrodt[1], Johannes Christian Bayer[1], Lars Schreiber[2,3], Janne Lehtinen[4], Marcelo Jaime[1], and Frank Hohls[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]RWTH Aachen University, Aachen, Germany — [3]Forschungszentrum Juelich, Juelich, Germany — [4]SemiQon Technologies Oy, Espoo, Finland

The 2019 redefinition of the SI system established fixed values for fundamental constants such as the elementary charge (e) and the Planck constant (h), enabling the quantum realization of the units of Ampere, Volt, and Ohm. While the quantum realization of Volt and Ohm is well-established, the realization of the Ampere, whether directly through Single Electron Pumps (SEPs) or indirectly via the Volt and Ohm, has yet to achieve the same level of accuracy. Moreover, further device applications in practical circuits require paralelization approaches to achieve higher current outputs. The international project "Advanced Quantum Technology for Metrology of Electrical Currents" (AQuanTEC) aims to upscale SEPs beyond the 1 nA threshold. To achieve this, AQuanTEC explores several strategies, including the use of silicon devices first designed for spin qubit realization. These devices are highly promising due to their potential scalability, driven by ongoing advancements in integrating large numbers of qubits.

TT 12.5 Mon 17:45 H15

Surface state dominated transport in HgTe topological insulator devices — •Maximilian Hofer[1,2], Christopher Fuchs[1,2], Lena Fürst[1,2], Tobias Kiessling[1,2], Wouter Beugeling[1,2], Hartmut Buhmann[1,2], and Laurens W. Molenkamp[1,2] — [1]Physikalisches Institut, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Institute for Topological Insulators, Am Hubland, 97074 Würzburg, Germany

Recently grown three dimensional topological insulators based on tensile strained HgTe exhibit an exceptionally high mobility and very low intrinsic carrier density. The high quality material has made it possible to study the Landau level dispersion at low magnetic fields and identify four distinct transport regimes. We demonstrate that while a contribution from the topological surface states to transport measurements is expected across the full experimentally accessible density range, there exists only a narrow density regime for which the electronic transport is exclusively carried by the topological surface states. We present the corresponding phase diagram for pure topological surface state transport depending on layer thickness and carrier concentration. For thick HgTe films grown pseudomorphically strained on CdTe, the total carrier density needs to be kept between $1.8 \times 10^{11}\,\mathrm{cm}^{-2}$ and $2.6 \times 10^{11}\,\mathrm{cm}^{-2}$ to remain in the pure surface state region and avoid contributions from bulk states. The experimental observations are supported by eight band $\boldsymbol{k} \cdot \boldsymbol{p}$ band structure calculations.

TT 12.6 Mon 18:00 H15

Designing a quantum sorter based on two-dimensional topological insulators — •Amanda Teodora Preda[1,2], Iulia Ghiu[2], Lucian Ion[2], Andrei Manolescu[3], and George Alexandru Nemnes[1,2] — [1]Horia Hulubei National Institute for Physics and Nuclear Engineering, Reactorului 30, Magurele- Ilfov, 077125, Romania — [2]University of Bucharest, Faculty of Physics, Atomistilor 405, Magurele-Ilfov, 077125, Romania — [3]Department of Engineering, Reykjavik University, Menntavegur 1, Reykjavik IS-102, Iceland

The idea of a quantum sorter emerged in quantum information, a field that aims to exploit quantum effects and manipulate qubits for information processing. In theory, it was proven that one can propose a universal quantum sorter for any arbitrary observable. To this point, suitable experimental schemes of implementation for this proposal were explored mainly in quantum optics. In our study, we introduce a solid-state version of a quantum sorter, based on a multi-terminal mesoscopic device with multiple output ports, that aims to separate the incoming states by both their spin and transversal mode. In order to maximize the state-separation efficiency of such a device, we chose to exploit the unique transport properties of topological insulators. Employing the tight-binding based simulation package Kwant, we modeled a device that meets the criteria of an irreversible quantum sorter, using the well-established BHZ Hamiltonian to simulate a multi-terminal quantum system made up of both trivial and topological materials.