BEYOND! Topology and Materials

abstract booklet

Ringberg, July 09-12th, 2017

Max Planck Institute of Microstructure Physics
Weinberg 2 | 06120 Halle (Saale) | Germany
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Aim of the Workshop

The workshop will allow for extensive discussion concerning the future of topology and its relationship and predictive power concerning novel materials, phenomena and potential application for devices.

Start | End Time

We invite you to arrive on July 09th at Ringberg between 3-6 pm. At that time rooms will be available for check-in and the registration will be open. On Monday you are invited to join a guided tour of the Castle by the manager Mr. Essl. He will show us around and provide us with some historical background information on the castle and its secrets. Be curious! We end our workshop on July 12th after lunch at around 1 pm. Please check-out after breakfast as rooms need to prepared for the new arrivals in the afternoon.

Address | Info on Accommodation

Schloss Ringberg - Schlossstraße 20 - 83708 Kreuth | Phone:+49 (0)8022 27 90 | http://www.schloss-ringberg.de/contact

The access code for internet access is available in the reception hall. Breakfast is served from 8-9 am.

Munich Airport to Tegernsee Bahnhof (by Train/Taxi)

For your arrival/departure by public transportation please check the time table of "Deutsche Bahn" at http://www.bahn.de/p_en/view/index.shtml and see attached time table to/ from Tegernsee. Make sure that you board the part of the train going to Tegernsee and not to Lenggries. Train will be split.

You can buy your ticket online, upon arrival at the vending machines or at the ticket counter before entering the S-Bahn area at the airport. Your destination is "Tegernsee Bahnhof" and the train ride takes approx. 2 hours.

Please use a taxi from the train station "Tegernsee" towards the castle. Taxi Kaufmann has a guest list and is informed about all arrival times that you have sent beforehand. You can reach the Taxi company by phone +49 (0)8022/ 5555 (code: MPI-Halle).

For any questions you can contact Simone Jäger at +49 (0) 172/ 76.79.965.

We look forward to welcoming you at Ringberg. Have a save trip and see you soon.

Stuart Parkin | Claudia Felser | Shoucheng Zhang

Discovery of the Chiral Majorana Fermion

| Shoucheng Zhang

Stanford University, Stanford, USA | sczhang@stanford.edu

Majorana fermion is a hypothetical fermionic particle which is its own anti-particle. Intense research efforts focus on its experimental observation as a fundamental particle in high energy physics and as a quasi-particle in condensed matter systems. I shall report the theoretical prediction and the experimental discovery of the chiral Majorana fermion in a topological state of quantum matter. In the hybrid system of a quantum anomalous Hall thin film coupled with a conventional superconductor, a series of topological phase transitions are controlled by the reversal of the magnetization, where the half-integer quantized conductance plateau (0.5e2/h) is observed as a compelling signature of the Majorana fermion.

Biographical Sketch

Prof. Shoucheng Zhang joined the faculty at Stanford in 1993, and is now the JG Jackson and CJ Wood professor of physics. He also holds joint appointment in the department of applied physics and electrical engineering. He is a member of the US National Academy of Science, the American Academy of Arts and Sciences and a foreign member of the Chinese Academy of Sciences. He discovered a new state of matter called topological insulator in which electrons can conduct along the edge without dissipation, enabling a new generation of electronic devices with much lower power consumption. For this ground breaking work he received numerous international awards, including the Buckley Prize, the Dirac Medal and Prize, the Europhysics Prize, the Physics Frontiers Prize and the Benjamin Franklin Medal.

The Berry Phase and the Spin Current in AFM Weyl Semimetals

| Binghai Yan

[1] Weizmann Institute of Science, Israel |[2]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany | binghai.yan@weizmann.ac.il

The Weyl semimetal is a new topological state of matter discovered recently. It exhibits not only topologically protected surface states (similar to the topological insulator), but also fascinating charge and spin transport properties in the bulk. In this talk, I will introduce a new type of Weyl semimetal in chiral AFM materials, Mn3Ge and Mn3Sn [1]. They show Weyl points where bands cross linearly with large Berry phases in the band structure [2], giving rise to large anomalous Hall effect observed in recent experiments [3]. Furthermore, we have found a unique spin Hall effect (SHE) in these materials [4], which converts a charge current into a transverse spin current and vice versa. Although the SHE has long been believed to be a phenomenon induced by the spin–orbit coupling, we have proposed an alternative mechanism to realize the SHE without requiring spin-orbit coupling.

[1] Yang et al. New J. Phys. 19, 015008 (2017).

[2] Zhang et al. Phys. Rev. B 95, 075128 (2017).

[3] Nayak et al. Science Advances 2, 150187 (2016).

[4] Zhang et al. arXiv:1704.03917 (2017).

Biographical Sketch

Dr. Binghai Yan is a physicist on the first-principles materials simulation. He has been working on the prediction and investigation of realistic materials for topological states of matter, for example topological insulators and topological Dirac and Weyl semimetals. He received his PhD degree in Tsinghua University, Beijing in 2008. Later he works as a Humboldt postdoc in the University of Bremen, as a postdoc in Stanford University and as a group leader in the Max Planck Institute in Dresden. Since Feb 2017, he starts a new position as an assistant professor in the Weizamann Institute of Science, Israel.

Two-Dimensional Limit of Crystalline Order in Perovskite Membrane Films

| Harold Y. Hwang

Departments of Applied Physics and Photon Science | Stanford University and SLAC National Accelerator Laboratory, Stanford, USA | hyhwang@stanford.edu

Long-range order and phase transitions in two-dimensional (2D) systems – such as magnetism, superconductivity, and crystallinity – have been important research topics for decades. 2D crystalline order is revisited recently, with the development of exfoliated atomic crystals. Understanding the dimensional limit of crystalline phases, with different types of bonding, are at the foundation of low-dimensional materials design. Here we study ultrathin membranes of SrTiO3, an archetypal perovskite oxide with isotropic (3D) bonding. Atomically controlled membranes are released by dissolving an underlying epitaxial layer. Although all unreleased films are initially single-crystalline, the SrTiO3 lattice collapses below a critical thickness (5 unit cells). This crossover from algebraic to exponential decay of the crystalline coherence length reflects the 2D topological Berezinskii-Kosterlitz-Thouless (BKT) transition, which has the unusual feature here of being driven by chemical bond breaking at the 2D layer - 3D bulk interface.

Biographical Sketch

Harold Y. Hwang is a Professor of Applied Physics and Photon Science (SLAC) at Stanford University. He received a B.S. in Physics, B.S. and M.S. in Electrical Engineering from MIT (1993), and a Ph.D. in Physics from Princeton University (1997). He was formerly a Member of Technical Staff at Bell Labs (1996-2003), Associate Professor and Professor at the University of Tokyo (2003-2010). His current research focuses on atomic-scale synthesis of heterostructures of quantum materials; control of the electronic structure at interfaces and in confined geometries; low-dimensional superconductivity; and novel devices based on interface and surface states in oxides. Recognitions include the MRS Outstanding Young Investigator Award (2005), the IBM Japan Science Prize (Physics, 2008), Fellowship in the American Physical Society (2011), the Ho-Am Prize (Science, 2013), and the Europhysics Prize (2014, with Jochen Mannhart and Jean-Marc Triscone).

Quantum Liquid State of J_{eff}=1/2 Isospins in Complex Ir Oxides

| Hidenori Takagi[1,2], Tomohiro Takayama[1] and Kentaro Kitagawa[2]

[1] Max Planck Institute for Solid State Research, Stuttgart, Germany |
[2] Department of Physics, University of Tokyo, Tokyo | h.takagi@fkf.mpg.de

In 5d Iridium oxides, the relativistic spin-orbit coupling for 5d electrons is as large as ~0.5 eV and not small as compared with other relevant electronic parameters, including Coulomb U, transfer t and crystal field splitting D. The large spin-orbit coupling and its interplay with the other parameters gives rise to a variety of exotic magnetic ground states. In the layered perovskite Sr_2IrO_4, spin-orbital Mott state with J_{eff}=1/2 is realized due to the novel interplay of those energy scales [1]. Despite the strong entanglement of spin and orbital degrees of freedom, J_{eff}=1/2 iso-spins in Sr_2IrO_4 was found to be surprisingly isotropic, very likely due to a super-exchange coupling through almost 180° Ir-O-Ir bonds [2]. The temperature dependence of in-plane magnetic correlation length of J_{eff}=1/2 iso-spins, obtained from inelastic x-ray resonant magnetic scattering, was indeed well described by that expected for two-dimensional S=1/2 Heisenberg antiferromagnet [3].

When J_{eff}=1/2 iso-spins interact with each other through 90° Ir-O_2-Ir bonds, an Ising ferromagnetic coupling with an easy axis perpendicular to the bond plane is expected, due to an interference of the two Ir-O-Ir superexchange paths [2]. In α, β,γ-Li_2IrO_3 with honeycomb based structure, J_{eff}=1/2 iso-spin are connected by the three competeting 90° Ir-O_2-Ir bonds, which could be a materialization of Kiatev model [4] with quantum spin liquid state. A long range magnetic ordering, however, was observed at low temperatures in α, β,γ-Li_2IrO_3, which is very likely due to the presence of additional magnetic couplings not included in the original Kitaev model [4]. The exploration of Kitaev state was recently extended to related compounds and pressure effect. We found that a quantum spin liquid state is realized in hydorogenated Ir α-type 2D honeycomb $H_3LiIr_2O_6$ and β-Li_2IrO_3 under high pressure [5]. In $H_3LiIr_2O_6$, unusual fermionic excitations with a magnetic field induced gap are identified in the NMR relaxation and the specific heat.

[1] B. J. Kim et al., Phys. Rev. Lett. ***101****, 076402 (2008), Science* ***323****, 1329 (2009).*
[2] G. Jackeli and G. Khaliullin, Phys. Rev. Lett. ***102****, 017205 (2009).*
[3] S. Fujiyama et al., Phys. Rev. Lett. ***108****, 247212 (2012).*
[4] A.Kitaev, Annals of Physics ***312*** *2 (2006).*
[5] T.Takayama, et al., Phys. Rev. Lett.114, 077202 (2015).

Biographical Sketch

Hidenori TAKAGI, born 1961 in Tokyo, is a Director and Scientific Member of the Max Planck Institute for Solid State Research in Stuttgart, a Professor of Physics at the University of Tokyo and an Alexander von Humboldt Professor at University of Stuttgart. He studied Applied Physics at the University of Tokyo, where he received his PhD in 1989. After joining AT&T Bell Laboratories as a Post-Doctoral member of technical staff in 1990, he returned to the University of Tokyo, becoming an Associate Professor in 1994 and a Professor in 1999. From 2002 to 2013, he was jointly appointed at RIKEN, Japan as a Chief Scientist and Group Director. In 2013, he became a Director of the Max Planck Institute for Solid State Research. His research interests include metal-insulator transition, superconductivity, and quantum magnetism in correlated transition metal oxides. He received the IBM science prize (1988), Nissan science prize (1994), K. H. Onnes prize (2006), Honda Frontier Award (2009), and is an Alexander von Humboldt Professor (2014-) and a Fellow of the American Physical Society (2010-).

A New Spin on Superconductivity

| Amir Yacoby

Harvard University, Cambridge, MA, USA | yacoby@physics.harvard.edu

Nearly a hundred years after its discovery, superconductivity remains one of the most intriguing phases of matter. In 1957 Bardeen, Cooper and Schrieffer (BCS) presented their theory of superconductivity describing this state in terms of pairs of electrons arranged in a spatially isotropic wave function with no net momentum and a spin singlet configuration. Immediately thereafter, a search began to find materials with unconventional superconductivity where pairing deviates from conventional BCS theory. One particular class of unconventional superconductors involves pairs arranged in triplet rather than singlet configurations. Such superconductors may enable dissipationless transport of spin and may also give rise to elementary excitations that do not obey the conventional Fermi or Bose statistics but rather have non-Abelian statistics where the exchange of two particles transforms the state of the system into a new quantum mechanical state.

In this talk I will describe some of our recent experiments that explore the proximity effect between a conventional superconductor and a semiconductor with strong spin-orbit interaction. Using supercurrent interference, we show that we can tune the induced superconductivity continuously from conventional to unconventional that is from singlet to triplet. Our results open up new possibilities for exploring unconventional superconductivity as well as new ways for detecting unconventional pairing in known materials.

Biographical Sketch

Amir Yacoby is a Professor of Physics and Applied Physics at Harvard University. He currently holds the Delft Kavli chair in Physics.

Following a bachelor's degree in aeronautical engineering and a master's degree in theoretical physics professor Yacoby turned to experimental condensed matter physics. He received his PhD in 1994 from the Weizmann Institute of Science in Israel. His work focused on understanding coherence in quantum mesoscopic systems. During his postdoc at Bell labs Prof. Yacoby developed new techniques to explore electrical conduction in quantum wires and was the first to observe spin-charge separation, a hallmark of Luttinger Liquids. In 1998 Prof. Yacoby joined the faculty of the Weizmann Institute where he developed new techniques for imaging electrical charge.

Professor Yacoby joined the Harvard faculty in 2006. His current interests are in understanding the behavior of lowdimensional systems and their applications to quantum information technology. His research topics include: Spin based quantum computing and metrology using semiconducting quantum dots and color centers in diamond; Topological quantum computing using semiconductors with strong spin-orbit interaction and fractional quantum Hall states; interacting electrons in layered materials; and imaging and exploring condensed matter physics using nano scale magnetic sensors made of color centers in diamond.

Large-Gap Quantum Spin Hall Effect in InAs/InGaSb

| Rui-Rui Du

Rice University, Houston, TX, USA | rrd@rice.edu

We have developed a Z2 topological insulator InAs/GaInSb by strained-layer molecular beam epitaxy and robust semiconductor processing. The bulk energy gap of this materials can reach ～50 meV, and the coherent length of the helical edge states is well exceeding ten micrometers. We have further shown that the Luttinger parameter of the edge states can be tuned between K ～0.2 and K ～ 0.5 covering from strongly interacting to weakly interacting regimes. For applications we will briefly describe a nanoribbon processing including epitaxial aluminum on InAs/GaInSb for unconventional Josephson junctions and Majorana Qubits.

Biographical Sketch

Rui-Rui Du is a Professor of Physics and Astronomy at Rice University, and since 2015, a director of the International Center for Quantum Materials, Peking University.

His experimental research interest is on fractional quantum Hall effect, semiconductors, and topological materials.

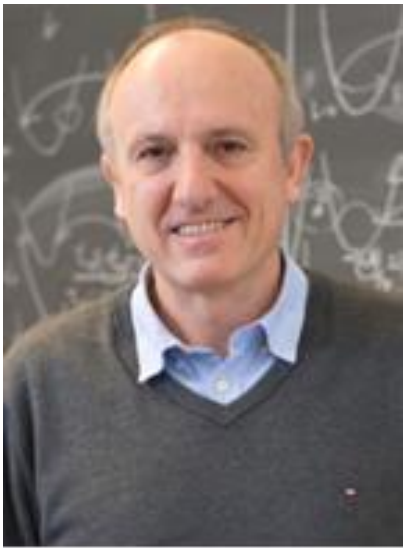
From Majorana- to Parafermions in Single and Double Nanowires

| Daniel Loss

University of Basel, Basel, Switzerland | daniel.loss@unibas.ch

I will present some recent results on single and double nanowires with proximity gap hosting Majorana and Para-fermions [1]. Typically, the topological phases are engineered by tuning the magnetic field to the topological threshold value of typically a few Teslas. However, the magnetic field has a detrimental effect on the host superconductor and so it is interesting to search for ways to achieve the topological phase without or with smaller B-fields. A particular way to achieve this goal is to exploit crossed Andreev pairing in a double nanowire setup [1,2,3] which destructively interferes with the direct pairing, and thereby lowers the threshold for the B-field substantially [3]. In re-examining the proximity effect in such finite-size geometries we discovered that the standard procedure of 'integrating out superconductivity' breaks down [2]. I will also present some recent results on hybrid platforms for quantum computing which combine spin qubits in quatum dots with topological qubits on a surface code architecture [4].

[1] J. Klinovaja and D. Loss, PRL 112, 246403 (2014); PRB 90, 045118 (2014).
[2] C. Reeg, J. Klinovaja, and D. Loss, arXiv:1701.07107.
[3] C. Schrade, M. Thakurathi, C. Reeg, S. Hoffman, J. Klinovaja, and D. Loss, arXiv:1705.09364.
[4] S. Hoffman, C. Schrade, J. Klinovaja, and D. Loss. Phys. Rev. B 94, 045316 (2016).



Biographical Sketch

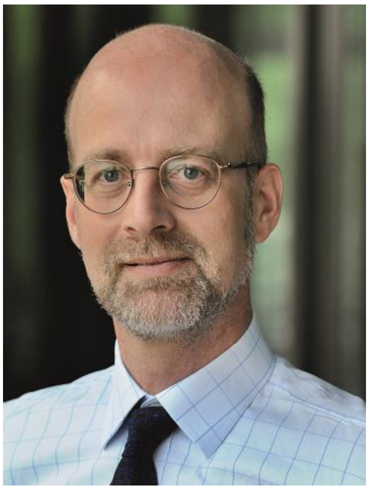
Daniel Loss received Diploma and Ph.D. in Theoretical Physics at the University of Zürich in 1983 and 1985, resp. From 1989 to 1991 he worked as postdoc in Urbana (USA) with Nobel Laureate A. J. Leggett and from 1991 to 1993 at IBM Research Center, NY (USA). In 1993 he moved to Vancouver (Canada) to become Assistant and then Associate Professor at Simon Fraser University. In 1996 he returned to Switzerland to become full Professor of Theoretical Physics at the University of Basel. Loss is director of the Basel Center for Quantum Computing and Quantum Coherence (QC2), and co-director of the Swiss Nanoscience Institute (SNI) at the University of Basel. He received several prestigious fellowships, is a Fellow of the American Physical Society (2000), and an elected member of the European Academy of Sciences and of the German Academy of Sciences Leopoldina (2014). He has been awarded the Humboldt Research Prize in 2005, the Marcel Benoist Prize in 2010 - the most prestigious science prize in Switzerland (see www.marcel-benoist.ch), the Blaise Pascal Medal in Physics 2014 from the European Academy of Sciences, and the King Faisal International Prize in Science in 2017 (shared with L. Molenkamp).

Magnetic Order and Excitations in Oxide Heterostructures

| Bernhard Keimer

Max-Planck-Institute for Solid State Research, Stuttgart, Germany | *b.keimer@fkf.mpg.de*

A grand challenge in the field of correlated-electron physics is the transition from conceptual understanding of collective ordering phenomena to their control and design. We will outline recent results of an experimental program designed to meet this challenge through the synthesis and characterization of metal-oxide superlattices, with particular emphasis on copper and nickel oxides. We will show how polarized photon-based methods such as resonant inelastic x-ray scattering and Raman scattering can be used to obtain a comprehensive description of magnetic order and excitations in metal-oxide superlattices, and outline perspectives for control of the phase behavior of correlated electrons in these structures by modifying the occupation of transition metal d-orbitals, the dimensionality of the electron system, and the electron-phonon interaction. We will also discuss new opportunities afforded by epitaxial integration of 3d and 4f spin systems.



Biographical sketch

Bernhard Keimer obtained his physics education at the Technical University of Munich and at the Massachusetts Institute of Technology, where he received his Ph.D. degree in 1991. He spent a year as postdoctoral associate at MIT and seven years on the faculty of Princeton University, where he was appointed Full Professor in 1997. In 1998 he was appointed Director at the Max Planck Institute for Solid State Research, where he and his research group investigate quantum materials using spectroscopic methods.

New Developments in Topological Phases: Topological Quantum Chemistry and Berry Phases of Berry Phases

| B. Andrei Bernevig

Department of Physics, Princeton University, USA |
bernevig@princeton.edu

I will present higher order topological insulators, states of matter that have gapped bulk and surfaces, but gapless protected boundaries. Some of These states of matter are the natural generalization of SSH chains to higher dimensions, and are distinguished by the berry phases of part of the holonomy matrix (berry phases of Berry phases)

Biographical sketch

B. Andrei Bernevig is a Eugene and Mary Wigner Assistant Professor of physics at Princeton University. He received his Ph.D. from Stanford University in 2006 on the Quantum Spin Hall effect. He performed his post-doctoral research at the Princeton Center for Theoretical Science from 2006-2009 working on Fractional Quantum Hall effect and topological phases as well as on the physics of iron-based superconductors. He joined the faculty at Princeton University in September 2009. His recent interests combine topological insulators, topological phases, fractional quantum Hall effect and iron-based superconductors.

Guided Design of Topological Semimetals

| Leslie Schoop

Max-Planck-Institute for Solid State Research, Stuttgart, Germany | l.schoop@fkf.mpg.de

In this talk I will give an introduction about how chemistry logic can be used to find new topological semimetals. I will introduce a family of materials that crystallize in space group 129 and show related electronic structures due to similar crystallographic motives. I will show how we can use solid state chemistry to tune the electronic structure to the desired need, form shifting Dirac cones to the Fermi level, to breaking time reversal symmetry in different ways and thus split degeneracies. This way a multitude of different non trivial states is accessible.

Biographical Sketch

07/2010: Diploma in Chemistry from the Johannes Gutenberg University Mainz. Undergraduate thesis adviser: Claudia Felser

12/2014: PhD in Chemistry from Princeton University. Thesis adviser: Robert Cava

01/2015-09/2017: Minerva fast track fellow at the Max Planck society. Max Planck Institute for Solid State Research. Incorporated in the group of Bettina Lotsch

Starting 09/2017: Assistant Professor of Chemistry, Princeton University

Topolectrical Circuits

| Ronny Thomale

University of Würzburg, Würzburg, Germany | *rthomale@physik.uni-wuerzburg.de*

First developed by Alessandro Volta and Felix Savary in the early 19th century, circuits consisting of resistor, inductor and capacitor (RLC) components are now omnipresent in modern technology. The behavior of an RLC circuit is governed by its circuit Laplacian, which is analogous to the Hamiltonian describing the energetics of a physical system. We show that “topolectrical” boundary resonances (TBRs) appear in the impedance read-out of a circuit whenever its Laplacian bandstructure resembles that of topological semimetals - materials with extensive degenerate edge modes known as Fermi arcs that also harbor enigmatic transport properties. Such TBRs not only provide unambiguous and highly robust signals for the presence of a topological phase, but also promise diverse applicability within high density electronic mode processing. Due to the versatility of electronic circuits, our topological semimetal construction can be generalized to topolectrical phases with any desired lattice symmetry, spatial dimension, and even quasiperiodicity. Topolectrical circuits establish a bridge between electrical engineering and topological states of matter, where the accessibility, scalability, and operability of electronics promises to synergize with the intricate boundary properties of topological phases.

Biographical sketch

2008 PhD, Universität Karlsruhe (with Peter Wölfle)

2009-2011 Feodor-Lynen Fellow, Humboldt Foundation at Princeton University (with Andrei Bernevig)

2011-2012 SITP Fellow, Stanford University (with Shoucheng Zhang and Steve Kivelson)

2012-2013 Assistant professor at EPF Lausanne

2013-dato Professor at the University of Würzburg

Color Code Quantum Computation with Majorana Bound States

| Felix von Oppen

Freie Universität Berlin, Berlin, Germany | vonoppen@physik.fu-berlin.de

While initial ideas for a Majorana-based quantum computer relied on braiding, more recent works propose to implement surface codes using a Majorana platform. In this work, we show that both approaches can be suitably merged using color codes. The resulting scheme simultaneously exploits both, the protection afforded by the topological hardware as well as the protection offered by a topological software in the form of an error correcting code.

Biographical Sketch

Felix von Oppen is a theoretical physicist working at the Dahlem Center for Complex Quantum Systems of Freie Universität Berlin. Prior to moving to Berlin, he received his PhD from the University of Washington and worked at the Max-Planck-Institute or Nuclear Physics in Heidelberg, the Weizmann Institute of Science, and the University of Cologne.

His research interests are in condensed matter physics, including the physics of electronic nanostructures, topological phases of matter, and topological quantum computation.

Topological Physics in HgTe-Based Quantum Devices

| Laurens Molenkamp

University of Würzburg, Würzburg, Germany |
laurens.molenkamp@physik.uni-wuerzburg.de

Suitably structured HgTe is a topological insulator in both 2- (a quantum well wider than some 6.3 nm) and 3 (an epilayer grown under tensile strain) dimensions.

The material has favorable properties for quantum transport studies, i.e. a good mobility and a complete absence of bulk carriers, which allowed us to demonstrate variety of novel transport effects.

One aspect of these studies is topological superconductivity, which can be achieved by inducing superconductivity in the topological surface states of these materials. Special emphasis will be given to recent results on the ac Josephson effect. We will present data on Shapiro step behavior that is a very strong indication for the presence of a gapless Andreev mode in our Josephson junctions, both in 2- and in 3-dimensional structure. An additional and very direct evidence for the presence of a zero mode is our observation of Josephson radiation at an energy equal to half the superconducting gap.

Controlling the strain of the HgTe layers strain opens up yet another line a research. We have recently optimized MBE growth of so-called virtual substrates ((Cd,Zn)Te superlattices as a buffer on a GaAs substrate), that allow us to vary the strain from 0.4% tensile to 1.5% compressive. While tensile strain turns 3-dimensional HgTe into a narrow gap insulator, compressive strain turns the material into a topological (Weyl) semimetal, exhibiting clear signs of the Adler-Bell-Jackiw anomaly in its magnetoresistance. In quantum wells, compressive strain allows inverted energy gaps up to 60 meV.

Biographical Sketch

Prof. Laurens W. Molenkamp was born August 4th 1956 in The Netherlands. From 1974 to 1980 he studied Physical Chemistry in Groningen (Netherlands). In 1985 he received his phD, followed by some years as research scientist at Philips Research Laboratories in Eindhoven.

From 1994 to 1999 he worked as Associate Professor at the Rheinisch-Westfälische Technische Hochschule (RWTH) in Aachen.

Since 1999 he is Full Professor and Head of MBE unit at the University of Würzburg.

For his scientific work he won many awards, among them the European Physical Society Europhysics Prize (2010), the Oliver E. Buckley Prize (2012), the Frontier Physics Prize (2013), the DFG's Gottfried-Wilhelm-Leibniz Prize (2014), the King Faisal International Prize (2017) and the Stern-Gerlach-Medal by the German Physical Society (2017)

Developing a New Experimental Tool for Studying Electronic Structures of Topological Materials

| Yulin Chen

Oxford University, Oxford, UK | *yulin.chen@physics.ox.ac.uk*

Angle-resolved photoemission spectroscopy (ARPES) has been an effective method in determining the electronic structures of materials. In the past decades, ARPES has been successfully applied to numerous important material system including topological quantum materials (TQMs), such as including topological insulators (TIs), topological Dirac and Weyl semimetals, cuprate, and Fe-based high transition temperature superconductors, as well as various functional materials including graphene and transition metal dichalcogenides (TMDs).

With the development in low dimensional topological edge states and artificial heterostructures, the need for understanding electronics bands with precise spatial information quickly emerged. However, as the mesoscopic length scale (10-8~10-5m) associated with these interesting materials/phenomena is too small for conventional ARPES (whose spatial resolution is typically 10-4~10-3m), while too large for the scanning tunneling microscopy (STM) studies (whose length scale is typically10-10-10-7m), the use of a new experimental method with proper length scale is urged.

Under this situation, the spatially resolved ARPES technique (i.e. Nano-ARPES), a new experimental tool with the capability of mapping out the band structures of materials with sub-micrometer (10-7m) spatial resolution (while keeping the other advantages of conventional ARPES such as the energy and momentum resolution) – has emerged. I will do a brief introduction on this new technique and discuss the perspective on applying this new experimental technique to the new topological quantum materials and heterostructures.

Biographical Sketch

TBA

Quantum Hall Effect and Topology: What Scanning Probe Experiments Tell us

| Jürgen Weis

Max-Planck-Institute for Solid State Research, Stuttgart, Germany | J.Weis@fkf.mpg.de

For more than a decade we have performed non-invasive scanning probe experiments on quantum Hall samples based on (Al,Ga)As heterostructures and graphene - in the integer and, recently, also in the fractional quantum Hall regime. The evolution of the electrically incompressible/compressible landscape within the two-dimensional electron system with raising magnetic field defines the local current and Hall potential distribution. For a quantized Hall resistance, the Hall current flows broadly distributed in incompressible regions for same integer/fractional-valued Landau level filling factor. It contradicts the commonly used edge-state picture carrying the biased current in chiral one-dimensional channels along the sample edges.

I will present the key results from the scanning probe experiments, the resulting microscopic picture, further experiments supporting this picture, and outline the prerequisites on the sample topology which leads to plateaus of quantized Hall resistance values.

http://www.fkf.mpg.de/NSL - see Publications

Biographical Sketch

-1990 Study of Physics at University of Ulm

1990 Diploma Work on Neuron/Silicon Junction (Prof. P. Fromherz, University of Ulm)

1994 PhD on Quantum Dots behaving as Single-Electron Transistors

(Prof. Klaus von Klitzing, Max-Planck Institute for Solid State Research / University of Stuttgart)

1995 Postdoc Stay at Bell Labs ('Mesoscopic devices for ultrahigh-integrated logic circuits ?')

1996 Senior Scientist and Group Leader in Dept. Klaus von Klitzing ('Electrical Transport through Quantum Dot Systems, Single-electron transistors, pseudo-spin Kondo Physics, Scanning Probe Experiments on Quantum Hall Systems, …')

2002 Habilitation in Physics at University of Stuttgart

2004 Rudolf Kaiser Prize

2006 Appointment to 'apl. Professor' at University of Stuttgart

2011 Head of the Scientific Facility 'Nanostructuring Lab' at Max-Planck-Institute for Solid State Research

http://www.fkf.mpg.de/NSL

Topology and Electronic Structure of Wrinkled Bismuth Monolayers

| Aharon Kapitulnik

Professor of Physics and Applied Physics, Stanford University, Stanford, USA | *aharonk@stanford.edu*

A new growth paradigm for bismuth monolayers is demonstrated. Using a freshly cleaved NbSe2 as a substrate, we show that the initial growth of Bi can conform to the lattice constant of the top Se-layer of NbSe2, resulting in a compressed and heavily wrinkled 2D triangular lattice. This as-grown metastable state typically anneals itself to the more `standard' bilayer Bi-(110) configuration if left long enough at elevated temperatures. To relieve the enormous strain, the single layer Bi develops a unique 3D strain pattern that is manifested in a unique pattern of wrinkles, which also introduce strong marks on the local density-of-states at the surface. We further discuss the way the Charge Density Wave and Superconductivity in the NbSe2 are proximitized to the bismuth layer.

Biographical Sketch

Aharon Kapitulnik is the Theodore and Sydney Rosenberg Professor in Applied Physics at the Departments of Applied Physics and Physics Stanford University. He is known for his experimental work in condensed matter physics, which covers a broad spectrum of phenomena associated with the behavior of correlated and disordered electron systems. Kapitulnik's current research activities focus on studies of quantum-mechanical dominated properties of materials, which exhibit unexpected `emergent' phenomena because of their unique electronic structure that is dominated by strong correlations and topology. Of particular interest to his group are phenomena related to the occurrence of novel forms of superconductivity and magnetism, and the interplay between them resulting in quantum critical phenomena. Kapitulnik received both, his B.Sc. (1978) and Ph.D (1983) degrees from Tel-Aviv University in Israel. Kapitulnik moved to the US in 1983 for a postdoctoral and a brief Assistant Professor in Residence positions at UC Santa Barbara's Physics. In 1985 he joined the Applied Physics department at Stanford University, and since 1993 was appointed jointly in the Applied Physics and Physics Departments. Among other recognitions, his activities earned him the Alfred P. Sloan Fellowship, a Presidential Young Investigator Award, the Heike Kamerlingh Onnes Prize for Superconductivity Experiment, and the Oliver E. Buckley Condensed Matter Prize of the American Physical Society. Aharon Kapitulnik is a member of the National Academy of Sciences, a Fellow of the American Physical Society, and a Fellow of the American Academy of Arts and Sciences.

Orbital Engineering as a Route Towards Large-Gap QSH Insulators

| Werner Hanke

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In recent work, we have established Bismuthene on a SiC substrate as a candidate for a new high-temperature Quantum-Spin-Hall paradigm.

The synopsis of a-priori (DFT) calculations, the theoretical modeling (low-energy, i.e., „downfolding"description) together with the experimental investigation form the central accomplishment. We report on an intriguing explicit material realization of bismuthene on SiC as a promising candidate for a large-gap quantum spin Hall (QSH) scenario, where a step-by-step comparison with theory confirms the experimental data.

On the basis of this agreement for a specific example, we have managed to understand the underlying mechanism more generally („downfolding"). This allows, in particular, to make predictions and to declare monolayer-substrate composites with the „orbital-filtering" mechanism to be a new paradigm for a large-gap QSH system, of which Bi/SiC is one first illustration.

Biographical Sketch

1975-1985 Associate Professor (C3) at the Max-Planck-Institute for Solid-State Research, Stuttgart

1985 Professor at the University of Stuttgart

since 1985 Full Professor and Chairholder at the University of Würzburg

since 2008 Senior and Research Professor, University of Würzburg

Research topics

Many-body physics applied to the theory of condensed matter:

- Competing phases in novel solid-state systems
- Superconductivity, in particular, high-TC superconductivity
- Magnetism and its interplay with superconductivity
- Topology, in particular, topological superconductivity
- Electronic correlation approaches:
    - Numerical (Quantum-Monte-Carlo, Exact Diagonalization, Variational Cluster techniques, etc.)
    - Analytical (Renormalization-group (RG) techniques, symmetry (such as SO(5) symmetry) analysis)

http://theorie.physik.uni-wuerzburg.de

A Gap-Protected, Zero-Hall State in a 3D Nonsymmorphic Metal[#]

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A new area of topological quantum matter is the investigation of materials with nonsymmorphic space groups, and their surface (or bulk) states protected by glide symmetry (glide is a combination of mirror reflection and half-lattice translation in the mirror plane). The compound KHgSb has been predicted to have “wrap around” quantum spin Hall states as well as “hourglass” fermion states. KHgSb grows as platelets that are very air sensitive. We have investigated in detail high-field transport in several bulk crystals with a range of n-type carriers. At low temperatures, we observe a striking ground state (lowest Landau level) in which the Hall conductivity is exponentially suppressed to zero (in increasing field or decreasing temperature). The zero-Hall property, which is protected by a large gap (14 mV at 60 Tesla), lies well beyond the purview of semiclassical transport. We will discuss the observed properties in the context of the predicted quantum spin Hall states.

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Biographical Sketch

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1971 B.A., Columbia College, N.Y.

1976 Ph.D. (Physics), University of California, Berkeley

1976-85 Assistant prof. (1976-82), Associate prof. (1982-84) and Professor (1985) of physics, University of Southern California

1985-present Professor of Physics, Princeton University

Ong's current interests are transport and magnetization phenomena in topological quantum matter, quantum magnets, QHE in GaAs, superconductivity.

Searching for High Temperature Quantum Anomalous/Spin Hall Materials

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The quantum anomalous Hall (QAH) effect is a quantum Hall effect induced by spontaneous magnetization instead of an external magnetic field. The effect occurs in two-dimensional (2D) insulators with topologically nontrivial electronic band structure characterized by a non-zero Chern number. The experimental observation of the QAH effect in thin films of magnetically doped (Bi,Sb)2Te3 topological insulators (TIs) paves the way for practical applications of dissipationless quantum Hall edge states, but an ultralow temperature of 30 mK is required to reach a perfect quantization. Further studies in this direction require magnetic TI materials that can show the QAH effect at higher temperature. I will introduce the systematic studies on the QAH effect in magnetically doped TI films of different thicknesses, magnetic dopants and compositions in the past years. The results clarify the relationship between the QAH effect and the energy band structure, electronic localization and ferromagnetism of magnetic TI films and provide insights into how to obtain high temperature QAH materials. Recently, by co-doping Cr and V in (Bi,Sb)2Te3 TI films, we significantly increase the temperature for the QAH effect to such a level that full quantization is achieved at 300 mK, and zero-field Hall resistance of 0.97 h/e2 is observed at 1.5 K. I will also introduce our recent progresses on searching for new 2D TI materials.

Biographical Sketch

Dr. Ke He graduated from Department of Physics, Shandong University in 2000, and received his PhD in 2006 from Institute of Physics, Chinese Academy of Sciences (IOP, CAS). After that he worked in Department of Physics and Institute of Solid State Physics of University of Tokyo as a postdoctoral researcher for three years. From 2009, he joined the State Key Laboratory for Surface Physics of IOP, CAS as an associate professor. He joined Department of Physics, Tsinghua University in 2013 and became a full professor from 2016. His researches in recent years focused on molecular beam epitaxy growth of low-dimensional topological materials and experimental studies on various topological quantum phenomena.

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