Topological Matter School
San Sebastian 2018

Book of abstracts

August 24, 2018

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Hidden order in '122' class of Fe-based superconductors

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Among high-temperature superconductors, Fe-based compounds have attracted much attention during past decade, where the parent compounds are metals exhibiting spin density wave (SDW) phase in the ground state and charge carrier doping leads to superconductivity via suppression of magnetic order. We studied the evolution of complex Fermiology of $CaFe_2As_2$ with temperature using Angle Resolved Photoemission (ARPES) spectroscopy. $CaFe_2As_2$ undergoes a transition from tetragonal paramagnetic to orthorhombic spin density wave (SDW) state at 170 K. Application of small pressure (>0.35 GPa) leads the system to non-magnetic collapsed tetragonal (cT) phase (c axis length is compressed) in the ground state [1,2]. The high Tc (> 45 K) in $CaFe_2As_2$ under pressure and/or chemical substitution was often attributed to cT phase [2], despite the belief that superconductivity and correlated antiferromagnetic fluctuations are closely related in Fe-based compounds making cT phase unfavorable for unconventional superconductivity.

ARPES measurements were carried out at the Electron Spectroscopy Lab, TIFR, India and VUV beamline, Elettra, Trieste using VG Scienta R4000 analyzer at an energy resolution better than 15 meV. Valence band spectra at different conditions reveal importance of the interplay between covalency and correlation induced effects in the electronic structure [3-5]. ARPES data [3, 6] show signatures of Fermi surface nesting due to SDW transition and an evolution from 2D to 3D Fermi surface consistent with earlier results [7]. Curiously, the signature of the Fermi surface reconstructions appears at temperatures much lower than 170 K, which is unusual. Moreover, some of the hole pockets appear to expand with the decrease in temperature. The spectra at 30 K are even more complex with distinct signature of an additional contribution due to cT phase indicating coexistence of the cT phase hidden within the orthorhombic phase although all the bulk studies do not show signature of such scenario [6]. Clearly, application of pressure helps to manifest such hidden phases and it appears difficult to rule out the role of cT phase in superconductivity in these materials although cT phase is non-magnetic.

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Unconventional superconductivity induced in s-wave superconductors by adsorbed chiral molecules

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Following recent discoveries regarding the unique properties of chiral molecules which serve as spin filters and induce spontaneous magnetization, we investigated the effect of chiral molecules on singlet s-wave superconductors. Using scanning tunneling spectroscopy on thin Nb films coated with chiral polyalanine alpha-helix molecules we found evidence for the emergence of a triplet-pairing chiral p-wave superconducting component. A similar effect was also shown to be prominent on thin Au films grown epitaxially onto NbN - a proximal superconductor where STS measurement in magnetic field further supported the emergence of p-wave superconductivity. Finally we performed Andreev spectroscopy measurements on thin $NbSe_2$ flakes exfoliated over Au electrodes before and after chiral molecules adsorption. Upon adsorption, the differential conductance spectra change their shape significantly, and in particular exhibit a narrow and pronounced zero bias conductance peak, which vanishes above $T \sim 0.5T_C$ and parallel magnetic fields well below H_{C2} of $NbSe_2$. These measurements provide further evidence for the emergence of unconventional superconducting order-parameter upon chiral molecule adsorption. The

accumulation of evidence for the ability of chiral molecules to alter the symmetry of conventional superconductors may open a novel way for realizing simple superconducting spintroinics devices.

Crystal phase control in an $YBiO_3$ thin film by using a $BaBiO_3$ buffer layer

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Topological insulators have a non-trivial band structure, forming gapless surface states when coupled to a normal insulator. Until now, applications are hindered by the competition between the insulating bulk and conducting surface states. Perovskite oxides offer a good alternative, since topological insulating phases are theoretically predicted with band gaps larger than the thermal excitation energy at room temperature [1]. Therefore, promising applications for these materials lie in the fields of quantum computing and spintronics.

In $YBiO_3$, a topological insulating phase is predicted for the perovskite crystal structure with yttrium and bismuth located at the A-site and B-site, respectively [2]. However, the fluorite phase is thermodynamically more stable than the perovskite phase as proven when an $YBiO_3$ film is grown directly on a $SrTiO_3$ substrate. By using a buffer layer, a possibility is given to stabilise the perovskite phase in the $YBiO_3$ film.

As buffer layer material $BaBiO_3$ is chosen, since it grows in the perovskite phase and has a comparable lattice constant as predicted for the perovskite $YBiO_3$ structure. By various characterisation techniques, it is shown that $BaBiO_3$ grows as a single oriented perovskite film in a relaxed state despite the large lattice mismatch with the underlying $SrTiO_3$ substrate.

When the $YBiO_3$ is deposited on top of the buffer layer, a single oriented perovskite phase is also observed in this film with the expected lattice constants. These findings pave a way towards the fabrication of quantum devices for testing the hypothesised topological insulating phase in $YBiO_3$.

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Effect of confinement and correlations in the 2-dimensional electron gas at the LAO/STO (111) interface

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The LAO/STO interface has been known since 2004 to host a 2-dimensional electron gas (2DEG). In this work we use the Poisson Schrodinger model to model the (111) interface which presents several differences with the (001) interface. In particular the symmetry between the t_{2g} orbitals keeps them equivalent with respect to confinement. Recent magneto-transport experiments probing the properties at the (111) interface have uncovered a transition from single electron-like to two-carrier electron-like transport as a positive backgate voltage is applied to the system. We show that this behavior can be explained by Coulomb interaction when we include Hubbard correlations as well as electrostatic gating to our model. The experimental trend is then favorably captured.

Topological phases on fractal geometries

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Existing classifications of topological phases rely on the symmetries as well as on the number of spatial dimensions being an integer. However, equipped with a notion of locality and the possibility to take a thermodynamic limit, the classification schemes can be extended to be suitable for quantum states on general graphs. In particular, one can consider fractal geometries characterized by (non-integer) Hausdorff dimension and ramification number. Here, we investigate two fractal lattices, Sierpiński carpet and gasket, exposed to an external magnetic field. By examining spectral and localization properties, together with the Chern number calculations and level spacings analysis in a presence of disorder, we would like to ask whether these systems can exhibit features normally associated with quantum Hall states. Based on arXiv:1807.00367.

$\mathbb{Z}_4$ parafermions on 1D fermionic lattices

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Parafermions are emergent excitations which generalize Majorana fermions and are potentially relevant to topological quantum computation. Using the concept of Fock parafermions, we present a mapping between lattice $\mathbb{Z}_4$-parafermions and lattice spin-1/2 fermions which preserves the locality of operators with $\mathbb{Z}_4$ symmetry. Based on this mapping, we construct an exactly solvable, local one-dimensional fermionic Hamiltonian which hosts parafermionic zero-energy states. We numerically show that the parafermionic phase remains stable in a wide range of parameters, and discuss its signatures in the fermionic spectral function.

Dynamically Induced Topology in the Fermi Sea

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(Dated: July 29, 2018)

We study the dynamics of topological bound states following their coupling to the Fermi sea of a topologically trivial, gapless lead. We consider both regular and Majorana fermion bound states; specifically, we study the quench dynamics of solitons in the Su-Schrieffer-Heeger model and of Majorana zero modes of the one-dimensional Kitaev model. Remarkably, we find that as the bound states leak into and propagate through the lead, physical properties that characterize their topological nature, such as fractional charge and exchange statistics, survive in the lead. We explain this phenomenon as a manifestation of *dynamically induced topology* in the Fermi sea arising from the entanglement between the topological and gapless systems. We obtain, both analytically and numerically, topological features of propagating bound states, including their fractional charge, charge fluctuations, entanglement entropy, and fractional statistics. This allows us to characterize the coherence time over which these topological features relax. We also study the effects of interactions and disorder in the lead on the integrity of the topological bound states and the coherence time of dynamically induced topology.

Towards exotic topological states in parallel semiconductor nanowires

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Recent advances in semiconducting nanowire device fabrication have resulted in the first tentative evidence for Majorana bound states in solids. Our aim is to extend the family of such semiconductor-superconductor hybrid structures to devices with two parallel nanowires, which might, for example, result in new types of topologically non-trivial electronic states like fractional Majorana bound states (parafermions), envisioned as potential building blocks for topological quantum computing.

The recent detection of signatures of Majorana bound states (MBSs) in semiconducting nanowires (NWs) coupled to a superconductor [1] has been a breakthrough in the field of topological condensed matter physics, and triggered a series of efforts to use MBSs as fault tolerant topological quantum bits. Parafermions, sometimes referred to as fractional MBSs, promise a more complete set of quantum gates, and are predicted to occur in parallel NWs coupled by a superconducting island [2].

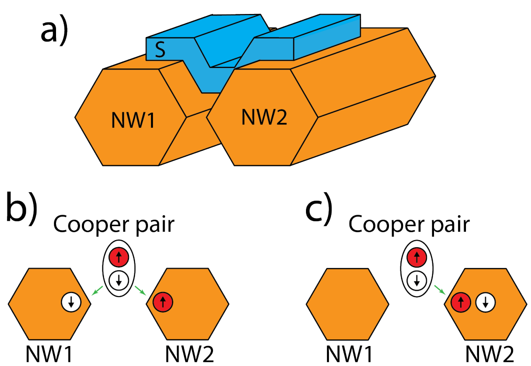

FIG. 1. **(a)** Schematic of a double NW device with an S island. The red asterisks indicate the formation of parafermions. (b) and (c) Illustrations of pairing by CPS and LAR, respectively.

The device concept is illustrated in Fig. 1(a): two NWs with differing spin-orbit interaction are coupled to a common superconducting island, S. In addition to the local Andreev reflection (LAR) between each NW and the island [see Fig. 1(c)], the electrons of a Cooper pair can also tunnel to different NWs [see Fig. 1(b)], in a nonlocal process called crossed Andreev reflection or Cooper pair splitting (CPS). If CPS domintates over LAR, it is expected that the S-NW system enters a topologically non-trivial phase, with parafermions forming at the boundary to the normal state NW segments, see Fig. 1(a).

We have recently demonstrated the first CPS device [3] based on parallel NWs, with a splitting efficiency of $\sim 20\%$. Previous experiments have shown that CPS can dominate over local processes in similar devices [4], with efficiencies $> 80\%$. The main focus of our current efforts lies on contacting individual NWs in a four-terminal parallel NW configuration. Figure 2 shows a prototype

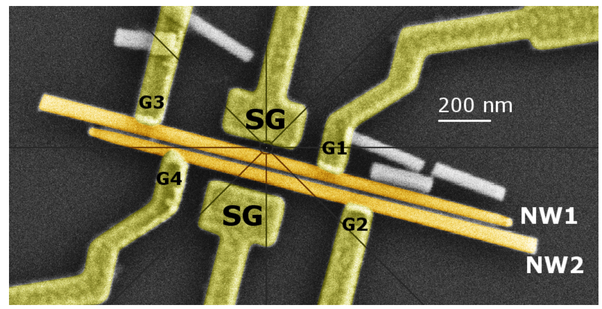

FIG. 2. False-color SEM image of a parallel NW device. Two InAs nanowires (NW1 and NW2) with ~ 40 nm diameter are individually contacted by normal metal gold contacts (G1-G4) and tuned capacitively by two sidegates (SGs).

device that resulted from our optimised alignment and electron beam lithography techniques. After having established a reliable fabrication process, our next goals is to characterise the spin-orbit interaction in the individual NWs and to couple them by a common superconducting island.

This project is financially supported by QuantERA - SuperTop project, the NCCR QSIT, the SNF as well as the Swiss nanoscience institute (SNI).

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Anomalous higher-order topological insulators

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Topological multipole insulators are a class of higher order topological insulators (HOTI) in which robust fractional corner charges appear due to a quantized electric multipole moment of the bulk. This bulk-corner correspondence has been expressed in terms of a topological invariant computed using the eigenstates of the Wilson loop operator, a so called "nested Wilson loop" procedure. We show that, similar to the unitary Floquet operator describing periodically driven systems, the unitary Wilson loop operator can realize "anomalous" phases, that are topologically non-trivial despite having a trivial topological invariant. We introduce a concrete example of an anomalous HOTI, which has a quantized bulk quadrupole moment and fractional corner charges, but a vanishing nested Wilson loop index. A new invariant able to capture the topology of this phase is then constructed. Our work shows that anomalous topological phases, previously thought to be unique to periodically driven systems, can occur and be used to understand purely time-independent HOTIs.

Majorana bound state engineering via efficient real-space parameter optimization

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Recent progress towards the fabrication of Majorana-based qubits has sparked the need for systematic approaches to optimize experimentally relevant parameters for the realization of robust Majorana bound states. Here, we introduce an efficient numerical method for the real-space optimization of tunable parameters, such as electrostatic potential profiles and magnetic field textures, in Majorana wires. Combining ideas from quantum control and quantum transport, our algorithm operates on a largely unexplored parameter space and opens new routes for Majorana bound states with enhanced robustness. Contrary to common belief, we find that spatial inhomogeneities of parameters can be a resource for the engineering of Majorana-based qubits with improved coherence.

Majorana flat bands in magnetic skyrmions

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Magnetic skyrmions are nanometer-scale magnetic textures that are easily created and manipulated in the laboratory[a]. Some previous work[b] has shown that under certain conditions magnetic skyrmions can host a Majorana zero-mode (MZM) in their core when proximitised by a s-wave superconductor (SC). We extend this work by analysing in greater detail some other spectral features of this system and find a Majorana flat band (MFB) located at the edge of the skyrmion. We show that these Majorana states can be viewed as the edge modes of a set of uncoupled Rashba wires. Based on a local real-space interpretation of these states, we prove, both analytically and numerically, that this Majorana flat band is stable with respect to different kinds of perturbations. Finally, we discuss experimental setups where this physics could be realised as well as observable consequences for Scanning Tunneling Spectroscopy/Microscopy.

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Two-dimensional Superconductivity at Oxide Interfaces and Topological Invariants

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The research in the field of topological insulators and superconductors is evolving progressively [1]. We focus on two-dimensional (2d) topological s-wave superconductivity which shows — exposed to external magnetic fields — non-trivial topological electron states when Rashba spin-orbit coupling is present [2]. Whithin this setup the 2d s-wave superconductor is topologically non-trivial for fields strengths above a critical field H_c while overall three different critical fields exist. Under field rotation the values for those critical fields can be lowered significantly and thus may be accessible experimentally. For magnetic fields with in-plane components finite center-of-mass momentum pairing (COMM) is encountered [3]. In reciprocal space, the non-trivial topological states are characterized by the existence of a meron-like spin texture and its counting number is shown to be a topological invariant [4]. An outstanding canditate for such a topological superconducting system is the interface of $BaBiO_3$ and $BaPbO_3$ where the superconducting interface was shown to be two-dimensional while strong Rashba spin-orbit coupling is supposed to be present [5].

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Universal quantum noise in adiabatic pumping

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We consider quantum pumping in a system of parafermionic zero-modes. Our pumping protocol, which employs the topologically protected degeneracy of parafermions, leads to an unconventional noisy behavior of the pumped current. Namely, as the adiabatic limit is approached, the noisy behavior persists, and the counting statistics of the pumped current becomes robust and universal. In particular, the resulting Fano factor is given in terms of the system's topological degeneracy and the pumped quasiparticle charge. Our results are also applicable to the more conventional Majorana fermions.

Transport properties and quantum oscillations in topological insulators Bi_2Te_3 and $BiSbTe_3$

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In this work we present results of the synthesis and electric transport measurements in Bi_2Te_3 and $BiSbTe_3$ single crystals. For the synthesis, high-purity (> 6N) elements were chosen for the melting and single-crystal growth, using the Bridgman-Stockbarger technique.

The crystals were studied by single-crystal and powder X-ray diffraction (XRD), scanning electron microscopy and energy dispersive X-ray spectrometry (SEM/EDS), to confirm a unique phase with correct structure and stoichiometry. The resistance, magnetoresistance, Hall effect and thermoelectric power were measured in the *ab* plane of the crystals, the resistance decreasing between 300 K and 1.8 K, with a ratio $R(300\,\mathrm{K})/\mathrm{R}(1.8\,\mathrm{K}) \sim 10$. The power factor, $P = \sigma S^2$, reaches a high value of $932\,\mu\mathrm{WK^{-2}m^{-1}}$ at 300 K, which confirms the capability of these materials as thermoelectric generators. The magnetoresistance, measured up to 9 T in a PPMS DynaCool system equipped with a rotor, clearly shows the existence of Shubnikov-de Haas (SdH) quantum oscillations at low temperature, with the temperature dependence following closely the Lifshitz-Kosevich law for the SdH effect. The fit of this law to the damping of the amplitude with temperature establishes an effective mass for the carriers $m*/m_e = 0.14$.

Polarized emission spectra of plasmon–molecule system

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It has been recently observed that a system consisting of strongly coupled surface plasmon polaritons (SPP) and fluorescent molecules can emit s-polarized light [S. Baieva et al., ACS Photonics, **2017**, 4(1), 28–37], even though the pure SPP produces only p-polarized light. To explain the s-polarized emission, we include the vibrations of the molecules in the microscopic Hamiltonian. This leads to an additional channel of decoherence in the SPP–molecule system. Using the input-output equations, we construct a modification of the $P(E)$ theory, used in the context of dynamical Coulomb blockade, to describe the vibrations. Both the s- and p-polarized spectra can be obtained from the $P(E)$ theory and can be characterized with only a few parameters.

Interacting majorana chain in presence of disorder

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We investigate a majorana chain model with potential applications to the description of Kitaev edges. The model exhibits various topological phases which are separated by critical lines. Since the non-interacting system belongs to class BDI one would expect these lines to remain critical in presence of disorder if the interaction is sufficiently weak. Recent numerical studies using DMRG confirm this for attractive interactions. For strong repulsive interactions, these studies find that the system localizes. Our preliminary results show localization also for weak repulsive interaction. We want to understand the mechanism that drives the system into localization despite topological protection. To reach this goal we employ both DMRG calculations and diverse analytical RG-schemes. Our results from DMRG suggest spontaneous breaking of the translation symmetry. This cannot be understood from the weak disorder and weak interaction RG around the clean noninteracting fixed point (FP), where the interaction is irrelevant. Hence we investigate the stability of the infinite randomness FP against weak interaction. The wave functions exhibit (multi)fractality. Correlators are again computed analytically using a SUSY transfer matrix techniques. This approach is augmented by results from exact diagonalization. From their scaling behaviour we want to deduce the interaction RG flow.

Inversion-symmetry protected chiral hinge states in stacks of doped quantum Hall layers

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We prove the existence of higher-order topological insulators with protected chiral hinge modes in quasi-two-dimensional systems made out of coupled layers stacked in an inversion-symmetric manner. In particular, we show that an external magnetic field drives a stack of alternating p- and n-doped buckled honeycomb layers into a higher-order topological phase, characterized by a non-trivial three-dimensional $\mathbb{Z}_2$ invariant. We identify silicene multilayers as a potential material platform for the experimental detection of this topological insulating phase.

Biorthogonal Bulk-Boundary Correspondence in Non-Hermitian Systems

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One of the main features of topological phases of matter is bulk-boundary correspondence, which links the presence of topological boundary states to a non-trivial topological bulk invariant. Recently, it was realized that this famed bulk-boundary correspondence generally breaks down in topological systems that are described by non-Hermitian Hamiltonians. While the Bloch bands of the periodic Hamiltonian thus fail to provide useful information for the open system, we show that such models can be accurately quantified by making use of so-called biorthogonal quantum mechanics leading to the concept of biorthogonal bulk-boundary correspondence, which is formulated directly in the open system. On my poster, I present our findings by showing explicit examples of the non-Hermitian SSH chain and a non-Hermitian Chern insulator by making use of a generic method with which we can find exact solutions for the right and left eigenvectors of the boundary modes. This poster is based on Phys. Rev. Lett. **121**, 026808 (2018).

Strained-induced Landau levels in graphene: a momentum-resolved perspective

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Graphene hosts massless Dirac fermions in its bandstructure. This opens the possibility of producing artificial gauge fields by strain engineering, leading to exotic effects such as Landau quantization in the absence of magnetic fields. Here we present theoretical modelling which supports the identification of momentum-resolved, strain-induced Landau levels in graphene with ARPES.

Signatures of Spin Polarized Drumhead Surface States in Quasi Particle Interference

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We investigate nodal line semimetals (NLSM) with reflection symmetry protected band crossings defined on a hexagonal lattice by means of a two orbital tight-binding model. Including spin-orbit coupling (SOC) either gaps the nodal line or splits a Dirac line node into two Weyl nodal lines, depending on the precise form of SOC allowed by symmetry. We investigate the fate of the nodal line and the associated drumhead surface states. We find that the drumhead surface states split and become spin polarized. They remain robust even under gapping the nodal line. It is shown that quasi particle interference (QPI) measured with spin resolved STM can be used to probe the dispersion and spin polarization of the drumhead surface states.

Study of topological wires: topological phases of a Kitaev ladder and transport through a Kitaev wire.

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This work is divided in two parts and is focused on topological wires. In the first one, we investigate the topological properties of a Kitaev ladder, i.e. a system made of two Kitaev chains coupled together site to site by transversal hopping and pairing term t_1 and Δ_1, respectively. Using the winding number invariant [4], we present the topological phase diagram of the system; in particular, we find that for some critical values of the transversal hopping t_1 and at a given transversal paring Δ_1, the topological phase survives also when the Kitaev criterion for the single chain ($\Delta > 0$, $|\mu| < 2t$) is violated [1],[2]. Using a numerical analysis we verify the bulk-edge correspondence. In the second part, we study the transport through a topological nanowire described by a Kitaev chain, tunnel coupled to a normal and a superconducting lead. We use a scattering matrix approach that allows us to study the evolution of the Andreev bound states (ABS) [3] and Majorana fermions at varying the position of the normal tip along the Kitaev wire. We analyze the conductance as a function of the applied bias voltage to characterize the topological phase via the zero bias peak. The results could be useful to describe local spectroscopic measurements of topological nanowires.

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A Scanning Tunneling Microscopy investigation of the Non-Centrosymmetric Sn_4As_3

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The lack of an inversion centre in non-centrosymmetric materials can lead to spin-split electronic states in the bulk of the material due to spin-orbit coupling (SOC). This can result in the appearance of complex electronic band structures and spin textures, such as Dirac surface states[1]. Moreover, when in addiction superconductivity is present, the inversion symmetry breaking makes the mixing of spin-singlet and spin-triplet Cooper pairing channels possible[2]. If the pairing interactions allow it, a triplet component in the superconducting order parameter is present, while on the other hand, conventional s-wave superconductivity prevails[3]. The detection of such a triplet component promises to open a window to study unconventional superconducting condensates as well as potential for applications in topological quantum computations.

The non-centrosymmetric Sn_4As_3 is metallic in nature and is a superconductor at temperatures below 1.2K [4, 5]. Although it has been known for the past 90 years, there is no extensive study of its electronic properties and its superconductivity. Only recently, interest has been revived [4]. Here we investigate both normal and superconducting phases of Sn_4As_3 by low-temperature scanning tunnelling microscopy (STM) and spectroscopy (STS). Topographic images reveal high-quality atomically resolved surfaces with different types of surface defects. Differential conductance maps were measured over large surface areas to study the existence of quasiparticle interference (QPI), to reveal more information on the electronic states. At a temperature of 50mK, the differential conductance spectra show a fully formed superconducting gap, which can be well described by a conventional s-wave gap, without the need for an unconventional component of the order parameter. Our results further reveal an upper critical field of only 10mT.

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Interfacing Topological Insulators with Magnetic Adlayers: Fe_3O_4 on Bi_2Te_3

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A gap opening at the Dirac point is predicted for topological insulators in the presence of a disorder potential that violates the time reversal symmetry. This can lead to many interesting novel phenomena, such as the quantum anomalous Hall effect. A breaking of the time reversal symmetry can be realized, for example, by introducing magnetic order. There are two experimental approaches: doping the topological insulator material with transition metal elements or interfacing the topological insulator with a layer of a magnetic insulator. To avoid effects of a non-uniform distribution of the doped elements, we follow the latter approach, and study the effect of a magnetic adlayer. In our previous work, we have successfully prepared Bi_2Te_3 films by molecular beam epitaxy with high purity and surface cleanliness [1]. This allows us to measure directly the conductivity of the topological surface states [1], and to cap and protect them without affecting their dispersions nor their charge filling [2]. In the next step we are taking up the challenge to prepare ultra clean interfaces of this type of topological insulators with magnetic layers and to measure their properties. Hereby we make use of our expertise of growing high quality films of Fe_3O_4 [3-5], and interface the well-defined Bi_2Te_3 films with these ferrimagnetic films. Here, we present our study on the growth of Fe_3O_4 on Bi_2Te_3.

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Towards atomically thin molybdenum disulfide nanostructures with gold bottom contact

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Investigation of transition metal dichalcogenide (TMDCs) semiconductors could bring interesting physical phenomena due to their strong spin orbit interaction in the conduction band and valence band. Despite the advances in investigation of van der Waals heterostructure, the very fundamental nature of metallic contact to TMDCs has been under debate. Here, we investigate the transport properties of molybdenum disulfide to Au metallic bottom contact. Fabrication of the stack of MoS_2 encapsulated with hexagonal boron nitride (hBN) is conducted in a N_2 atmosphere. We speculate that Au contact provides a small Schottky barrier height which facilitates the transport study of MoS_2.

INTRODUCTION

Semiconducting TMDCs have been widely investigated to be utilized in quantum computing and study of physical phenomena [1]. For instance, magnetotransport measurements on bilayer MoS_2 revealed large effective mass and density-dependent Zeeman splitting, since top and bottom MoS_2 feel different electric potentials upon gating [2]. MoS_2 is formed by hexagonal arrangement of metal atoms sandwiched by a strong covalent bond between chalcogenide atoms. The broken inversion symmetry in the crystallographic structure of MoS_2 leads to novel applications in the field of electronics and optoelectronics. The observed splitting of the valence band maximum around the high-symmetry point K in MoS_2 is attributed to the spin orbit interaction [3].

The formation of low-resistance contacts is an obstacle which requires to be addressed carefully. The Schottky barrier height (SBH) not only depends on the work function of the contact metal and the band structure of the semiconductor, but also to the cleanness of the contact interface. While Au has a weak adhesion to surface sulfur atom, Ti has a strong adhesion to the surface sulfur atom. Consequently, Ti contact leads to Fermi level pinning near the conduction band of MoS_2, due to the metallization of the MoS_2 in the proximity of the contact area. However, Au contact leaves the Fermi level in the middle of the conduction band and valence band leaves the material intrinsic [4].

Here in this study, we are introducing the very first steps to fabricate Au bottom contacts to n-type MoS_2. The advantage of this method is the MoS_2 flake is not introduced to any agent or any processing step. Moreover, encapsulation of MoS_2 with hexagonal boron nitride (hBN) flakes suppresses scattering event in the bulk of MoS_2, screens trapped charges in the substrate and enhances mobility [5]. Fig. 1(a), and (b) show the schematic and the optical microscopy of the device respectively. After deposition of bottom contacts on bottom hBN, we mentored atomic force microscopy (AFM) in contact mode at medium force in order to clean the surface from residual polymer left from lithography steps. A selected set of top hBN and MoS_2 has been transferred on the stack within an inert N_2 atmosphere (partial pressure O_2 and H_2O <0.1 ppm).

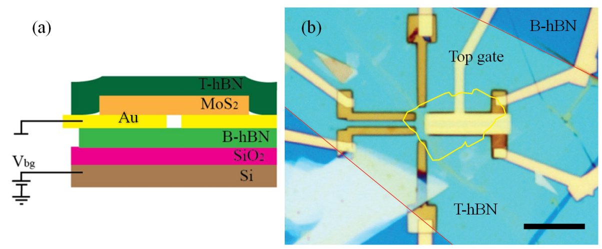

FIG. 1. (a) Schematic and (b) optical microscopy of the bottom contact Au/MoS_2. Outline shows the edge of monolayer flake. The scale bar is 10 μm.

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Linear optical responses of chiral multifold fermions

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It has been recently discovered that the traditional classification of fermions in Majorana, Weyl and Dirac types can be enhanced in solid-state systems with additional types of fermionic excitations known as multifold fermions, protected by point group symmetries. In this work we calculate their linear optical conductivity, in realistic low energy and lattice models of materials that exhibit multifold fermionic excitations.

Higher-Order Topological Phases

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The mathematical field of topology has become a framework to describe the low-energy electronic structure of crystalline solids. A typical feature of a bulk insulating three-dimensional topological crystal are conducting two-dimensional surface states. This constitutes the topological bulk-boundary correspondence. Here, we extend the notion of three-dimensional topological insulators to systems that host no gapless surface states, but exhibit topologically protected gapless hinge states. Their topological character is protected by spatio-temporal symmetries. We furthermore establish that the electronic structure of bismuth, an element consistently described as topologically trivial, is in fact topological and follows this generalized bulk-boundary correspondence of higher-order. The type of hinge states discussed here may be used for lossless electronic transport, spintronics, or – when proximitized with superconductivity – for topological quantum computation.

Topological superconductivity in the extended Kitaev-Heisenberg model

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We discover new superconducting pairing symmetries in the doped Kitaev-Heisenberg model when including the recently proposed symmetric off-diagonal exchange Γ. By performing a mean-field analysis, we classify all possible superconducting phases in terms of symmetry, explicitly taking into account effects of spin-orbit coupling. Solving the resulting gap equations self-consistently, we map out a phase diagram that involves several topologically nontrivial states. For $\Gamma < 0$, we find a competition between a time-reversal symmetry breaking chiral phase with Chern number ± 1 and time-reversal symmetric nematic superconductivity that breaks the rotational symmetry of the lattice. Both of these states yield clear experimental signatures that distinguish them from the time-reversal symmetric, lattice symmetric superconducting state realized for $\Gamma \geq 0$. For high doping levels, both time-reversal symmetric states are classified by a non-trivial $\mathbb{Z}_2$ invariant.

Topological Phases in Superconductors with Intrinsic Textured Magnetic Order

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Systems that inherently exhibit topological superconductivity are rare in nature and the highly coveted Majorana fermions are mainly pursued in engineered hybrid devices. Here we propose to harness the possible microscopic coexistence of superconductivity and magnetism as an alternative pathway to craft intrinsic topological superconductors [1]. We focus on materials with spontaneous textured magnetic order driven by Fermi surface nesting. Our work is motivated by the iron pnictides, in which such a coexistence has been shown experimentally, and a recent theoretical analysis [2] has revealed that textured magnetism is also accessible. We explore the arising topological superconducting phases in layered multiband materials with magnetic spiral, whirl or skyrmion order, coexisting with various types of spin-singlet superconductivity. The diverse magnetic phases lead to a variety of flat, unidirectional, helical and chiral Majorana edge modes. We show that this multifaceted manifestation of Majorana fermion modes stems from the interplay of topological phases with both gapped and nodal bulk energy spectra.

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Quasiparticle interference of the Dirac nodal-line semimetal ZrSiTe

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Topological Dirac semimetals are interesting for their degenerate linear crossing in the bulk bands, resulting in a range of fascinating electronic properties, such as high electron mobility. Recently, research into Dirac nodal-line semimetals, which have a line or loop of linear band crossings within the Brillouin zone, has become abundant in the study of topological materials. Zirconium silicon sulfide (ZrSiS) was shown via ARPES to exhibit a Dirac nodal line crossing approximately 0.5 eV below the Fermi energy [1]. Using this material as a template crystal structure, zirconium silicon telluride (ZrSiTe) was predicted to strain the crystal lattice, pushing the Dirac crossing very near to the Fermi energy. This makes ZrSiTe a perfect candidate to study the properties of Dirac Fermions. Using scanning tunneling microscopy, we performed low temperature (4.5 K) bias spectroscopy and quasiparticle interference measurements, and I will present data helping to uncover the unique electronic band structure of this material. Furthermore, an outlook into future measurements to elucidate the magnetic and electronic properties of defect atoms using atomic force microscopy will be discussed.

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Volkov-Pankratov states in the BHZ model

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Besides the well known topologically protected surface or edge states, topological insulators can also have trivial Volkov-Pankratov states. The existence of such states has been pointed out almost forty years ago[1], but recently interest has been renewed as these states have been observed in topological heterojunctions[2, 3]. Here we show that VP states can be encountered within the simple BHZ model for 2D topological insulators. We use the model to show the effect of VP states on the spectral and transport properties. We propose an experiment that could demonstrate the presence of such states in 2D topological insulators.

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TrARPES measurements of Giant Photo-Voltage effect in doped TIs

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In the present work[1] we investigated five different configurations of doped TIs by means of time- and angle- resolved photoemission spectroscopy (TrARPES). Used setup [2] gives us the ability to measure direct photoemission, photoemission of excited system after different delay times and then in different states of relaxation (time-delay scan) and photo–voltage effect [3-4].

First, we show the comparison studies of time-delay measurements for investigation of unoccupied states and relaxation processes. Second, we present the dependence of photo-voltage effect on pump power and rate of sample doping. We propose that photo–voltage effect is lager in case the rate of doping is higher and topological states are more occupied. In this case relaxation take place though the topologocal surface states and might lead to spin current on the surface. Another explanation that the charge is better accumulated in more doped samples as they contain more defects as it was shown in [5]

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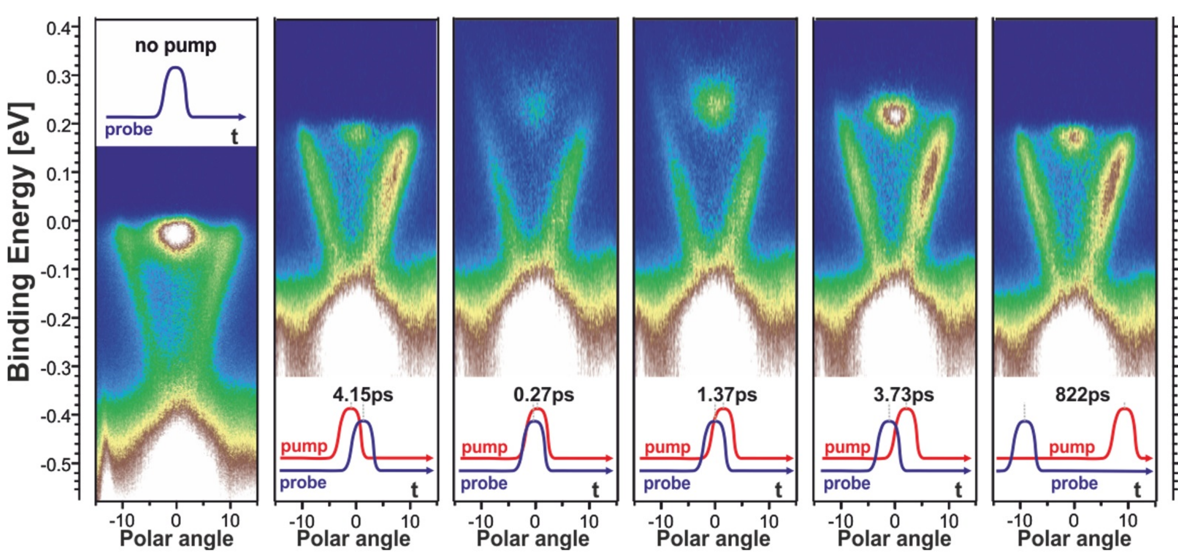

FIG. 1. TrARPES measurements for the system V-doped BiTeSe sample

Edgeless and purely gate-defined nanostructures in InAs quantum wells and 2D InAs-superconductor hybrid systems

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Due to its strong spin-orbit interaction, high g factor, and low effective mass, InAs quantum wells (QW) are a semiconductor hetrostructure of much interest. A new prospect of this material is to realize a topological superconducting phase supporting Majorana fermions with the hybrid system of InAs and s-wave superconductors [1,2]. Fabricating structures in a two-dimensional electron gas (2DEG) for mesoscopic transport usually requires etching processes, creating surfaces along the sidewalls of the etched geometry. However, for InAs QWs, because of the Fermi level pinning, these sidewalls show carrier accumulation and thus form trivial edge states [3,4], which hinter the design and fabrication of nano-constrictions, such as quantum point contacts (QPC) and quantum dots (QD). For current Majorana devices, to fully identify the existence of Majorana modes, more key features, including braiding statistics and quasiparticle poisoning processes, need to be investigated. Thus, Majorana devices with multi-wire structures and high mobility are required.

Here we first present a technique to circumvent the trivial edge conduction and define nanostructures exclusively by electrostatic gating. A large rectangular frame gate (FG) separated from the sample surface by a dielectric layer is employed that defines an inner and an outer part of the chip. A second dielectric layer allows for another layer of gates, which can be used to electrostatically define QPCs or QDs without any parallel conduction. Our preliminary measurement results on QPCs show the complete pinch-off of the electronic channel with decreasing split gates voltage. Multiple resonances are observed, which form plateaus under an applied magnetic field. This opens the path to observing quantized conductance without parallel conductance and manipulating single electrons in InAs 2DEGs.

Second, we show a proposal of developing cleaner InAs-based systems that allow the integration of multiple Majorana wires. Based on the high-quality III-V two-dimensional heterostructures where the superconductor, aluminum, will be grown in-situ, i.e., directly in the molecular beam epitaxy system, a device with gate defined quantum dots can be developed to host Majorana modes. With this technique, realizing charge detectors and the braiding statistics of Majorana modes is feasible. This research will pave a way to Majorana mode based decoherence-free and fault-tolerant topological quantum computation.

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