Magnetic Interfaces and Nanostructures
Room: 311 - Session MI-MoA

Topological Insulators/Rashba Effect

Moderator: Rosa Alejandra Lukaszew, The College of William and Mary

2:00pm **MI-MoA1 Spin-Polarized Electronic Structure at Strongly Spin-Orbit Coupled Surface**, ***Koji Miyamoto***, Hiroshima Synchrotron Radiation Center, Japan **INVITED**

Topological insulators and Rashba systems possess peculiar spin dependent electronic structure arising from a combination between a broken space inversion symmetry and strong spin-orbit interaction and are expected as key materials to revolutionize spin current devices without external magnetic field. However, the spin-orbit interaction cause the spin diffuse scattering and spin relaxation time shortens. For promoting practical use, it is necessary to enhance the short spin relaxation time. Topological insulators and Rashba systems possess peculiar spin dependent electronic structure arising from a combination between a broken space inversion symmetry and strong spin-orbit interaction and are expected as key materials to revolutionize spin current devices without external magnetic field. However, the spin-orbit interaction cause the spin diffuse scattering and spin relaxation time shortens.

For promoting practical use, it is necessary to enhance the short spin relaxation time. The spin relaxation time is also dependent on the spin texture caused by spin-orbit interaction, therefore, it enhance demand to directly observe the spin dependent electronic structure. The spin- and angle-resolved photoemission spectroscopy (spin-ARPES) is a most powerful tool to do it. However, it is not enough energy- and angle-resolution (ΔE~100 meV, $\Delta\theta$~2°) of common spin-ARPES systems to clarify the detail spin texture due to the low efficiency (ε~10^{-4}) of the conventional Mott-type spin detector. Recently, our group have developed novel high-efficient spin-ARPES system[1]. The system consists of a highe performance hemispherical analyzer (VG-Scienta R-4000) and high efficient spin detector based on very low energy electron diffraction of Fe(001)p(1x1)-O, which has 100 times higher efficiency. Finally, the highest ΔE and $\Delta\theta$ have been improved to 8meV and 0.37°.

In this symposium, I present the researches on spin texture for several strongly spin-orbit coupled system such as Rashba systems [2] and topological insulators [3] studied by our developed high efficient spin-ARPES system.

Reference

[1] T. Okuda, K. Miyamoto et al., Rev. Sci. Instrum. **82**, 103302 (2011).

[2] K. Miyamoto et al., New. J. Phys. accepted.

[3] K. Miyamoto et al., Phys. Rev. Lett. **109**, 166802(2012).

2:40pm **MI-MoA3 Spin Chirality in Momentum Space for Surface States on Tl/Si(111) and Tl/Ge(111)**, ***Markus Donath***, *S.D. Stolwijk, P. Eickholt, A.B. Schmidt,* Muenster University, Germany, *K. Sakamoto,* Chiba University, Japan, *P. Krueger*, Muenster University, Germany

The Tl/Si(111)-(1x1) surface is known for its outstanding properties due to spin-orbit interaction: a rotating spin pattern in momentum space and an unoccupied surface state with giant spin splitting at the K point [1,2]. In this contribution, we focus on the unoccupied surface electronic structure along the ΓM and MK high-symmetry directions. Spin- and angle-resolved inverse-photoemission experiments with sensitivity to the in-plane and the out-of-plane components of the spin-polarization vector were performed with our recently developed rotatable spin-polarized electron source [3]. Along both high-symmetry directions, our experiments reveal a surface-derived state with giant spin-orbit-induced splitting, in agreement with our theoretical findings. The state is purely in-plane polarized along ΓM, whereas the out-of-plane component is dominant along KM. As a consequence, spin chirality is found in momentum space around the M point.

We will compare our results for Tl/Si(111) with data for the isoelectronic Tl/Ge(111) surface. Differences in the surface electronic structure between the two surfaces appear along ΓM, where the Rashba-type spin-split surface state on Tl/Ge(111) lies within a band gap, while it is degenerate with bulk bands on the Si substrate. Consequences for the spin texture will be discussed.

[1] K. Sakamoto *et al*., Nature Commun. **4**, 2073 (2013).

[2] S.D. Stolwijk *et al*., Phys. Rev. Lett. **111**, 176402 (2013).

[3] S.D. Stolwijk *et al*., Rev. Sci. Instrum. **85**, 013306 (2014).

3:00pm **MI-MoA4 Spin-Orbit-Induced Spin Polarization in the Unoccupied Electronic Structure of W(110)**, ***Henry Wortelen****, Westfälische Wilhelms-Universität Münster, Germany, *H. Mirhosseini*, Johannes Gutenberg-Universität, Germany, *J. Henk*, Martin-Luther-Universität Halle-Wittenberg, Germany, *A.B. Schmidt, M. Donath*, Westfälische Wilhelms-Universität Münster, Germany

The spin texture in the electronic structure of heavy elements and topological insulators, which is caused by spin-orbit interaction, is a hot topic of today´s research in condensed matter physics. On W(110), a spin-polarized Dirac-cone-like surface state has been found recently, which is reminiscent of topological surface states [1, 2]. While the occupied bands including this surface state are well investigated by spin- and angle-resolved photoemission, there is basically a blank area on the $E(k_{||})$-map above the Fermi level.

We present a combined experimental and theoretical study on the unoccupied electronic structure of W(110). We interpret our spin- and angle-resolved inverse photoemission experiments on the basis of band structure and one-step-model calculations. We compare results for Γ-N and Γ-H, which are nonequivalent due to the two-fold symmetry of the W(110) surface.

A complex spin structure is observed for the surface-state emissions, in which the symmetry of the respective states plays a crucial role. Using several photon detectors and therefore being sensitive to different photon takeoff angles result in different spin-polarization signals of the same electronic state even for normal electron incidence. This shows that the measured spin polarization is highly dependent on the geometry of the experimental setup and does not necessarily resemble the spin structure of the state under investigation. To derive the spin texture of the electronic states experimentally, the photon-emission process has to be taken into account. In this context, we will address how the symmetry of the states influences the observed spin polarization.

[1] K. Miyamoto *et al.*, Phys. Rev. Lett. **108**, 066808 (2012)

[2] H. Mirhosseini *et al*., New J. Phys. **15**, 033019 (2013)

3:40pm **MI-MoA6 Reorganization and Annihilation of Topologically Nontrivial Surface and Interface States**, ***Jürgen Henk***, Martin Luther University Halle-Wittenberg, Germany **INVITED**

Topological insulators are characterized by an insulating bulk and topologically protected surface states. The latter bridge the fundamental band gap und often show linear dispersion, i.e., a Dirac cone. In this presentation, I am going to answer two questions: how is the Dirac surface state of Bi_2Te_3 modified upon deposition of noble metal atoms? And second, is it possible to confine nontrivial interface states between two topological insulators? The findings have impact for spin-dependent transport.

The electronic structure of Au-covered Bi_2Te_3 is investigated by first-principles calculations [1]. The Dirac surface state of Bi_2Te_3 hybridizes with the Au sp states, which gives rise to strong reorganization of the surface electronic structure. Striking features of the modified Dirac surface state are (i) the introduction of new Dirac points within the fundamental band gap of Bi_2Te_3, (ii) an extremely weak dispersion, and (iii) an anisotropic number of conducting channels in the fundamental band gap of Bi_2Te_3 which leads to a complicated Fermi surface.

I shall also show that nontrivial electronic states exist at an interface of a Z_2 topological insulator and a topological crystalline insulator [2]. At the exemplary (111) interface between Bi_2Te_3 and SnTe, the two Dirac surface states at the Brillouin zone center annihilate upon approaching the semi-infinite subsystems but one topologically protected Dirac surface state remains at each time-reversal invariant momentum M. This leads to a highly conducting spin-momentum-locked channel at the interface but insulating bulk regions. For the Sb_2Te_3/Bi_2Te_3 interface, there is complete annihilation of Dirac states because both subsystems belong to the same topology class.

This work is supported by the Priority Program 1666 of DFG.

[1] Francisco Muñoz, Jürgen Henk, and Ingrid Mertig, submitted (2014).

[2] Tomáš Rauch, Markus Flieger, Jürgen Henk, and Ingrid Mertig, Phys. Rev. B **88** (2013) 245120.

*** Falicov Student Award Finalist**

4:20pm **MI-MoA8 Unconventional Relativistic Electron Structure on Polar Bi Chalcogenide Sufaces**, ***Andrew Weber****, University of Missouri-Kansas City, *I. Pletikosic, Q.D. Gibson, H. Ji,* Princeton University, *T. Yilmaz,* University of Connecticut, *J.T. Sadowski, E. Vescovo,* Brookhaven National Laboratory, *A.V. Fedorov,* Lawrence Berkeley National Laboratory, *A.N. Caruso,* University of Missouri-Kansas City, *G. Gu,* Brookhaven National Laboratory, *B. Sinkovic,* University of Connecticut, *R.J. Cava,* Princeton University, *T. Valla*, Brookhaven National Laboratory

Spin-polarized surface electronic structures arising from broken inversion symmetry and a topologically non-trivial excitation gap in the underlying bulk show promise as platforms for realizing of exotic quantum phases (e.g. Majorana fermion modes) and spin-filter transport applications, however, the opportunities presented by these systems for exploring fundamental aspects of the spin-orbit interaction (SOI) in 2D have been underemphasized. The effect of SOI in solids can deviate from conventional models because it is sensitive to the full quantum description of the system, including atomic quantum numbers, the effective electric field, and spatial orbital and crystal symmetries. Together, these conditions shape the band structure and spin- and orbital-texture, and dictate the strength and anisotropy of interband hybridizations. Through spin- and angle-resolved photoemission spectroscopy of semi-ionic topological $(Bi_2)_m(Bi_2X_3)_n$ (X= Se, Te) superlattice materials, we have identified a variety of unconventional SOI effects acting on topological surface states. We will discuss how tuning the surface charge dipole and termination chemistry controls: (1) the electron band dispersion, (2) interband hybridizations, (3) the size, shape, and spin-topology of the Fermi surface and (4) the sign and magnitude of the Fermi velocity.

4:40pm **MI-MoA9 Identifying the Intrinsic Atomic Defects in Bi_2Se_3 with Scanning Tunneling Microscopy**, ***Jixia Dai***, Rutgers University, *D. West,* Rensselaer Polytechnic Institute, *X.-Y. Wang, Y.-Z. Wang, D. Kwok,* Rutgers University, *S.B. Zhang,* Rensselaer Polytechnic Institute, *S.-W. Cheong, W. Wu*, Rutgers University

In topological insulators the helical Dirac fermions are immune to backscattering as long as the time reversal symmetry is preserved. However, the existence of intrinsic atomic defects in materials such as Bi_2Se_3 and Bi_2Te_3 still represents one of the major issues for applications. Intrinsic atomic defects such as vacancies or antisites not only could dope charges, make the insulators conductive and shift the Dirac electrons away from the fermi energy but also affect the mobility of the materials by introducing disorder. By studying a series of Bi_2Se_3 samples that were grown with different conditions with atomic resolving scanning tunneling microscopy, we have successfully identified several types of intrinsic defects, including Se vacancies and Bi-Se antisites. The densities of these different types of defects could be correlated with growth conditions and the total density is related to the band shift measured by tunneling spectroscopy. Our study demonstrates the capability of scanning tunneling microscopy in diagnosing materials like Bi_2Se_3 and similar ones at the atomic level.

5:00pm **MI-MoA10 Probing Topological Crystalline Insulator SnTe (001) Surface States via Energy Resolved Quasiparticle Interference**, ***Duming Zhang***, NIST and University of Maryland, *H. Baek,* NIST and Seoul National University, Korea, *J. Ha, T. Zhang,* NIST and University of Maryland, *J.E. Wyrick, A.V. Davydov,* National Institute of Standards and Technology, *Y. Kuk,* Seoul National University, Korea, *J.A. Stroscio*, National Institute of Standards and Technology

Recently, the topological classification of electronic states has been extended to a new class of matter known as topological crystalline insulators. Similar to topological insulators, topological crystalline insulators also have spin-momentum locked surface states; but they only exist on specific crystal planes that are protected by crystal reflection symmetry. Here, we report an ultra-low temperature scanning tunneling microscopy and spectroscopy study on topological crystalline insulator SnTe nanoplates grown by molecular beam epitaxy. We observed quasiparticle interference patterns on the SnTe (001) surface that can be interpreted in terms of electron scattering from the four Fermi pockets of the topological crystalline insulator surface states in the first surface Brillouin zone. A quantitative analysis of the energy dispersion of the quasiparticle interference intensity shows two high energy features related to the crossing point beyond the Lifshitz transition when the two neighboring low energy surface bands near the X point merge. We present two possible interpretations for the two high energy features due to different scattering vectors along the ΓX and XM line cuts. A comparison between the experimental and computed quasiparticle interference patterns reveals possible spin texture of the surface states.

5:20pm **MI-MoA11 Control of Graphene Nucleation on Magnetic Oxides: Spintronics without Spin Injection**, ***Yuan Cao***, University of North Texas, *P. Kumar,* Indian Institute of Technology-Mandi, India, *I. Tanabe,* University of Nebraska-Lincoln, *J. Beatty, M. Driver,* University of North Texas, *A. Kashyap,* Indian Institute of Technology-Mandi, India, *P.A. Dowben,* University of Nebraska-Lincoln, *J.A. Kelber*, University of North Texas

Graphene direct growth by molecular beam epitaxy (MBE) occurs on a p-type but not n-type oxide, with resulting charge transfer and substrate-induced graphene spin polarization to > 400 K. C MBE on 10 Å p-type Co_3O_4(111)/Co(0001) at ~ 800 K yields layer-by-layer growth of graphene sheets in azimuthal registry. Significant charge transfer -- ~ 0.04 e^-/C atom -- confined to the first 1-2 graphene layers, results in oxide reduction at the oxide/Co(0001) interface. In contrast, MBE on 10 Å n-type Cr_2O_3(0001)/Co(0001) under similar conditions yields only the desorption of C and lattice O, despite similar oxide lattice constants and a stronger Cr-O vs. Co-O bond strength. These results demonstrate that downward band bending at the Co_3O_4/Co interface enhances charge transfer and graphene formation. Upward band bending at the Cr_2O_3/Co interface inhibits such charge transfer. DFT electronic structure calculations show that such charge transfer leads to strong Co(II)/graphene carrier exchange interactions, yielding an enhanced magnetic moment and spin ordering temperature, in excellent agreement with experiment. Such substrate-induced graphene spin polarization makes possible a variety of spintronic devices operating at >> 300 K, without the bottleneck of spin injection, and with predicted magnetoresistance values of ~ 500% or more. The model further predicts such results for other p-type magnetic oxides, making possible high magneto-resistance voltage-switchable devices.

*** Falicov Student Award Finalist**

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