Topological Matter Conference TMC2023

March 28 - 31, 2023
(Athens, Greece)

Topological Matter
March 28-31, 2023

FOREWORD

On behalf of the Organising and the Program Committees, we take great pleasure in welcoming you to Athens (Greece) for this new edition of the Topological Matter Conference (TMC2023), which succeeds the very successful first TMC event held on-line in 2021.

TMC2023 focuses on recent developments in fundamental and applied aspects of broad classes of topological quantum systems and the synergy between them. Topics include topological insulators and Weyl and Dirac semimetals, topological phononics and photonics, skyrmions, quantum metrology and more.

The TMC event is a joint effort between the H2020 FET-PROACTIVE projects SKYTOP (GA: 824123) and TOCHA (GA: 824140) with the objective to establish synergies and to mobilize the Topological Matter community.

We also would like to thank all the speakers and participants that joined us in person this year.

Hope to see you again in the next edition of TMC.

TMC2023 Organising Committee

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SKYTOP Skyrmion-Topological insulator and Weyl semimetal technology

TOCHA New Generation of Devices to Harness Topology

CONTRIBUTIONS LIST

Deconfinement of Majorana vortex modes in a topological superconductor

Carlo Beenakker
Instituut-Lorentz, Leiden University, The Netherlands
beenakker@lorentz.leidenuniv.nl

A topological superconductor can bind a Majorana fermion as a midgap state in the core of a magnetic vortex. This Majorana zero-mode has been dubbed the "Zen particle", because it embodies nothingness: it has zero charge, zero spin, zero energy, and zero mass. It does have a definite chirality, set by the sign of the winding of the superconducting phase around the vortex.

A superflow couples to the circulating phase, producing a sideways force on the vortex known as the Magnus force. It was recently discovered [1] that the superflow also acts on the zero-mode, causing a deconfinement transition when the Cooper pair momentum exceeds a critical value. The deconfined Majorana fermion forms a dispersionless Landau level, protected by chiral symmetry against broadening due to vortex scattering. Unlike a conventional electronic Landau level, the Majorana Landau level has a non-uniform density profile: quantum interference of the electron and hole components creates spatial oscillations with a wave vector set by the Cooper pair momentum that drives the deconfinement transition. The striped pattern also provides a means to measure the chirality of the Majorana fermions.

Here we discuss this development, in connection with experiments on topological insulators and with an outlook towards the dynamical manipulation of "flying" Majorana fermions.

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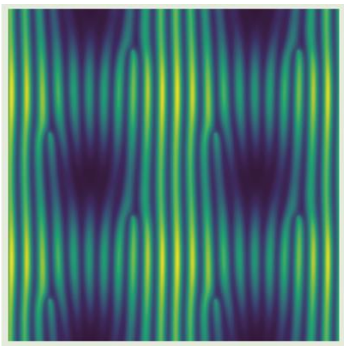

Figure 1: Computer simulation of the striped density of a Majorana Landau level in the 2D plane of a proximitized topological insulator.

Claudia Felser
Max Planck Institute for Chemical Physics of Solid.Germany
felser@cpfs.mpg.de

Chirality is a very active field of research in organic chemistry, closely linked to the concept of symmetry. Topology, a well-established concept in mathematics, has nowadays become essential to describe condensed matter [1,2]. At its core are chiral electron states on the bulk, surfaces and edges of the condensed matter systems, in which spin and momentum of the electrons are locked parallel or anti-parallel to each other. Magnetic and non-magnetic Weyl semimetals, for example, exhibit chiral bulk states that have enabled the realization of predictions from high energy and astrophysics involving the chiral quantum number, such as the chiral anomaly, the mixed axial-gravitational anomaly and axions [3-5]. Chiral topological crystals exhibit excellent chiral surface states [6,7] and different orbital angular momentum for the enantiomers, which can be advantageous in catalysis. The potential for connecting chirality as a quantum number to other chiral phenomena across different areas of science, including the asymmetry of matter and antimatter and the homochirality of life, brings topological materials to the fore [8].

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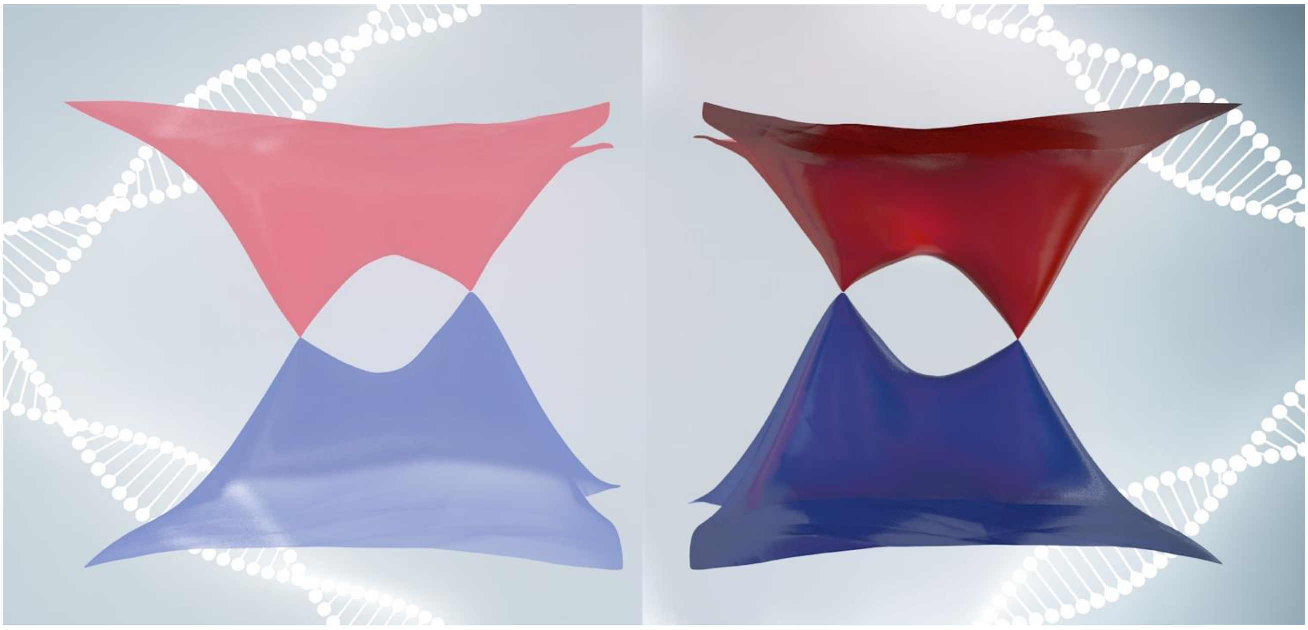

Figure 1: the Weyl points in Chiral Fermions for the two enantiomorphs

A New Era in Ferroelectrics

R. Ramesh
Rice University, Houston TX 77005
Rr73@rice.edu

Complex topological configurations are a fertile playground to explore novel emergent phenomena and exotic phases in condensed-matter physics. I will describe the discovery of polar skyrmions and vortices in a lead-titanate layer confined by strontium-titanate layers by atomic-resolution scanning transmission electron microscopy. Phase-field modeling and second-principles calculations reveal that the polar skyrmions have a skyrmion number of +1 and resonant soft X-ray diffraction experiments show circular dichroism confirming chirality. Such nanometer-scale polar skyrmions exhibit a strong signature of negative permittivity at the surface of the skyrmion, which is furthermore highly tunable with an electric field. They are a new state of matter and electric analogs of magnetic skyrmions, and may be envisaged for potential applications in information technologies.

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Figures

Figure 1: Turing patterns formed by polar skyrmions.

Macroscopic Quantum Tunneling of a Topological Ferromagnet

Charles Gould
Kajetan M. Fijalkowski, Nan Liu, Pankaj Mandal, Steffen Schreyeck, Karl Brunner, and Laurens W. Molenkamp
Faculty for Physics and Astronomy (EP3), Universität Würzburg, and Institute for Topological insulators (ITI), Am Hubland, D-97074 Würzburg, Germany
gould@physik.uni-werzburg,de

Since the early days of quantum mechanics, physicists have been trying to understand how the laws governing the microscopic world merge into those describing the classical mechanics at macroscopic size scales. A trademark quantum mechanical phenomenon that has no direct analog in classical physics is quantum tunnelling between different eigenstates of the system. This posed an intriguing question regarding the possibility of existence of quantum tunnelling in systems that can be regarded as macroscopic.

Only in the recent couple of decades the experimental techniques have reached a level of advancement that allowed to directly address that question experimentally. This was done in the context of macroscopic quantum tunnelling between different states in the Josephson junctions [1], as well as quantum tunnelling of magnetic domain walls [2], and magnetization [3] in magnetic systems.

Here, we investigate the electronic transport in a $(V,Bi,Sb)_2Te_3$ ferromagnetic topological insulator nanostructure in the quantum anomalous Hall regime. This provides access to the dynamics of an individual ferromagnetic domain. Telegraph noise resulting from the magnetization fluctuations of this domain is observed in the Hall signal. Careful analysis of the domain switching statistics provides evidence for macroscopic quantum tunneling of magnetization [4]. This ferromagnetic macrospin is not only the largest magnetic object in which quantum tunneling has been observed, but also the first observation of the effect in a topological state of matter.

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Topological interplay between photons and electrons

Mohammad Hafezi
University of Maryland, USA
hafezi@umd.edu

A seminal gedankenexperiment by Laughlin describes the charge transport in quantum Hall systems via the pumping of flux. An optical excitation could probe and manipulate quantum Hall systems in a similar way: When light containing orbital angular momentum interacts with electronic Landau levels, it acts as a flux pump that radially moves the electrons through the sample, as a radial photocurrent. We experimentally investigate this effect for a graphene system in a Corbino geometry and discuss potential theoretical explanations. The key insight is the violation of dipole approximation for itinerant electrons. This approach could open new avenues for direct measurement of the spatial and spectral coherence of an electron's wavefunction, with fundamental and practical implications in coherent light-matter interaction.

Local-moment fluctuations and Kondo physics in twisted bilayer graphene

Haoyu Hu
Donostia International Physics Center, *Spain*
haoyu.hu@dipc.org

Abstract

Twisted bilayer graphene (TBG) has shown two seemingly contradictory characters: (1) quantum-dot-like behavior in STM indicates that then electrons are localized; (2) the transport experiments suggest the itinerant character. Two features can both be captured by a topological heavy-fermion model, in which the topological conduction electron bands couple to the local moments on a triangular lattice [1]. We study the local moment physics and the Kondo effect in this model. We first calculate the RKKY interactions between the local moments. We demonstrate that the RKKY interactions will lead to a U(4) Hund's rule of the ground states, and study the corresponding local moment fluctuations on top of the ground states [2]. We then analyze the Kondo effect induced by the hybridization between topological conduction electrons and local moments. The stability and topology of the Kondo phase are also discussed [3].

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Terahertz spin and charge photocurrents in topological spintronic structures

Tobias Kampfrath
Department of Physics, Freie Universität Berlin, Germany
Fritz Haber Institute of the Max Planck Society, Berlin, Germany
tobias.kampfrath@fu-berlin.de

To take advantage of the electron spin in future electronics, spin angular momentum needs to be transported and detected. In this respect, topological Weyl semimetals and topological insulators are considered as promising materials for spin-current generation and spin-charge interconversion. To probe the initial ultrafast elementary steps that lead to the formation of spin and charge currents, we launch and measure transport by employing ultrashort optical and terahertz electromagnetic pulses (Fig. 1). Based on this approach [1], new insights into important spintronic phenomena such as spin-current generation in Weyl semimetals [2], spin-charge conversion in ferromagnet/topological-insulator heterostructures and photocurrents in three-dimensional topological insulators [3] can be obtained. Interesting photonic applications such as the generation of ultrashort terahertz electromagnetic pulses also emerge [4].

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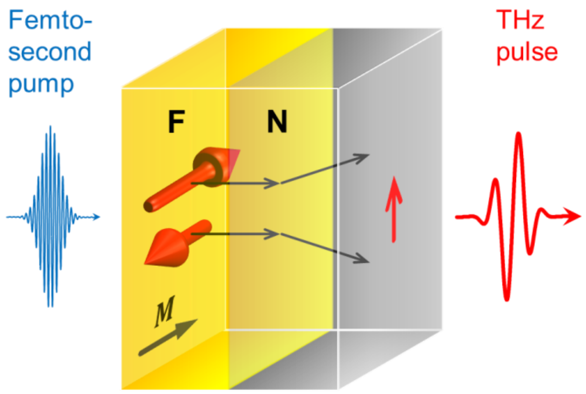

Figure 1: Schematic of ultrafast spin and charge photocurrents in F|N stacks. A femtosecond laser pulse drives spin transport from a ferromagnetic metal layer F into a non-ferromagnetic layer N. Spin-charge conversion results in an in-plane charge-current burst that emits a detectable terahertz electromagnetic pulse [1].

Bismuth antiphase domain wall:
A three-dimensional manifestation of the Su-Schrieffer-Heeger model

Jinwoong Kim[1], Cheng-Yi Huang[2], Hsin Lin[3], David Vanderbilt[4], and Nicholas Kioussis[1]

[1]*Department of Physics and Astronomy, California State University, Northridge, California 91330, USA*
[2]*Department of Physics, Northeastern University, Boston, Massachusetts 02115, USA*
[3]*Institute of Physics, Academia Sinica, Taipei 11529, Taiwan and*
[4]*Department of Physics and Astronomy, Rutgers University, Piscataway, New Jersey 08854-8019, USA*

nick.kioussis@csun.edu

The Su, Schrieffer, and Heeger (SSH) model[1], describing the soliton excitations in polyacetylene due to the formation of antiphase domain walls (DW) from the alternating bond pattern, has served as a paradigmatic example of one-dimensional (1D) chiral topological insulators. While the SSH model has been realized in photonic and plasmonic systems, there have been limited analogues in three-dimensional (3D) electronic systems, especially regarding the formation of antiphase DWs. Here, we propose that pristine bulk Bi, in which the dimerization of (111) atomic layers renders alternating covalent and van der Waals bonding within and between successive (111) bilayers, respectively, serves as a 3D analogue of the SSH model. First, we confirm that the two dimerized Bi structures belong to different Zak phases[2] of 0 and π by considering the parity eigenvalues and Wannier charge centers, while the previously reported bulk topological phases of Bi remain invariant under the dimerization reversal. Next, we demonstrate the existence of topologically non-trivial (111) and trivial (11-2) DWs in which the number of in-gap DW states (ignoring spin) is odd and even respectively, and show how this controls the interlinking of the Zak phases of the two adjacent domains. Finally, we derive general criteria specifying when a DW of arbitrary orientation exhibits a π Zak phase based on the flip of parity eigenvalues.

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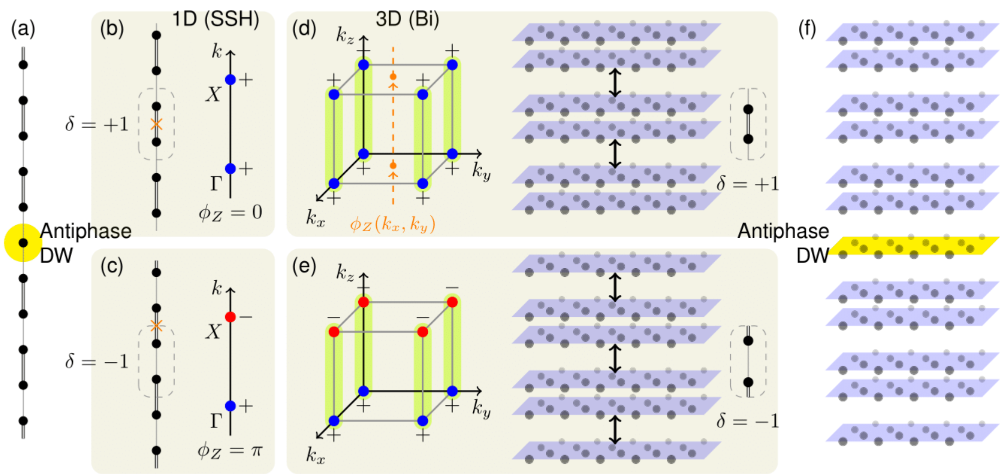

Figure 1: Schematic view of the SSH model and comparison with the 3D analogue. (a) Antiphase DW of the SSH model. (b, c) Two dimerized phases (δ=±1) and corresponding parity eigenvalues, whose product determines the Zak phase (Φ_Z). (d, e) 3D analogue of the SSH model where the Zak phase also depends on the dimerization. (f) Antiphase DW as the 3D analogue of the SSH model.

Superconducting diode effect due to magnetochiral anisotropy in topological insulator and Rashba nanowires

Jelena Klinovaja
Henry F. Legg, Daniel Loss
Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland
jelena.klinovaja@unibas.ch

The critical current of a superconductor can depend on the direction of current flow due to magnetochiral anisotropy when both inversion and time-reversal symmetry are broken, an effect known as the superconducting (SC) diode effect [1]. In our work, we consider one-dimensional (1D) systems in which superconductivity is induced via the proximity effect [2,3]. In both topological insulator and Rashba nanowires, the SC diode effect due to a magnetic field applied along the spin-polarization axis and perpendicular to the nanowire provides a measure of inversion symmetry breaking in the presence of a superconductor. Furthermore, a strong dependence of the SC diode effect on an additional component of magnetic field applied parallel to the nanowire as well as on the position of the chemical potential can be used to detect that a device is in the region of parameter space where the phase transition to topological superconductivity is expected to arise [3-5].

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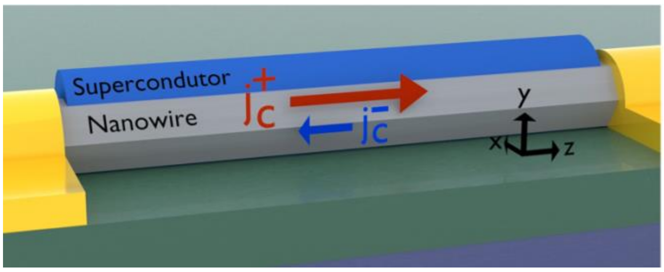

Figure 1: *SC diode effect due to magnetochiral anisotropy in nanowire devices.* When the subbands of a nanowire possess a finite spin polarization due to broken inversion symmetry, a magnetic field applied along the spin-polarization direction results in a relative Zeeman shift of the subbands. The magnetochiral anisotropy (MCA) of the energy spectrum can lead to MCA rectification in the diffusive normal state . On the other hand, if a nanowire is brought into proximity with a superconductor, the MCA of the energy spectrum results in a critical supercurrent in the proximitized nanowire that is different depending on whether current flows to the left or right of the device, the SC diode effect. The dependence of this diode effect on an additional magnetic field component parallel to the nanowire can be used to detect that the nanowire is in parameter regime where topological superconductivity is expected.

Chiral conduction channels in van der Waals topological magnets

Lia Krusin-Elbaum
Department of Physics, The City College of New York, CUNY, New York, NY 10031, USA
lkrusin@ccny.cuny.edu

Recent realizations of a nontrivial quantum anomalous Hall (QAH) and axion insulator states, featuring dissipation-free chiral edge currents, made it apparent that when long-range magnetism and band topology combine the consequences of ubiquitous disorder can be particularly acute and yet surprising. Structural disorder can induce spin correlations even in a non-magnetic system [1], while magnetic doping disorder in topological insulators restricts QAH temperature to the mK range and ultrathin layers. We have recently discovered a new Berry-curvature-driven QAH regime at higher temperatures [2] in the $Mn(Bi,Sb)_2Te_4$ class of van der Waals (vdW) intrinsic topological magnets (ITM), where Mn ions self-organize into a superlattice of Mn monolayers that can be separated on-demand. Robust ferromagnetism of such superlattice opens up a large surface gap, and anomalous Hall conductance reaches an e^2/h quantization plateau when the Fermi level is within this gap, even in the presence of the 2D bulk states. The complex electronic structure and limited tunability of both the electron density and exchange interactions in these bulk materials pose significant challenges in accessing chiral channels. In this talk I will describe a new tuning technique we have developed in ITM towards QAH [3] and our most recent results on inducing chiral spin textures in ITM by disorder control with a reversible intake and release of ionic hydrogen. Our findings offer a scalable strategy to manipulate chiral channels for chiral logic and topological spintronics. *Supported in part by NSF grants DMR-2011738 and HRD-2112550.

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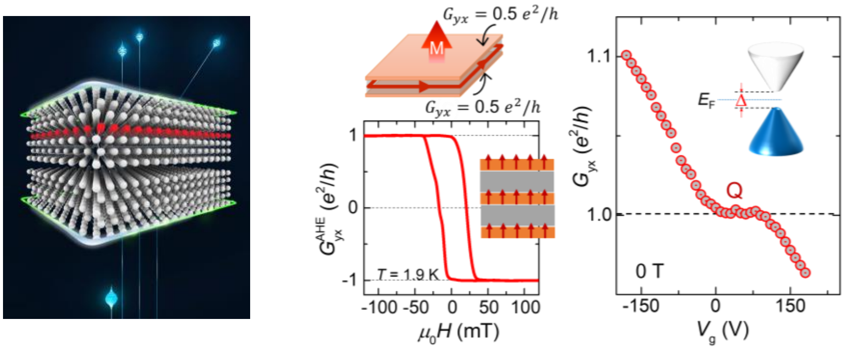

Figure 1: Chiral edge currents and QAH in a self-assembled bulk $MnBi_2Te_4/Bi_2Te_3$ superlattice.

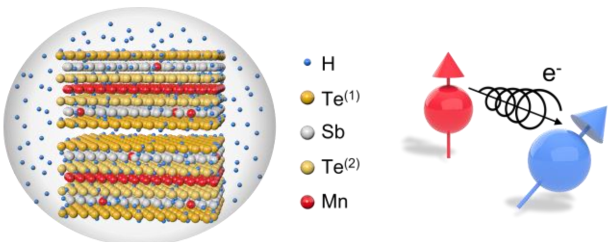

Figure 2: Hydrogenation process of a vdW ITM $MnSb_2Te_4$ that can lead to chiral transport.

Topological interface mode by simultaneous optical and nanophononic band inversion

N. D. Lanzillotti-Kimura
M. Esmann, P. Priya, A. Rodriguez, O. Ortiz, C. Gomez, M. Morassi, A. Lemaitre
Université Paris Saclay, CNRS, Centre de Nanosciences et de Nanotechnologies
daniel.kimura@c2n.upsaclay.fr

Nanophononics, the control of acoustic phonons at ultrahigh frequencies, appears as a suitable platform for single-particle quantum simulations and to study general wave phenomena. Band inversion in one-dimensional superlattices is a strategy to generate topological interface modes in electronics, optics, acoustics, and nanophononics [1-4]. Despite their potential for the control of topologically robust interactions, most realizations of these states have so far explored only a single kind of excitation. Here, we construct an optical and phononic interface mode by simultaneous band inversion for photons and phonons. [5] We rely on GaAs/AlAs heterostructures that exhibit a naturally occurring colocalization of the optical and acoustic fields, resulting in enhanced optomechanical interactions. We designed and fabricated a heterostructure presenting a topological interface mode for photons at 1.34 eV and phonons at 18 GHz. We experimentally observe colocalized interface modes for NIR photons by optical reflectivity and 18 GHz phonons by coherent phonon generation and detection.
Through numerical simulations, we demonstrate the ensuing robustness of the Brillouin interaction between them with respect to a specific type of disorder. Furthermore, we theoretically deduce a set of engineering rules in different topological designs presenting colocalized states. Potential future applications include the engineering of robust optomechanical resonators in a material system compatible with quantum wells and quantum dots.

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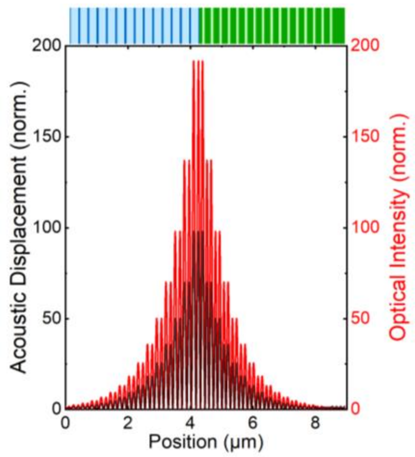

Figure 1: Schematic of multilayered structure formed by two concatenated GaAs/AlAs superlattices presenting band inversion (top). Acoustic and optical field distributions corresponding to the simultaneous confined interface mode (botom) [5].

Non-collinear three-dimensional textures in magnetic multilayers: Hatching of skyrmionic cocoons

Nicolas Reyren,[1] M. Grelier,[1] R. Battistelli,[2] H. Popescu,[3] S. Finizio,[4] B. Watts,[4] C. Léveillé,[3,1] Y. Sassi,[1] W. Legrand,[1] F. Ajejas,[1] E. Burgos-Parra,[1,3] S. Collin,[1] F. Godel,[1] A. Vecchiola,[1] K. Bouzehouane,[1] C. Donnelly,[5] F. Büttner,[2] N. Jaouen,[3] V. Cros,[1] A. Fert[1]

1. *Unité Mixte de Physique, CNRS, Thales, Université Paris-Saclay, Palaiseau, France*

2. *Helmholtz-Zentrum Berlin, Berlin, Germany ; 3. Synchrotron SOLEIL, L'Orme des Merisiers, Gif-sur-Yvette, France ; 4. Swiss Light Source, Paul Scherrer Institut, Villigen, Switzerland ; 5. Department of Physics, Cavendish Laboratory, University of Cambridge, JJ Thomson Ave, Cambridge, United Kingdom; Max Planck Institute for Chemical Physics of Solids, Dresden, Germany*

nicolas.reyren@cnrs-thales.fr

Two-dimensional magnetic textures such as skyrmions or chiral domain walls were mostly under focus for the last decade, but recently interest has surged for more complex objects which display an inhomogeneous behaviour over the vertical dimension. Interesting examples include bobbers which could become remarkable assets for the development of logic devices [1], the recently observed hopfions [2], or even different skyrmions phases [3].

In this study, we engineer and explore aperiodic metallic multilayers stabilizing new magnetic textures, which we named skyrmionic cocoons [4]. At low magnetic field, they resemble tubular skyrmions but upon an increase of the out-of-plane field, they shrink and disappear from the outer layers becoming elongated ellipsoids. By carefully tuning the thickness of each magnetic layer, it is possible to observe concomitantly two distinct objects in a single sample, as shown by the strong difference in the magnetic force microscopy (MFM) contrasts in Fig. 1. X-ray holography confirms the MFM observations and provides information about the averaged magnetization through the layers, and allow the cocoon-cocoon interaction to be observed. Finally, their 3D nature was recently confirmed using laminography.

Combining all these observation techniques with magneto-transport as well, we can reliably compare our experimental observations with micromagnetic simulations, displaying these new 3D textures. The existence and field-dependent behaviour of such textures could represent interesting possibilities for potential applications.

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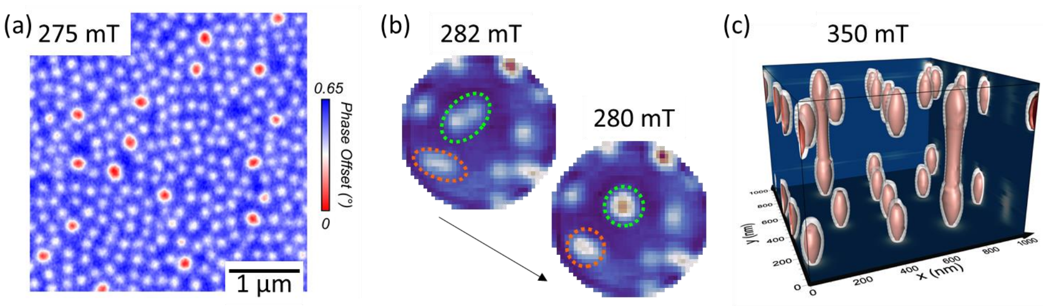

Figure 1: Cocoons and skyrmion tubes. (a) Experimental MFM phase maps displaying two types of textures. (b) Holography images showing alignment of cocoons before their fusion at lower field. Blue and red colours are associated to up and down magnetizations. (c) Corresponding micromagnetic simulations, evidencing the 3D nature of the cocoons and the skyrmion tubes (magnetization iso surfaces at m_z = -0.8 are displayed in red).

Persistence of symmetry-protected Dirac points at the surface of the topological crystalline insulator SnTe upon doping

Olga Arroyo Gascón[1,2]
Yuriko Baba[2], Jorge I. Cerdá[1,*], Oscar de Abril[3], Ruth Martinez-Casado[2], Francisco Domínguez-Adame[2] and Leonor Chico[2]
[1] *Instituto de Ciencia de Materiales de Madrid, Consejo Superior de Investigaciones Científicas, C/ Sor Juana Inés de la Cruz 3, E–28049 Madrid, Spain.*
[2] *GISC, Departamento de Física de Materiales, Universidad Complutense, E-28040 Madrid, Spain.*
[3] *Departamento de Estructuras y Física de Edificación, Universidad Politécnica de Madrid, E–28031 Madrid, Spain.*
* *Deceased.*
o.arroyo.gascon@csic.es

We investigate the effect of a non-magnetic donor impurity located at the surface of a topological crystalline insulator, SnTe [1]. Specifically, the changes on the surface states due to a Sb impurity atom are analyzed by means of first-principles simulations of pristine and impurity-doped SnTe. While semi-infinite and slab geometries are considered within the ab-initio approach, minimal and Green's function continuum models are also proposed with the same goal. We find that the Dirac cones are shifted down in energy upon doping; this shift strongly depends on the position of the impurity with respect to the surface. Moreover, the width of the impurity band shows an even-odd behavior by varying the impurity position. Comparing slab and semi-infinite geometries, we demonstrate that in the doped semi-infinite system the surface states remain gapless and their spin textures are unaltered. Besides its fundamental interest, tuning the Dirac cones of topological insulators can be of interest for transport and spintronic applications [2].

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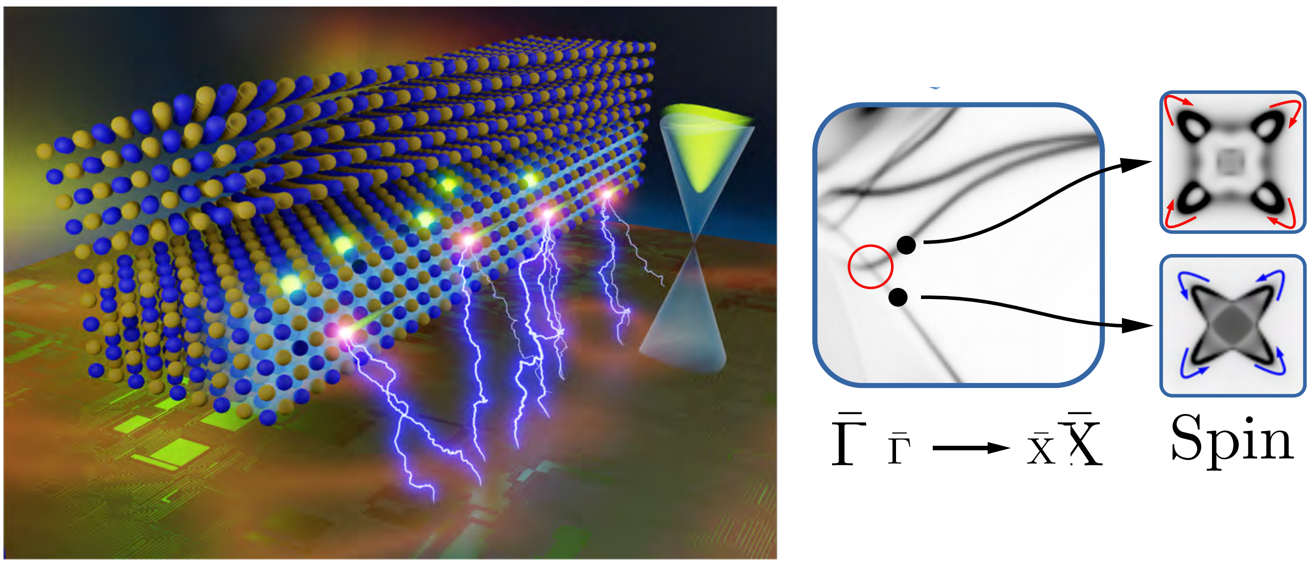

Figure 1: Left panel: Recreation of a SnTe slab. The Sb impurities and their contribution to the Dirac cone are highlighted in yellow. Central panel: projected density of states (PDOS(k,E)) maps of Sb-doped SnTe, with the Dirac cone circled in red. Right panel: PDOS(k_x,k_y,E) maps and spin textures above and below the Dirac point.

Connecting Fermi-surface topology and spin-orbit torques in Weyl Semimetal/Ferromagnet Heterostructures

Amilcar Bedoya-Pinto[1,2]
A.K. Pandeya[2], D. Liu[2] and S.S.P. Parkin[2]
[1]*Insitute of Molecular Science (ICMol),University of Valencia, Spain*
[2]*NISE-Department, Max-Planck Insitute of Microstructure Physics, Halle, Germany*
Amilcar.Bedoya@uv.es

Weyl Semimetals (WSMs), materials with three-dimensional topologically protected electronic states, show highly interesting physical properties including surface Fermi-arcs, the chiral magneto-transport anomaly and extremely high electron mobilities. One promising application field of WSMs is spin-orbitronics, as the Fermi-surface is expected to play an important role in the spin-to-charge conversion efficiency, according to theoretical investigations [1,2].
In this work, we report the growth of epitaxial, single-crystalline NbP and TaP Weyl Semimetal thin films [3] by means of molecular beam epitaxy, and their successful integration in spin-torque devices. We have assessed the structural quality of the films (Fig.1a) featuring an atomically flat, ordered surface, essential for the observation of topological bands by photoemission (Fig. 1b). Furthermore, we rely on the preparation of high-quality in-situ TaP/Permalloy interfaces to investigate the spin-orbit torques produced by the topological WSM by means of spin-torque ferromagnetic resonance (ST-FMR). First results of TaP/Py/MgO device structures show readily signatures of large spin-orbit torques induced by the Weyl Semimetal: (i) a very strong symmetric component of the voltage lineshape across the resonance related to damping-like torques (Fig.1c), much different than the FMR response of a reference ferromagnet, and (ii) a clear scaling of the resonance linewidth by applying an external DC bias through the bilayer (Fig. 1d). **The connection between Fermi-surface topology and spin-to-charge conversion** is addressed by performing angle-resolved photoemission measurements on the TaP thin film surfaces prior to the *in-situ deposition* of the magnetic layers, and probing the spin-torque efficiency along the high-symmetry directions of the WSM, where the surface states are expected to have a substantial contribution.

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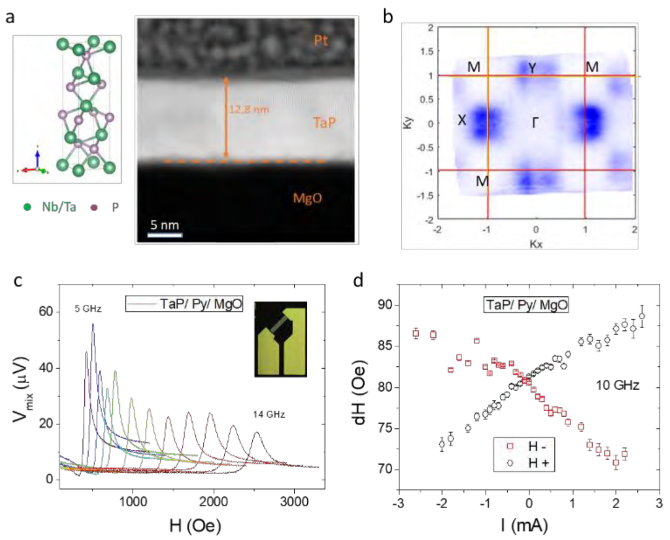

Figure 1: (a)Transmission electron microscopy image of a TaP thin film, showing ordered epitaxial lattice planes and an atomically flat surface. The crystal structure is drawn for clarity. (b) Angle-resolved photoemission measurements of the TaP thin films, showing four-fold symmetric electronic pockets at the Fermi-energy. (c) Frequency-dependent ST-FMR of a TaP/Py/MgO device, evidencing a strong symmetric lineshape component indicative of damping-like spin-orbit torques. Inset: Optical image of ST-FMR device. (d) Linewidth dependence of the ST-FMR signal, showing a consistent scaling with applied DC bias. The slope is proportional to the magnitude of the induced spin-orbit torques per charge unit.

Interference, diffraction, and diode effects in superconducting arrays based on $Bi_{0.8}Sb_{1.2}Te_3$ topological insulator

Alexey Bezryadin(1)
Xiangyu Song(1), Soorya Suresh-Babu(1), Yang Bai(1), Dmitry Golubev(2), Irina Burkova(1), Alexander Romanov(1), Eduard Ilin(1), James N. Eckstein(1)
(1) Department of Physics, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA
(2) Department of Applied Physics, Aalto University School of Science, Aalto 00076, Finland
bezryadi@illinois.edu

Abstract

t is a well known phenomenon in optics that spectroscopic resolution of a diffraction grating is much better compared to an interference device having just two slits, as in the Young's famous double-slit experiment. On the other hand, it is well known that a classical superconducting quantum interference device (SQUID) is analogous to the optical double-slit experiment. Here we report experiments and present a model describing a superconducting analogue to the diffraction grating, namely an array of superconducting islands positioned on a topological insulator (TI) film Bi0.8Sb1.2Te3 [1]. Previously, the proximity effect has been studied extensively on epitaxial topological films which are not intrinsic, due to unintentional doping, such as Bi_2Se_3 [2]. Here we are able to induce a strong proximity superconductivity into an epitaxial film of an intrinsic topological insulator. In the limit of extremely weak field, of the order of one vortex per the entire ar ray, such devices exhibit a critical current peak that is much sharper than the analogous peak of an ordinary SQUID. Because of this, such arrays can be used as sensitive absolute magnetic field sensors. An important finding is that, due to the inherent asymmetry of such ar rays, the device also acts as a superconducting diode.[3]

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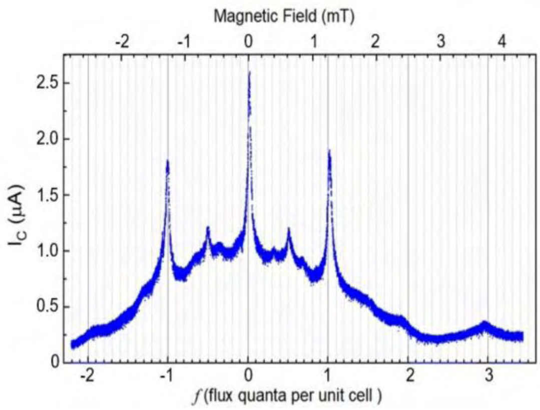
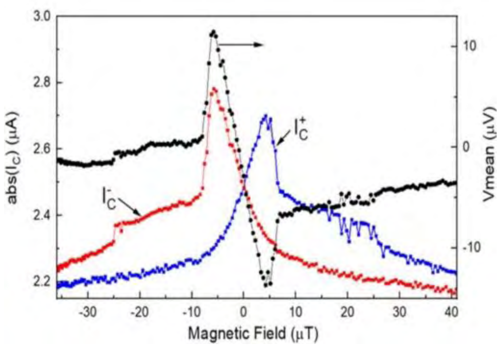


(a)



(b)

Figure 1: (a) Critical current versus the normalized flux per unit cell, f . The critical current shows sharp peaks coinciding with integer values of f. The peak f = 2 is suppressed more than n=0 and n=3. (b) Mean voltage, critical current on positive and negative branches plotted as a function of magnetic field.

Microwave transport in HgTe topological insulators

E. Bocquillon
M. C. Dartiailh, A. Gourmelon, H. Kamata, S. Hartinger, K. Bendias, J.-M. Berroir, G. Fève, B. Plaçais, L. Lunczer, R. Schlereth, H. Buhmann, L. W. Molenkamp
II. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Germany
bocquillon@ph2.uni-koeln.de

Research on helical edge states in 2D topological insulators is motivated by exotic fundamental physics, prospects for robust topological quantum computation and novel spinorbitronics. However, topological transport is often visible only on short distances. On larger distances, microwave transport offers powerful tools to investigate the origin of this fragility, or to dynamically enhance topological signatures by exploiting the high mobility of edge states with respect to bulk carriers.

In this talk, we report on microwave transport in HgTe 2D topological insulators [1, 2]. Via microwave capacitance spectroscopy, we highlight the response of the edges which host very mobile carriers, while bulk carriers are present as puddles but are drastically slowed down in the gap. This suggests that edge states can be selectively addressed on timescales over which bulk carriers are frozen. In a second study [3], we measure the velocity of edge states in both the quantum Hall and quantum spin Hall regime. The low observed velocities again point towards the prominent role of charge puddles in the topological gap.

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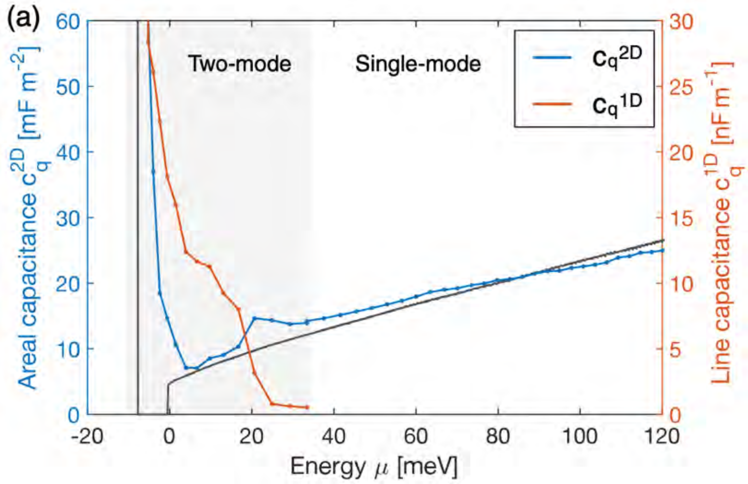

Figure 1: Measured edge and bulk quantum capacitance of a HgTe 2D topological insulator

Intermixing-driven ferromagnetism in the quantum anomalous Hall candidate $MnBi_6Te_{10}$

Laura T. Corredor Bohorquez[1]
A. Tcakaev[2,3], B. Rubrecht[1], J. I. Facio[1,4], V. B. Zabolotnyy[2,3], L. C. Folkers[3,5], E. Kochetkova[1], J. van den Brink[1], B. Büchner[1,3,5], A. U. B. Wolter[1,3], A. Isaeva[1,6] and V. Hinkov[2,3]

[1] Leibniz IFW Dresden, Helmholtzstraße 20, D-01069 Dresden, Germany
[2] Physikalisches Institut (EP-IV), Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany
[3] Würzburg-Dresden Cluster of Excellence ct.qmat, Germany
[4] Centro Atómico Bariloche, Instituto de Nanociencia y Nanotecnología (CNEA-CONICET) and Instituto Balseiro. Av. Bustillo 9500, Bariloche (8400), Argentina
[5] Institut für Festkörper- und Materialphysik, Technische Universität Dresden, 01062 Dresden, Germany
[6] Van der Waals-Zeeman Institute, Department of Physics and Astronomy, University of Amsterdam, Science Park 094, 1098 XH Amsterdam, The Netherlands

Contact: l.t.corredor.bohorquez@ifw-dresden.de

The recent realizations of the quantum anomalous Hall effect (QAHE) in $MnBi_2Te_4$ and $MnBi_4Te_7$ benchmark the $(MnBi_2Te_4)(Bi_2Te_3)_n$ family as a promising playground for further QAHE improvements. The family owes its potential to its ferromagnetically (FM) ordered $MnBi_2Te_4$ septuple layers (SL). However, the QAHE realization is complicated in $MnBi_2Te_4$ and $MnBi_4Te_7$ due to the substantial antiferromagnetic (AFM) coupling between the SL. A ferromagnetic state, advantageous for the QAHE, can be stabilized by interlacing the SL with an increasing number *n* of Bi_2Te_3 quintuple layers (QL). In [1] we experimentally and theoretically establish the Mn/Bi intermixing as a new mechanism that can drive the FM state in $MnBi_6Te_{10}$, an intrinsic magnetic topological insulator [2] and QAHE candidate [3]. X-ray diffraction reveals an intermixing pattern of Mn/Bi that favors ferromagnetic coupling according to density functional theory (DFT) calculations. In consonance with these results, our samples show prominent ferromagnetic characteristics, with a rather large **$T_C \approx 12$** K and a substantial ordered, out-of-plane moment both in the bulk and at the surface [3]. Our results demonstrate that carefully engineered intermixing can accomplish a robust FM order and, therefore, is the key towards enhanced QAHE properties in the $(MnBi_2Te_4)(Bi_2Te_3)_n$ family of intrinsic magnetic topological insulators.

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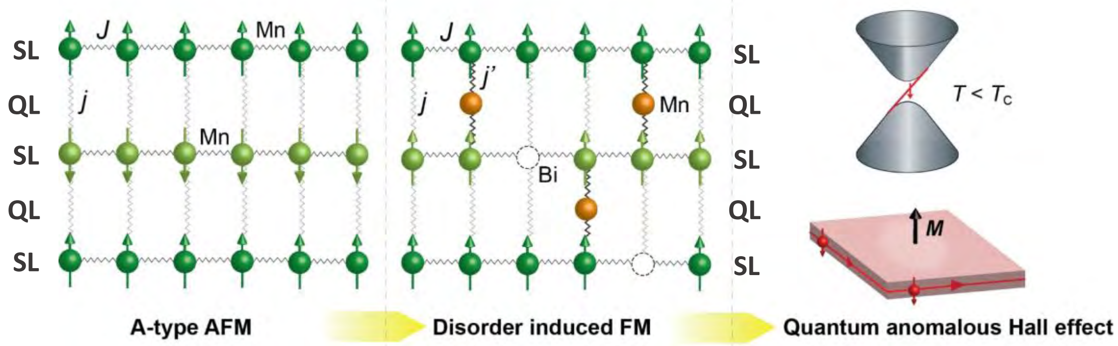

Observation and applications of non-Hermitian topology in a multi-terminal quantum Hall device

Joseph Dufouleur[1]
Kyrylo Ochkan[1], Raghav Chaturvedi[1], Viktor Könye[1], Anastasiia Chyzhykova[1], Louis Veyrat[1], Romain, Giraud[1,2], Dominique Mailly[3], Ulf Gennser[3], Jan Budich[4], Ewelina Hankiewicz[5], Jeroen van den Brink[1], Cosma Fulga[1]
[1] *IFW Dresden, Deutschland*
[2] *Spintec, Grenoble, France*
[3] *Centre de Nanosciences et de Nanotechnologies, Palaiseau, France*
[4] *TU Dresden, Deutschland*
[5] *Julius-Maximilians-Universität Würzburg, Deutschland*
j.dufouleur@ifw-dresden.de

One of the simplest examples of non-Hermitian topology is encountered in the Hatano-Nelson (HN) model, a one-dimensional chain where the hopping in one direction is larger than in the opposite direction. We present here the first experimental observation of non-Hermitian topology in a quantum condensed-matter system. The measurements are done in a multi-terminal quantum Hall device etched in a high mobility GaAs/AlGaAs two-dimensional electron gas ring (Fig. 1). The conductance matrix that connects the currents flowing from the active contacts to the ground with the voltage of the active contacts is topologically equivalent to the HN Hamiltonian.

In our device, we directly measure and evidence the non-Hermitian skin effect. We also compute for our experimental device two topological invariants that are found to be more robust than the Chern number. We finally use the unique properties of our system and continuously tune the system configuration between open and periodic boundary conditions [1].

In this talk, we present the latest developments with regard to the application of the devices with these topological properties.

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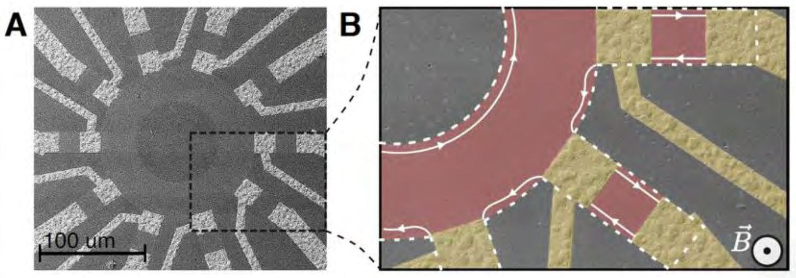

Figure 1: (A) Scanning electron microscopy (SEM) image of the AlGaAs 2DEG device. (B) Zoomed-in false-color SEM image. White lines indicate the edge quantum Hall states in the presence of a perpendicular magnetic field at filling factor ν = 1. The 2DEG and ohmic contacts are highlighted in red and yellow, respectively. White dashed lines show the boundaries of the 2DEG.

Spin-orbit torques, topological Hall effect, and current induced magnetization reversal in MBE-grown $Cr_{1+\delta}Te_2/Bi_2Te_3$ 2D-ferromagnet/topological insulator heterostructure

Nicholas Figueiredo-Prestes[1]
P. Tsipas[2], S. Krishnia[1], P. Pappas[2], J. Peiro[1], S. Fragkos[2], V. Zatko[1], A. Lintzeris[2,3], B. Dlubak[1], S. Chaitoglou[2], M. Heuken[3], N. Reyren[1], H. Jaffrès[1], P. Seneor[1], A. Dimoulas[2], and J.-M. George[1]
[1] Unité Mixte de Physique, CNRS, Thales, Université Paris-Saclay, 91767, Palaiseau, France
[2] *NCSR "Demokritos", Patr. Gregoriou E & 27 Neapoleos STR, 15341 Agia Paraskevi, GREECE*
[3] *Department of Physics, National Technical University of Athens, 15780, Athens, Greece*
nicholas.figueiredo@cnrs-thales.fr

In the last decade, spintronics research has ventured into the investigations of novel materials and highly engineered structures like Topological Insulators (TI) and artificial Rashba-Like systems [1,2]. Although these systems are predicted to allow advances in efficiency they also bring their own set of challenges such as interfacial quality and current shunting, for example. The discovery of two-dimensional ferromagnetic materials (2D-FM) brought about new perspectives to address these issues [3]. In the present work, we have studied epitaxially grown $Cr_{1+\delta}Te_2/Bi_2Te_3$ heterostructures [4]. $Cr_{1+\delta}Te_2$ is a quasi-2D ferromagnet where stacked Van der Waals (VdW) $CrTe_2$ trilayers have their VdW gaps partially filled by additional Cr atom. Bi_2Te_3 is a VdW topological insulator in which the fermi level crosses not only surface states but also the conduction band. We report, for the grown heterostructure, low temperature magnetization with Tc about 150 K and perpendicular anisotropy. We also report a puzzling magnetotranport result where the amplitudes of the Anomalous Hall Effect (AHE) curves inverts their signs at different temperatures below Tc. Furthermore, around the inversion temperature the AHE field profile exhibit peak-like features compatible with the Topological Hall Effect (THE) (see Fig. 1), which is generally attributed to skyrmion phases. Second Harmonic magnetotrasport techniques revealed large values of Field-like (FL) torques and FL to Damping-Like torque ratios. These both properties are compatible with an interfacial source for the spin current across the structure such as the Rashba and Topological surface states. Finally, current induced magnetization reversal experiments revealed a combination of SOT-compatible reversible switching and non-reversible thermally-induced domain nucleation.

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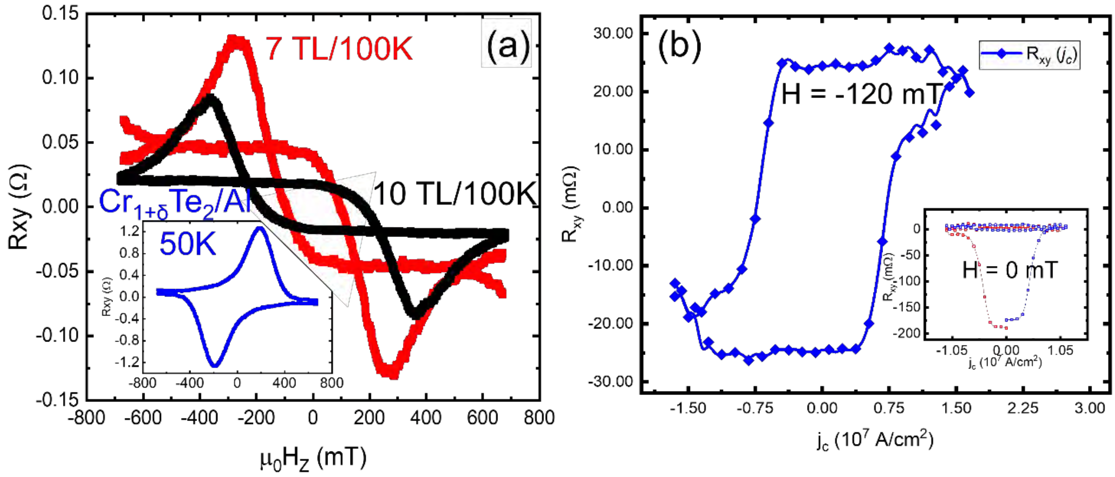

Figure 1: (a) AHE field profile for three different samples: $Cr_{1+\delta}Te_2$ covered Al at 50 K (in blue), $Cr_{1+\delta}Te_2$ (7 TL)/Bi_2Te_3 (10 nm) (in red), and $Cr_{1+\delta}Te_2$ (10 TL)/Bi_2Te_3 (10 nm) at 100 K (in black). (b) Current induced switching in at $Cr_{1+\delta}Te_2$ (10 TL)/Bi_2Te_3 140 K with an in-plane field of about 120 mT. The inset shows the same experiment with any applied field.

Quantum Anomalous Hall Edge Channels Survive up to the Curie Temperature

Kajetan M. Fijalkowski
Nan Liu, Pankaj Mandal, Steffen Schreyeck, Karl Brunner, Charles Gould, and Laurens W. Molenkamp
Faculty for Physics and Astronomy (EP3), Universität Würzburg, and Institute for Topological insulators (ITI), Am Hubland, D-97074 Würzburg, Germany
kfijalkowski@physik.uni-werzburg,de

The past couple of decades saw the rise of topology in condensed matter, which led to the discovery of various new quantum states of matter. One of the more prominent examples is the quantum anomalous Hall effect [1], first observed in Cr (as well as V)-doped $(Bi,Sb)_2Te_3$ material. This effect was quickly recognized as a promising platform for potential applications in quantum metrology [2] and for academic investigations of axion electrodynamics [3].

One of the biggest open questions surrounding the quantum anomalous Hall effect in Cr/V-doped $(Bi,Sb)_2Te_3$ is the temperature discrepancy between the thermal breakdown of quantized transport (around 100 mK) and the Curie temperature of bulk ferromagnetism (around 20 K). In the intermediate temperature range, while the material remains robustly ferromagnetic, the electronic transport is no longer quantized. Based on traditional Hall bar measurements it is impossible to rule out that the observed signals originate from the ordinary anomalous Hall effect from thermally activated bulk states, and in the absence of any edge channels. Since it is of paramount importance to increase the operational temperature of the quantum anomalous Hall effect, a natural first step is to verify that the edge channels indeed exist at higher temperatures.

Here, in order to address this question, we move away from a traditional Hall bar, and instead implement a novel multi-terminal Corbino geometry. By physically separating the bulk and edge state current paths, this allows us to investigate a variety of non-local measurement configurations at higher temperatures, where the presence of edge channels produces large unambiguous signals. Indeed our results suggest that the quantum anomalous Hall edge channels survive all the way up to the bulk Curie temperature, and that thermally activated bulk conductance is solely responsible for the quantization breakdown, by electrically shorting the edges of the sample [4]. Our results offer important insights on the nature of the topological protection of these edge channels and provide an encouraging sign for potential applications.

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Waveguides and sources for topological phononics

Omar Florez[1]
G. Madiot[1], M. Poblet[1], R.C. Ng[1], G. Arregui[2], M. Albrechtsen[2], S. Stobbe[2], Sara Pourjamal[3], J. Ahopelto[3] and C.M. Sotomayor Torres[1,4]
[1] ICN2, Campus de la UAB, Bellaterra, 08193 Barcelona, Spain
[2] DTU Center for Nanophotonics, Ørsteds Plads 345A, DK-2800 Kgs. Lyngby, Denmark
[3] VTT Technical Research Centre of Finland Ltd, P.O. Box 1000, Espoo, VTT FI-02044, Finland
[4] Institució Catalana de Recerca i Estudis Avançats, 08010 Barcelona, Spain

omar.florez@icn2.cat

In the quest to realize topological phononic waveguides, we have simulated Quantum Valley Hall waveguides structures using COMSOL building on a recent realization of a mechanical gap at 6.5 GHz [1]. Currently, we are targeting a gap also centred in the GHz range which would sustain an isolated non-trivial topological phononic mode (see simulations in figure 1).
Samples have been designed and recently fabricated in SOI wafers and Brillouin light scattering experiments are in progress. Since the main objective is to integrate these waveguides in a phononic circuit, we have tested concepts of phonon excitation and detection [2] showing that coherent acoustic phonon generation can be achieved using an optomechanical interface [3] (see figure 2). For validation in the low GHz range, an independent test using Laser Doppler Vibrometry is being developed which will allow a comprehensive characterization of out-of-plane acoustic waves.

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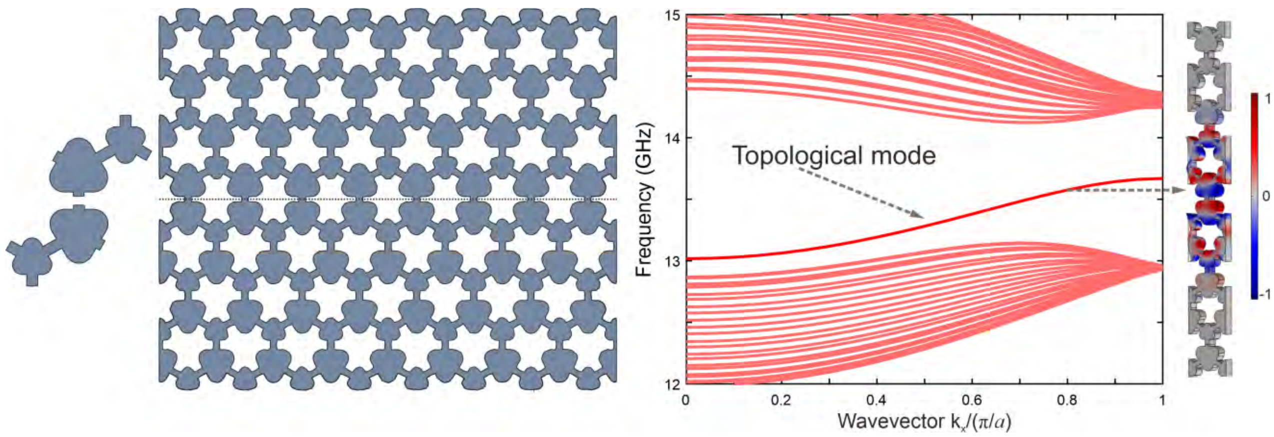

Figure 1: Waveguide modes simulation. Left: Geometry of the topological crystal based on the valley Hall approach. Right: Phononic dispersion relation showing the isolated topological mode inside the gap.

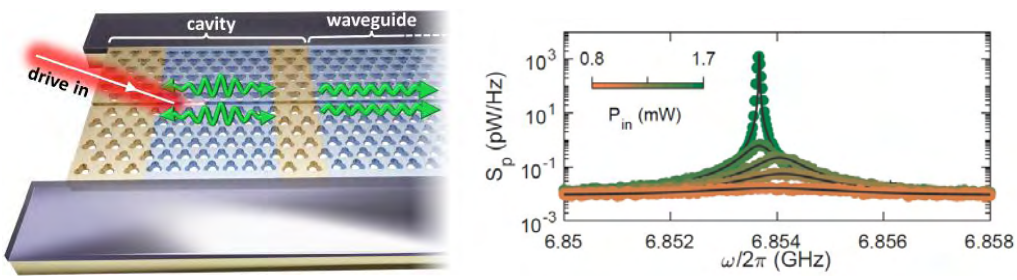

Figure 2: A phonon source. Left: Optomechanical device based on a phononic crystal design. Right: phonon emission of a coherent phonon flow near 7 GHz [3]

Evidence for intrinsic magnetic scatterers in the topological semimetal $(Bi_2)_5(Bi_2Se_3)_7$

Valentin Fonck[1]
Pascal Gehring[1,2]
Clement Merckling[2,3]
Ruishen Meng[4]
Bart Raes[5]
Michel Houssa[4,2]
Joris Van de Vondel[5]
Stefan De Gendt[2,6]
1. IMCN/NAPS, Université Catholique de Louvain (UCLouvain), 1348 Louvain-la-Neuve, Belgium
2. IMEC, Kapeldreef 75, 3001 Leuven, Belgium
3. KU Leuven, Departement of Material Engineering, Kasteelpark Arenberg 44, 3001 Leuven, Belgium
4. Semiconductor Physics Laboratory, Department of Physics and Astronomy, KU Leuven, Celestijnenlaan 200D, B-3001 Leuven, Belgium
5. Quantum Solid-State Physics, Department of Physics and Astronomy, KU Leuven, Celestijnenlaan 200D, B-3001, Leuven, Belgium
6. KU Leuven, Department of Chemistry, Celestijnenlaan 200f, 3001 Leuven, Belgium
valentin.fonck@uclouvain.be

We report the synthesis and characterization of high-quality thin films of the topological semimetal $(Bi_2)_5(Bi_2Se_3)_7$. [1,2] Cryogenic magneto-transport experiments reveal strong metallic character and spin-orbit coupling in the films. By studying the temperature dependence of the electrical resistance of the topological semimetal, we observe a pronounced Kondo effect which points towards the presence of magnetic scatterers. [3,4] With the aid of density functional theory calculations we identify Bi vacancies as intrinsic magnetic scatterers in this topological semimetal.

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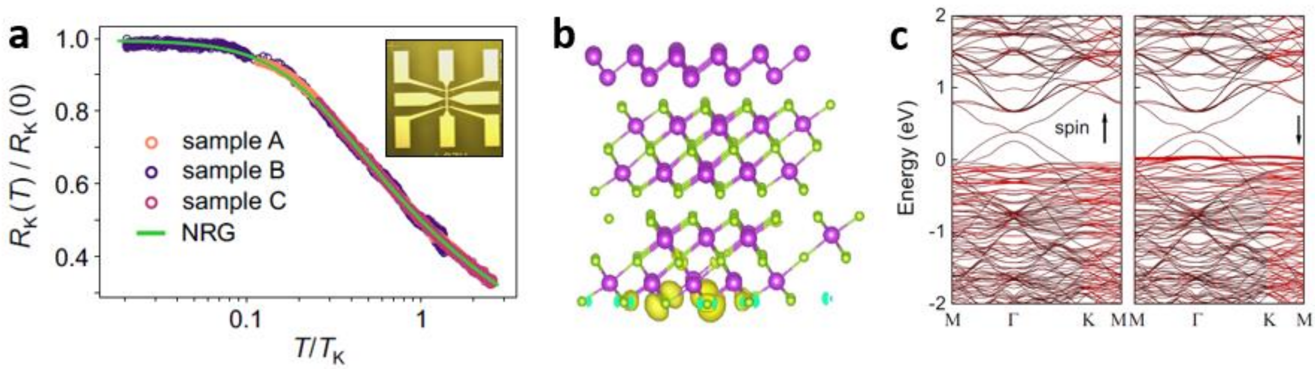

Figure 1: (**a**) Normalized Kondo resistivity as a function of temperature (normalized by the Kondo temperature) for samples A, B and C (open circles) together with the universal functional predicted by NRG calculations (green line). [4] Example device as inset image. (**b**) Atomic structure of a Bi2/(Bi2Se3)2 stack with a Bi vacancy in the bottom Bi2Se3 layer. The band-decomposed charge densities in the energy range between -0.02 and 0.03 eV are also shown in yellow. (**c**) Projected band structures of the system, for spin-up and spin-down electrons. The red lines correspond to the contributions from the 4p-Se orbitals around the Bi vacancy.

Dirac semimetals in group IV transition metal ditellurides

Sotirios Fragkos [1,2]
E. Xenogiannopoulou[1], P. Tsipas[1], P. Pappas[1], E. Symeonidou[1], Y. Panayiotatos[2], P. Le Fèvre[3], A. Dimoulas[1]
[1] *NCSR "Demokritos", Institute of Nanoscience and Nanotechnology, 15341 Athens, Greece*
[2] *Department of Mechanical Engineering, University of West Attica, 12241 Athens, Greece*
[3] *Synchrotron SOLEIL, L'Orme des Merisiers, 91192 Gif-sur-Yvette, France*
s.fragkos@inn.demokritos.gr

Topological semimetals are hosts of interesting types of low-energy quasiparticles such as type-I and type-II Dirac and Weyl fermions. Yet a type-III [1-3] emerges as a theoretical possibility exactly at the border between type-I and II (Fig. 1a), characterized by a line-like Fermi surface and a flat energy dispersion along one direction in the Brillouin Zone. We theoretically predict that 1T-$HfTe_2$ and 1T-$ZrTe_2$ transition metal dichalcogenides are type-I and type-II Dirac semimetals (Fig. 1b,c), respectively. By alloying the two materials, a new $Hf_xZr_{x-1}Te_2$ alloy with type-III Dirac cone emerges at x=0.2 [4] (Fig. 1d). We also provide experimental evidence that by using MBE, $HfTe_2$ [5], $ZrTe_2$ [6] and $Hf_{0.2}Zr_{0.8}Te_2$ [4] can be grown on InAs(111) substrates, and by using in-situ ARPES, that the Dirac point lies at -or very close to- the Fermi level (Fig. 1e). Our synchrotron ARPES results show that the Dirac cone remains unaltered as the photon energy is varied, indicating that there is no energy dispersion along the k_z axis, as expected for type-III Dirac semimetal.

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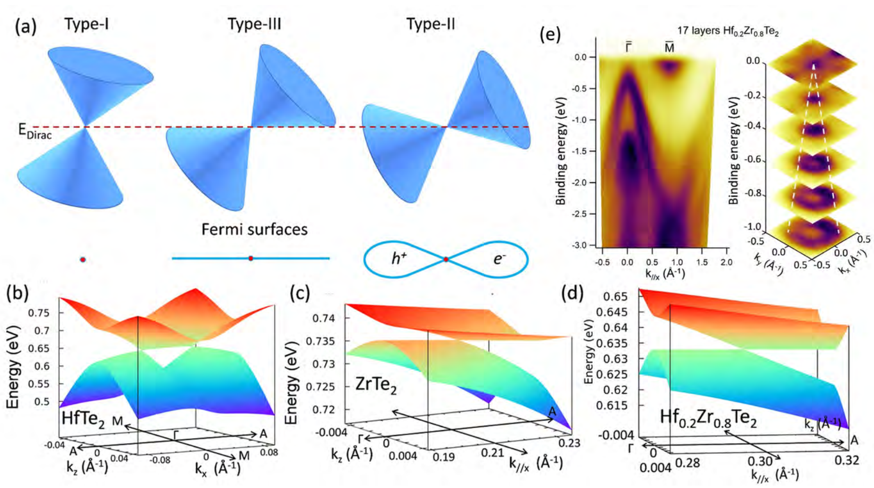

Figure 1: (a) Schematic illustration of the different types of DSMs. (b-d) show the energy dispersion in the k_z–k_x plane near the crossings for $HfTe_2$, $ZrTe_2$ and $Hf_{0.2}Zr_{0.8}Te_2$, respectively. (e) . ARPES spectra and k_x–k_y energy contour plots at different binding energies of 17 layers $Hf_{0.2}Zr_{0.8}Te_2$ along the ΓM direction of the BZ.

All-electrical spin control in low-symmetry materials

Jose H. Garcia
Jose H. Garcia, Jinxuan You, Mónica García-Mota, Peter Koval, Pablo Ordejón, Ramón Cuadrado, Matthieu J. Verstraete, Zeila Zanolli, and Stephan Roche
Catalan Institute of Nanoscience and Nanotechnology - ICN2, (CSIC and BIST), Campus UAB, Bellaterra, 08193 Barcelona, Spain
Simune Atomistics S.L., Tolosa Hiribidea, 76, 20018 Donostia-San Sebastian, Spain
Department of Materials Science, Universitat Autónoma de Barcelona, Cerdanyola del Vallès, 08193 Bellaterra, Spain
nanomat/QMAT/CESAM and European Theoretical Spectroscopy Facility Universite de Liege, Allee du 6 Aout 19 (B5a), 4000 Liege, Belgium
Dept. of Chemistry, Debye Institute for Nanomaterials Science, and ETSF, Utrecht University, The Netherlands
ICREA–Institució Catalana de Recerca i Estudis Avançats, 08010 Barcelona, Spain
Josehugo.garcia@icn2.cat

The existence of the quantum spin Hall (QSH) insulator has boosted opportunities for spintronics and quantum metrology, given the ability of topologically protected states to convey spin information over long distances at ultralow dissipation rate. QSH is a manifestation of strong spin-orbit coupling. However, even in time-reversal symmetric systems, the lack of a spin conservation axis in QSH insulators allows backscattering effects for edge states, limiting their ballistic transport. In some situations, the emergence of a phenomenon known as persistent spin texture (PST) enforces spin conservation and favors long spin lifetimes even in the presence chemical disorder and structural imperfections. Such an effect is deeply rooted in the underlying symmetries of the system and opens promising prospects for spintronics when combined with the manifestation of dissipationless chiral edge states. The recent prediction and experimental observations of a PST-driven canted quantum spin Hall effect in low-symmetry monolayer WTe_2 provide new ingredient for the use of topological materials in spintronic applications.

This work reports on the possibility of a fully controllable variation of up to 90 degrees rotation of the spin polarization of chiral edge-states, dictating the canted QSH effect, while preserving spin conservation. By combining density functional theory (DFT) with tight-binding methods and quantum transport simulations, we show that the emerging PST can be continuously varied from in-plane to out-of-plane under electric fields below 0.1 V/nm, making this effect experimentally accessible. The experimental confirmation of such fully electrically tunable spin-polarized topological currents would establish a new milestone towards replacing magnetic components in spintronic devices and all-electric spin circuit architectures, as well as optimized resistance

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Record high $T_c \sim 570$ K and saturation magnetization enhancement in 2D $Fe_{5-\delta}GeTe_2$ / Bi_2Te_3 heterostructures grown by MBE

E. Georgopoulou-Kotsaki[a,b]
P. Pappas[a], A. Lintzeris[a,c], P. Tsipas[a], S. Fragkos[a,d], A. Markou[e], C. Felser[e], E. Longo[f], M. Fanciulli[g], R. Mantovan[f], F. Mahfouzi[h], N. Kioussis[h], A. Dimoulas[a]
[a]*NCSR Demokritos, 15341, Athens, Greece.*
[b]*Department of Physics, National and Kapodistrian University of Athens, 15784, Athens, Greece.*
[c]*Department of Physics, National Technical University of Athens, 15780, Athens, Greece.*
[d]*Department of Mechanical Engineering, University of West Attica, 12241, Athens, Greece.*
[e]*Max Planck Institute for Chemical Physics of Solids, 01187, Dresden, Germany.*
[f]*CNR-IMM, 20864 Agrate Brianza, Italy.*
[g]*Department of Material Science, University of Milano Bicocca, 20125, Milan, Italy.*
[h]*Department of Physics and Astronomy, California State University, CA 91330-8268 Northridge, USA.*
e.georgopoulou@inn.demokritos.gr

Two-dimensional (2D) van der Waals (vdW) metallic ferromagnets Fe_xGeTe_2 (x = 3 – 5) are promising candidates for spintronics [1], [2] as well as for fundamental physics studies since they are found to possess skyrmions and topological nodal lines with high anomalous Hall current [3]. Thin films of Fe_5GeTe_2 have been grown by Molecular Beam Epitaxy (MBE) with a T_c close to room temperature (RT) [4]. In the present work [5], ferromagnetic $Fe_{5-\delta}GeTe_2$/Bi_2Te_3 topological insulator (TI) heterostructures were grown by MBE on insulating substrates and they have been compared to bare $Fe_{5-\delta}GeTe_2$ films. In situ RHEED and ex-situ XRD confirm the x = 5-δ phase indicating good epitaxial quality of the films. The magnetic properties were investigated using Magneto-optical Kerr (MOKE) microscopy/magnetometry and SQUID magnetometry. The main result is that the growth of Bi_2Te_3 TI on $Fe_{5-\delta}GeTe_2$ films significantly enhances both, the in-plane saturation magnetization and the T_c well above room temperature reaching a record value of 570 K. First principles calculations, indicate that the proximity of Bi_2Te_3 to $Fe_{5-\delta}GeTe_2$ increases the density of states at the Fermi level and/or induces tensile strain which stabilizes a high magnetic moment phase which could explain the observed enhancement of ferromagnetism. In ferromagnetic resonance measurements, a large spin mixing conductance is observed in $Fe_{5-\delta}GeTe_2$/Bi_2Te_3 system, suggesting that this heterostructure could be suitable to exploit spin to charge conversion in spintronic devices at room temperature.
We acknowledge EU funding from project H2020 FET PROAC SKYTOP-824123.

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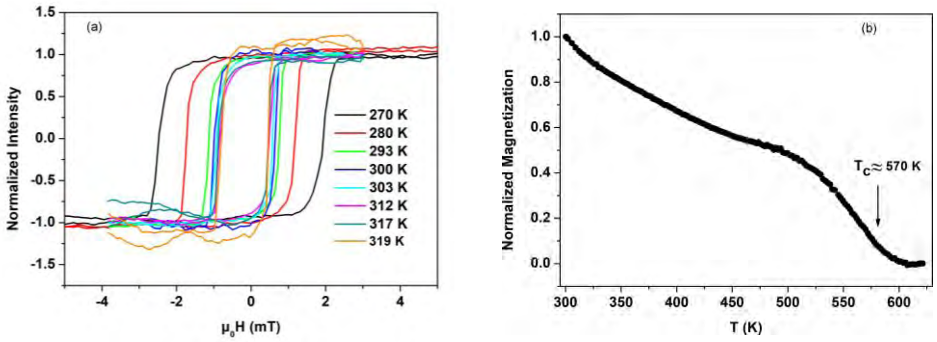

Figure 1: (a) MOKE hysteresis loops and (b) Temperature dependence of the Normalized magnetization for $Fe_{5-\delta}GeTe_2$/Bi_2Te_3 heterostructures

Nonlocality of local Andreev conductances as a probe for topological Majorana wires

Poliana H. Penteado1
Rodrigo A. Dourado1
J. Carlos Egues1,2
Instituto de Física de São Carlos, Universidade de São Paulo, 13560-970 São Carlos, São Paulo, Brazil
Department of Physics, University of Basel, CH-4056, Basel, Switzerland
polianahp@gmail.com

Identifying topological phases via zero-bias conductance peaks in superconducting Majorana wires is not trivial. Here we propose a method of distinguishing trivial and topological phases in realistic three-terminal proximitized superconducting (disordered) nanowires coupled to normal leads by exploiting a peculiar nonlocality of the Majorana-mediated local Andreev reflection (LAR). By combining the scattering matrix formalism and the Green's function approach, we calculate the conductance and the local density of states (LDOS). We show that when left and right leads are asymmetrically coupled, i.e., when the ratio Γ_L/Γ_R is increased, the local conductances G_{LL} and G_{RR} are equally suppressed in the topological phase. In the trivial phase, on the other hand, G_{LL} is essentially constant while G_{RR} is exponentially suppressed. These distinct behaviors can be understood by analyzing the LDOS; a zero-energy gap develops at the left end of the wire as the asymmetry in the couplings increases. In addition, the local conductances show the exact same dependence on the lead-asymmetry in the presence of Majorana zero modes (MZMs), in stark contrast to trivial subgap states arising from inhomogeneities in the wire. Our work shows a distinctive signature of the Majorana nonlocality in terms of nonlocal effects on LAR. Finally we propose a protocol for identifying zero-bias peaks signaling topological phases that rely on only local conductance measurements [1].

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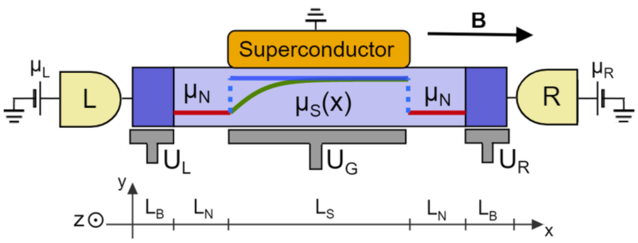

Figure 1: Semiconductor-superconductor Rashba nanowire with a magnetic field B along the x axis coupled to left (L) and right (R) normal leads, via the gates U_L and U_R, respectively.

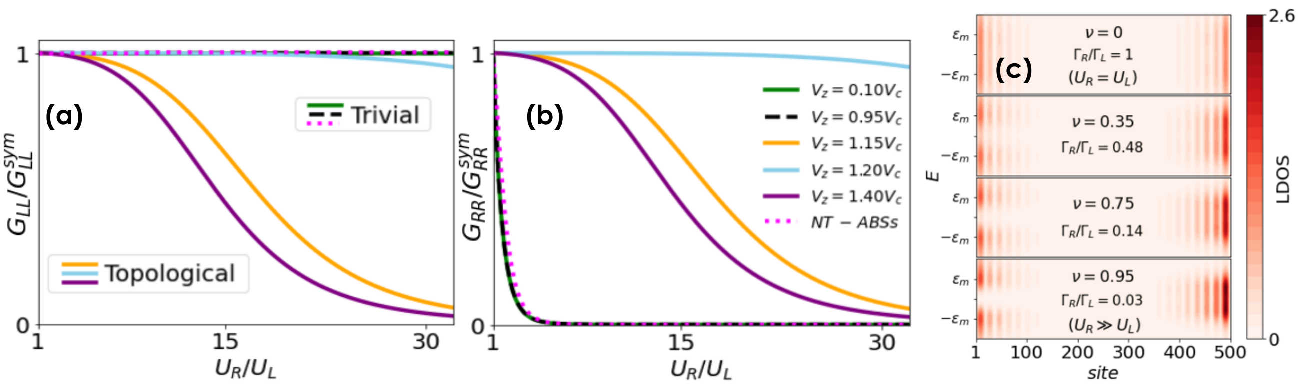

Figure 2: (a) G_{LL} and (b) G_{RR} as functions of UR/UL. (c) LDOS color map for different values of the asymmetry ν.

Terahertz magneto-photocurrents in the topological insulator Bi_2Se_3

Chihun In[1,2]
Genaro Bierhance[1,2], Tom Seifert[1,2], Deepti Jain[3], Seongshik Oh[3], and Tobias Kampfrath[1,2]
[1]*Department of Physics, Freie Universität Berlin, 14195 Berlin, Germany*
[2]*Department of Physical Chemistry, Fritz Haber Institute of the Max Planck Society, 14195 Berlin, Germany*
[3]*Department of Physics & Astronomy, Rutgers, The State University of New Jersey, Piscataway, New Jersey 08854, USA*
tobias.kampfrath@fu-berlin.de

Femtosecond laser excitation can drive ultrafast photocurrents in topological insulators (TIs) such as Bi_2Se_3 (Fig. 1a). The photocurrent can be monitored by detection the terahertz (THz) radiation it emits [1], thereby providing insights into the current generation and relaxation [1]. Application of a static magnetic field *B* was reported to modify the photocurrent response on nanosecond time scales [2].

Here, we report THz emission from 30-quintuple-layers (QL) of Bi_2Se_3 thin films by applying a field of $|B| = 0.3$ T parallel to the film plane (Fig. 1a). Figure 2b shows that the *B*-induced THz photocurrent signal ΔS_B and the residual THz signal $S(0)$ for $B = 0$ T exhibit different THz waveforms. In addition, we observe a strong reduction of the ΔS_B amplitude as an increasing fraction x of bismuth is substituted by indium (Fig. 1c). According to ref. [3-5], an increase of x reduces the spin-orbit coupling strength of $(Bi_{1-x}In_x)_2Se_3$ and eventually removes the Dirac surface state at a critical concentration of $x \approx 0.07$. Therefore, the suppressed ΔS_B signal of $(Bi_{1-x}In_x)_2Se_3$ for $x > 0.07$ (Fig. 1c) suggests that the Dirac surface state and the spin-momentum locking are critical to the emergence of the observed THz magneto-photocurrent. The time-dependence of the photocurrent will be extracted, and possible interpretations discussed.

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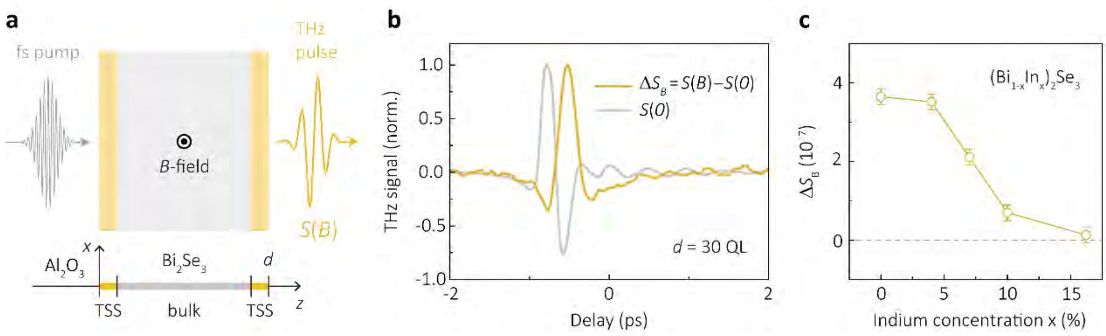

Figure 1: (a) THz emission spectroscopy of Bi_2Se_3 thin films with thickness d. The static magnetic field B is applied parallel to the film plane. A femtosecond (fs) pump pulse is incident from the Al_2O_3 substrate and triggers a photocurrent that gives rise to the emission of a THz electromagnetic pulse. (b) Waveforms of the *B*-induced THz signal ΔS_B and the residual THz signal $S(0)$, normalized to their maxima. (c) Peak values of ΔS_B of $(Bi_{1-x}In_x)_2Se_3$ as a function of the indium concentration x.

(111) $Pb_{1-x}Sn_xSe$ TCI epilayers across band inversion point probed by magnetotransport and spin-resolved ARPES

Aleksandr Kazakov,[1] W. Brzezicki,[1,2] T. Hyart,[1,3] B. Turowski,[1] W. Zaleszczyk,[4] R. Rudniewski,[4] T. Sobol,[5] E. Partyka-Jankowska,[5] J. Polaczyński,[1] J.Z. Domagała,[4] M. Aleszkiewicz,[4] Z. Adamus,[4] O. Caha,[6] A. Varykhalov,[7] G. Springholz,[8] T. Wojciechowski,[1] M. Szczepanik,[5] V. Volobuev,[1,9] T. Wojtowicz,[1] T. Dietl[1,10]

[1]International Research Centre MagTop, Institute of Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, PL-02668 Warsaw, Poland, [2]Institute of Theoretical Physics, Jagiellonian University, ul. S. Łojasiewicza 11, PL-30348 Kraków, Poland, [3]Department of Applied Physics, Aalto University, FI-00076 Aalto, Espoo, Finland, [4]Institute of Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, PL-02668 Warsaw, Poland, [5]National Synchrotron Radiation Centre SOLARIS, Jagiellonian University, Czerwone Maki 98, Kraków PL- 30392, Poland, [6]Department of Condensed Matter Physics, Faculty of Science, Masaryk University, Kotlá˘rská 2, Cz-611 37 Brno, Czech Republic, [7]Helmholtz-Zentrum Berlin für Materialien und Energie, Albert-Einstein Strasse 15, D-12489 Berlin, Germany, [8]Institut für Halbleiter- und Festkörperphysik, Johannes Kepler University, Altenbergerstrasse 69, A-4040 Linz, Austria, [9]National Technical University "KhPI", Kyrpychova Str. 2, 61002 Kharkiv, Ukraine, [10]WPI Advanced Institute for Materials Research, Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan

kazakov@magtop.ifpan.edu.pl

Topological surface states (TSSs) of 3D topological insulators have a linear Dirac dispersion and are suitable for spintronic applications due to spin-momentum locking. Topological crystalline insulators (TCIs) based on narrow-gap IV-VI lead-tin chalcogenide semiconductors also have these peculiar properties. In these compounds, gap inversion can be induced by both temperature changes and changes in tin content. Here we studied TCI $Pb_{1-x}Sn_xSe$ epilayers grown by molecular beam epitaxy in the (111) orientation. By varying the Sn content we investigated the evolution of their magnetotransport properties and spin-resolved photoemission (SR-ARPES) spectra in the band inversion region. The high surface quality of the obtained samples was confirmed by RHEED and AFM. The Sn content was determined by XRD and EDX-SEM. The samples with compositions corresponding to trivial and topological phases were investigated and similar properties were found in both phases. Although ARPES measurements proved that the surface gap closes after the topological transition is induced, weak anti-localization (WAL) [1] and spin texture in the reciprocal space [2] remain unchanged. SR-ARPES measurements indicated 30% spin-polarization for the in-plane spin component in both phases. Behaviour of magnetoresistance showed that WAL effect depends on the symmetries present in the system, rather than on topology. These results agree with the theoretical calculations predicting π Berry phase for both trivial and topological phases, and with the importance of the symmetries present. The results pave the way for the application of surface states of not only topological but also trivial IV-VI semiconductors in spin-charge conversion devices.

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Proximity effects in graphene on alloyed transition metal dichalcogenides

Zahra Khatibi
Stephen Power
School of Physics, Trinity College Dublin, Dublin 2, Ireland
School of Physical Sciences, Dublin City University, Dublin 9, Ireland
khatibiz@tcd.ie

Stacked heterostructures of graphene and transition metal dichalcogenides (TMDs) are particularly interesting for spin- and valleytronics since spin-orbit coupling (SOC) can be induced in the graphene layer by proximity effects with a strong valley dependence [1]. The induced proximity SOC, and associated imprinted spin-valley locking, enable experimentally verified spin-charge conversion and anisotropic spin relaxation effects that are absent in pristine graphene [2-3]. Recent high precision experiments based on currently available water-assisted CVD technique reveal composition-dependent band alignments in alloyed TMD lateral heterostructures with homogeneous intradomain composition [4]. Thus, in graphene/TMD heterostructures the nature and strength of the induced SOC depends on the composition of the underlying TMD layer. In this study we investigate the proximity induced SOC in graphene/TMD heterostructures by deliberate defecting of the TMD layer [5]. We analytically study simple alloyed $G/W_{1-x}Mo_xSe2$ heterostructures with diverse concentrations (x) and geometrical distribution of defects in the TMD layer. Utilizing density functional theory-computed electronic dispersions, spin textures, and an effective medium model, we evaluate the role of locally perturbed SOC on spin- and electronic signatures. We use the gained microscopic insight via tight-binding model to further examine the impact of defects in larger and more realistic heterostructures. We find that despite some dramatic perturbation of local SOC for individual defects, the low energy spin- and electronic behaviour yet follows the effective medium model. Furthermore, we demonstrate that the topological state of such alloyed systems can be feasibly tuned by controlling this ratio.

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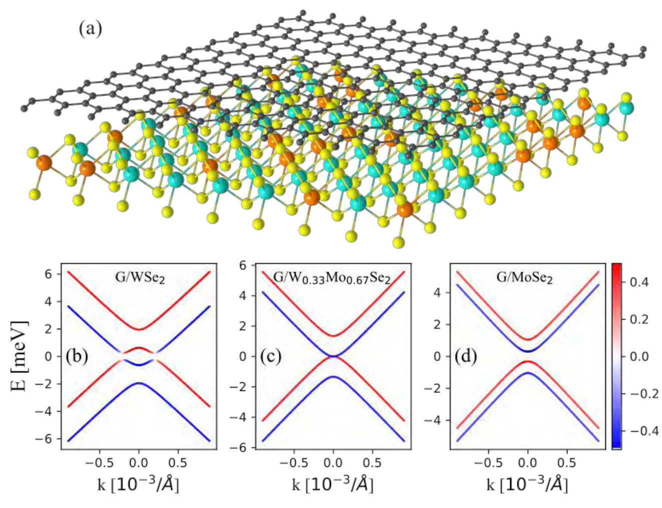

Figure 1: (a) Schematic representation of a composite graphene/TMDC heterostructure. [(b)–(d)] The proximity-induced band structure and topology transition for different TMDC layers.

Engineering spin-orbit torques for efficient skyrmions dynamics

Sachin Krishnia[1]
Yanis Sassi[1], Dédalo Sanz-Hernández[1], Nicolas Sebe[1], Sophie Collin[1], Karim Bouzehouane[1], J.-M George[1], Henri Jaffres[1], Albert Fert[1], Nicolas Reyren[1], Vincent Cros[1]
[1]*Unité Mixte de Physique, CNRS, Thales, Université Paris-Saclay, Palaiseau, France*
vincent.cros@cnrs-thales.fr; sachin.krishnia@cnrs-thales.fr

Magnetic skyrmions have been identified as extremely promising candidates for future spintronic applications and for fundamental interest [1]. In order to improve skyrmion dynamics via spin-orbit torques (SOT), numerous efforts have been made in recent years albeit with a restricted velocity due to pining and edge effect. In this study, we investigate the role of light element interface on the SOTs to improve the skyrmion dynamics in Co/Pt-based magnetic multilayers [2]. First, we quantify the amplitude of the damping-like and field-like SOT components in Pt|Co|X based multilayers, with X= Al, Ir, Pt and Cu (Fig.1a). We observe significant increase of the damping-like torque with Al due to formation of Rashba like interface. The direct consequence of the enhanced torques can be observed in the skyrmion motion in the Pt|Co|Al based skyrmionics heterostructures (Fig.1b) where the mobility increases by a factor four. Then, we investigate the behaviour of the skyrmions in different tracks using MOKE microscopy where we observe a cancellation of the skyrmion Hall angle especially at the edges of the tracks. We also underline their strong resilience to potential defects, for eg. their tendency of avoiding the notches along the edges during their motion. We further observe that the skyrmions are guided along the domains inside track due to repulsion from the DWs. Ultimately, we observe that there is a change in skyrmion velocity as a function of position in rounded geometries.
This work is supported by the Horizon2020 Research Framework Programme of the European Commission under Grant No. 824123 (SKYTOP). We also acknowledge FLAG-ERA SographMEM (ANR-15-GRFL-0005) and DARPA TEE program grant (MIPR#HR0011831554), for their financial support.

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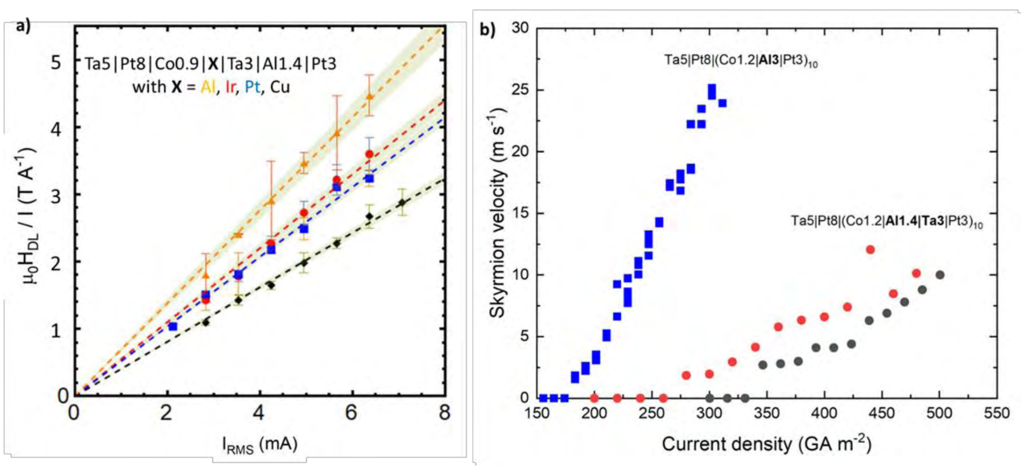

Figure 1: a) HDL measurement for Ta|Pt|Co|X|Ta|Al|Pt with (X=Al, Ir, Pt & Cu) b) Skyrmion velocity as a function of the current density for (Pt|Co|Al|Pt)10 and (Pt|Co|Al|Ta|Pt)10 (for two different track width).

Ferromagnetic resonance for spectroscopic investigation of topological surface states

Matthias Kronseder[1]

Laura Pietanesi[2], Thomas Mayer[1], Magdalena Marganska[1], Michael Barth[1], Lin Chen[2], Ji Zou[3], Rebeca Diaz-Pardo[2], Dhavala Suri[2], Adrian Weindl[1], Alexander Liebig[1], Florian Schmid[1], Franz J. Gießibl[1], Yaroslav Tserkovnyak[3], Christian H. Back[2]

1. Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany

2. Department of Physics, Technical University of Munich, 85748 Garching, Germany

3. Department of Physics and Astronomy, University of California, Los Angeles, California 90095, USA

Matthias.kronseder@ur.de

In most cases, the electronic band structure of a system can only be studied on clean surfaces, e.g., with angle-resolved photoemission electron spectroscopy or scanning tunnelling spectroscopy. Moreover, most applications depend on the interplay between different materials, so the interface has become the crucial factor. We present a spectroscopic tool to study the band structure of an interface, here in the case of a heterostructure comprising topological insulators and a ferromagnetic layer. Since the large spin-to-charge conversion in this hybrid structure might become relevant for future applications [1-2], knowledge of the band structure at the interface of a topological insulator is of particular interest. We use a single ferromagnetic layer, Fig. 1 a), as source and sensor for the angular momentum transferred into an adjacent TI-layer via the spin-pumping mechanism. The dissipation of the angular momentum is based on the spin-to-charge conversion in the topological surface state (TSS), Fig. 1 b). By application of a backgate to a compensated TI [3] fingerprints of the TSS are found, Fig. 1 c).

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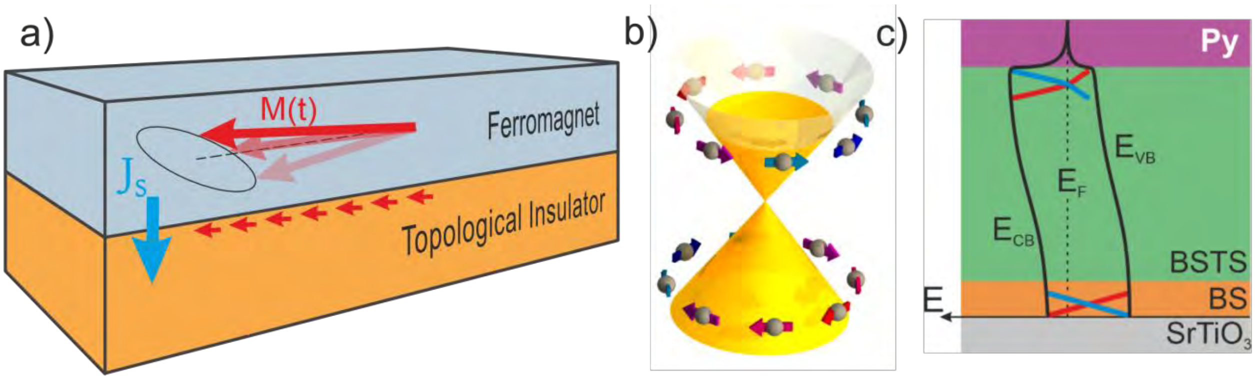

Figure 1: a) FMR-spin-pumping is the basis to investigate a topological surface state in b). The sample structure is a TI comprising a Bi_2Se_3 (BS) seed layer and a $(Bi_{1-x}Sb_x)_2(Te_{1-y}Se_y)_3$ (BSTS) layer, with a ferromagnetic permalloy (NiFe) layer on top. The substrate is $SrTiO_3(111)$, while E_{CB}, E_{VB} are the conduction and valence band energies, and E_F is the Fermi energy.

Majorana bound states in topological insulator nanowire devices

Henry F. Legg
Daniel Loss, Jelena Klinovaja
Department of Physics, University of Basel
henry.legg@unibas.ch

I will consider devices made from three-dimensional topological insulator (TI) nanowires. I show that a non-uniform chemical potential across the cross-section of the nanowire lifts the degeneracy between two one-dimensional surface state subbands. Such a nonuniformity in chemical potential can be induced, for example, by gating [1,3] or the induced potential at the interface to a superconductor [2]. A magnetic field parallel to the nanowire breaks time-reversal symmetry and, primarily due to orbital effects, lifts the Kramers degeneracy at zero momentum. As a result, when brought into proximity with an s-wave superconductor, Majorana bound states (MBSs), localised at the ends of the TI nanowire, emerge and are present for an exceptionally large region of parameter space in realistic systems[1,2]. Finally, I will show how this phase space can be dramatically enhanced further in a setup where the TI nanowire forms part of a planar Josephson junction [4].

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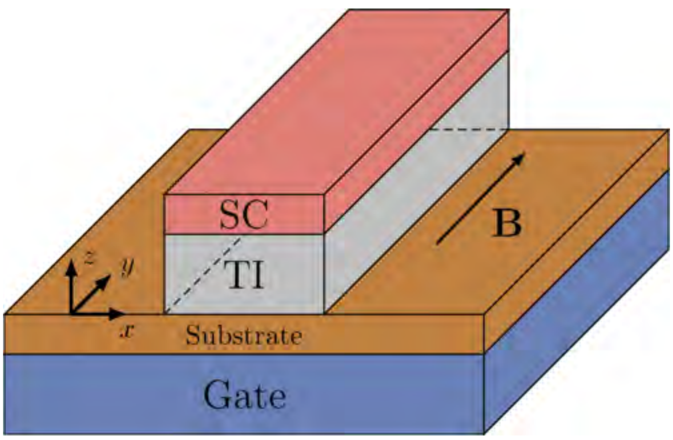

Figure 1: A schematic of a topological insulator nanowire devices.

Spin-momentum locking and spin-charge conversion in ultra-thin epitaxial $Bi_{1-x}Sb_x$ topological insulator

Aristide Lemaître[4]
E. Rongione[1,2], L. Baringthon[1,3,4], D. She[1,3,4], G. Patriarche[4], R. Lebrun[1], M. Morassi[4], N. Reyren[1], M. Mičica[2], J. Mangeney[2], J. Tignon[2], F. Bertran[3], S. Dhillon[2,5], P. Le Fèvre[3], H. Jaffrès[1,5] and J.-M. George[1]
1 - Unité Mixte de Physique, CNRS, Thales, Université Paris-Saclay, Palaiseau, France
2 - Laboratoire de Physique de l'Ecole Normale Supérieure, Paris, France
3 - Synchrotron SOLEIL, Saint-Aubin, France
4 - Université Paris-Saclay, CNRS, Centre de Nanosciences et de Nanotechnologies, France
aristide.lemaitre@c2n.upsaclay.fr

Very efficient spin current to charge current conversion is reported in ultra-thin topological BiSb films (down to 2.5 nm), where confinement effects become predominant. The films were epitaxially grown on Si [111] substrates [1]. The surface state robustness was first confirmed by ARPES, indicating no overlap between the topological 2D states of opposite surfaces. This is consistent with our tight-binding calculations, which indicate that the surface states are strongly confined, over a few bilayers, at the interface. Spin resolved ARPES reveals their spin-momentum locking (Fig. 1 left) [2].

The spin to charge conversion was then measured by ultra-short laser-pulse induced THz emission spectroscopy in Co/BiSb layers (Fig. 1 right). The conversion efficiency is larger than in our best optimized Co/Pt structure [2]. Our results show that the conversion mostly occurs, through the inverse Edelstein effect, in the surface states, with little or no contribution from bulk states. We attribute this result, in part, to the large bandgap increase (several hundred of meV) due to confinement in ultra-thin films.

These results indicate that ultra-thin BiSb films, although less investigated than the $(Bi,Sb)_2(Te,Se)_3$ family, are of great interest to spintronics applications.

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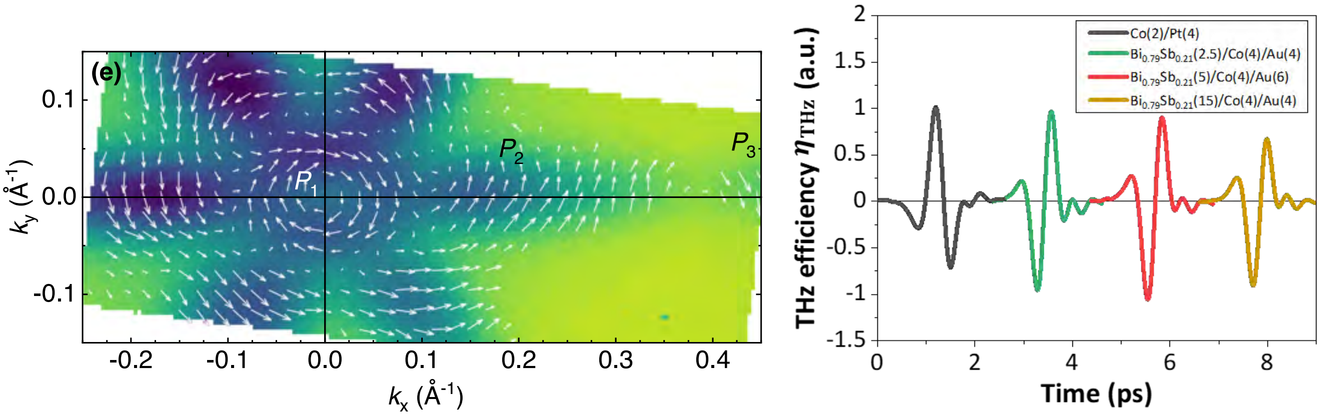

Figure 1: (left) Color map representing the measured ARPES intensity close to the Fermi energy of a 5 nm thick $Bi_{0.85}Sb_{0.15}$ film grown on Si [111]. The dark regions correspond to the surface state DOS. The arrows represent the measured spin polarization direction and amplitude at room temperature. (right) Time-resolved THz emission signal (corrected for absorption) from BiSb layers with thicknesses 2.5, 5 and 15 nm, after ultra-short laser-pulse induced demagnetization of an adjacent Co layer. This signal results from the spin current to charge current conversion. For comparison, the signal obtained from an optimized Co/Pt layer is given.

One-dimensional topological interface states: a novel approach for optical pressure sensors

Jakob Lindenthal[1,2]
Anton Widulla[1], Johannes Benduhn[1], Karl Leo[1,2]
TU Dresden, Institute of Applied Physics, Nöthnitzer Str. 61, Dresden, Germany
ct.qmat Würzburg-Dresden Cluster of Excellence/University of Würzburg, Sanderring 2, Würzburg, Germany
jakob.lindenthal@tu-dresden.de

The research field of nano-optics in connection with topological photonics has quickly evolved over the past decades. Topological architecture in the design of photonic crystals enables disorder-protected interface states at crystal interfaces[1]*. The present contribution explores topological interface states in the context of pressure-sensitive nano-optical resonators*[2].
A novel, highly versatile pressure sensor concept is demonstrated, utilizing Zak phase inversion around a shared bandgap in one-dimensional photonic crystals to generate a pressure-sensitive interface state (thin film stack shown in Fig. 1A*). The use of an organic absorber molecule together with a topologically optimised electric field alignment is shown to provide pathways to significant force sensitivity enhancement of such systems (*Fig. 1B*). In the context of optical microcavities and interface states, systems supporting coupled photonic states*[3] *or modes are demonstrated as a promising architecture to provide additional sensing information*[4]*. The presented pressure-sensitive photonic crystal system may serve as a building block to support the design of ultra-compact optoelectronic pressure sensors.*

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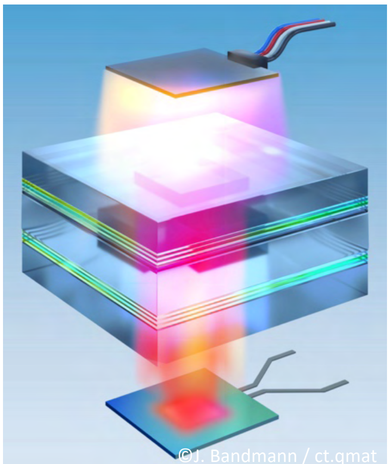

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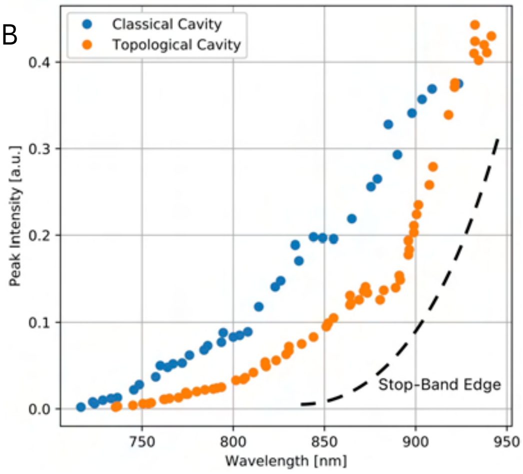

Figure 1: (A) Schematic illustration of a photonic crystal stack with a compressible cavity resonator. (B) Comparison of wavelength tuning in topological and trivial photonic crystal stacks under compression of the photonic crystal interface, steeper slope resulting from topology-induced enhanced absorption.

Large area MOCVD growth of Bi_2Te_3 on top of Sb_2Te_3 to shift the Fermi level close to the Dirac point

L. Locatelli [a,c]
P. Tsipas [b], A. Dimoulas [b], A. Lintzeris [b], E. Longo [a], M. Longo [d], R. Mantovan [a]
[a] *CNR-IMM, Unit of Agrate Brianza, 20864 Agrate Brianza (MB), Italy.*
[b] *National Centre for Scientific Research 'DEMOKRITOS', Patriarchou Grigoriou & Neapoleos 27 15310, Agia Paraskevi, Athens, Greece*
[c] *Department of Material Science, University of Milano Bicocca, 20125, Milan, Italy.*
[d] *CNR-IMM, Unit of Rome, 00133, Rome (RM), Italy*
lorenzo.locatelli@mdm.imm.cnr.it

Topological insulators (TIs) are attracting high interest for applications based on spin-charge interconversion mechanisms [1]. We have recently demonstrated the topological character of Sb_2Te_3 and Bi_2Te_3 TIs, as grown on top of 4'' Si(111) by Metal Organic Chemical Vapour Deposition (MOCVD) [2]. In particular, the existence of topological surface states (TSS) has been demonstrated on the basis of angle-resolved photoemission spectroscopy (ARPES) and magnetoelectrical measurements [2]. On the other hand, especially in the case of Bi_2Te_3, a relevant contribution from bulk states (BS) is still present at the Fermi level, which largely affects the overall electrical conduction of the TI. As reported in Refs. [3,4], the position of the Fermi level could be manipulated by growing heterostructures made of Sb_2Te_3 and Bi_2Te_3. With the aim of exploring such a possibility, we performed the MOCVD growth of Bi_2Te_3 on top of Sb_2Te_3, and the comparison of the surface band structures in Si/Bi_2Te_3 and Si/Sb_2Te_3/Bi_2Te_3, as imaged by ARPES, is displayed in Figure 1. Clearly, the Fermi level in the Sb_2Te_3/Bi_2Te_3 heterostructures shifts towards the valence band, Figure 1(b), thus not showing the relevant contribution from the BS, as in the single Bi_2Te_3 layer, Figure 1(a). In this work, we will report how such a Fermi-level engineering is reflected in the (magneto)transport properties of the Sb_2Te_3/Bi_2Te_3 heterostructure, by following the same methodology previously employed to analyze single TI layers, within the Hikami-Larkin-Nagaoka model [2]. In particular, we measured an α= - 0.5, which indicates the existence of an "ideal" TSS completely decoupled from the BS. We will also report on the first attempts in integrating ferromagnetic layers on top of Sb_2Te_3/Bi_2Te_3 heterostructures, with the aim of exploiting their TSS for spin-charge interconversion.

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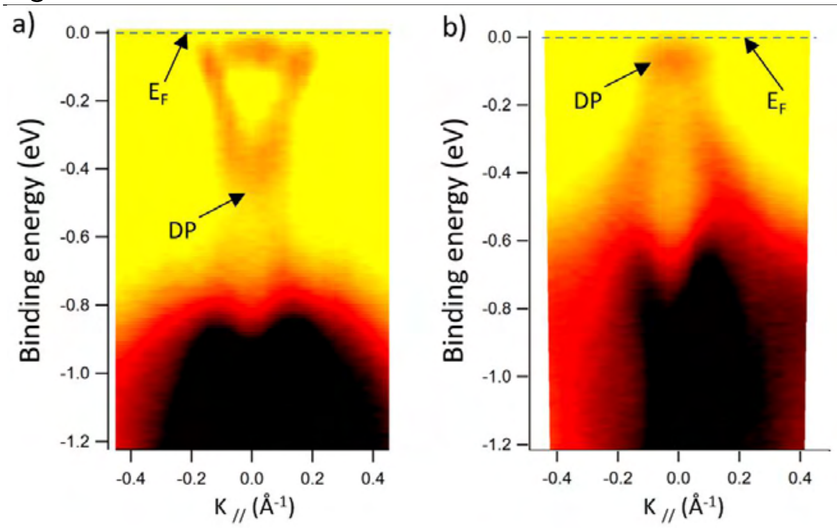

Figure 1: Comparison of the band structures observed by ARPES at the surface of (a) Si/Bi_2Te_3 and (b) Si/Sb_2Te_3/Bi_2Te_3.

Driving skyrmions with high mobility in synthetic ferrimagnets

Sougata Mallick[1]
Nicholas Figueiredo Prestes[1], Yanis Sassi[1], Nicolas Reyren[1], Karim Bouzehouane[1], Sachin Krishnia[1], Vincent Jeudy[2], André Thiaville[2], Thibaud Denneulin[3], Rafal E. Dunin-Borkowski[3], Vincent Cros[1], and Albert Fert[1]
[1]Unité Mixte de Physique, CNRS, Thales, Université Paris-Saclay, Palaiseau, France
[2]Laboratoire de Physique des Solides, Université Paris-Saclay, Orsay, France
[3]Forschungszentrum Jülich, ER-C for Microscopy and Spectroscopy with Electrons, Jülich, Germany
vincent.cros@cnrs-thales.fr; sougata.mallick@cnrs-thales.fr

Being at the same time, a direct signature of the topological nature of magnetic skyrmions and an issue for their implementation in renewed logic and memory devices, the so called skyrmion Hall effect (SkHE) has been the focus of many researches in the last few years [1]. In this context, investigation of ferrimagnetic systems in which two sublattices with opposing spin orientations can compensate each other to achieve behaviour similar to that of an antiferromagnet, are of interest thanks to the additional flexibility of tuning the properties by varying temperature, the individually detectable proportion of the constituting materials, etc. In this context, we focus on multilayers of Pt/Co/Tb by controlling the thickness of Co and Tb, as well as the numbers of repetition to obtain a signature of antiferromagnetic coupling between the Co and Tb moments. The comparison of skyrmion velocity in Co-Tb multilayers with different Tb thicknesses is shown in Fig. 1(a). We observed a significant enhancement of skyrmion velocity and decrease in the net magnetization as the Tb thickness is increased. In the best samples, we obtained velocity up-to ~400 m/s for skyrmions with diameter of 160 nm. The correlation between field-induced domain wall (DW) motion and current induced skyrmion motion with prediction of DW creep, depinning, and flow is demonstrated in Fig. 1(b). In conclusion, we show that with the control of ferrimagnetic ordering in Co-Tb multilayers by varying the Tb thicknesses, we can achieve high skyrmion mobility in *DW flow* regime with reduced SkHE. We acknowledge French ANR grant TOPSKY (ANR-17-CE24-0025), DARPA TEE program grant (MIPR#HR0011831554), FLAG-ERA SographMEM (ANR-15-GRFL-0005), for their financial support.

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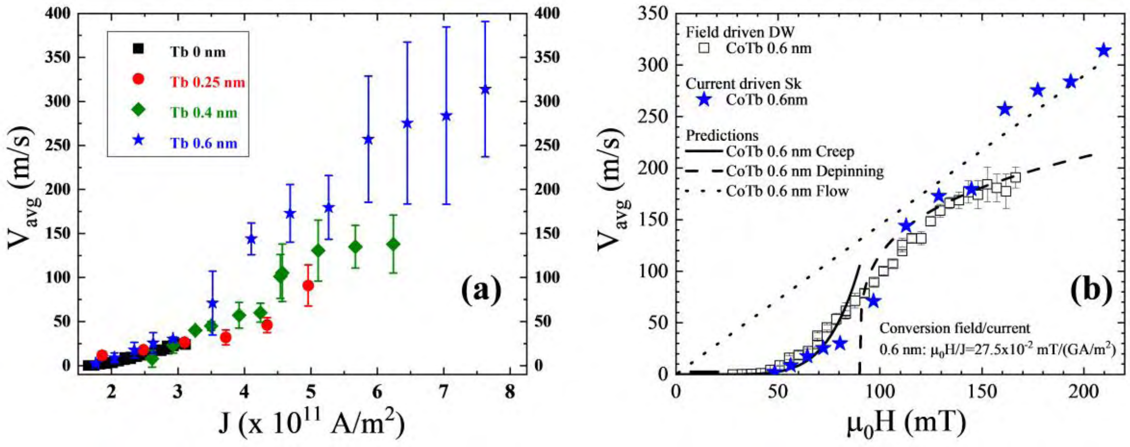

Figure 1: (a) Comparison of skyrmion velocity in Co-Tb multilayers with different Tb thicknesses. (b) Correlation between field-induced DW motion and current induced skyrmion motion with prediction of DW creep, depinning, and flow.

Development of large-area topological insulators on Silicon for spintronics

R. Mantovan[a]
E. Longo[a], L. Locatelli[a], M. Belli[a], M. Alia[a], M. Longo[b], Fanciulli[c], C. Wiemer[a]
[a] *CNR-IMM, Unit of Agrate Brianza, 20864 Agrate Brianza (MB), Italy.*
[b] *CNR-IMM, 00133 Rome, Italy*
[c] *Department of Material Science, University of Milano Bicocca, 20125, Milan, Italy.*
roberto.mantovan@mdm.imm.cnr.it

Topological insulators (TIs) are gaining a huge attention from a technological point of view due to highly efficient spin-charge interconversion phenomena occurring at their interface with magnetic materials, which is of interest for spin-orbit torque MRAM [1] and novel processing-in-memory devices such as the MESO proposed by Intel [2]. We developed Metal Organic Chemical Vapour Deposition (MOCVD) processes to grow epitaxial-quality Sb_2Te_3 and Bi_2Te_3 3D-TIs on 4" Si(111) substrates [3-5], see Figure. 1. First, their topological character has been demonstrated by combining magnetotransport and angular photoemission spectroscopy studies [6]. Then, we built simple spin-charge converters by interfacing the TIs with ferromagnetic layers (FM=Fe,Co). Within this talk, we report a large spin-charge conversion efficiency in the FM/Sb_2Te_3-based systems, as expressed in terms of the generated inverse Edelstein Effect (λ_{IEE}) extracted from spin pumping ferromagnetic resonance (SP-FMR) [7,8]. Values of λ_{IEE} up to 0.61 nm were measured [8], indicating quite a large conversion efficieny within the class of second generation 3D chalcogenide-based Tis (Figure 2). Our results open interesting routes toward the use of chemical methods to produce TIs over large area Si substrates and characterized by highly performing spin-to-charge conversion, thus marking a milestone toward future technology-transfer.

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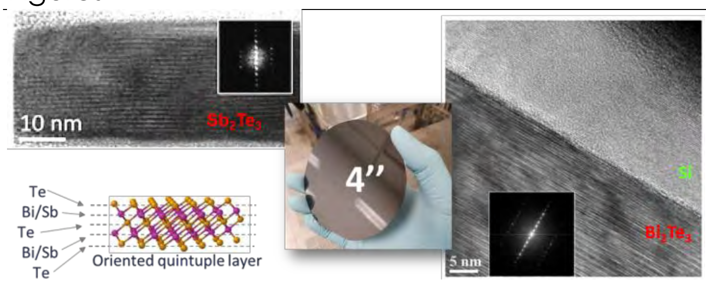

Figure 1: Transmission electron microscopy images of MOCVD-grown TIs on 4'' Si(111).

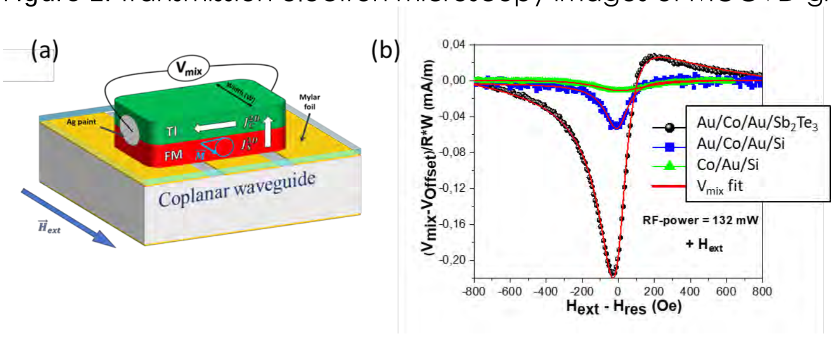

Figure 2: SP-FMR (a) sample's configuration and (b) results obtained in Au/Co/Au/Sb_2Te_3/Si(111) spin-charge converter.

Noncollinear magnetic order in epitaxial thin films of Heusler compounds

Anastasios Markou[a,b]
Edouard Lesne[a], Rebeca Ibarra[a], Peter Swekis[a], Claudia Felser[a]
[a] *Max Planck Institute for Chemical Physics of Solids, 01187 Dresden. Germany*
[b] *Physics Department, University of Ioannina, 45110 Ioannina, Greece*
Anastasios.Markou@cpfs.mpg.de

Magnetic systems exhibiting spin-canted states have garnered much attention recently for their promising rich exotic properties driven by the real-space spin textures and competing magnetic orders. Thin films and single crystals of the noncentrosymmetric inverse tetragonal Heusler compounds Mn_2RhSn and Mn_xPtSn ($x = 1.4$–2) were found to host a variety of nontrivial magnetic structures, ranging from elliptical skyrmions to antiskyrmions and noncoplanar spin textures [1-4]. This phenomenon, to host multiple topological spin textures, is especially interesting for applications when observed through real-space imaging techniques, such as magnetic force microscopy (MFM), and transport signatures. One such transport signature is the topological Hall effect (THE), which is a transverse response to an applied current, and it is distinct for each topological texture. These THE's can be generally be classified in the size of the magnetic texture and the strength of coupling to the magnetic texture. In this work, we present the magnetic and magnetotransport properties of high-quality epitaxial thin films of the tetragonal Mn_xPtSn and Mn_2RhSn, and the hexagonal MnPtGa Heusler compounds. We show that the Mn_xPtSn displays two magnetic regions, a collinear state above the spin reorientation and noncoplanar below. We have measured THE and anomalous Hall effect (AHE) in these regions and they remarkably show the same magnitude. Further, we tune the Mn content (x), which allows for microscopic control of the magnetic exchange parameters (Fig. 1a). With our thin film method, we can access a novel and fundamental understanding of this compound not possible with other methods. We show a microscopic control of the exchange parameters that influence the size of the magnetic textures and thereby the transport signatures. Furthermore, in Mn_2RhSn films, we observe two peaks in the THE, which allow us to determine the existence of two distinct topological objects over a wide range of temperature and magnetic fields (Fig. 1b) [3,4]. Finally, in the hexagonal MnPtGa films, we find that below a thermally induced spin reorientation transition at 160 K, the magnetic groundtstate, determined by a single-crystal neutron diffraction, is a noncollinear spin canted state where the Mn moments tilt 20° away from the *c*-axis (Fig. 1c) [5].

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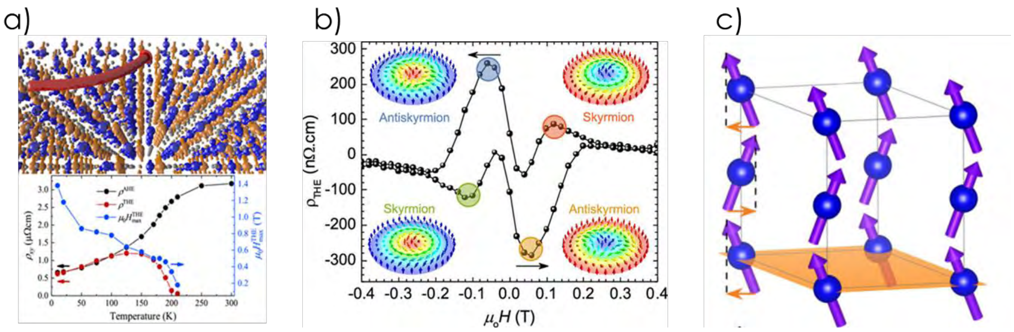

Figure 1: THE in Mn_xPtSn (a) and Mn_2RhSn (b) films. c) Noncollinear magnetic groundstate of MnPtGa.

Experimental observation of a magnetic warping transition in a topological insulator mediated by rare-earth surface dopants

Beatriz Muñiz Cano[1]
Y. Ferreiros[1], P. A. Pantaleón[1], A. Figueroa[2,3], J. Dai[4], M. Tallarida[4], V. Marinova[5], K. García[2,4], A. Mugarza[2,6], S. O. Valenzuela[2,6], R. Miranda[1,7], J. Camarero[1,7], F. Guinea[1,8], J. A. Silva-Guillén[1] and M. A. Valbuena[1]
[1] *Instituto Madrileño de Estudios Avanzados, IMDEA Nanociencia, Calle Faraday 9, 28049, Madrid, Spain*
[2] *Catalan Insitute of Nanoscience and Nanotechnology (ICN2), Campus UAB, CSIC and BIST, 08193, Barcelona, Spain*
[3] *Universitat de Barcelona, Gran Vía de les Corts Catalanes 585, 08007, Barcelona, Spain*
[4] *ALBA Synchrotron Light Source, 08290, Cerdanyola del Vallès, Barcelona, Spain*
[5] *Intitute of Optical Materials and Techologies, Bulgarian Academy of Sciences, Str. 109, 1113, Sofia, Bulgaria*
[6] *ICREA Institució Catalana de Recerca I Estudis Avançats, Lluis Companys 23, 08010, Barcelona, Spain*
[7] *Departamento de Física de la Materia Condensada; Instituto ''Nicolás Cabrera'' and Condensed Matter Physics Center (IFIMAC)*
[8] *Donostia International Physics Center, Paseo Manuel de Lardizábal 4, 20018, San Sebastián, Spain; and Ikerbasque, Basque Foundation for Science, 48009, Bilbao, Spain*
beatriz.muniz@imdea.org

Magnetic topological insulators (MTIs) are a novel class of materials where the topologically protected band structure coexists with long-range ferromagnetic order, which can lead to the breaking of time-reversal symmetry (TRS), introducing a bandgap in the Dirac cone-shaped topological surface state (TSS) [1, 2]. Recently, the gap opening in MITs has been predicted to be accompanied by a distortion in the TSS, evolving its typically warped shape from hexagonal to trigonal [3, 4].

In this work, we demonstrate such transition by means of angle-resolved photoemission spectroscopy after the deposition of low concentrations of magnetic rare earths (RE), namely Er and Dy, on the ternary three-dimensional prototypical topological insulator Bi_2Se_2Te. Indeed, indications of the gap opening occurring as a consequence of the TRS breaking have also been observed, whose existence is supported by the observation of the aforementioned transition. Moreover, increasing Er coverage results in a tunable p-type doping of the TSS. As a consequence the Dirac point and therefore the magnetically induced bandgap can be both tuned towards the Fermi level as the RE concentration is increased, thus fulfilling the two necessary prerequisites for the realization of the quantum anomalous Hall effect (QAHE). The experimental results are rationalized by a theoretical model where a magnetic Zeeman out-of-plane term is introduced in the hamiltonian governing the TSS band dispersion. Our results offer new strategies to control magnetic interactions with TSS based on a simple approach and open up viable routes for the realization of the QAHE and their implementation in new spintronic devices.

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High Chern number van der Waals magnetic topological multilayers $MnBi_2Te_4$/hBN

Mikhail M. Otrokov[1,2]
Mihovil Bosnar[3,4], Alexandra Yu. Vyazovskaya[5], Evgeniy K. Petrov[5], Evgueni V. Chulkov[3,4,6]
[1]*Centro de Física de Materiales (CFM-MPC), Centro Mixto (CSIC-UPV/EHU), 20018 Donostia-San Sebastián, Spain*
[2]*IKERBASQUE, Basque Foundation for Science, 48009 Bilbao, Spain*
[3]*Donostia International Physics Center, 20018 Donostia-San Sebastián, Spain*
[4]*Departamento de Polímeros y Materiales Avanzados: Física, Química y Tecnología, Facultad de Ciencias Químicas, Universidad del País Vasco UPV/EHU, 20018 Donostia-San Sebastián, Spain*
[5]*Tomsk State University, Tomsk, Russia, 634050*
[6]*Saint Petersburg State University, Saint Petersburg, Russia, 199034*

mikhail.otrokov@gmail.com

Chern insulators are two-dimensional magnetic topological materials that conduct electricity along their edges via the one-dimensional chiral modes. The number of these modes is a topological invariant called the first Chern number *C*, that defines the quantized Hall conductance as $S_{xy} = Ce^2/h$. Increasing *C* is pivotal for the realization of low-power-consumption topological electronics, but there has been no clear-cut solution of this problem so far, with the majority of existing Chern insulators showing *C* = 1. Here, by using state-of-the-art theoretical methods, we propose an efficient approach for the realization of the high-*C* Chern insulator state in van der Waals multilayer heterostructures of the intrinsic magnetic topological insulator $MnBi_2Te_4$ [1,2] and hexagonal boron nitride, $MnBi_2Te_4$/hBN [3]. We show that a stack of *n* $MnBi_2Te_4$ films with *C* = 1 intercalated by hBN monolayers gives rise to a high Chern number state with *C* = *n*, characterized by *n* chiral edge modes (Figure 1). This state can be achieved both under the external magnetic field and without it, both cases leading to the quantized Hall conductance $S_{xy} = Ce^2/h$. Our results therefore pave way to practical high-*C* quantized Hall systems.

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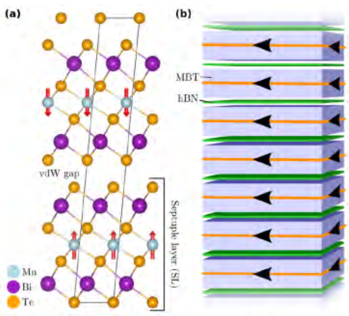

Figure 1: (a) Side view of the bulk $MnBi_2Te_4$ (MBT) crystal structure. Red arrows denote Mn local moments. (b) Schematic depiction of the proposed system: MBT films are separated by hBN monolayers to make a van der Waals multilayer heterostructure with Chern number equal to the number of MBT films, *C* = *n*. Black arrows depict the direction of the edge currents.

Detection of Dirac/Weyl Fermions via electron-states resolved NMR crystallography.

Wassilios Papawassiliou[1], Hae Jin Kim[2], Michael Fardis[3], Georgios Papavassiliou[3]
1. *CEA, IRIG-MEM, Grenoble, France*
2. *Electron Microscopy Research Center, Korea Basic Science Institute, 169-148 Gwahak-ro, Yuseong-gu, Daejeon 34133, Republic of Korea*
3. *Institute of Nanoscience and Nanotechnology, National Center for Scientific Research "Demokritos", 153 10 Aghia Paraskevi, Attiki, Greece*
wassilios.papawassiliou@cea.fr

The interest in the role of topology in condensed matter physics has been significantly increased over the last decade, with topological insulators and Dirac/Weyl semimetals being the most relevant systems featuring non-trivial topology. The state-of-the-art method to detect topological electron energy bands is Angle Resolved Photoemission Spectroscopy. However, despite its great effectiveness, there is a particular shortage in monitoring and manipulating Dirac and Weyl fermions, which appear as low energy quasiparticle excitations.

Herein, we show that by applying DFT-assisted broadband high-resolution solid-state Nuclear Magnetic Resonance (NMR) methods on microcrystalline WTe_2 [1] (type-II Weyl semimetal) and Bi_2Te_3 nanoplatelets [2] (topological insulator), it is possible to routinely resolve complex ssNMR patterns into individual NMR resonances and precisely tie those resonances to the Dirac/Weyl electron states via their electron-nuclear hyperfine coupling. Electron-states resolved NMR crystallography is thus enabling the detection of Dirac and Weyl Fermions.

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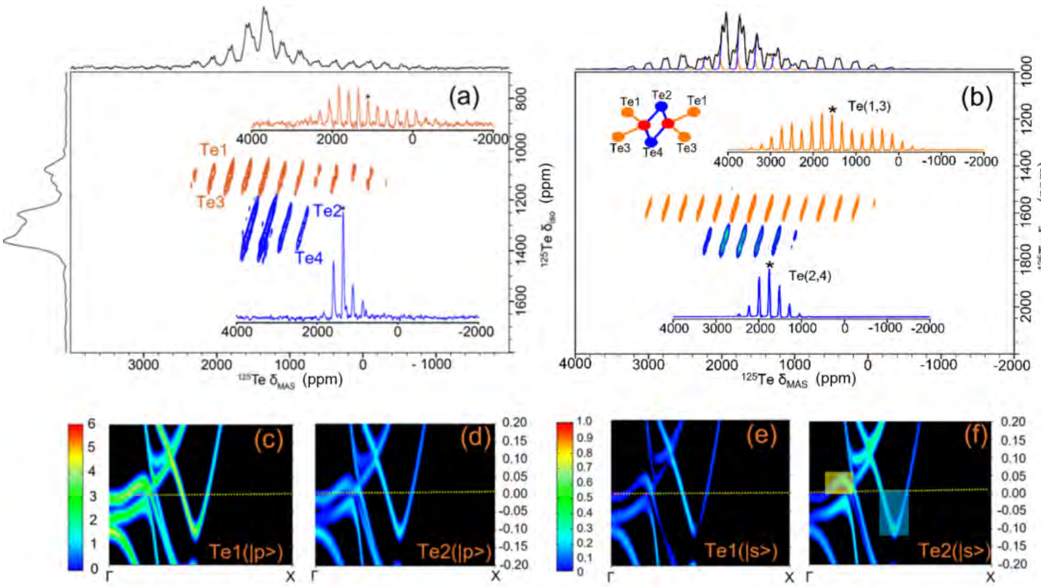

Figure 1: Experimental (a) and DFT calculated (b) ^{125}Te aMAT NMR spectra of microcrystalline WTe_2. (c-f) The k-resolved p-DOS of the p-orbitals (c,d) and s-orbitals (e,f) for each of the inequivalent sites present in the crystal structure. The large anisotropy of the NMR shift of Te(1,3)is driven by the p-orbital character of these sites, while the occupied s-orbitals of Te(2,4) are responsible for the observed positive shift in the NMR spectrum with respect to the Te(1,3) resonance [1].

Exploring the creation of topological magnetic structures by interfacial DMI and magnetic field in 2D ferromagnets

P. Pappas[a]
S. Fragkos[a,b], E. Georgopoulou-Kotsaki[a,c], A. Lintzeris[a,d], E. Symeonidou[a,e], A. Dimoulas[a]
[a]*NCSR Demokritos, 15341, Athens, Greece.*
[b]*Department of Mechanical Engineering, University of West Attica, 12241, Athens, Greece.*
[c]*Department of Physics, National and Kapodistrian University of Athens, 15784, Athens, Greece.*
[d]*Department of Physics, National Technical University of Athens, 15780, Athens, Greece.*
[e]*School of Chemistry, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece*
p.pappas@inn.demokritos.gr

Topological magnetic structures and especially magnetic skyrmions are the prime candidates for introducing topological systems to the state of the art spintronics [1]. Since the presence of the Dzyaloshinskii–Moriya exchange interaction (DMI) is the main mechanism for the stabilization of magnetic skyrmions we explored the introduction of interfacial DMI in centrosymmetric 2D ferromagnets. In this work we present two case studies where topological magnetic structures emerge in two of the most promising 2D ferromagnets, namely $CrTe_2$ [2] and Fe_3GeTe_2 [3]. In the first case we studied with ab initio and atomistic spin simulations the effect of the interfacial DMI, in the heterostructures $CrTe_2/WTe_2$ and $CrTe_2/MoTe_2$, on the stabilization of magnetic skyrmions. In addition, we engineered a field-controlled Néel-type skyrmion lattice (Figure 1. a), where the skyrmion lattice is robust against thermal fluctuations close to T_c (Figure 1. b) [4]. In the second case we studied a Fe_3GeTe_2 thick flake where the interfacial DMI emerged from the presence of the native oxide epilayer. Here by combining experimental magneto-optical Kerr effect (MOKE) imaging and micromagnetic simulations we studied the emergence of two magnetic phases close to the saturation by employing a specific magnetic field protocol. The first one consisting of Néel-type double wall domains showing the structure of a skyrmionium [5] that order to a regular lattice (Figure 2. a). Those double wall domains collapse at higher fields to solid magnetic bubbles which, based on our micromagnetic calculations, are Néel-type skyrmions (Figure 2. b). Thus, by choosing appropriate combinations of interfacial DMI and magnetic field one can produce tailor made topological magnetic structures in 2D ferromagnets heterostructures.

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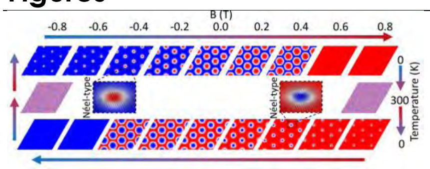
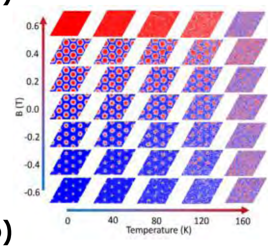


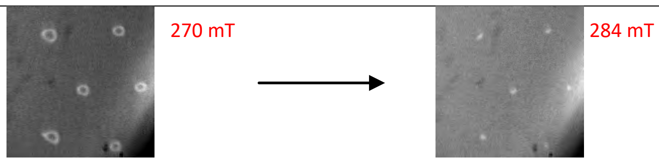
a)



b)

Figure 1: a) A complete transition cycle of the spin texture from -0.8 to 0.8 T, b) Skyrmion phase diagram as a function of the temperature and magnetic field.

a)



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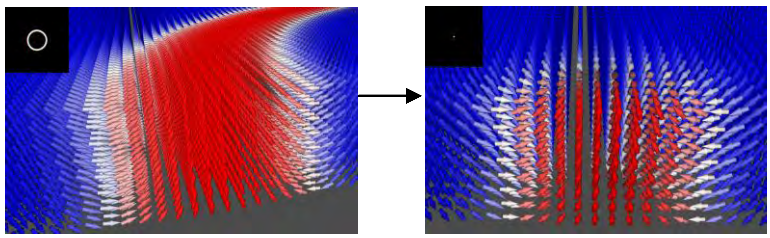

Figure 2: a) Polar-MOKE images of double wall domains (left) and their collapse to spot domains (right),
b) 3D representation of the simulated spin configuration of the double wall domains (left) and Néel skyrmion (right).

Quantum Anomalous Hall Effect Devices for Resistance Metrology

Dinesh K. Patel*, Mattias Kruskopf*, Martin Götz*, Eckart Pesel*, Hansjörg Scherer*, Kajetan M. Fijalkowski§‡, Steffen Schreyeck§‡, Karl Brunner§‡, Charles Gould§‡, Laurens W. Molenkamp§‡

*Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany
§Physikalisches Institut (EP3), Universität Würzburg, Am Hubland, 97074 Würzburg, Germany
‡Institute for Topological Insulators, Am Hubland, 97074 Würzburg, Germany
dinesh.patel@ptb.de

Abstract: The quantum anomalous Hall effect (QAHE), as manifested in ferromagnetically-doped topological insulator (TI) materials [1, 2] is of high interest in fundamental physics and in metrology. For metrology, the effect has enormous potential because it provides Hall resistance quantization in units of the von-Klitzing constant in zero external magnetic field. We have extensively characterized Hall-bar-shaped devices from V-doped $(BiSb)_2Te_3$ by means of a state-of-the-art precision resistance bridge based on a 14-bit cryogenic current comparator (CCC) at PTB [3]. In comparison with former experiments using a 12-bit CCC bridge, the 14-bit CCC bridge has a significantly improved resolution, especially at low currents in the nA range. Our latest experiments include current and temperature dependent measurements of magneto-transport quantities in the QAHE regime, performed on recently fabricated devices with improved contact technology. The results to be presented at the conference clearly show improved results at higher currents compared to previous investigations on V-doped $(BiSb)_2Te_3$ devices [1].

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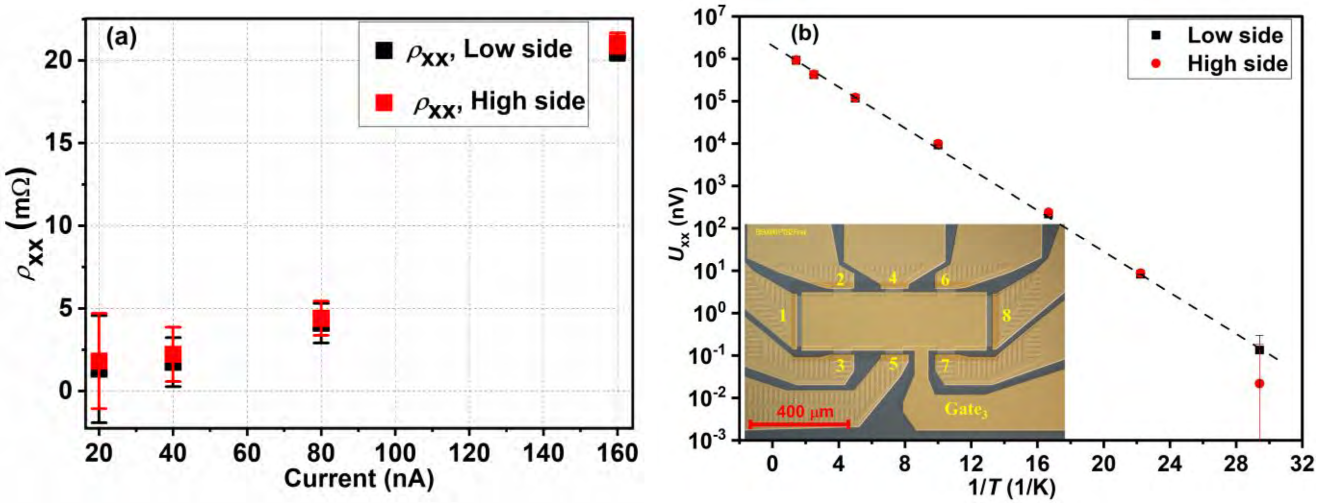

Figure 1: (a) It shows the current dependence of the longitudinal resistivity. (b)Arrhenius plot of the temperature dependent longitudinal voltage obtained at a current of ±40 nA, a gate voltage of 5.8 V and a measurement time of 32 minutes. The inset is the optical image of an as-fabricated device with labled contacts.

Tunable interface states between Floquet-Weyl semimetals

Francesco M.D. Pellegrino
Dipartimento di Fisica e Astronomia Ettore Majorana, Università di Catania, Via S. Sofia 64, I-95123 Catania, Italy
INFN, Sez. Catania, I-95123 Catania, Italy
CNR-IMM, Via S. Sofia 64, I-95123 Catania, Italy

Federico Bonasera
Dipartimento di Fisica e Astronomia Ettore Majorana, Università di Catania, Via S. Sofia 64, I-95123 Catania, Italy
INFN, Sez. Catania, I-95123 Catania, Italy

Song-Bo Zhang
Institute for Theoretical Physics, University of Zurich, 8057 Zurich, Switzerland

Lorenzo Privitera
Institute for Theoretical Physics and Astrophysics, University of Würzburg, D-97074 Würzburg, Germany
Corporate Research, ABB Switzerland Ltd., Segelhofstrasse 1K, Baden-Dättwil 5405, Switzerland

francesco.pellegrino@dfa.unict.it

Abstract

Weyl semimetals and nodal line semimetals are characterized by linear electronic bands touching at zero-dimensional points and one-dimensional lines, respectively. Recently, it has been predicted that nodal line semimetals can be driven into tunable Floquet-Weyl semimetals by circularly polarized light. Here, we study the occurrence of interface states between two regions of a nodal line semimetal shined by two beams of light with opposite circular polarizations. Within a minimal model, we find remarkable modifications of the energy structure by tuning the polarized light, such as the possible generation of van Hove singularities. Moreover, by adding a δ -doping of magnetic impurities along the interfacial plane, we show the occurrence of a switchable and topologically non-trivial, vortex-like pseudo-spin pattern of the interface states.

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Strain-engineered topological Dirac fermions in epitaxial α-Sn

Jakub Polaczyński[1]
Alexandr Kazakov[1], Wojciech Zaleszczyk[1], Bartłomiej Turowski[1], Tomasz Wojciechowski[1], Piotr Dłużewski[2], Bogusława Kurowska[2], Rafał Rudniewski[1], Tomasz Wojtowicz[1] and Valentine V. Volobuev[1,3]
[1]*International Research Centre MagTop, Institute of Physics, Polish Academy of Science, Al. Lotników 32/46, PL-02668 Warsaw, Poland*
[2]*Institute of Physics, Polish Academy of Science, Al. Lotników 32/46, PL-02668 Warsaw, Poland*
[3]*National Technical University "KhPI", Kyrpychova Str. 2, Kharkiv 61002, Ukraine*
polaczynski@ifpan.edu.pl

Breaking the symmetry, e.g. by applying strains, makes it possible to create various topological phases in α-Sn (a.k.a. grey tin), nominally a zero-gap semiconductor with an inverted band structure [1]. In particular, in-plane compressive strain in epitaxial grey tin layers leads to the formation of Dirac semimetal (DSM). The external magnetic field additionally breaks time-reversal symmetry and creates Weyl semimetal (WSM). This tunability of topological properties makes α-Sn an attractive material platform for studying the physics of Dirac fermions [2].
Here, we present a comprehensive study of grey tin layers grown by molecular beam epitaxy. The CdTe/GaAs (001) hybrid substrates used for the growth introduce a compressive in-plane strain of 0.13%, as determined from X-ray diffraction. According to the results of **k·p** calculations, this value is large enough to create the DSM phase, which we characterize by low-temperature magnetotransport ($T \geq 300$ mK, $B \leq 14.5$ T). Significantly, a non-saturating negative longitudinal magnetoresistance (NLMR) occurs in magnetic fields parallel to the current for all samples studied. After ruling out alternative mechanisms, such as current jetting and weak localization, we associate this feature with a chiral anomaly – the WSM signature. To our knowledge, this is the first detailed study of NLMR in α-Sn. The non-trivial nature of our samples is supported by the π Berry phase extracted from Shubnikov-de Haas oscillations. Their presence in various orientations of magnetic field indicates the 3D character of observed carriers. Our results are consistent over a wide thickness range (50 nm – 200 nm) and provide a comprehensive description of grey tin in agreement with the predicted Dirac and Weyl semimetal phases [2].
The research was partially supported by the Foundation for Polish Science through the IRA Programme co-financed by EU within SG OP (Grant No. MAB/2017/1).

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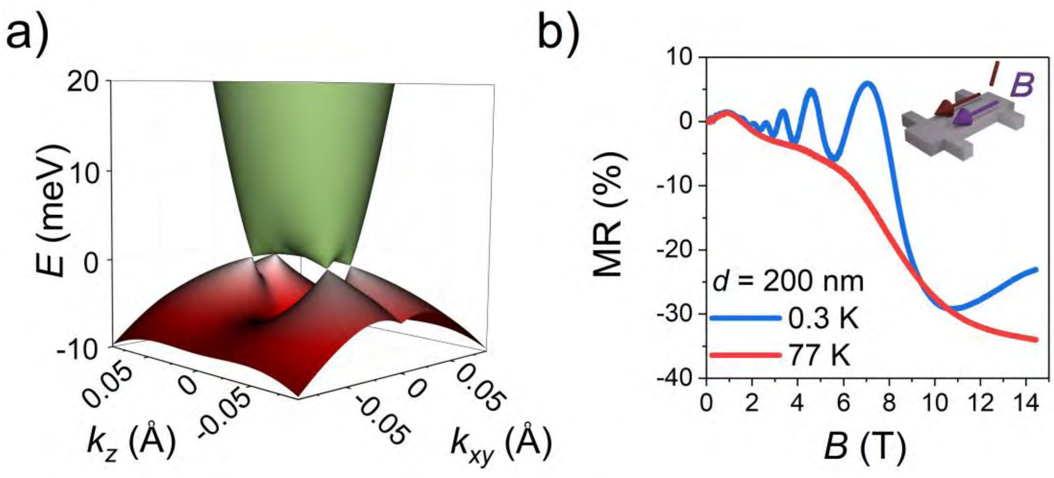

Figure 1: a) Band structure of compressively strained α-Sn in in-plane magnetic field B = 10 T. b) Example of NLMR in grey tin in magnetic field parallel to the current, measured for two temperatures.

Using Topological Insulators as Quantum Hall Resistance Standards

Albert F. Rigosi
Linsey K. Rodenbach, Alireza R. Panna, Shamith U. Payagala, Ilan T. Rosen, Joseph A. Hagmann, Peng Zhang, Lixuan Tai, Kang L. Wang, Dean G. Jarrett, Randolph E. Elmquist, Jason M. Underwood, David B. Newell, and David Goldhaber-Gordon
National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899, United States
afr@nist.gov

Since 2017, epitaxial graphene has been the base material for the US national standard for resistance. A future avenue of research within electrical metrology is to remove the need for strong magnetic fields, as is currently the case for devices exhibiting the quantum Hall effect. New materials, like magnetically doped topological insulators (MTIs), offer access to the quantum anomalous Hall effect, which in its ideal form, could become a future resistance standard needing only a small permanent magnet to activate a quantized resistance value [1-3]. Furthermore, these devices could operate at zero-field for measurements, making the dissemination of the ohm more economical and portable. Here we present results on precision measurements of the h/e^2 quantized plateau of Cr-Doped $(Bi_xSb_{1-x})_2Te_3$ and give them context by comparing them to modern graphene-based resistance standards. Ultimately, MTI-based devices could be combined in a single system with magnetic-field-averse Josephson voltage standards to obtain an alternative quantum current standard.

Work presented herein was performed, for a subset of the authors, as part of their official duties for the United States Government. Funding is hence appropriated by the United States Congress directly. This material is based upon work supported by the Department of Energy, Office of Science, Basic Energy Sciences, Materials Sciences and Engineering Division, under Contract DE-AC02-76SF00515.

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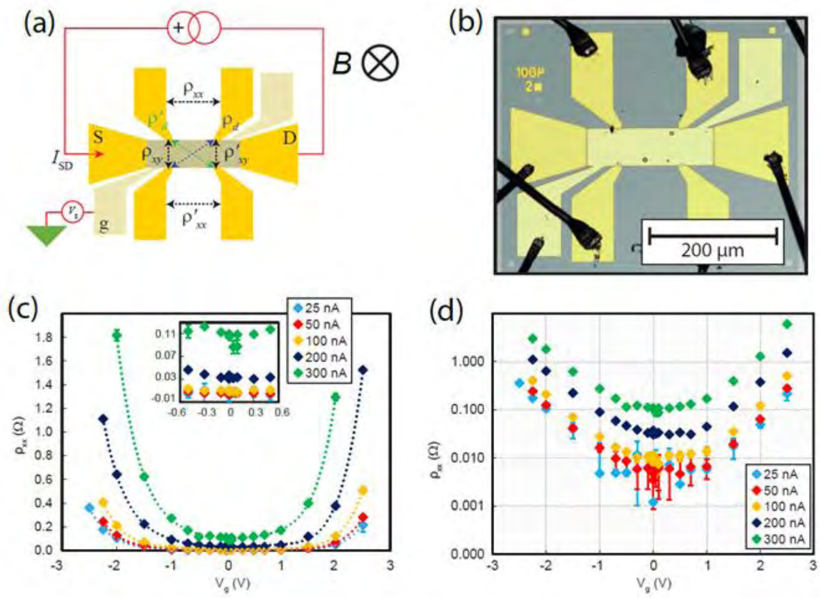

Figure 1: (a), (b) Fabrication of a MTI-based device and a basic top gate characterization of the longitudinal resistance. (c), (d) Longitudinal resistance tests were conducted to optimize device functionality for quantum Hall precision measurements.

Multiple topological states in nanophononic superlattice devices

Anne Rodriguez
Edson Cardozo de Oliveira, Daniel Lanzillotti-Kimura
Centre of Nanosciences and Nanotechnologies, CNRS, Université Paris-Saclay, Palaiseau, France
anne.rodriguez@c2n.upsaclay.fr

Topological interface states have been demonstrated for a wide range of excitations (photons, phonons, vibrations, polaritons). In particular, nanoacoustic interface states have been evidenced in superlattices working at acoustic frequencies in the tens to hundreds of GHz [1–3]. A scheme to generate interface states in one-dimensional nanoacoustic superlattices is based on the principle of band inversion, which can be achieved by concatenating two periodic lattices with inverted spatial mode symmetries around the bandgap [4]. Most realizations optimize the thickness ratio to reverse the symmetries to create an interface mode at a specific bandgap.

In this work, we present topological nanophononic interface states at high-order bandgaps in multilayered structures based on GaAs/AlAs. We achieve band inversion by modifying the internal unit cell structure of the two lattices [5]. We extend the principle of band inversion to create an interface state at the second or higher-order bandgaps (see Fig.1). By carefully choosing the appropriate material thickness ratio of the two concatenated nanoacoustic superlattices we demonstrate that we can engineer interface states at the n^{th} bandgap. We can design versatile topological devices where nanoacoustic interface states are simultaneously created in a broad frequency range. In addition, we can generate interface states in hybrid structures by combining two superlattices presenting bandgaps of different orders centered around the same frequency.

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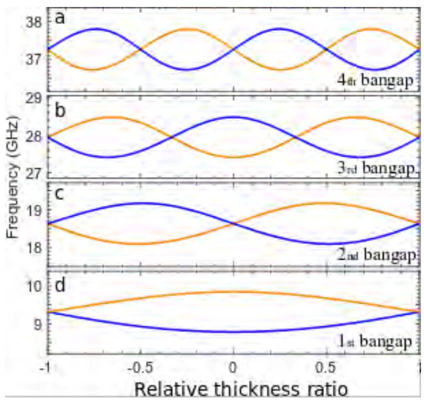

Figure 1: Band inversion of the acoustic bandgap. The mode symmetries are indicated with orange (symmetric) and blue (anti-symmetric) lines.

Low-Dimensional Topological Insulator Nanodevices

Daniel Rosenbach[1,2,3,*]
Abdur R. Jalil[1], Kristof Moors[1], Sofie Kölling[3], Feike van Veen[3], Roel M. Metsch[3], Liesbeth Mulder[3], Hanne vd Glind[3], Jaric Wiegman[3], Alexander Brinkman[3] Detlev Grützmacher[1,2] and Thomas Schäpers[1,2]
[1]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany
[2]Jülich-Aachen Research Alliance (JARA), Forschungszentrum Jülich and RWTH Aachen University, Germany
[3]MESA+ Institute for Nanotechnology, University of Twente, 7500AE Enschede, The Netherlands
[*]present address: Physics Institute II, University of Cologne, 50937 Köln, Germany
rosenbach@ph2.uni-koeln.de

Abstract

In pursue of the long sought Majorana fermion, hybrid systems of topologically insulating materials (TI) and superconducting metals (SC) are investigated. Due to the proximity coupling of the SC to the spinless TI surface states Majorana zero modes (MZMs) emerge, which are the condensed matter equivalent to the Majorana fermion. In experiment, the dimensionality of the TI has to be reduced for the investigation and manipulation of only a single pair of MZMs. We discuss two possibilities (see fig. 1) to define nanodevices of three-dimensional TIs of reduced dimensionality using molecular beam epitaxy. The first is to define TI nanoribbons using selective area growth [1]. In combination with in situ shadow evaporation techniques for electrode deposition this allows for great scalability and high quality devices. The drawback is that large magnetic fields need to be applied, parallel to the nanoribbon main axis, for the system to be in its topological phase [2]. The second approach is based on the hybridization of top and bottom surface of a three-dimensional TI in ultra-thin films [3], that gives rise to quantum spin Hall edge states. We introduce both systems, present recent experimental findings and discuss the versatility of both approaches.

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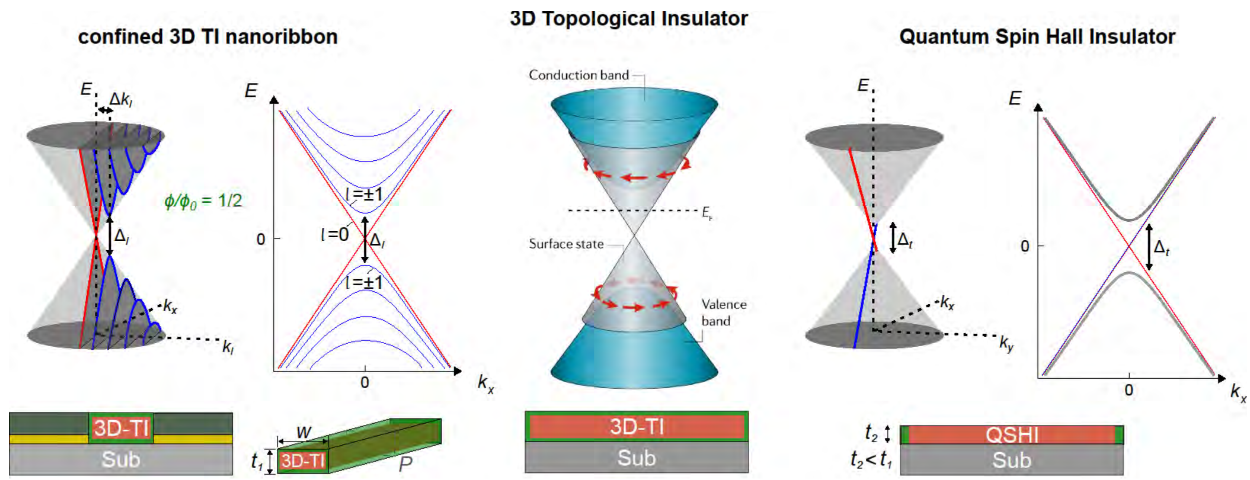

Figure 1: Pathway from MBE grown 3D TI thin films (center, scheme taken from [4]) to 1D confined nanoribbons [5] (left) or the hybridization evoked quantum spin Hall insulator (right).

Role of anti-site intermixing in the magnetic structure of intrinsic magnetic topological insulator: $Mn_{1\pm x}Sb_{2\pm x}Te_4$

Manaswini Sahoo[1,2,3]
Giuseppe Allodi[2], Zaher Salman[4], Laura T Corredor Bohorquez[1], Laura Folkers[3,5], Fabian Lukas[1], Anja Wolter-Giraud[1], Bernd Büchner[1,3], Roberto De Renzi[2], Anna Isaeva[1,5]

[1]Leibniz IFW Dresden, 01069 Dresden, Germany.
[2]Dipartimento di Scienze Matematiche, Fisiche ed Informatiche, Università di Parma, Parco Area delle Scienze 7A, I-43100 Parma, Italy.
[3]Institut für Festkörper- und Materialphysik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062 Dresden, Germany.
[4]Laboratory for Muon Spin Spectroscopy, Paul-Scherrer-Institute, CH-5232 Villigen PSI, Switzerland.
[5]Van der Waals-Zeeman Institute, University of Amsterdam, The Netherlands.

Contact: m.sahoo@ifw-dresden.de

Time-reversal symmetry breaking in a topological insulator (TI) opens a surface gap and distinguishes chiral quantum states that could eventually be exploited in electrically controlled spintronic devices. The new approach to create this state in a TI is with the intrinsic magnetic proximity of a magnetic insulator that can be achieved with layered van der Waals materials. Soon after the exploration of antiferromagnetic $MnBi_2Te_4$ its isostructural sister compound $MnSb_2Te_4$ gained popularity because of its high transition temperature and possible ferromagnetic interlayer interaction between the septuple layers, resulting in a remnant magnetic moment without the application of a magnetic field [1]. Additionally,recent combined spin- and angle-resolved photoemission spectroscopy and scanning tunneling microscopy studies on epitaxial high-Tc $MnSb_2Te_4$ film pinned down a non-trivial band topology, essential for the Quantum anomalous hall effect in this compound [1]. Both, experimental and theoretical investigations have separately revealed that the magnetic and electronic topological state strongly depends on the amount and type of anti-site intermixing and/or Mn content in these layered van-der-Waals compounds [2]. In our joint bulk magnetic and local spectroscopic experimental study, we investigate the effect of such intermixing on the magnetic properties of $Mn_{1\pm x}Sb_2Te_4$ single crystals and powders. We combine Nuclear Magnetic Resonance (NMR), and Muon Spin Relaxation(μSR), with bulk SQUID magnetometry to reveal the local magnetic properties of the Mn ions. Our single crystal studies are in accordance with the ferrimagnetic state of our $Mn_{1+x}Sb_2Te_4$ single crystals with a high amount of anti-site intermixing as well as with frozen spin clusters just below the ordering temperature. NMR on powder samples clearly indicates the intermixing of Mn/Sb on their respective sites and the Mn at 3a and 6c positions are aligned in the opposite direction which gives rise to an overall ferrimagnetic behavior as suggested by bulk magnetometry. Zero-field μSR shows an overall broad distribution of magnetic field at the muon position due to the site intermixing. However, the weak transverse field shows a sharp magnetic transition, taking place in the whole volume of the material.
In light of our results, the role of anti-sites in the magnetic structures is discussed, as well as new perspectives for this family of materials.

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Isotropic 3D statistical topological insulator

Helene Spring
Daniel Varjas, Anton Akhmerov
TU Delft, Lorentzweg 1 2628CJ, Delft, The Netherlands
h.spring@tudelft.nl

Abstract
Inversion and time-reversal symmetry typically coexist in nature. However, this is not universally required to always be the case. We present a 3D Hamiltonian that systematically breaks time-reversal symmetry and receives topological protection solely from inversion and continuous rotation symmetry. We demonstrate topologically-protected transport using regular and amorphous network models. We show that the doubled transition is not protected from localization, but is still protected from gapping out, and a finite density of states persists on the surface while the bulk is insulating.

Figures

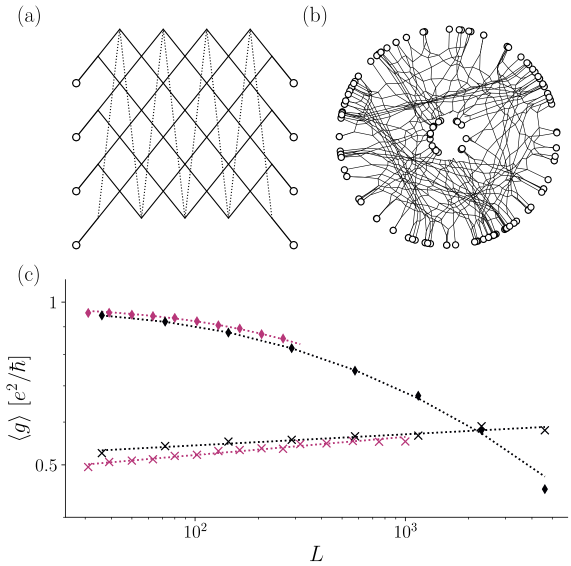

Figure 1: (a)-(b) Regular and amorphous networks and (c) the conductance scaling for single (x markers) and double (diamond markers) transitions.

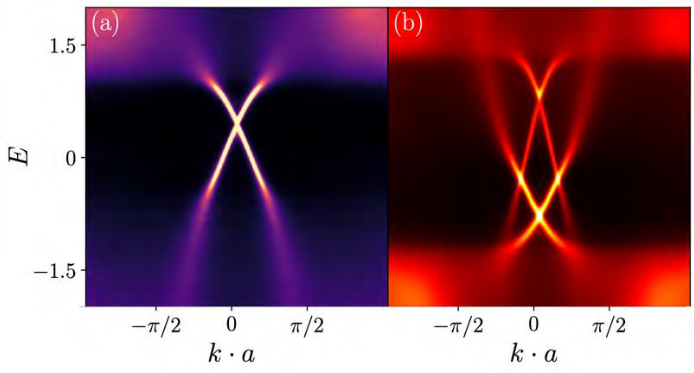

Figure 2: Spectral functions of the (a) single and (b) double transition.

Quartet-rule-coupling engineering of Majorana fermions in FM-SC heterostructures and topological states in all AFM films

G. Livanas[1], N. Vanas[1], M. Sigrist[2] and G. Varelogiannis[1]

[1] *Department of Physics, National Technical University of Athens, GR-15780 Athens, Greece*
[2] *Institut für Theoretische Physik, ETH Zürich, CH-8093 Zürich, Switzerland*

Quartet-Rule-Coupling (QRC) introduced by one of us (GV) is a universal hidden interaction that is triggered only when any three members of quartets of fields and/or order parameters with représentations obeying a specific rule coexist and induces the missing fourth one. For example, particle-hole asymmetry with CDW and SDW and FM form a quartet proposed to explain colossal magnetoresistance in manganites [1]. Particle-hole asymmetry with SDW and d-wave-SC and staggered π-triplet SC form another quartet proposed to explain the high field induced SDW state in the SC state CeCoIn5 [2]. Dozens of other quartets have been identified and verified numerically and analytically.

Exploiting the rule that allows to predict quartets [3], we noticed that the coexistence of current with ordinary s-SC and a Zeeman field triggers QRC inducing p-wave triplet SC that combined with other related quartets led us to the discovery of *alternative paths for the realization and manipulation of Majorana fermions* in ferromagnet-superconductor heterostructures without need of any material or structure with intrinsic spin-orbit coupling [4]. We propose an original platform [5] for the manipulation of multiple Majorana qubits based on supercurrents and/or gate voltage manipulation of the polarization of ferromagnetic insulators able to produce braiding operations for all necessary topological quantum gates with available technology.

Some recent extraordinary results in collaboration with the group of Dr. T. Kontos (ENS Paris) for QRC engineering of topological states in any antiferromagnetic film [6], their relation with previous results on topological density-wave condensates and their potential for hosting Majorana zero modes will be briefly presented as well.

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Topological light-matter interfaces with large topological invariants

Carlos Vega García
Migual Bello, Diego Porras, Alejandro González-Tudela
Institute of Fundamental Physics IFF-CSIC, Calle Serrano 113b, 28006 Madrid, Spain
carlos.vega@iff.csic.es

Topological light-matter interfaces, that are, systems where quantum emitters interact with topologically non-trivial photonic modes is one of the frontiers of topological photonics. The interplay between topology and strong interactions from the non-linear emitter level structure can lead to qualitatively different quantum optical phenomena [1, 2], and open new avenues for engineering robust quantum gates between emitters or photons that can be harnessed for different quantum technologies. These exciting perspectives have lead to the first implementations based on coupling quantum dots to topological photonic crystals [3] or superconducting qubits to coupled microwave resonators [4], among others. In this presentation, we will discuss about the physics emerging when the topological photonic systems display large winding phases in 1D [5] or large Chern numbers in 2D [6] topological insulators. In particular, we will show how in the 1D scenario the topological phases lead to qualitatively different shapes for the emitter-emitter interactions induced in topological band-gaps, among other effects. In 2D systems, we discuss the emergence of a topological multi-mode waveguide in their edges, and show how it leads to time-bin-like entangled emission patterns or exotic collective decays.

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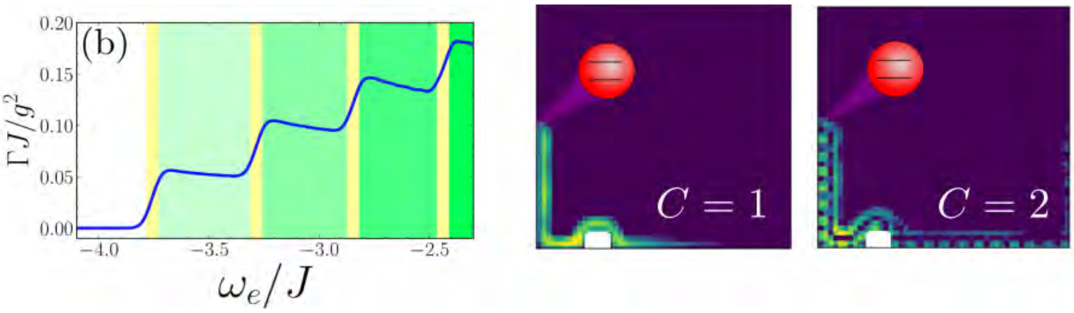

Figure 1: Quantized and robust photon emission with large Chern numbers.

ARPES on Surface of Topological Crystalline Insulator $Pb_{1-x}Sn_xSe$ Epilayers with Transition Metal Adsorbates

V. V. Volobuev[1,2]

B. Turowski[1], O. Caha[3], R. Rudniewski[1], N. Olszowska[4], J. Kołodziej[4], G. Springholz[5], T. Wojtowicz[1]

[1]*International Research Centre MagTop, Institute of Physics, Polish Academy of Sciences, Aleja Lotników 32/46, PL-02668 Warsaw, Poland*

[2]*National Technical University "KhPI", Kyrpychova Str. 2, Kharkiv 61002, Ukraine*

[3]*Masaryk University, Kotlářská 2, 61137 Brno, Czech Republic*

[4]*National Synchrotron Radiation Centre SOLARIS, Jagiellonian University, Czerwone Maki 98,PL-30392 Kraków, Poland*

[5]*Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Altenbergerstr. 69, A-4040 Linz, Austria*

volobuiev@magTop.ifpan.edu.pl

Understanding the band structure of the transition metal/topological insulator (TM/TI) interface is of importance for future TI applications. For example, topological states (TSS) on magnetic TM/TI interface can provide an efficient mechanism for charge-spin interconversion and create a platform for future spintronic devices [1]. Topological crystalline insulators (TCIs) exhibit TSS protected by mirror crystal symmetry that are very sensitive to external perturbations [2, 3]. Here we report ARPES experiments on topological crystalline insulator $Pb_{1-x}Sn_xSe$ epilayers with Fe, Mn transition metal adsorbates of submonolayer thickness. The high-quality epilayers were grown by molecular beam epitaxy in (111) and (001) orientation and were transported to a synchrotron without breaking the ultra-high vacuum, where subsequent in-situ deposition of metals and ARPES measurements were performed. Formation of Rashba split surface states (RSS) was detected in the conduction band for (111) oriented samples (Fig. 1a). Estimated Rashba parameter α_R can be tuned over a wide range from 0 to 1.5 eV·Å as a function of deposited TM. For (001) oriented films, a decrease of separation in *k*-space between Dirac points of the double Dirac cone was observed (Fig. 1b). The reasons for band structure modification with TM deposition will be discussed.

The work is supported by the Foundation for Polish Science through the IRA Programme co-financed by EU within SG OP. We thank NSRC SOLARIS for beamtime allocation.

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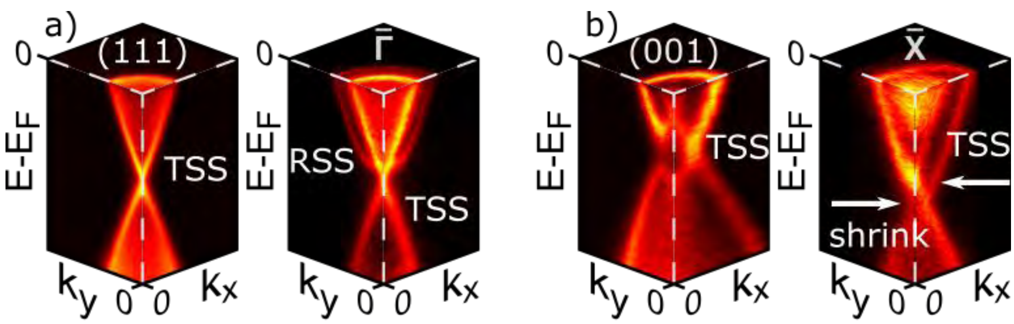

Figure 1: ARPES spectra of a) (111) and b) (001) $Pb_{0.75}Sn_{0.25}Se$ epilayer before and after transition metal deposition.

Terahertz dynamic signatures of spin accumulation and spin-to-charge conversion at topological insulator–ferromagnet interfaces

Genaro Bierhance[1,2]
Chihun In[1,2], Enzo Rongione[3], Reza Rouzegar[1,2], Oliver Gueckstock[1,2], Polychronis Tsipas[4], Jean-Marie George[3], Athanasios Dimoulas[4], Henri Jaffrès[3], and Tobias Kampfrath[1,2]
[1]Fritz Haber Institute of the Max Planck Society, Faradayweg 4-6, 14195 Berlin, Germany
[2]Freie Universität Berlin, Department of Physics, Arnimallee 14, 14195 Berlin, Germany
[3]Unité Mixte de Physique, CNRS, Thales, Université Paris-Saclay, F-91767 Palaiseau, France
[4]Institute of Nanoscience and Nanotechnology, N.C.S.R. "Demokritos", Agia Paraskevi, 15341 Athens, Greece
bierhance@fhi-berlin.mpg.de

Topological insulators are a promising class of materials for terahertz spintronics research and devices. Their topologically protected surface states with spin-momentum locking unveil additional channels for spin-charge interconversion and, thus, offer the opportunity to improve the spin-charge interconversion efficiency. While in the inverse (Rashba) Edelstein effect, the charge current scales with the interfacial accumulation of spin angular momentum, the charge current due to the inverse spin Hall effect is proportional to the spin current and occurs in the bulk. Because these bulk and interface effects have identical macroscopic symmetries, they are difficult to separate experimentally.

Here, we use femtosecond laser pulses to excite F|TI heterostructures consisting of a ferromagnetic metal layer F and a topological-insulator film TI. The resulting transient spin voltage in F [1,2] drives an ultrafast spin current from F into the adjacent TI. Spin-to-charge conversion launches a transverse charge current that emits a broadband terahertz electromagnetic pulse. The field of the latter is recorded in the time-domain via electro-optic sampling.

Our measurements allow us to extract phase-sensitive changes in the dynamics of spin transport and spin-to-charge conversion on femtosecond timescales. We find significantly longer charge-current relaxation times in different TIs in comparison to a reference Pt layer, which we assign to spin accumulation at the topological insulator interface.

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Electronic fluctuations in the skyrmion phase of room temperature skyrmionic systems

Hurmal Saren[1]

Yogesh Kumar[1], Nicolas Reyren[2], Sachin Krishnia[2], Yanis Sassi[2], F. Ajejas[2,*], K. Bouzehouane[2], Vincent Cros[2] and Pintu Das[1]

[1]*Department of Physics, Indian Institute of Technology Delhi, Hauzkhas, New Delhi, India-110016*

[2]Unité Mixte de Physique, CNRS, Thales, Université Paris-Saclay, 91767 Palaiseau, France

*Present address: Department of Physics and Center for Advanced Nanoscience, University of California, San Diego, La Jolla, California 92093, USA

pintu@physics.iitd.ac.in

Magnetic skyrmions, which are topologically protected whirling spin textures, are viewed as important potential candidates for future data storage devices [1]. In order to integrate the skyrmionic systems in spintronic devices, electrical detection of the skyrmions is necessary [2]. A complete understanding of the electrical behaviour of charge carriers in skyrmion phase requires a detailed investigation of how the dynamics of charge carriers evolve in the skyrmionic phase [3]. In this work, we carried out electrical fluctuation (noise) studies in the skyrmion phase of Pt|Co|Al|Pt based ultra thin film multilayer samples [4]. Magnetic force microscopy (MFM) measurements in presence of external magnetic field of these samples show skyrmion phases in the range of ~ 70 -150 mT. See Fig.1. for a representative MFM image taken at 95 mT. Below 70 mT, the local magnetization is characterized by worm-like features. Low-frequency resistance fluctuation measurements show an increase of fluctuations in the skyrmion phase. Also an increased fluctuation is observed at the transition region from worm-like phase to skyrmion phase. The data allows us to throw light on the low-frequency dynamics of carriers in the skyrmionic phase. A clear indication of relatively slower dynamics of charge carriers in the skyrmion phase is observed.

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Figures

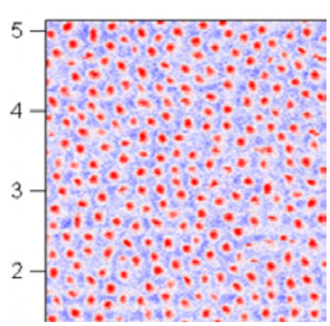

Figure 1: Representative room temperature magnetic force microscopy image of area 5 × 5 μm² taken at external field of 95 mT.

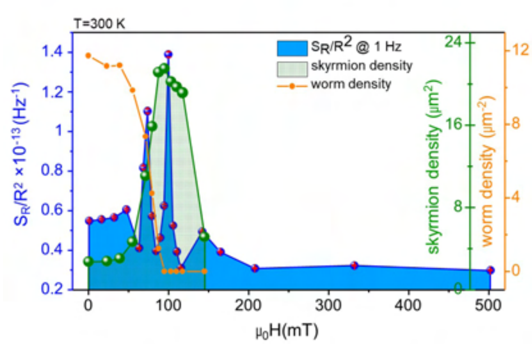

Figure 2: Normalized noise power spectral density (S_R/R^2) and skyrmion/worm density as a function of external magnetic field

Majorana Modes Break Voltage Gauge Invariance in NSN Junctions of Magnetic Topological Insulators

Daniele Di Miceli
Llorenç Serra
IFISC, Institute for Cross-Disciplinary Physics and Complex Systems, 07122, Palma, Spain
daniele@ifisc.uib-csic.es

Magnetic topological insulators (MTIs) are outstanding candidates for the realization of topological 1D and 2D superconducting phases [1,2], which can host end-localized or propagating Majorana modes. However, experimental detection of these elusive modes is still a matter of concern [3].
We propose to detect such topologically-protected edge states in a NSN junction between normal and proximitized MTIs by applying an asymmetric bias on the two normal leads of the device.
Without Majorana modes in the superconducting sector, the conductance is independent of the way the total voltage drop is distributed across the junction.
We refer to this physical property as "gauge invariance" of the electric current in the NSN junction, and we argue that the emergence of Majorana states in the condensate breaks the invariance.
Indeed, in the presence of Majorana states and with an unbalanced bias, the electric current is not symmetrical on the two sides of the device, and the charge conservation implies a Cooper pair current from the superconductor to ground.
This electric current, which can be easily measured in a real device, is a characteristic signal of zero-energy Majorana quasiparticles and can be used for their experimental detection.

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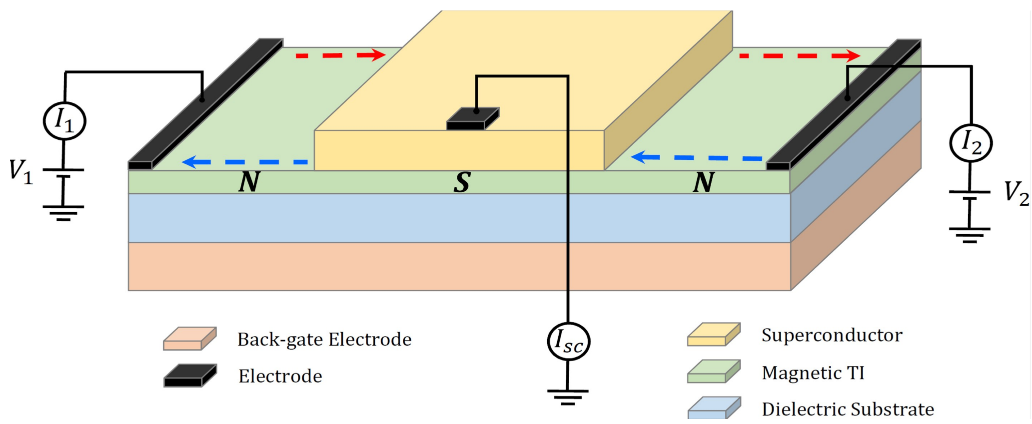

Figure 1: Proposed experimental setup for the detection of topologically-protected Majorana edge modes in a magnetic topological insulator.

Synthesis and Characterization of V-doped WTe_2 Nanolayers

Dimitre Dimitrov Vera Marinova, Peter Rafailov, Nikola Malinowski
Institute of Solid State Physics, Bulgarian Academy of Sciences, 72 Tzarigradsko Chaussee Blvd., 1784 Sofia, Bulgaria
Institute of Optical Materials and Technologies, Bulgarian Academy of Sciences, Acad. G. Bonchev Str., Bl.109, 1113 Sofia, Bulgaria
dzdimitrov@issp.bas.bg

Abstract

The discovery of 2D topological insulator in monolayer 1T'-WTe_2 indicates great potential for novel electronic, spintronic, and quantum metrology. Theoretically, the interaction between the topological states and the magnetic ordered states of Td-WTe_2 enables the modulation of Weyl semimetal states by an external magnetic field and potentially the creation of a quantum anomalous Hall phase [1]. However, currently, ferromagnetism in layered 1T'-WTe_2 is still not observed. We are attempting to synthesize nanolayers/flakes of 1T'-WTe_2 with vanadium doping in order to induce magnetism. V-doped WTe_2 nanolayers/flakes were synthesized in an atmospheric pressure CVD (APCVD) quartz tube reactor with three independent thermal zones. LP (liquid precursors) method based on ammonium metatungstate hydrate (AMT) and ammonium metavanadate (AMV) or vanadium(IV) oxide sulfate ($VOSO_4$) with addition of PTAS was used for the synthesis. The obtained nanolayers/clusters/flakes were studied by optical microscopy and Raman spectroscopy.

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Figures

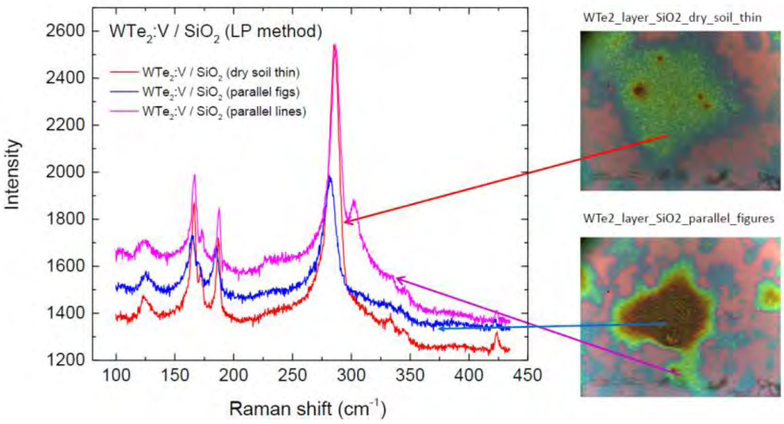

Figure 1: l *Raman analysis of different flakes spots taken when using AMT and AMV with PTAS salt for APCVD synthesis of V -doped WTe_2 nanolayers*

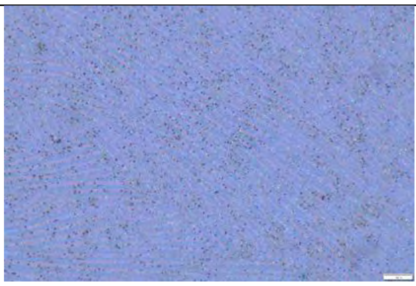

Figure 2: Optical microscope image WTe_2:V, BF, x100 on Si/SiO_2

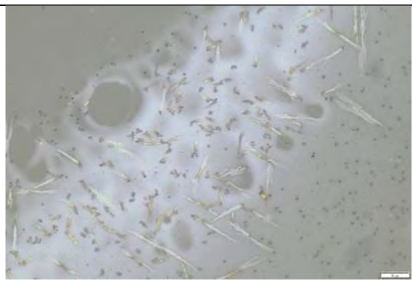

Figure 3: Optical microscope image WTe_2:V, BF, x100 on sapphire

Discrete chiral jumping in a 1D XY spin chain with chiral spin interactions.

Ewan A. Forbes
Jiannis K. Pachos
University of Leeds, Woodhouse, Leeds, LS2 9BW, *England*
Py17eaf@leeds.ac.uk

Abstract:

A 1D XY spin chain with chiral spin interactions can model Dirac particles in black hole background [1]; here I will analyse the chiral characteristics of the system. When the chiral interactions become dominant, modelling the inside of the black hole, the dispersion relation shows a splitting of Fermi Sea. Discrete jumps of the system's chirality emerge as a function of the chiral coupling, with step spacing corresponding to the jumping of fermions in the Fermi Sea. A quantum and classical analysis is conducted to identify topological objects formed in this quantum phase of the system induced by the chiral interactions.

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Birth Quota of Non-Generic Degeneracy Points

György Frank[1,2]
Gergő Pintér,[1,2] Dániel Varjas,[3] and András Pályi[1,2]
[1]*Department of Theoretical Physics, Budapest University of Technology and Economics, Műegyetem rkp. 3., 1111 Budapest, Hungary*
[2]*MTA-BME Exotic Quantum Phases Group, Budapest University of Technology and Economics, Műegyetem rkp. 3., 1111 Budapest, Hungary*
[3]*Department of Physics, Stockholm University, AlbaNova University Center, 106 91 Stockholm, Sweden*
frank.gyorgy@ttk.bme.hu

Weyl points are generic and stable features in the energy spectrum of Hamiltonians that depend on a three-dimensional parameter space. Non-generic isolated two-fold degeneracy points, such as multi-Weyl points [1], split into Weyl points upon a generic perturbation that removes the fine-tuning or protecting symmetry. The number of the resulting Weyl points is at least $|Q|$, where Q is the topological charge associated to the non-generic degeneracy point. Here, we show that such a non-generic degeneracy point also has a birth quota, i.e., a maximum number of Weyl points that can be born from it upon any perturbation [2]. The birth quota is a local multiplicity associated to the non-generic degeneracy point, an invariant of map germs known from singularity theory [3]. This holds not only for the case of a three-dimensional parameter space with a Hermitian Hamiltonian, but also for the case of a two-dimensional parameter space with a chiral-symmetric Hamiltonian. We illustrate the power of this result for band structures of two- and three-dimensional crystals. Our work establishes a strong and powerful connection between singularity theory and topological band structures, and more broadly, parameter-dependent quantum systems.
Funding acknowledgment: This research was supported by the National Research, Development and Innovation Office (NKFIH) via the OTKA Grant No. FK 132146, by the Ministry of Culture and Innovation of Hungary and NKFIH within the Quantum Information National Laboratory of Hungary (Grant No. 2022-2.1.1-NL-2022-00004).

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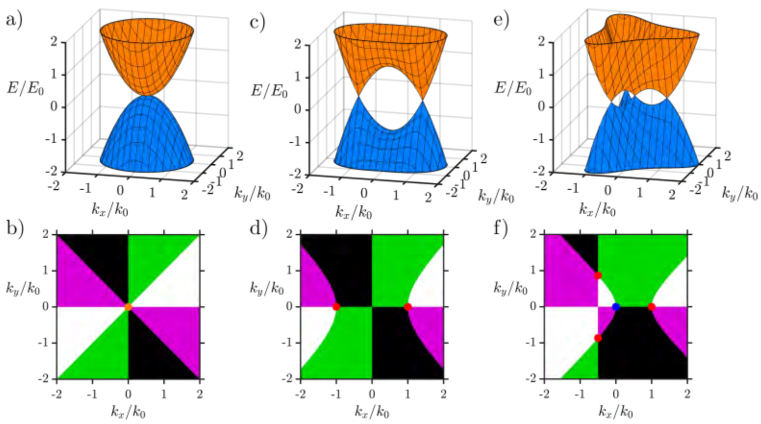

Figure 1: Birth of 2D Weyl points from a non-generic degeneracy point in bilayer graphene. a,b) Non-generic degeneracy point. c,d) Two 2D Weyl points born due to mechanical strain. e,f) Four 2D Weyl points born upon due to trigonal warping. a,c,e) Dispersion relation of the valence and conduction bands. b,d,f) Colored plane shows the sign structure of the effective Hamiltonian map of bilayer graphene.

Study of $MnBi_2Te_4$ growth on BaF_2 and Sapphire

Carmen Gómez Carbonell[1,2]
Iván Fernandez[1,2], Michael Wissmann[3], Romain Giraud[4], Adriana I. Figueroa[1], Sergio O. Valenzuela[1,5]
1. *Institut Català de Nanociència I Nanotecnologia, UAB Campus, Bellaterra (Barcelona), Spain*
2. Universitat Autònoma de Barcelona, Bellaterra, 08193 Barcelona, Spain
3. Leibniz Institute for Solid State and Materials Research (IFW Dresden), Helmholtzstraße 20, D-01069Dresden, Germany
4. Université Grenoble Alpes, CNRS, CEA, Grenoble-INP, Spintec, F-38000Grenoble, France
5. Institució Catalana de Recerca i Estudis Avançats (ICREA), 08010 Barcelona, Spain
carmen.gomez@icn2.cat

Abstract

Magnetic topological insulators (TIs) are expected to open new doors in the field of spintronics, electronics, quantum computation and metrology. $MnBi_2Te_4$ has attracted great interest because it combines non-trivial band topology and antiferromagnetic order [1,2]. Bulk $MnBi_2Te_4$ has a Néel temperature of 25K and a spin-flop transition at a magnetic field of about 3.5T [1,3].
In this work, we report a study of the structural, magnetic and magnetotransport properties of the $MnBi_2Te_4$ films grown by MBE. Films have been grown on BaF_2 (111), and on C-plane and A-plane sapphire (11-20). We identify the corresponding Néel temperatures and compare the response of the films with SQUID magnetometry and x-ray circular dichroism. We further analyse their structural differences and correlate them with their magnetic properties.
We acknowledge support from H2020 FET-PROACTIVE project TOCHA under Grant No. 824140.

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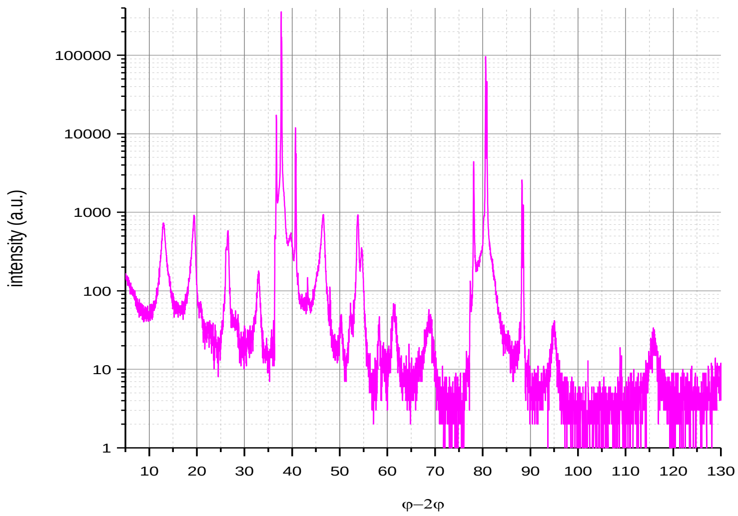

Figure 1: θ-2θ scan for Bi2MnTe4 on sapphire A-plane (11-20)

2π domain walls for tunable Majorana devices

Daniel Hauck
Stefan Rex, Markus Garst
Karlsruhe Institute of Technology, Institute for Theoretical Solid State Physics, Wolfgang-Gaede-Str. 1, 76131 Karlsruhe, Germany
daniel.hauck@kit.edu

Superconductor-magnet hybrid structures provide a platform for investigating topological phases with localized Majorana states. Such states have previously been predicted for elongated Skyrmions in the magnetic layer[1,2]. Here we consider 2**π** domain walls that can be easily controlled experimentally. Depending on the boundary conditions, we demonstrate that localized Majorana states can be found at both ends of such walls. This establishes 2**π** domain walls as tunable elements for the realization of Majorana devices.

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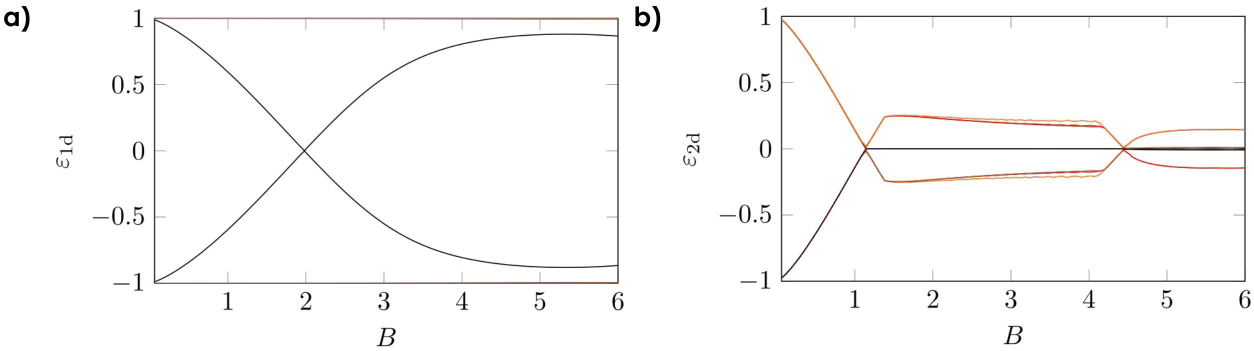

Figure 1: Dependence of the 8 lowest eigenvalues on field strength for the bulk model (a) and a finite 2d system (b).

Figure 2: Local density of states of a Majorana bound state for an example set of parameters.

Trivial Andreev band mimicking topological bulk gap reopening in the nonlocal conductance of long Rashba nanowires

Richard Hess
Henry F. Legg, Daniel Loss, and Jelena Klinovaja
Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland
richardgerhard.hess@unibas.ch

We consider a one-dimensional Rashba nanowire in which multiple Andreev bound states [1,2,3] in the bulk of the nanowire form an Andreev band. We show that, under certain circumstances, this trivial Andreev band can produce an apparent closing and reopening signature of the bulk band gap in the non-local conductance of the nanowire. Furthermore, we show that the existence of the trivial bulk reopening signature (BRS) in non-local conductance is essentially unaffected by the additional presence of trivial zero-bias peaks (ZBPs) in the local conductance at either end of the nanowire, see Fig. 1. The simultaneous occurrence of a trivial BRS and ZBPs mimics the basic features required to pass the so-called 'topological gap protocol' [4,5]. Our results therefore provide a topologically trivial minimal model by which the applicability of this protocol can be benchmarked.

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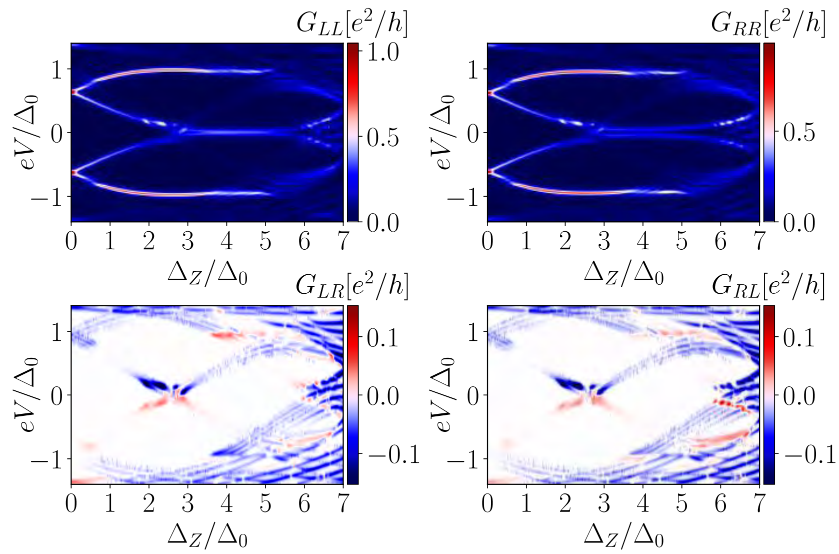

Figure 1: Local and non-local conductance of a system hosting an Andreev band and trivial zero-energy states as a function of the Zeeman field strength. Figure taken from Hess et al., arXiv:2210.03507v2 (2022)

Supercurrent interference in HgTe-wire Josephson junctions

Wolfgang Himmler
Ralf Fischer, Michael Barth, Jacob Fuchs, Dmitriy A. Kozlov, Nikolay N. Mikhailov, Sergey A. Dvoretsky, Christoph Strunk, Cosimo Gorini, Klaus Richter, Dieter Weiss
Institute of Experimental and Applied Physics, University of Regensburg, D-93040 Regensburg, Germany
wolfgang.himmler@ur.de

Wires made of topological insulators (TI) are a promising platform for searching for Majorana bound states. These states can be probed by analyzing the fractional ac Josephson effect in Josephson junctions with the TI wire as a weak link [1]. An axial magnetic field can be used to tune the system from trivial to topologically nontrivial [2]. Here we investigate the oscillations of the supercurrent in such wire Josephson junctions as a function of the axial magnetic field strength and different contact transparencies. Although the current flows on average parallel to the magnetic field we observe h/2e, h/4e- and even h/8e-periodic oscillations of the supercurrent in samples with lower contact transparencies. Corresponding tight-binding transport simulations using a Bogoliubov-de Gennes model Hamiltonian yield the supercurrent through the Josephson junctions, showing in particular the peculiar h/4e-periodic oscillations observed in experiments. A further semiclassical analysis based on Andreev-reflected trajectories connecting the two superconductors allows us to identify the physical origin of these oscillations. They can be related to flux-enclosing paths winding around the TI-nanowire, thereby highlighting the three-dimensional character of the junction geometry compared to common planar junctions.

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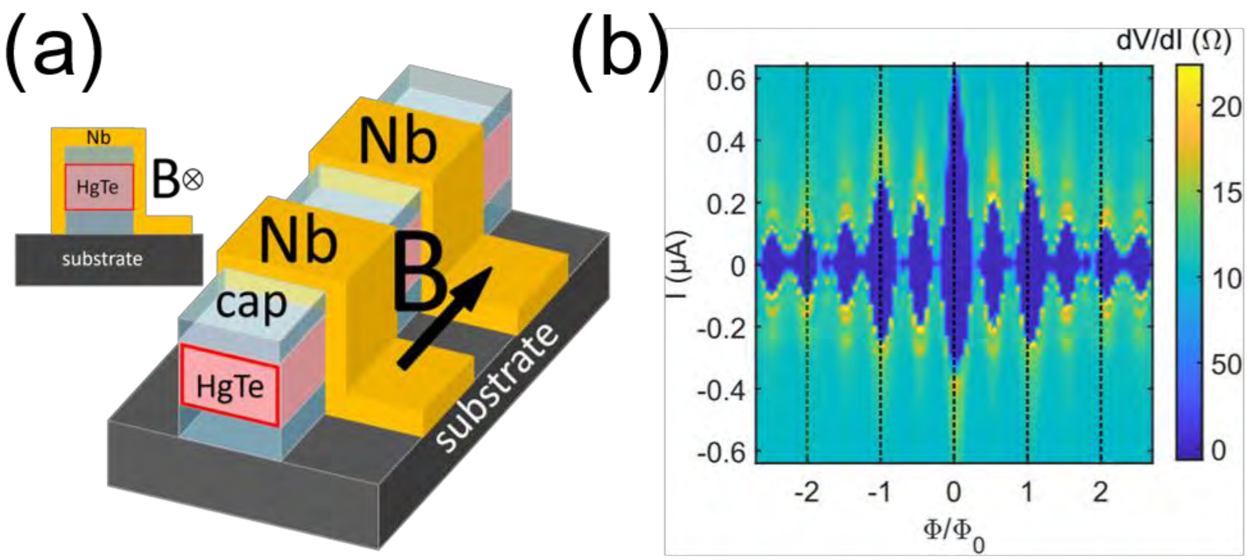


Figure 1: (a) Sample geometry: CdTe/HgTe/CdTe nanowire contacted by superconducting Nb leads. (b) Oscillations of the critical current w.r.t. the axial magnetic flux penetrating the wire.

Bulk and surface – related nature of Ge(111) spin-orbit split bands

Marius-Adrian Husanu
Alexandru C. Iancu, Ruxandra M. Costescu, Dana G. Popescu
National Institute of Materials Physics, Atomistilor 405 A, 077125 Magurele, Romania
ahusanu@infim.ro

Abstract

The emergence of the spin-orbit interaction (SOI) manifests in condensed matter in either momentum-splitting of the bands when the SOI is Rashba-like or energy-splitting when the SOI is of atomic origin. In Ge(111) both mechanism are active. Our density functional theory (DFT) and photoemssion results discuss the nature of both type of interactions and their signature in the experimental band structure.
By using soft X-ray ARPES, with its intrinisic 3D resolution we probe the bulk band structure of epitaxial Ge(111) grown on either Ge(111) substrate or on Si (111).
The epitaxial-induced strain lifts the degeneracy of the light and heavy hole bands, while compared to Si case, the larger Z of Ge promotes also stronger atomic SOI.
The signatures of these effects are distinguished and separated while applications of these findings are discussed.

Control of Majorana zero modes hybridization via a single magnetic adatom

Presenting Author (Ioannis Ioannidis)
O. Awoga, A. Mishra. T.Posske .M. Leijnse. M. Trif
I. Institute for Theoretical Physics, Hamburg University, Notkestrasse 9, Hamburg, Germany
ioannis.ioannidis@uni-hamburg.de

Advances in controlling impurity spins of magnetic impurities deposited on superconductors have enabled observations of promising signatures of Majorana zero modes. However, detecting their fusion rules, that reflect their non-Abelian character, requires control of their hybridization which still remains an unresolved problem. We take the first step in this direction and propose a protocol using a Yu-Shiba-Rusinov state induced by a magnetic adatom deposited on the superconductor. Considering two chains of magnetic impurities on an s-wave superconductor in the topological regime with a single magnetic atom in between, we observe that the overlap of the Yu-Shiba-Rusinov state with Majorana zero modes modulates their bare hybridization energy. We show that the parameters associated with this single adatom, namely, its orientation, distance from the chains and exchange coupling to the SC, can act as control knobs for tuning the hybridization of the Majorana zero modes within a wide range of values starting from zero. Using multiple experimentally relevant models we demonstrate that our proposal is general and model independent. We also discuss the possible experimental realization using the scanning tunneling microscopy-electron spin resonance techniques. Our results pave way for the possibility of controlled fusion and braiding experiment on magnetic impurity-superconductor experimental setups.

Figures

Figure 1: Sketch of the system: Two chains of magnetic adatoms separated by distance R with a single magnetic impurity (blue) placed at between the two chains.

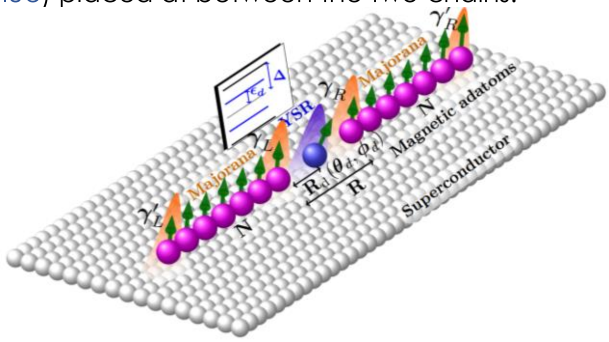
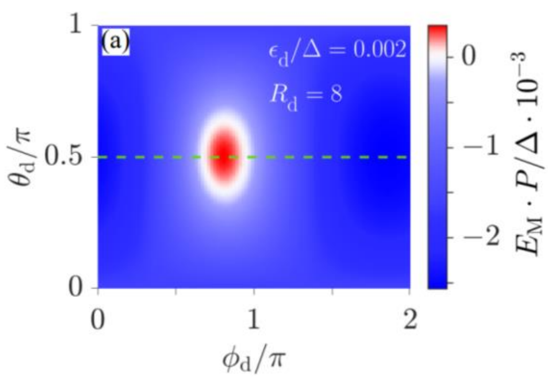


Figure 2: Analytical results for the effective Majorana-Majorana hybridization as a function of the orientation of the single magnetic adatom.



Topological Hall effect in heterostructures of ferromagnetic material/non-coplanar antiferromagnetic material

Jae Ho Jeon
Hong Ryeol Na[1], Heeju Kim[2], Sehwan Song[3], Sungkyun Park[3], Gunn Kim[2], Sahng-Kyoon Jerng[1], Seung-Hyun Chun[1]
[1]*Department of Physics, Sejong University, Seoul 05006, Korea*
[2]*Department of Physics and HMC, Sejong University, Seoul 05006, Korea*
[3]*Department of Physics, Pusan National University, Busan 46241, Korea*
Jeonjh713@gmail.com

Abstract

Chiral spin structures play key roles in spintronics and recent progresses are being made on magnetic skyrmion structures [1]. Dzyaloshinskii–Moriya interaction (DMI) in magnetic materials or heterostructures of strong spin-orbit coupling materials and ferromagnetic materials can generate topological Hall effect implying the existence of skyrmion. In this study, we present a large topological Hall effect in heterostructures of Cr_2Te_3 (ferromagnet) and Cr_2Se_3 (non-coplanar antiferromagnet) grown by the molecular beam epitaxy. Density function theory calculations confirm that the interface can enhance the DMI [2]. We believe that our study paves a way to manipulate the DMI and generate skyrmions in familiar magnetic heterostructures.

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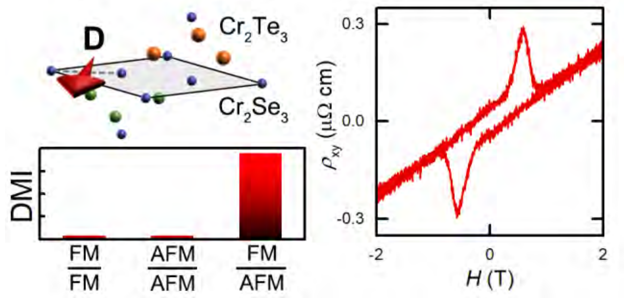

Figure 1: Strength of Dzyaloshinskii–Moriya interaction and topological Hall resistivity in heterostructure of Cr_2Te_3/Cr_2Se_3.

Evolution of Edge Modes in Photonic Topological Insulators

Koijam Monika Devi[1]
Gaetan Leveque[1], Clivia M. Sotomayer-Torres[2], Bahram Djafari-Rouhani[1], and Yan Pennec[1]
[1]*IEMN (UMR CNRS 8520), University of Lille, Lille -59650, France*
[2]*ICN2, Campus UAB, Bellaterra, 08193 Barcelona, Spain*
koijamm@univ-lille.fr

Abstract

Photonic topological insulators (PTIs) have been extensively studied in recent years owing to their properties like unidirectional propagation of light which remain backscattering-free even in the presence of structural defects/disorders [1]. One way to achieve such a robust feature would consist of creating a topological mode localized in a Dirac gap at the interface between two topologically different valley photonic crystals (VPCs) [1, 2]. In this study, we numerically investigate the evolution of topological modes in different types of topological interfaces of PTIs. Here, the topological interfaces (i.e., zigzag-type interface and bridge-type interface [3]) are formed by merging two VPCs, wherein each VPC is formed by an array of air grooves patterned on silicon in a honeycomb lattice. The unit cell comprises two cylindrical air grooves of radii r_1 and r_2 (Fig. 1(a)) and the variable interface radius is denoted by r_i (Fig. 1(b)). By merely changing the value of r_i, the zigzag interface is gradually transformed into a bridge interface as shown in Fig. 1(b). As r_i varies, one of the edge modes of the zigzag interface is gradually pushed toward the bulk bands, ultimately resulting in a single edge mode for the bridge interface. Currently, we are also extending such investigation to phononic topological crystals consisting of patterned plates, based on the valley Hall effect. Such studies could be beneficial in designing different topological insulators for the realization of low loss integrated photonic/phononic components.

Acknowledgments

The authors acknowledge the support from the project LEIT funded by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Grant Agreement No. 885689).

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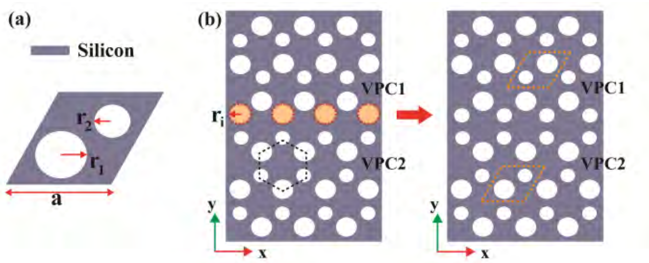

Figure 1: a) Unit cell of the VPC comprising two air grooves of radii r_1 and r_2, (b) Schematic illustration for the gradual evolution of the topological interface formed at the edge of VPC1 and VPC2. The variable interface radius is denoted by r_i.

Epitaxial 2D ferromagnet Cr_xTe_y/Bi_2Te_3 topological insulator heterostructures

Akylas Lintzeris[1, 2]
Elli Georgopoulou-Kotsaki[1, 3], Panagiotis Pappas[1], Polychronis Tsipas[1], Athanasios Dimoulas[1]
Nicholas Figeuiredo - Prestes[4], J.-M. George[4]
[1]*NCSR "Demokritos", Patr. Gregoriou E & 27 Neapoleos STR, 15341 Agia Paraskevi, GREECE*
[2]*Department of Physics, National Technical University of Athens, 15780, Athens, Greece*
[3]*Department of Physics, National and Kapodistrian University of Athens, 15784, Zografou, Athens*
[4] Unité Mixte de Physique, CNRS, Thales, Université Paris-Saclay, 91767, Palaiseau, France
a.lintzeris@inn.demokritos.gr

The discovery of two-dimensional (2D), van der Waals (vdW), ferromagnetic materials (among them Cr_xTe_y) has opened new routes in low-dimensional magnetism and new opportunities for spintronics. Depending on the stoichiometry Cr_xTe_y [1] compounds show different behaviors such as high T_c up to room temperature and perpendicular magnetic anisotropy (PMA) [2], [3]. Combined with Topological Insulators (T.I.) or heavy-metals like Pt, Cr_xTe_y compounds form heterostructures that host skyrmions [4] and can be used to achieve all-electrical switching of the magnetization [5]. In the present work, we study the influence of the growth temperature T_g on the composition and the magnetic properties of Cr_xTe_y thin films grown by MBE. We show that at low $T_g \sim 220^oC$, a pure phase $Cr_{1+\delta}Te_2$ and $Cr_{1+\delta}Te_2/Bi_2Te_3$ is obtained with PMA and a $T_c \sim 150^oC$-170^oC. This phase yields indirect evidence of skyrmions via the topological Hall Effect, large fieldlike torque indicative of topological surface states dominated charge to spin conversion and (partial) current induced magnetization reversal [5]. At higher $T_g \sim$ 400-490°C, more than one phases coexist which have higher T_c near or above 300K (fig.1a), one of them with lower coercivity and predominately in-plane magnetization. The high T_c phases are attributed to Cr-rich phases due to Cr self-intercalation and the influence from the substrate. We will focus on a detailed investigation of the growth and the control of the composition of Cr_xTe_y phases by various techniques including in-situ RHEED, STM and ARPES and ex-situ XRD. The magnetic properties were studied using Magneto-optical Kerr (MOKE) magnetometry/microscopy, SQUID and Hall-effect measurements. Cr_xTe_y grown at high T_g, show MOKE magnetic hysteresis at T>300K with in-plane anisotropy (Fig. 1b) Anomalous Hall Effect (AHE) is observed in low T_g samples with the magnetization easy axes out of the plane of the films.

We acknowledge EU funding from project H2020 FET PROAC SKYTOP-824123.

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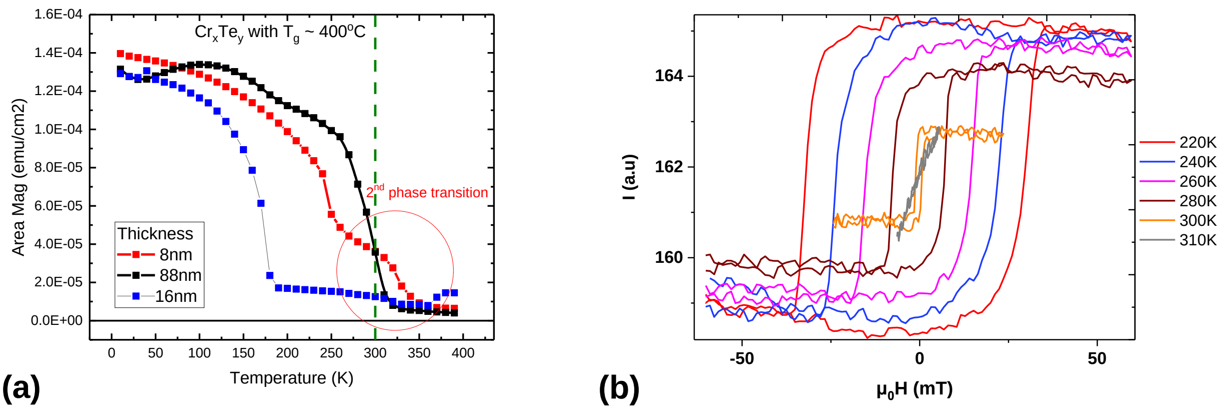

Figure 1: (a) SQUID magnetometry for 3 Cr_xTe_y samples with thickness from ~8nm – 88nm. The thinner sample presents a second magnetic phase with T_c above RT. (b) MOKE of Cr_xTe_y showing in-plane ferromagnetism above 300K.

Current-induced breakdown of the quantum anomalous Hall effect

Gertjan Lippertz[1,2]
Anjana Uday[1], Andrea Bliesener[1], Lino M. C. Pereira[2], Alexey Taskin[1], and Yoichi Ando[1]
[1]*Physics Institute II, University of Cologne, Zülpicher Straße 77, 50937 Köln, Germany*
[2]*KU Leuven, Quantum Solid State Physics, Celestijnenlaan 200D, 3001 Leuven, Belgium*
lippertz@ph2.uni-koeln.de

The quantum anomalous Hall (QAH) effect is characterized by zero longitudinal resistivity and quantized Hall resistance without the need of an external magnetic field, see Fig. 1(a). However, when reducing the device dimensions or increasing the current density, an abrupt breakdown of the dissipationless state occurs, see Fig. 1(b). In this poster, the mechanism of breakdown will be addressed, and the electric field created between opposing chiral edge states will be shown to lie at its origin. Electric-field-driven percolation of two-dimensional charge puddles in the gapped surface states of compensated topological-insulator films is proposed as the most likely cause of the breakdown [1]. Moreover, it was recently reported that the interplay between the 1D chiral edge state and the 2D surface state can give rise to nonreciprocity in the longitudinal resistance [2]. In this poster, it will be shown that the onset of 2D conduction due to breakdown is sufficient to create the nonreciprocal effect, allowing for efficient switching between the dissipationless and nonreciprocal transport regime of the QAH state.

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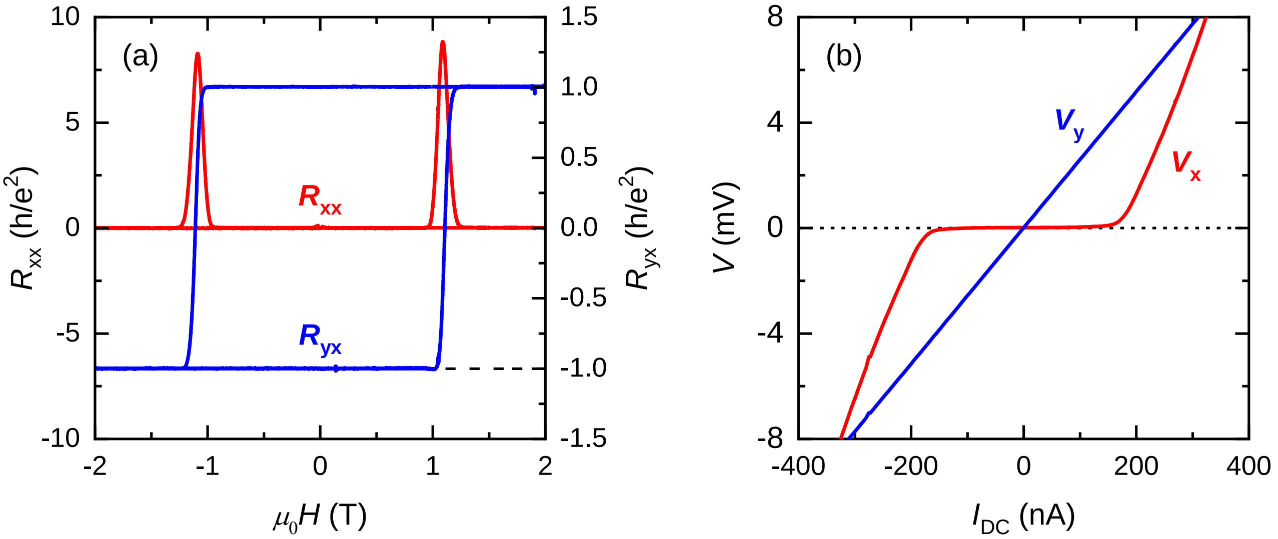

Figure 1: (a) The longitudinal and transverse resistance as a function of the applied magnetic field, showing the quantum anomalous Hall effect. (b) The current-induced breakdown of the QAH effect for a 100-µm-wide Hall-bar device.

Growth of V - doped WTe_2 Single Crystals by Self-flux Method

Vera Marinova
Dimitre Dimitrov, Nikola Malinowski, Sergio O. Valenzuela, Juan F. Sierra
Institute of Optical Materials and Technologies, Bulgarian Academy of Sciences, Acad. G. Bonchev Str., Bl.109, 1113 Sofia, Bulgaria)
Institute of Solid State Physics, Bulgarian Academy of Sciences, 72 Tzarigradsko Chaussee Blvd., 1784 Sofia, Bulgaria
Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and The Barcelona Institute of Science and Technology (BIST), Campus UAB, Bellaterra, 08193 Barcelona, Spain
vmarinova@iomt.bas.bg

Abstract
Magnetic element doping is studied with the aim of inducing ferromagnetism in layered 1T'-WTe_2 single crystal [1]. We are attempting to grow V -doped WTe_2 by using flux (high-temperature solution) method. Particularly the self- flux method was used for crystal growth, and tellurium was used as a solvent (flux). The grown crystals were studied by XRD, XPS and Raman spectroscopy. The results are shown on Figures 1-3. Typical for WTe_2 X-ray diffraction patterns and Raman modes were observed. Vanadium incorporation (1.8 at. %) in the crystal structure was detected by XPS measurements. The estimated elemental composition in at. % is shown in the figure confirming the incorporation of vanadium.

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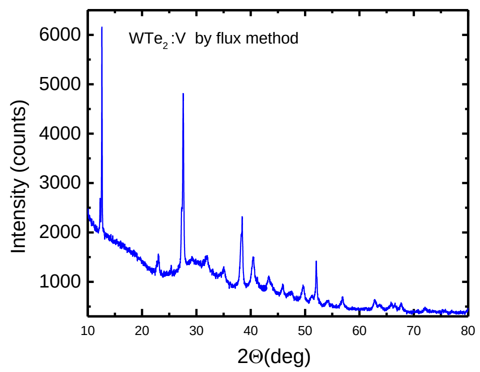

Figure 1: XRD analysis of WTe_2:V grown by flux method

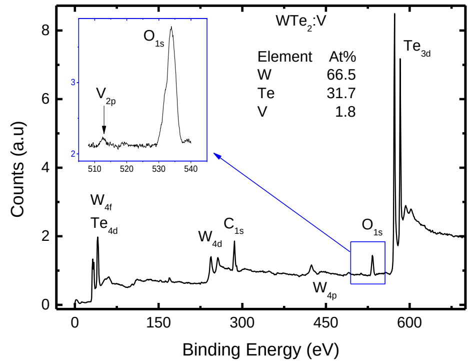

Figure 2: XPS analysis of WTe_2:V grown by flux method

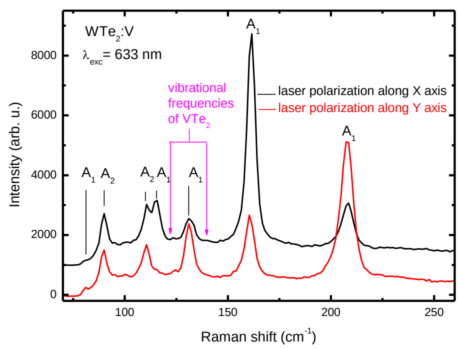

Figure 3: Raman analysis of WTe_2: V

Searching for Majorana zero modes using persistent currents.

Dunkan Martínez Camacho
F. Gonzalo-Medina, A. Díaz-Fernández, F. Domínguez-Adame, L. Rosales, P. A. Orellana
Universidad Complutense de Madrid, Plaza de las Ciencias 1, E28040-Madrid, Spain
dunmar01@ucm.es

Abstract

The quest for Majorana zero modes (MZM) in the laboratory is an active field of research in condensed matter physics. In this regard, there have been many theoretical proposals but their experimental detection remains elusive. In this contribution, we present a realistic setting by considering a quantum ring with Rashba spin-orbit coupling and threaded by a magnetic flux, in contact with a topological superconducting nanowire. We focus on spin-polarized persistent currents to assess the existence of Majorana zero modes. We find that the Rashba spin-orbit coupling allows for tuning the position of the zero energy crossings in the flux parameter space and has sizable effects on spin-polarized persistent currents. We believe that our results will contribute towards probing the existence of Majorana zero modes.

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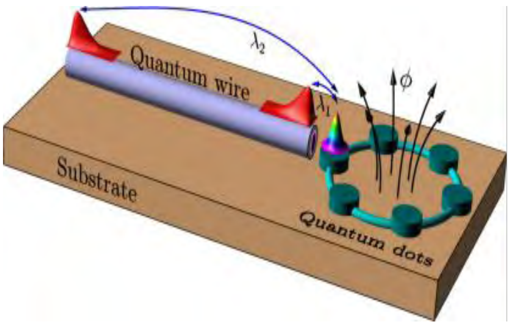
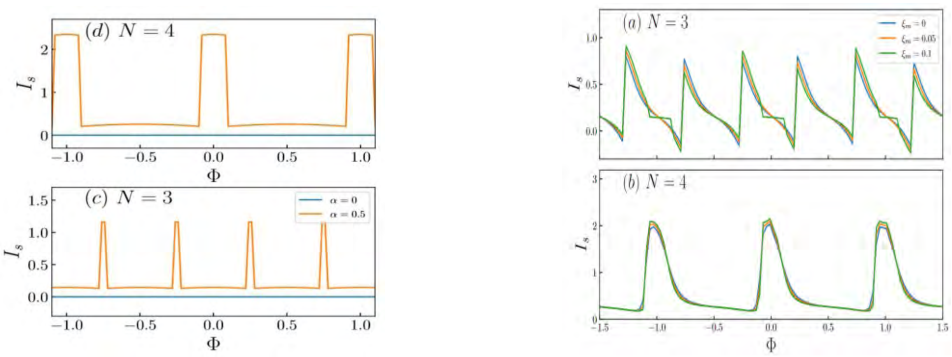


Figure 1: Schematic representation of the system under study. A nanowire driven into a superconducting regime supports a MZM at each edge and influences the persistent currents of a quantum ring, threaded by a magnetic flux.



Quantum Hall effect and Landau levels without spatial long-range correlations

Moein N. Ivaki
Isac Sahlberg, Kim Pöyhönen, Teemu Ojanen
Computational Physics Laboratory, Physics Unit, Faculty of Engineering and Natural Sciences, Tampere University, P.O. Box 692, FI-33014 Tampere, Finland and
Helsinki Institute of Physics P.O. Box 64, FI-00014, Helsinki, Finland
moein.najafiivaki@tuni.fi

The spectrum of charged particles in translation-invariant systems in a magnetic field is characterized by the Landau levels, which play a fundamental role in the thermodynamic and transport properties of solids. The topological nature and the approximate degeneracy of the Landau levels are known to also survive on crystalline lattices with discrete translation symmetry when the magnetic flux through a primitive cell is small compared to the flux quantum. Here we show that the notion of Landau levels and the quantum Hall effect can be generalized to 2d non-crystalline lattices without spatial long-range order. Remarkably, even when the spatial correlations decay over microscopic distances, 2d systems can exhibit several well-resolved Landau-like bands. The existence of these bands implies that non-crystalline systems in magnetic fields can support the hallmark quantum effects which have been typically associated with crystalline solids.

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Proximity enhanced room temperature ferromagnetism in $Fe_5GeTe_2/PtSe_2$ van der Waals heterostructure

Roselle Ngaloy
Bing Zhao
Saroj P. Dash
Department of Microtechnology and Nanoscience, Chalmers University of Technology, SE-41296, Göteborg, Sweden
ngaloy@chalmers.se

The van der Waals (vdW) ferromagnets and their heterostructure with complementary quantum materials are emerging systems for spintronics and quantum technologies. However, it has been highly challenging to achieve above room-temperature ferromagnetism and their heterogeneous integration with other vdW materials. The family of Fe_5GeTe_2 is among the first room-temperature metallic vdW material to be synthesized. In our previous work, we have demonstrated room temperature spin-valve devices with Fe_5GeTe_2 (FGT)[1] – characterized with a canted magnetic moment, and Co-doped Fe_5GeTe_2 (CFGT) – with in-plane anisotropy, in graphene transport channels. Anomalous Hall effect measurements of FGT flakes in these devices show soft ferromagnetic behaviour, which poses a problem for device stability in memory and logic applications. Here, we report the proximity enhanced above room temperature ferromagnetism in FGT in van der Waals heterostructure with a semimetal $PtSe_2$. Using anomalous Hall effect (AHE) measurements, we observe a substantial increase in remanence and coercivity of FGT with a perpendicular magnetic anisotropy in a hybrid structure with $PtSe_2$ at room temperature, indicating a proximity-induced effect. We suspect that the interfacial proximity exchange coupling could significantly enhance the intralayer spin interaction in FGT, hence giving rise to enhanced magnetic moments and anisotropies. Our findings provide the potential for the vdW heterostructure interface engineering and its implementation towards an all-vdW high-performance spin-orbit torque memory and logic devices.

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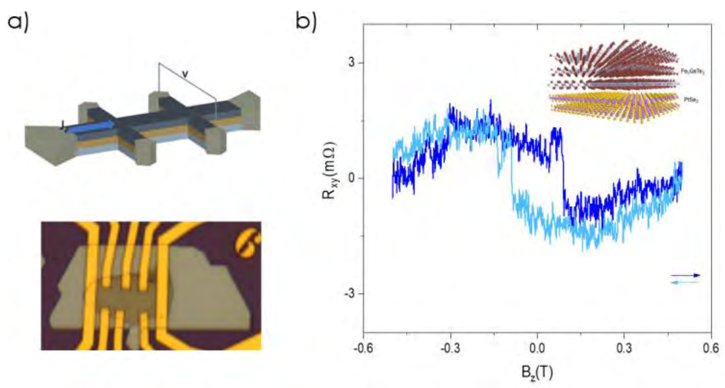

Figure 1: AHE effect of $FGT/PtSe_2$ at room temperature. (a) Microscopic picture of the devices with AHE measurement geometry. (b) Rxy vs. magnetic field at room temperatures for Fe_5GeTe_2 on $PtSe_2$ at room temperature (293 K). The ordinary Hall contribution with a linear background is subtracted from the measured data.

Bulk band splitting due to spin-orbit interaction in ferroelectric oxides

Dana Gerogeta Popescu
Lucian D. Filip, Cristina Chirila, Luminita Hrib, Marius A. Husanu
National Institute of Materials Physics, Atomistilor 405 A, 077125 Magurele, Romania
ahusanu@infim.ro

Abstract

Ferroelectricity resulted from off-centering of cations in perovskite oxides breaks the space inversion symmetry. This, in conjunction with the presence of heavy atoms such as Bi in $BiFeO_3$ or Pb in $PbTiO_3$ is a natural ingredient to promote large spin-orbit interaction, accompanied by splitting of the bulk band structure, with well-defined spin orientation.
Our DFT calculations with and without spin-orbit interaction indicate that the valence band maximum of $PbZrTiO_3$ – PZT is featured by spin-split bands. This is decided by comparing calculations perfromed in the ferroelectric state and in an artificial, paralectric and centrosymmetric case.
The theoretical calculations are compared with the experimental band structures, where spin-resolved photoemission is employed to record the spin polarized band structure.
The challanges of resolving the band structure of ferrolectric materials in well-defined ferroelectric state are also discussed.

Room Temperature Nonlocal Detection of Charge-Spin Interconversion in a Topological Insulator

Lars Sjöström
Anamul Md. Hoque, Dmitrii Khokhriakov, Bing Zhao, Saroj P. Dash
Chalmers University of Technology, Kemivägen 9, SE-41296, Gothenburg, Sweden
sjolars@chalmers.se

Topological insulators (TIs) are emerging materials for next-generation nanoelectronic devices, thanks to the non-trivial spin-momentum locking of their topological surface states. Although charge-spin conversion (CSC) has previously been reported in TIs by potentiometric measurements [1-2], reliable nonlocal detection has so far been observed only at cryogenic temperatures up to *T* = 15 K [3]. Here, we report nonlocal detection of CSC and its inverse effect in the TI compound $Bi_{1.5}Sb_{0.5}Te_{1.7}Se_{1.3}$ at room temperature using a van der Waals heterostructure with a graphene spin valve device (see Figure 1). The lateral nonlocal device design with graphene allows observation of both spin switch and Hanle spin precession signals for generation, injection and detection of spin currents by the TI. Detailed bias- and gate-dependent measurements in different geometries prove the robustness of the CSC effects in the TI. These findings demonstrate the possibility of using topological materials to make all-electrical room-temperature spintronic devices.

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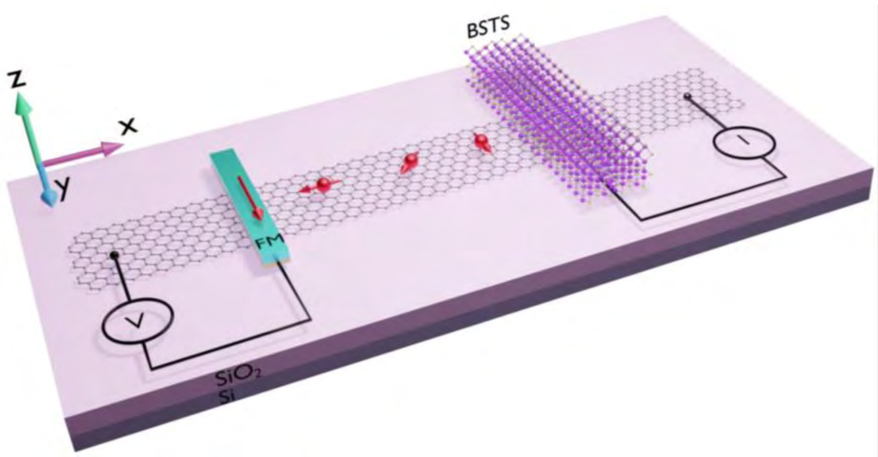

Figure 1: Schematic of the graphene/$Bi_{1.5}Sb_{0.5}Te_{1.7}Se_{1.3}$ heterostructure device with nonlocal measurement geometry, with reference nonmagnetic and ferromagnetic contacts.

Sulfurization of Molybdenum and Tantalum Oxide Thin Films

Georgios Chatzigiannakis[1,2]
Spiros Gardelis[2], Vasilis Psycharis[1], Maria Vasilopoulou[1], Dimitris Davazoglou[1], Anastasia Soultati[1,*]
[1]*Institute of Nanoscience and Nanotechnology (INN), National Center for Scientific Research Demokritos, 15341 Agia Paraskevi, Athens, Greece*
[2]*Solid State Physics Section, Physics Department, National and Kapodistrian University of Athens, Panepistimioupolis, 15784 Zografos, Athens, Greece*
a.soultati@inn.demokritos.gr

Transition metal dichalcogenides (TMDs), such as molybdenum (MoS_2) and tantalum (TaS_2) disulfides are interesting 2D-materials applied in transistors, organic and perovskite optoelectronic devices. [1,2] TMDs flakes are mainly deposited in substrates with mechanical exfoliation, which is inappropriate for large-scale device application. In this work, we investigated the deposition of MoS_2 and TaS_2 films on large area substrates. At first, molybdenum (MoO_x) and tantalum (Ta_2O_x) oxides were deposited using a hot-wire chemical vapour deposition system (HWCVD) on a few cm^2 silicon (Si) and silicon/silicon oxide (Si/SiO_2) substrates. Then, the prepared samples were subjected to sulfurization. In particular, the metal oxide films were placed in the middle (hottest zone) of a CVD tube, while sulphur powder was placed in a crucible at a lower temperature zone. During sulfurization process, a continuous flow of nitrogen (N_2) and hydrogen (H_2) was maintained. Figure 1 illustrates the metal oxide thin films sulfurization. One of the most critical parameter in the sulfurization process was the temperature, which varied from 450°C to 850°C. Therefore, the influence of sulfurization's temperature on the optoelectronic, morphological, and structural properties of the metal oxide films was investigated. It was observed that the higher temperature led to higher sulfurization degree, as evident by Fourier-transform infrared spectroscopy (FTIR). For example, the broad transmittance peaks at 892 cm^{-1} and 453 cm^{-1} observed in the spectrum of sulfurized-MoO_x and attributed to MoS_2 and S-S bond [3], respectively, were more pronounced in higher temperature. Changes were also occurred in the crystallinity and nanomorphology of the prepared films. Pristine MoO_x and Ta_2O_x films were amorphous, with no peak appeared in the X-ray diffraction (XRD) patterns having also small grains on their surface. However, in the case of sulfurized-metal oxides, XRD peaks of high intense appeared, indicating the formation of large crystalline domains, as also revealed from atomic force microscopy measurements.

Acknowledgment
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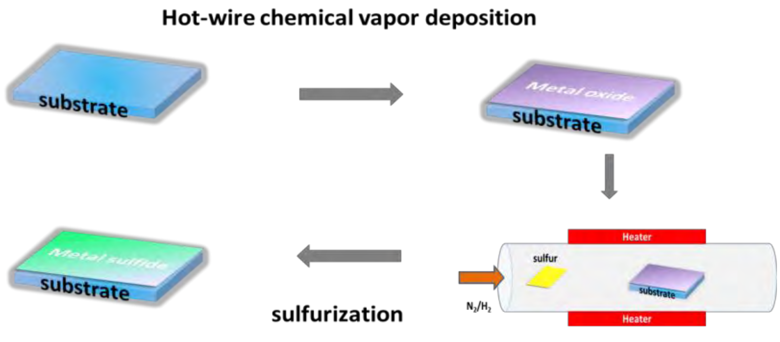

Figure 1: Schematic illustration of Mo and Ta sulfurization.

Can a SnTe/CdTe(001) heterostructure be a promising material to open an energy gap in its topological surface states?

Adrian Sulich[1]
Elżbieta Łusakowska[1], Wojciech Wołkanowicz[1], Piotr Dziawa[1], Janusz Sadowski[1,2], Badri Taliashvili[1], Tomasz Wojtowicz[3], Tomasz Story[1,3], and Jaroslaw Z. Domagala[1]
[1]Institute of Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, PL 02 668 Warsaw, Poland
[2]Department of Physics and Electrical Engineering, Linnaeus University, 391 82 Kalmar, Sweden
[3]International Research Centre MagTop, Institute of Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, PL 02 668 Warsaw, Poland
sulich@ifpan.edu.pl

Topological crystalline insulators (TCI) with a possibility of distortion-induced opening of an energy gap in their metallic surface states are attractive materials in the context of spintronics and infrared optoelectronics development. The potential candidates for such materials can be, for example, SnTe or SnSe-based crystals. For our studies [1] we selected a SnTe/CdTe(001) heterostructure on 2° off-cut GaAs(001), because the technology of TCI is based nowadays mostly on bulk crystals and it needs a development of layered materials grown on commercially available substrates (see also: [2]).
SnTe layers with the rock-salt structure and with different thicknesses ranging from 20 to 1000 nm were deposited by means of molecular beam epitaxy on CdTe buffer with zinc-blende structure and with a standard thickness of 4 µm. To study an impact of the growth conditions on the structural properties of the topological crystalline insulator layer, SnTe beam equivalent pressure (used as a parameter to control the layer growth rate) was changed from 4.4 to 4.8×10^{-7} mbar and Te/SnTe molecular beam flux ratio was changed from 0 to 0.0156.
Crystallographic and morphological analysis of the samples was performed, using high-resolution X-ray diffraction and atomic force microscopy, since breaking crystal symmetry is known to affect the material's topological properties [3]. The results showed almost complete relaxation of the CdTe lattice and partial relaxation of SnTe, increasing from 86.2% to 98.3% (together with the layer thickness). Anisotropy of the spatial distribution of defects was found, leading to the SnTe unit cell monoclinic distortion, detected in some samples. A new, curious SnTe surface morphology with reduced symmetry was observed, analysed and compared with a recent study, devoted to morphological and electrical properties of a related material (SnTe films deposited directly on GaAs (100) substrates) [4]. Due to the magnitude of the SnTe lattice strain ($\sim 10^{-3}$) measured in our samples, it can be predicted that it would be sufficient to affect the topological properties of this material.

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Resolving spin currents and spin densities generated by charge-spin interconversion in systems with reduced crystal symmetry

Josef Světlík[1,2]
L. Camosi[1], M. V. Costache[1], W. Savero Torres[1], I. Fernández Aguirre[1,2], V. Marinova[3], D. Dimitrov[3,4], M. Gospodinov[3,4], J. F. Sierra[1], S. O. Valenzuela[1,5]
[1]*Institut Català de Nanociència i Nanotecnologia, UAB Campus, Bellaterra (Barcelona), Spain*
[2]*Universitat Autònoma de Barcelona, Bellaterra, 08193 Barcelona, Spain*
[3]*Institute of Optical Materials and Technologies, Bulgarian Academy of Science, 1113 Sofia, Bulgaria*
[4]*Institute of Solid State Physics, Bulgarian Academy of Sciences, 1784 Sofia, Bulgaria*
[5]*Institució Catalana de Recerca i Estudis Avançats (ICREA), 08010 Barcelona, Spain*
Josef.svetlik@icn2.cat

Abstract

Charge-spin interconversion (CSI) phenomena in systems with spin-orbit coupling allow us to generate and detect spin information [1]. Crystal symmetries impose constrains on the CSI components and, in high-symmetry materials, the spin polarisation and the charge and spin currents are mutually perpendicular. Conversely, low-symmetry materials enable unconventional CSI components [2] which are potentially relevant for a new generation of efficient spintronic devices, such as spin orbit torque non-volatile memories [1,2,3]. The WTe_2 crystal is an example of a material with reduced symmetry that can exhibit unconventional CSI components. By performing multi-terminal nonlocal spin precession experiments, we investigate CSI phenomena in WTe_2-graphene heterostructure and discuss their origin by considering the symmetries of the WTe_2 bulk and of its interface with the proximitized graphene [4]. We acknowledge support from H2020 FET-PROACTIVE project TOCHA under Grant No. 824140. J S acknowledges funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 754558.

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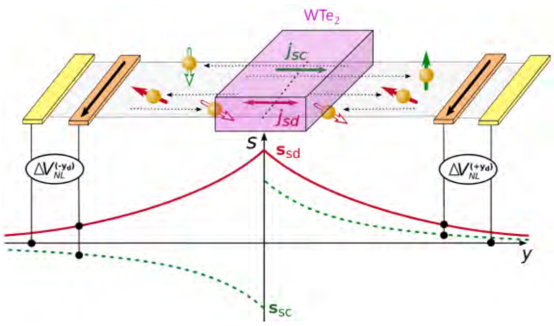

Figure 1: Sketch of the device geometry and generated spin currents (top) and spin electrochemical potential ***S*** (bottom). Spins generated in the CSI region diffuse in the spin channel towards ±y and are detected remotely in the FM electrodes (orange) by measuring the nonlocal voltage ΔV_{NL}. The spin currents J_{sc} and spin densities J_{sd} originate from the spin Hall current and the uniform spin accumulation in the CSI region associated to inverse spin galvanic effect, respectively.

Design of a Majorana trijunction

Juan Daniel Torres Luna
Sathish R. Kuppuswamy, Anton Akhmerov
Technische Universiteit Delft, Lorentzweg 1, Delft, The Netherlands
j.d.torresluna@tudelft.nl

Abstract
Braiding of Majorana states demonstrates their non-Abelian exchange statistics. Braiding requires control of the pairwise couplings between all Majorana states in a trijunction device [1]. In order to have adiabaticity, a trijunction device requires the desired pair coupling to be sufficiently large and the undesired couplings to vanish. In this work, we design and simulate of a trijunction device in a two-dimensional electron gas focusing on the normal region that connects three Majorana states. We use an optimization approach to find the operational regime of the device in a multi-dimensional voltage space. We then compare the performance of devices with different shapes and disorder strengths to determine the feasibility criteria for a braiding experiment.

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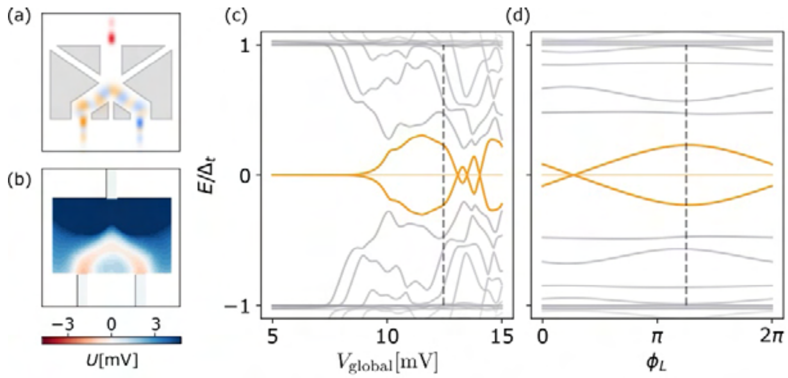

Figure 1: Coupling procedure of two Majorana states in a trijunction device. (a) Majorana wavefunctions. (b) Electrostatic potential. Spectra w.r.t. gate voltage (c) and phase difference (d).

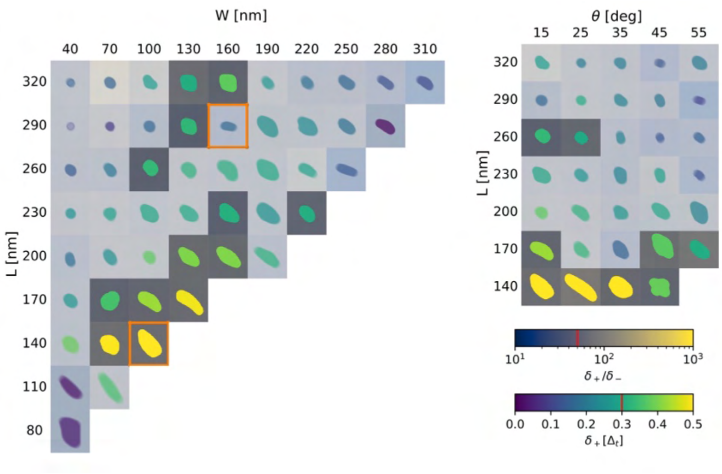

Figure 2: Device geometry dependence of the braiding quality metrics. Shapes correspond to operation voltage space. Geometries suitable for braiding are highlighted.

Induced superconducting correlations in the quantum anomalous Hall insulator

Anjana Uday[1]
Gertjan Lippertz[1,2], Kristoff Moors[3], Henry F. Legg[4], Andrea Bliesener[5], Lino M. C. Pereira[2], Alexey Taskin[1], Yoichi Ando[1]
[1]Physics Institute II, University of Cologne, Zülpicher Str. 77, 50937 Köln, Germany
[2]KU Leuven, Quantum Solid State Physics, Celestijnenlaan 200 D, 3001 Leuven, Belgium
[3]Institute for Semiconductor Nanoelectronics, Peter Grünberg Institute 9, Forschungszentrum Jülich, Germany
[4]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland
anjana@ph2.uni-koeln.de

Crossed Andreev reflection (CAR) has been reported in a hybrid quantum Hall (QH)/Superconductor (SC) system [1]. Similar experiments would be of great interest for quantum anomalous Hall (QAH) systems. It has been predicted that if Cooper pairing is induced in a QAH insulator, the system turns into a stereotypical spinless chiral p-wave superconductor associated with chiral Majorana edge states. In the QAH/SC system superconductivity can be suppressed by applying a magnetic field while keeping the 1D chiral edge state intact. Here, we report on multi-terminal hall-bar devices of V-doped $(Bi_xSb_{1-x})_2Te_3$ thin films with Nb electrodes of different widths. We observe a notable drop in the R_D when the SC electrode undergoes the normal-to-superconducting phase transition with decreasing magnetic field. Furthermore, a negative nonlocal voltage was observed for the narrowest Nb electrode contacting the chiral edge state of a QAHI, indicative of the CAR process. By changing the Nb width, the characteristic length of the CAR process is identified to be about 100 nm, which is three times longer than the superconducting correlation length in Nb. Our theoretical simulations suggest that strong disorder and induced superconductivity in the QAH insulator are crucial for this CAR process.

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Electron transport through a Majorana wire subject to quasiparticle poisoning

Florinda Viñas Boström
Patrik Recher
Institut für Mathematische Physik, Technische Universität Braunschweig, D-38106 Braunschweig, Germany
florinda.vinas-bostroem@tu-braunschweig.de

Majorana bound states (MBS) in semi-conductor quantum wires with proximity-induced superconductivity are promising candidates for storing and processing quantum information.[1,2] However, for such applications to become reality, several obstacles has to be overcome. One problem, common for all superconducting qubits, is quasiparticle poisoning.[3,4] Quasiparticle poisoning are processes where non-equilibrium quasi-particles interact with the superconductor, causing the total parity of the system to change. Such processes will destroy stored quantum information, and cannot be suppressed by increasing the spatial separation (hence decreasing the overlap) of a MBS pair.
We study electron transport through a quantum wire with MBSs, subject to an electrical bias via two leads with spin-momentum-locked electron channels. In an open systems approach, we find the current and the noise of the setup, with and without the quasi-particle poisoning present in the quantum wire. The quasi-particle poisoning is included as a phenomenological term in the Liouvillian of the master equation.
The results show how the current and noise behave in the presence of quasi-particle poisoning.

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Two-Dimensional-Dirac Surface States and Bulk Gap Probed via Quantum Capacitance in a Three-Dimensional Topological Insulator

Jimin Wang[1]
Cosimo Gorini[2], Klaus Richter[2], Zhiwei Wang[3,4], Yoichi Ando[3], and Dieter Weiss[1]
1 Institute of Experimental and Applied Physics,
University of Regensburg, 93040 Regensburg, Germany
2 Institute of Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany
3 Physics Institute II, University of Cologne, 50937 Köln, Germany
4 Key Laboratory of Advanced Optoelectronic Quantum Architecture and Measurement, Ministry of Education, School of Physics, Beijing Institute of Technology, Beijing 100081, China
jimin.wang@physik.uni-regensburg.de / dieter.weiss@physik.uni-regensburg.de

$BiSbTeSe_2$ is a 3D topological insulator (3D-TI) with Dirac type surface states and low bulk carrier density, as donors and acceptors compensate each other. Dominating low temperature surface transport in this material is heralded by Shubnikov–de Haas oscillations and the quantum Hall effect. Here, we experimentally probe and model the electronic density of states (DOS) in thin layers of $BiSbTeSe_2$ by capacitance experiments both without and in quantizing magnetic fields. By probing the lowest Landau levels, we show that a large fraction of the electrons filled via field effect into the system ends up in (localized) bulk states and appears as a background DOS. The surprisingly strong temperature dependence of such background DOS can be traced back to Coulomb interactions. Our results point at the coexistence and intimate coupling of Dirac surface states with a bulk many-body phase (a Coulomb glass) in 3D-TIs.

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Figures

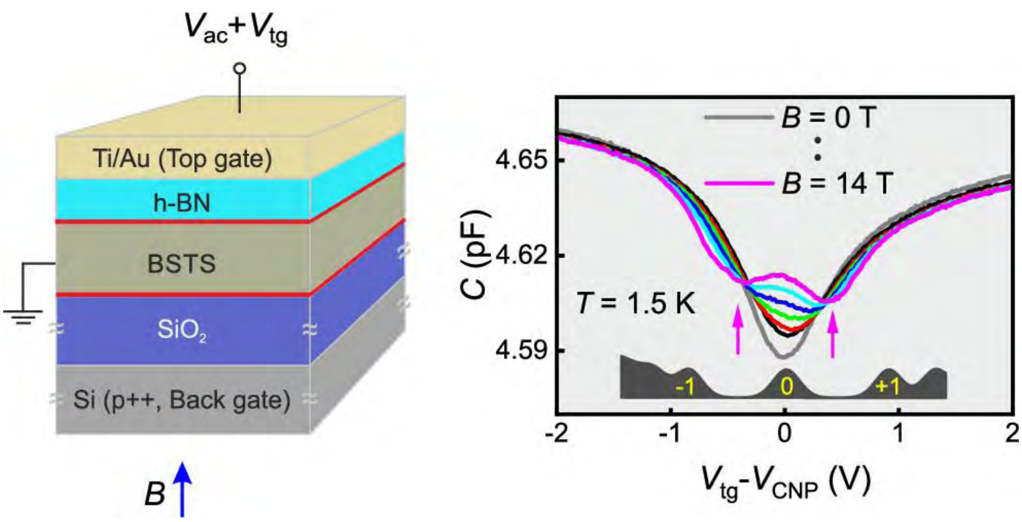

Figure 1: BSTS device schematic (a) and the magnetic field dependent quantum capacitance (b)

Magneto-transport properties of nanoflakes of the ferromagnetic topological insulator $MnSb_2Te_4$

Michael Wissmann[1,2]
Laurent Vila[1], Joseph Dufouleur[2], Bernd Büchner[2,3], Anna Isaeva[4] and Romain Giraud[1,2]
1 Université Grenoble-Alpes, CNRS, CEA, SPINTEC, F-38000 Grenoble, France
2 Leibniz Institute for Solid State and Materials Research IFW Dresden, 01069 Dresden, Germany
3 Institute of Solid State Physics, TU Dresden, 01069 Dresden, Germany
4 Department of Physics and Astronomy, University of Amsterdam, 1098 XH Amsterdam, Netherlands
Michael.wissmann@cea.fr

The new family of intrinsically magnetic van-der-Waals layered topological insulators Mn(Bi,Sb)Te, with strong spin-orbit coupling, is of great interest to investigate the interplay between topology and magnetic order in electronic band structures [1]. In presence of a long-range magnetic order in a 3D topological insulator, an exchange gap and/or the magnetic symmetry can generate topological quantum states, like the quantum anomalous Hall effect (QAH) or the axion insulator [2], which can be tuned by the magnetization.

Our recent studies consider the $MnSb_2Te_4$ compound, a ferromagnet with a perpendicular-to-plane anisotropy and a critical Curie-Weiss temperature as high as 35K. $MnSb_2Te_4$ has been controversially discussed to be a magnetic Weyl semimetal or a candidate to realize the axion insulator [3,4]. We investigated the thickness-dependent properties of exfoliated nanoflakes using magneto-transport measurements, revealing the change of important parameters such as the resistivity, the Curie temperature and the magnetic coercive field. Our results confirm the influence of both the intrinsic electrical doping and disorder in this material, and an analysis of the anomalous Hall conductivity does not give a proof of the existence of a magnetic Weyl semimetal.

More generally, a major limitation to realizing the topological quantum states in this material family is the intrinsic bulk charge carrier doping, effectively hiding the topological signatures in transport measurements. We present some results of a promising technique to passivate bulk charge carriers and tune the Fermi level using a low-power hydrogen plasma.

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Spin-charge interconversion in Topological insulator Sb_2Te_3

Salvatore Teresi[a], **Michael Wissmann**[a,], Maxen Cosset-Cheneau[a], Théo Frottier[a], Aurélie Kandazoglou[a], Paolo Sgarro[a], Cécile Grèzes[a], Nicolas Sebe[a], Pierre Noe[b], Jessy Patterson[b], Françoise Hippert[c], Jean-Philippe Attané[a], Laurent Vila[a]
[a]*Université Grenoble Alpes / CEA / IRIG / SPINTEC, Grenoble, France*
[b]*Université Grenoble Alpes / CEA / LETI, Grenoble, France*
[c]*Université Grenoble Alpes / CNRS / Grenoble INP / LMGP, Grenoble, France*
Michael.wissmann@cea.fr

Topological insulators (TIs) were strongly investigated in the last years in spintronics due to their large spin-orbit coupling that allows the onset on topological properties such as in Sb_2Te_3. This permits to obtain large spin-charge interconversion efficiencies. Furthermore, a big advantage of Sb_2Te_3 is the possibility of being deposited on a large-scale using magnetron sputtering. The combination of a good spin-to-charge interconversion efficiency and large resistivity makes TIs a good alternative to heavy metals to realize the read-out block of the MESO device [1]. The final goal is to achieve the 100 mV output necessary for spin-logic application. Alternatively, the inverse effect (charge-to-spin interconversion) can be useful in SOT applications.
There are mainly two ways of increasing the spin-charge interconversion output signal. By scaling device dimensions [2] and through the optimization of the spin injection [3]. Up to now, all these studies have been done in heavy metals. Our work instead focuses on applying these results to our magnetron sputtered TI. One of the biggest difficulties for their use is being able to nanopattern them without altering their physical properties, and to control the origin of the measured signal.
We will present the all-electrical measurement of the spin to charge interconversion in large-scale grown Sb_2Te_3 using nanodevices, which correspond to the read-out block of the spin-logic devices.

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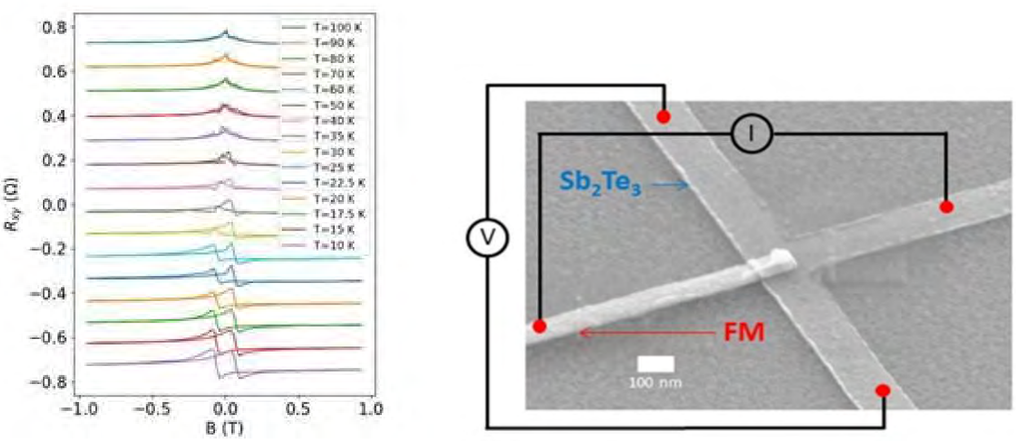

Figure 1: Left: Temperature dependence of the interconversion signal on Sb2Te3. Right: Nano patterned devices used for the measurement of the interconversion.

Phenomena of Majorana Wavefunctions in arbitrarily shaped Topological Superconductors.

Johanna Zijderveld
A. Mert Bozkurt, İnanç Adagideli, Michael Wimmer
TU Delft, Lorentzweg 1, Delft, Netherlands
Johanna@zijderveld.de

Majorana billiards are finitely sized and arbitrarily shaped topological superconductors which feature fermion parity switches. We investigate the properties of the Majorana wavefunction in these system through the lens of quantum chaos. For a certain parameter range, we map the problem of finding Majorana wavefunctions to finding the eigenfunctions of a normal state Hamiltonian. Within this regime, we find that Majorana wavefunctions are scarred along the same trajectory of their normal state counterpart. Furthermore, we observe that, before becoming a fully localized chiral edge state, the Majorana wavefunction displays signatures similar to caustics. Finally, we establish a connection between chiral Majorana modes and eigenfunctions of a normal state Hamiltonian under a magnetic field. Overall, our findings offer valuable insights into the properties of the Majorana wavefunctions and their relation to semiclassical physics and quantum chaos.

Figures

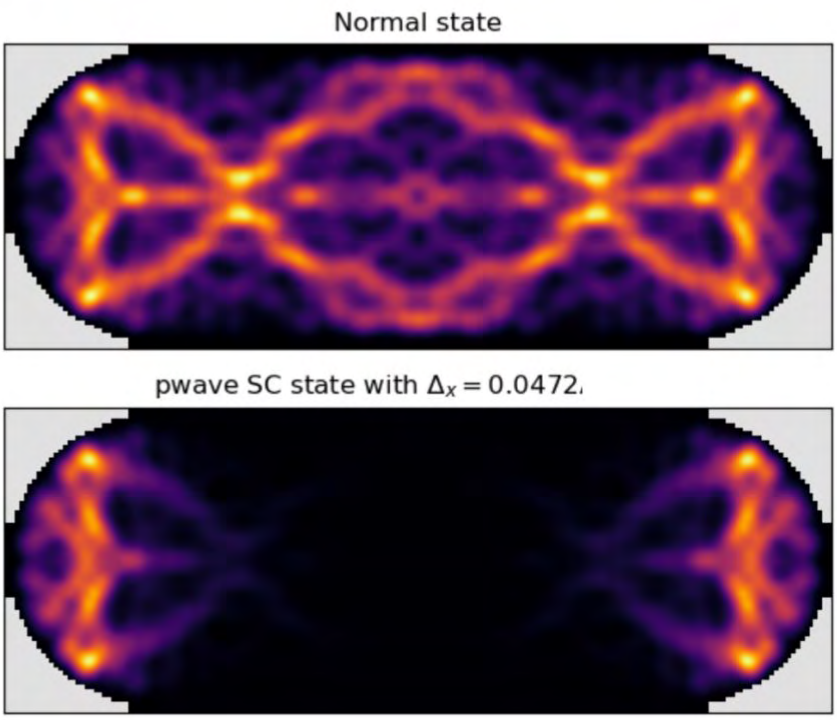

Figure 1: Top figure shows a scar in a stadium billiard shape governed by a regular Hamiltonian. Bottom figure shows the Majorana wavefunction localized at the ends of the same scar, where the Hamiltonian is a p-wave Hamiltonian with a superconducting gap in one direction.

What it takes to make a Majorana quantum computer

Anton Akhmerov
Kavli Institute of Nanoscience, Delft University of Technology, the Netherlands
topologicalmatterconf@antonakhmerov.org

Majorana modes are the simplest nonabelian anyons, and braiding them exerts a unitary gate on the state of a quantum system. In this tutorial I will explain what it takes to go from this fundamental property to making a quantum computer. This will require us to understand how to control many-body Majorana interactions and how to combine fermionic degrees of freedom with macroscopic coherent modes of superconducting circuits. I will also explain what distinguishes this approach from the mainstream implementations, and what the community still needs to make it work

Majorana modes are the simplest nonabelian anyons, and braiding them exerts a unitary gate on the state of a quantum system. In this tutorial I will explain what it takes to go from this fundamental property to making a quantum computer. This will require us to understand how to control many-body Majorana interactions and how to combine fermionic degrees of freedom with macroscopic coherent modes of superconducting circuits. I will also explain what distinguishes this approach from the mainstream implementations, and what the community still needs to make it work.

Physics of topological magnetic skyrmions and potential skyrmion-based applications

Vincent Cros
Unité Mixte de Physique, CNRS, Thales, Université Paris-Saclay
Vincent.cros@cnrs-thales.fr

The aim of the tutorial will be to introduce why, and to present how, the concept of topology and chirality can also be exploited in modern magnetism [1] as a mean to stabilize and manipulate some novel magnetic quasi-particles such as magnetic skyrmions (see Fig. 1a) that might be technologically relevant [2-3]

I will first shortly introduce the micromagnetic modelling of these magnetic skyrmions and review the material multi-layered systems which have been developed in the last couple of years allowing the room temperature stabilization of these non-collinear spin nano-textures. I will then describe what are the different mechanisms for skyrmion nucleation and introduce the mechanisms of spin-orbit torque responsible for the motion of skyrmions in nanostructures. Another important experimental demonstration achieved recently has been the electrical detection of topological spin textures. Finally, I will describe how these basic bricks i.e. skyrmion nucleation, motion and detection can be combined for the development of skyrmion based devices for logic gate operations or neuromorphic computing.

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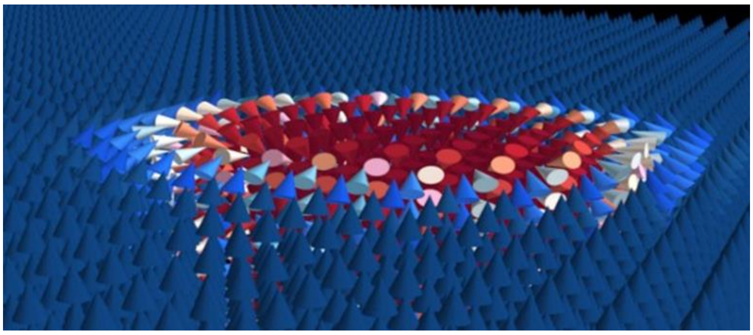

Figure 1: Schematic view of an isolated magnetic skyrmion

EU grant SKYTOP (H2020 FET Proactive 824123), FLAG-ERA SOgraphMEM, FET Pathfinder TSAR (964931 and ANR-20-CE42-0012-01(MEDYNA) are acknowledged for their financial support.

Synthetic magnets, spins, and dimensions: Topological phases in nanophotonics and nanophononics

Ewold Verhagen
Center for Nanophotonics, AMOLF, Science Park 104, Amsterdam, the Netherlands
verhagen@amolf.nl

The fascinating properties of electronic topological insulators have inspired the investigation of analogous effects for bosonic degrees of freedom such as light and sound [1,2]. The idea of topological protection is especially appealing for photons and phonons in nanoscale, chip-based platforms, due to their rich application potential and the importance of disorder. However, the absence of magnetic-field interactions and Kramers degenacy necessitates the pursuit of alternative mechanisms for bosons than the well-known quantum (spin) Hall effects. In this tutorial, I will discuss several alternative mechanisms, placing special emphasis on experimental implementations.
First, I discuss the creation of topological insulators based on the tailored breaking of crystal symmetries [3]. As this requires only passive, structured media, it is especially suited to be realized in two-dimensional photonic and phononic crystals. With full control over unit cell geometries, this concept offers a lot of versatility to design effective material properties at will and observe various kinds of topological states [4,5], while their bosonic nature also presents some important limitations and differences with respect to electronic alternatives.
Second, we take a look at suitable forms of spatiotemporal modulation to effectively break time-reversal symmetry and create synthetic magnetic fields for light and sound [6]. As an interesting testbed, we consider optomechanical systems, where multiple coupled optical and mechanical resonators, interacting through radiation pressure and controlled through laser fields, can be configured to emulate physics similar to the quantum Hall effect [7,8]. I will discuss future opportunities in this area, and specifically highlight the special properties that emerge when combining breaking of time-reversal symmetry with controlled amplification and damping, to induce non-Hermitian topological phases with new properties.

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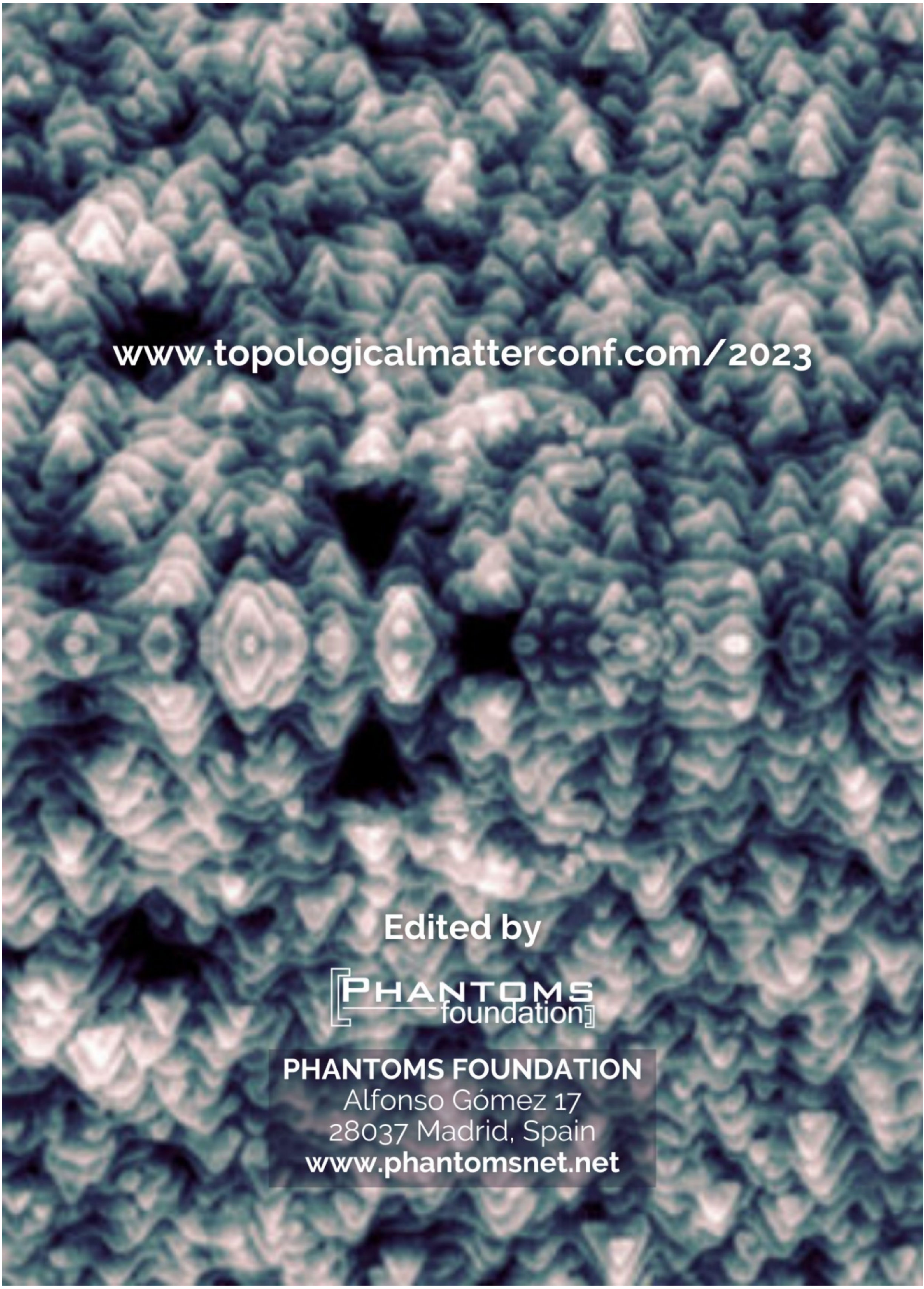

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PHANTOMS FOUNDATION
Alfonso Gómez 17
28037 Madrid, Spain
www.phantomsnet.net