TT 4: Topological Insulators

Time: Monday 9:30–13:00 Location: H33

TT 4.1 Mon 9:30 H33

Magnetotransport measurements on magnetic topological insulator nanostructures fabricated with shadow wall epitaxy — •Jan Karthein[1,2], Gion Toehgiono[1,2], Max Vassen-Carl[1,2], Taizo Kawano[3], Sosuke Otsubo[3], Makoto Kohda[3], Peter Schüffelgen[1,2], Detlev Grützmacher[1,2], and Thomas Schäpers[1,2] — [1]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology, Jülich-Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University, 52425 Jülich, Germany — [3]Department of Materials Science, Graduate School of Engineering, Tohoku University, 6-6-02 Aramaki-Aza Aoba, Aoba-ku, 980-8579 Sendai, Japan

We present a novel way to fabricate magnetic topological insulator nanostructures based on digital alloying and shadow wall epitaxy. The combination of these two techniques allows the preparation of structures in the micrometer and nanometer range without the need for lithography and etching steps on the material under investigation. The magnetotransport properties of micro and nano Hall bars fabricated in this way are investigated at cryogenic temperatures and in high magnetic fields. Different sizes of Hall bars are measured and their magnetic properties are studied. An anomalous Hall effect is observed, indicating the successful preparation of Hall bars based on magnetic topological insulator thin films. The Curie temperature of Hall bars with different widths is extracted and found to be systematically dependent on the dimensions.

TT 4.2 Mon 9:45 H33

Thermopower and resistivity of the topological insulator Bi_2Te_3 in the amorphous and crystalline phase — •Ena Osmic[1,2], Jose Barzola Quiquia[3], Stephan Winnerl[4], Winfried Böhlmann[5], Peter Häussler[3], and Joachim Wosnitza[1,2] — [1]Hochfeld-Magnetlabor Dresden (HLD-EMFL), HZDR, Dresden, Germany — [2]Institut für Festkörper- und Materialphysik, TU Dresden, Germany — [3]Division of Thin Film Physics, TU Chemnitz, Germany — [4]Institut für Ionenstrahlphysik und Materialforschung, HZDR, Dresden, Germany — [5]Felix-Bloch Institute for Solid-state Physics, Universität Leipzig, Germany

We investigated the temperature dependence of the thermopower $S(T)$ and resistance $R(T)$ in thin films of the topological insulator Bi_2Te_3, prepared *in situ* by sequential flash-evaporation at 4 K. In the amorphous phase, $S(T)$ is negative and significantly larger than in other amorphous materials, while in the crystalline phase, it remains negative and shows a linear temperature dependence. The resistivity $\rho(T)$ transitions from semiconducting behavior in the amorphous state to linear metallic behavior upon crystallization. For $T > 15$ K, the linear $\rho(T)$ reflects metallic surface states typical of topological insulators, while for $T < 10$ K, the conductivity shows a logarithmic temperature dependence dominated by electron-electron interactions. Raman spectroscopy confirms crystallization in the trigonal $R3m$ space group, and energy-dispersive X-ray spectroscopy indicates high compositional homogeneity with no magnetic impurities.

TT 4.3 Mon 10:00 H33

Phonon thermal Hall effect in weakly compensated topological insulators — •Rohit Sharma[1], Yongjian Wang[1], Yoichi Ando[1], Achim Rosch[2], and Thomas Lorenz[1] — [1]II. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Germany — [2]Institute for Theoretical Physics, University of Cologne, 50937 Cologne, Germany

The phonon thermal Hall effect has recently been observed in various classes of insulating materials, yet its origin remains unresolved [1-3]. In a series of well-compensated $Bi_{2-x}Sb_xTe_{3-y}Se_y$ samples, the thermal Hall conductivity $\kappa_{xy}(B)$ exhibits a linear and negative field dependence, with a thermal Hall ratio κ_{xy}/κ_{xx} on the order of 10^{-3}, consistent with observations in other insulating materials. Conversely, weakly compensated samples of $TlBi_{0.15}Sb_{0.85}Te_2$ exhibit a nonlinear dependence of $\kappa_{xy}(B)$, with κ_{xy}/κ_{xx} exceeding 2% across an extended temperature range. The electronic contribution to thermal transport, $\kappa^{\rm el}_{xy} = \sigma_{xy}L_0T$, was calculated using the Wiedemann-Franz law and compared to the measured κ_{xy}. Remarkably, the measured κ_{xy} is significantly larger than $\kappa^{\rm el}_{xy}$ throughout the temperature range investigated. Possible mechanisms driving the nonlinear $\kappa_{xy}(B)$ and the large thermal Hall ratio in $TlBi_{0.15}Sb_{0.85}Te_2$ will be discussed.

Funded by the DFG via CRC 1238 Projects A04, B01, and C02.

[1] R. Sharma *et al.*, Phys. Rev. B **109**, 104304 (2024).
[2] R. Sharma *et al.*, Phys. Rev. B **110**, L100301 (2024).
[3] X. Li *et al.*, Nat. Commun.**14**, 1027 (2023).

TT 4.4 Mon 10:15 H33

Scattering theory of chiral edge modes in topological magnon insulators — •Stefan Birnkammer[1,2], Michael Knap[1,2], Johannes Knolle[1,2], Alexander Mook[3], and Alvise Bastianello[1,2] — [1]Technical University Munich, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), München, Germany — [3]Johannes Gutenberg Universtät, Mainz, Germany

Topological magnon insulators exhibit robust edge modes with chiral properties similar to quantum Hall edge states. However, due to their strong localization at the edges, interactions between these chiral edge magnons can be significant, as we show in a model of coupled magnon-conserving spin chains in an electric field gradient. The chiral edge modes remain edge-localized and do not scatter into the bulk, and we characterize their scattering phase: for strongly-localized edge modes we observe significant deviation from the bare scattering phase. This renormalization of edge scattering can be attributed to bound bulk modes resonating with the chiral edge magnons, in the spirit of Feshbach resonances in atomic physics. We argue a real-time measurement protocol using spin-polarized scanning tunneling spectroscopy to study their scattering dynamics. Our result show that interaction among magnons can be encoded in an effective edge model of reduced dimensionality, where the interactions with the bulk renormalize the effective couplings. This work paves the way to develop a many-body effective theory for chiral edge magnons.

TT 4.5 Mon 10:30 H33

Multiplicative Chern insulators — •Archi Banerjee[1,2] and Ashley M. Cook[1,2] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Max Planck Institute for the Chemical Physics of Solids, Dresden, Germany

Extending on the previous work on multiplicative topological phases, here we study bulk-boundary correspondence and response signatures of multiplicative Chern insulators (MCIs). Constructing the MCI Bloch Hamiltonian as a symmetry-protected tensor product of two topologically non-trivial parent Chern insulators (CIs), we study 2D MCIs and introduce 3D MCIs, constructed by requiring the two 2D parent Hamiltonians share only one momentum component, rather than both as in the case of the 2D MCI. We study the robustness of bulk-boundary correspondence against bulk perturbations breaking the tensor product structure of the child Hamiltonian, and find the bulk-boundary correspondence remains gapless and evolves to that of a topological skyrmion phase in cases considered here. We also study the response of the 2D MCI to time reversal symmetric flux insertion through two spatially-separated locations in the lattice. We observe a 4π periodic Aharonov-Bohm (AB) effect in which unpaired Majorana zero-modes and associated spin angular momentum are transferred between these two locations. We interpret the AB effect from the perspective of the effective field theories of the quantum skyrmion Hall effect as corresponding to a generalised $\nu = 1/2$ FQHE.

TT 4.6 Mon 10:45 H33

Probing the tomographic regime by nonlinear thermoelectric and magneto-transport in topological Fermi liquids — •Habib Rostami[1] and Johannes Hofmann[2] — [1]Department of Physics, University of Bath, United Kingdom — [2]Department of Physics, Gothenburg University, Sweden

In 2D Fermi liquids, odd-parity Fermi surface deformations [PRL. 123, 116601 (2019)] exhibit anomalously slow relaxation rates, suppressed as $\tau^{-1}_{\rm AN} \sim T^4$ with temperature T, deviating from the standard Fermi-liquid scaling, $\tau^{-1}_{\rm FL} \sim T^2$. This near ballistic (tomographic) regime currently lack a precise experimental probes. We link light-induced nonlinear thermoelectric currents to prolonged relaxation times, $\tau_{\rm AN}$ [Phys. Rev. Research 6, L042042 (2024)]. These currents, arising in topological Fermi liquids, depend on novel heat capacities, including the Berry curvature capacity $C_\Omega = \partial_T \langle \Omega^2 \rangle$ and velocity-curvature capacity $C_v = \partial_T \langle v\Omega \rangle$. Quantified in Bi_2Te_3, these effects predict non-monotonic thermoelectric responses, providing features for experimental testing. In another study [arXiv:2411.08102v1], we show that weak magnetic fields suppress tomographic transport signatures by breaking time-reversal symmetry, a prerequisite for the odd-parity collisional relaxation effect. This suppression, occurring at much lower fields than those needed to disrupt hydrodynamic transport, suggests a practical experimental method to extract the odd-parity mean free path.

TT 4.7 Mon 11:00 H33

Finite size topology in magnetic topological insulators — •Joe Winter[1,2], Michał Pacholski[1], and Ashley Cook[1] — [1]MPI PKS, Dresden, Germany — [2]University of St Andrews, St Andrews, Scotland

The antiferromagnetic topological insulator phase is a foundational realization of three-dimensional topological phases of matter with magnetic order. It is furthermore an example of an axion insulator and condensed matter platform for realizing exotic axion dynamics of high-energy physics. At systems sizes where the sample size is comparable with the correlation length of the topological surface states, it is expected for these states to hybridise. We however show the strength of this hybridisation is oscillatory with respect to system parameters and resonances occur where the surface states can reform. We then confirm the defining response signature of the underlying 3D AFM TI phase persists in this geometry, at these resonances. We then open boundary conditions in a second direction to confirm the additional bulk-boundary correspondence of the finite-size topological phases spectral flow, finding q(3-2)D topologically-protected, gapless edge modes. The co-existence of the q(3-2)D topologically non-trivial edge states with a topological response associated with the 3D bulk topological invariant, the magnetoelectric polarizability, confirms finite-size AFM topological phases occur. This further demonstrates that finite-size topology is a generic feature of topological phases and very relevant experimentally.

15 min. break

TT 4.8 Mon 11:30 H33

Genuine topological Anderson insulator from impurity induced chirality reversal — •Avedis Neehus, Frank Pollmann, and Johannes Knolle — Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany

We investigate a model of Dirac fermions with topological mass impurities which open a global topological gap even in the dilute limit. Surprisingly, we find that the chirality of this mass term, i.e., the sign of the Chern number, can be reversed by tuning the magnitude of the single-impurity scattering. Consequently, the disorder induces a phase disconnected from the clean topological phase, i.e., a genuine topological Anderson insulator. In seeming contradiction to the expectation that mass disorder is an irrelevant perturbation to the Dirac semimetal, the tri-critical point separating these two Chern insulating phases and a thermal metal phase is located at zero impurity density and connected to the appearance of a zero energy bound state in the continuum corresponding to a divergent topological mass impurity. Our conclusions based on the T-matrix expansion are substantiated by large scale Chebyshev-Polynomial-Green-Function numerics. We discuss possible experimental platforms.

TT 4.9 Mon 11:45 H33

Topological phases of arbitrary numbers of coupled Su-Schrieffer-Heeger wires — •Anas Abdelwahab — Leibniz Univesität Hannover, Institut für Theoretische Physik, Hannover

The phase diagrams of arbitrary number N_w of Su-Schrieffer-Heeger (SSH) wires have been identified, with respect to the dimerization and the single particle wire-wire coupling, where the latter is either perpendicular or diagonal between adjacent wires. Even number of perpendicularly coupled wires exhibit either gapless or trivial topological phases. Odd number of perpendicularly coupled wires can exhibit gapless, trivial or nontrivial topological phases with winding number $w = 1$. The diagonally coupled wires reveal topological phases with winding numbers in the range $0 \le w \le N_w$. The critical lines in their phase diagrams can reveal topological critical phases [1]. Each band of the diagonally coupled wires becomes a comletely flat band at specific lines in the phase diagram. The presence of W states [2] at the edges of coupled SSH wires with open boundary conditions will be dicussed.

[1] R.Verresen, R.Thorngren, N.G.Jones,F.Pollmann, Phys. Rev. X, 120, 057001 (2018).
[2] W.Dür, G.Vidal, J.I.Cirac, Phys. Rev. A 62, 062314 (2000).

TT 4.10 Mon 12:00 H33

Local and energy-resolved topological invariants for Floquet systems — •Arnob Kumar Ghosh, Rodrigo Arouca, and Annica M. Black-Schaffer — Department of Physics and Astronomy, Uppsala University, Box 516, 75120 Uppsala, Sweden

Periodically driven systems offer a perfect breeding ground for out-of-equilibrium engineering of topological boundary states at zero energy (0-mode), as well as finite energy (π-mode), with the latter having no static analog. The Floquet operator and the effective Floquet Hamiltonian, which encapsulate the stroboscopic features of the driven system, capture both spectral and localization properties of the 0- and π-modes but sometimes fail to provide complete topological characterization, especially when 0- and π-modes coexist. In this work [1], we utilize the spectral localizer, a powerful local probe that can provide numerically efficient, spatially local, and energy-resolved topological characterization. In particular, we apply the spectral localizer to the effective Floquet Hamiltonian for driven one- and two-dimensional topological systems with no or limited symmetries and are able to assign topological invariants, or local markers, that characterize the 0- and the π-boundary modes individually and unambiguously. Due to the spatial resolution, we also demonstrate that the extracted topological invariants are suitable for studying driven disordered systems and can even capture disorder-induced phase transitions.

[1] A.K.Ghosh, R.Arouca, A.M.Black-Schaffer, arXiv:2408.08548.

TT 4.11 Mon 12:15 H33

Characterizing exceptional topology through tropical geometry — •Ayan Banerjee[1], Rimika Jaiswal[2], Madhusudan Manjunath[3], and Awadhesh Narayan[4] — [1]Max Planck Institute for the Science of Light, Erlangen — [2]University of California Santa Barbara, USA — [3]Indian Institute of Technology Bombay, India — [4]Indian Institute of Science, Bangalore

Non-Hermitian Hamiltonians describing open quantum systems have been widely explored in platforms ranging from photonics to electric circuits [1]. A defining feature of non-Hermitian systems is exceptional points (EPs), where both eigenvalues and eigenvectors coalesce. The study of EPs has become an exciting frontier at the crossroads of optics, photonics, acoustics, and quantum physics. Tropical geometry is an emerging field of mathematics at the interface between algebraic geometry and polyhedral geometry, with diverse applications to science [2]. Here, we introduce Newton's polygon method and adopt the notion of a geometrical object known as amoeba in developing a unified tropical geometric framework to characterize different facets of non-Hermitian systems [3]. We introduce a framework linking tropical geometry to non-Hermitian physics, enabling the study of EPs, skin effects, and disorder properties.

[1] E.J.Bergholtz, J.C.Budich, F.K.Kunst, Rev.Mod.Phys.93, 015005 (2021).
[2] D.Maclagan, B.Sturmfels, Graduate Stud. Math.161, 75 (2009).
[3] A.Banerjee, R.Jaiswal, M.Manjunath, A.Narayan, Proc. Natl. Acad. Sci. U.S.A. 120, e2302572120 (2023).

TT 4.12 Mon 12:30 H33

Operator approach to quantum geometry and semi-classical dynamics — •Chen Xu[1,2], Andreas Haller[1], Suraj Hegde[3], Tobias Meng[2], and Thomas Schmidt[1] — [1]Department of Physics and Materials Science, University of Luxembourg, Luxembourg — [2]TU Dresden, Department of Physics — [3]IISER-Thiruvananthapuram, India

We develop an operator-based approach for computing the quantum geometric contributions to the equations of motion of the position and momentum operators in an multiband system, without resorting to semiclassical wave-packet approximations. We identify contributions such as the Berry curvature and the quantum metric tensor induced anomalous velocity as fundamentally effective multiband effects. We show using this approach that in general higher-order operator-valued geometric quantities emerge in studying the dynamics in the presence of inhomogeneous external fields. We also demonstrate how to derive the dynamics from a generic coupling between Bloch momentum and an inhomogeneous external field, thus generalizing previous studies.

TT 4.13 Mon 12:45 H33

Exciton condensation driven by bound states of Green's function zeros — •Ivan Pasqua, Andrea Blason, and Michele Fabrizio — International School for Advanced Studies (SISSA), Via Bonomea 265, I-34136 Trieste, Italy

The spectral properties of electronic systems are encoded in the single-particle Green's function, with theoretical efforts traditionally focusing on the position and nature of its poles. Only recently, Green's function zeros have been recognized as important hallmarks of non-symmetry breaking strongly correlated insulators and, possibly, of fractionalized excitations. The analysis of the zeros offers a new perspective on the increasingly studied topic of excitonic insulators (EI), typically understood as the condensation of bound states between the valence and conduction bands of poles of the Green's function. Indeed this picture appears paradoxical in Mott insulators (MI), where the large gap between the Hubbard bands seemingly precludes the formation of such bound states. Yet, a continuous transition from a MI and an EI is observed in the Bernevig-Hughes-Zhang model using the dynamical cluster approximation. We find that a nontopological EI intrudes between the QSH and MI regimes. Our analysis suggests that excitons in the MI, which soften at the transition to the EI, could be bound states between valence and conduction bands of Green's function zeros. Our work proposes a novel mechanism for exciton condensation and highlights the role of Green's function zeros in diagnosing the properties of correlated phase of matter.