Monday Morning, October 28, 2013

Magnetic Interfaces and Nanostructures
Room: 202 A - Session MI-MoM

Topological Materials, Rashba Systems, and Heusler Alloys
Moderator: V. Lauter, Oak Ridge National Laboratory

8:20am **MI-MoM1 Rotating Spin and Giant Splitting: Unoccupied Surface State at Tl/Si(111)**, ***M. Donath***, *S.D. Stolwijk, A.B. Schmdit,* Muenster University, Germany, *K. Sakamoto,* Chiba University, Japan, *P. Krueger*, Muenster University, Germany

Tl/Si(111)-(1x1) is an outstanding example for a system with peculiar spin-orbit-induced spin effects in the surface electronic structure. An occupied surface state with classical in-plane Rashba-type spin topology around the center of the surface Brillouin zone was found to exhibit an out-of-plane spin rotation upon approaching the K point [1].

We used spin- and angle-resolved inverse photoemission with sensitivity to the in-plane and the out-of-plane spin-polarization directions to explore the unoccupied states. A recently developed rotatable source for spin-polarized electrons provided access to two spin-polarization directions. We identified an unoccupied surface state with the same spin topology as the occupied state, yet with a much larger spin-dependent splitting in energy of 0.6 eV. Theoretical calculations provide an explanation for this giant splitting. It is attributed to the strong localization of the unoccupied surface state close to the heavy Tl atom in contrast to the occupied state, which is located at the outermost Si atoms.

Since the lower-lying spin component approaches the Fermi level, this leads to almost completely out-of-plane polarized valleys in the vicinity of the Fermi level. As the valley polarization is oppositely oriented at the K and K' points, backscattering should be strongly suppressed in this system.

[1] K. Sakamoto *et al*., Phys. Rev. Lett. **102**, 096805 (2009).

8:40am **MI-MoM2 Searching Majorana Fermion in Topological Insulator/Superconductor Heterojunction**, ***J. Jia***, Shanghai Jiao Tong University, China

Topological superconductors (TSCs) have attracted a great deal of attention recently because of the Majorana modes they host, which can be used in fault-tolerant quantum computation relying on their non-Abelian braiding statistics. While TSCs are very rare in nature, it has been proposed that an alternative way to realize them is by inducing superconductivity in the surface states of a topological insulator (TI) through the proximity effect (PE). Here we report the first experimental evidence for PE induced TSC in $Bi_2Te_3/NbSe_2$ heterojunction and the observation of Abrikosov vortices and core states. In particular, we found unusual splitting behavior in the zero-bias peak of the core states that may be attributed to the formation of Majorana fermions. Our work demonstrates the promise of using proximity effect induced TSC for realizing Majorana fermions and topological quantum computing.

9:00am **MI-MoM3 Visualizing Topological States of Matter**, ***A. Yazdani***, Princeton University **INVITED**

Soon after the discovery of quantum mechanics it was realized why some solids are insulating (like diamond) and others are highly conducting (like graphite),even though they could be comprised of the same element. Now, 80 years later, the concept of insulators and metals is again being fundamentally revised. During the last few years, it has become apparent that there can be a distinct type of insulator, which can occur because of the topology of electronic wavefunctions in materials comprised of heavier elements. Strong interaction between the spin and the orbital angular momentum of electrons in these compounds alters the sequence in energy of their electronic states. The key consequence of this topological characteristic (and the way to distinguish a topological insulator from an ordinary one) is the presence of metallic electrons with helical spin texture at their surfaces. I will describe experiments that directly visualize these novel quantum states of matter and demonstrate their unusual properties through spectroscopic mapping with thescanning tunneling microscope (STM). These experiments show that the spin texture of these states protects them against backscattering and localization. These states appear to penetrate through barriers that stop other electronic states. I will describe these experiments and our most recent attempts to create and visualize other topological states such as creation of Majorana fermions, which are another instance of boundary state associated with topological order.

[1] P. Roushan et al. Nature 460 1106 (2009).

[2] J. Seo et al. Nature, 466 434 (2010).

[3] H. Beidenkpof et al. Nature Physics, (2011).

9:40am **MI-MoM5 Probing Spin Textures of Topological Surface States in Ternary Chalcogenides**, ***A. Kimura***, Hiroshima University, Japan **INVITED**

Three-dimensional topological insulators (3D TIs) with a gapless topological surface state (TSS) in a bulk energy gap induced by a strong spin-orbit coupling have attracted much attention as key materials to revolutionize current electronic devices. A spin helical texture of a TSS, where the electron spin is locked to its momentum, is a manifestation of a 3D TI.

A number of well-known thermoelectric and phase-change materials have so far been predicted to be 3D TIs. In order to experimentally confirm their topological natures, spin- and angle- resolved photoemission spectroscopy (SARPES) is one of the most powerful tools and it has actually been playing major roles in finding some real 3D TIs [1, 2]. Among the established 3D TIs, Bi_2Se_3 has been most extensively studied because of its relatively large energy gap and the simplest TSS. However, the topological surface state is energetically obscured by bulk continuum near and below the Dirac point, which is disadvantageous for spintoronic applications.

SARPES experiments were performed at the ESPRESSO end station attached to the APPLE-II type variable polarization undulator beam line (BL-9B) at Hiroshima Synchrotron Radiation Center (HSRC) [3]. The VLEED-type spin detector utilized in the ESPRESSO machine achieves a 100 times higher efficiency compared to that of conventional Mott-type spin detectors [2]. Photoelectron spin polarizations are measured by switching the direction of in-plane target magnetizations, thereby simultaneously eliminating the instrumental asymmetry, which is a great advantage for a quantitative spin analysis of nonmagnetic systems such as 3D TIs.

In this talk, some of the ternary 3D TIs such as $TlBiSe_2$ [4], $GeBi_2Te_4$ [5], Bi_2Te_2Se, and Bi_2Se_2Te [6] are shown to possess TSSs with marked spin polarizations. It has been revealed for $GeBi_2Te_4$ that a disorder in the crystal has a minor effect on the surface-state spin polarization, which is ~70% near the Dirac point in the bulk energy gap region (~180 meV). Highly spin-polarized features are also found for Bi_2Te_2Se and Bi_2Se_2Te, which are persistent across the Dirac point. The availability of both upper and lower TSSs promises to extend the variety of spintoronic application, for instance, to dual gate TI devices and topological p-n junctions.

[1] M. Z. Hasan et al., Rev. Mod. Phys. **82**, 3045 (2010).

[2] T. Okuda and A. Kimura, J. Phys. Soc. Jpn. **82**, 021002 (2013).

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

[4] K. Kuroda et al., submitted.

[5] K. Okamoto et al., Phys. Rev. B **86**, 195304 (2012).

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

10:40am **MI-MoM8 (Un)expected Spin Topology in Unoccupied Bands of Bi/Ag(111)**, ***S.N.P. Wissing***, *A.B. Schmidt,* Westfälische Wilhelms-Universität Münster, Germany, *Chr.R. Ast,* Max-Planck-Institut für Festkörperforschung Stuttgart, Germany, *H. Mirhosseini,* Max-Planck-Institut für Mikrostrukturphysik Halle, Germany, *J. Henk,* Martin-Luther-Universität Halle-Wittenberg, Germany, *M. Donath*, Westfälische Wilhelms-Universität Münster, Germany

The spin topology of electronic bands, caused by spin-orbit interaction in Rashba systems and topological insulators, is subject of current debate. In some cases, the experiments findings are in conflict with theoretical predictions. In this contribution, we will discuss this issue with respect to the spin-resolved unoccupied electronic structure of the surface alloy Bi/Ag(111) $(\sqrt{3}\times\sqrt{3})R30°$.

Surface alloys of heavy elements on noble metal fcc(111) surfaces exhibit surface states with giant Rashba-type spin splittings. Therefore, they have been investigated thoroughly in recent years, in particular their occupied band structure by spin- and angle-resolved photoemission. Above the Fermi level, however, there is basically a blank area on the $E(k_{\parallel})$ map.

We present a study on the unoccupied electronic structure of Bi/Ag(111) with spin- and angle-resolved inverse photoemission. Above the Fermi level, we identified several states with distinct spin dependence. We determined their nature concerning symmetry, bulk vs. surface character, energy vs. momentum dispersion, and spin dependence. In particular, we focused our attention to the spin character of the m_j=1/2 surface state. While theoretical calculations [1] predict a complex spin topology, where the spin polarization changes sign at the band maximum, our experimental findings indicate a spin splitting compatible with the classical Rashba model. To shed more light on this issue, we investigated the spin topology with the help of first-principles electronic-structure calculations. We will discuss the difficulty of assigning a pure spin character to a particular Rashba band, especially in view of the experimental geometry, which itself influences the measured spin character.

[1] G. Bihlmayer *et al.*, Phys. Rev. B **75**, 195414 (2007)

11:00am **MI-MoM9 Growth and Properties of Skyrmionic MnSi Thin Film**, ***J.Y. Yi***, *S.W. Tang*, University of Tennessee, *G.X. Cao*, Oak Ridge National Laboratory, *D.G. Mandrus*, University of Tennessee, *Z. Gai*, Oak Ridge National Laboratory

MnSi is well-known for its magnetic chiral structure due to lack of inversion symmetry of B20 crystal structure at 29.5K to 43K. The helical magnetic structure results from Dzyaloshinsky-Moriya (DM) spin-orbit interactions. Inspired by its magnetic structure, which is left-handed spiral oriented along <111> axes, and low mismatch between Si(111) and MnSi(111) as well, we successfully grew the MnSi(111) thin film by co-evaporating Mn and Si on Si(111) in UHV. The structural, electric properties and magnetic properties of MnSi(111) thin film are examined using in-situ low temperature STM, STS and ex-situ SQUID magnetometer.

11:20am **MI-MoM10 Skyrmionic MnSi Nanowires on Si: SiO_2 Layer as a Catalyst Assistant for the CVD Growth**, ***S.W. Tang***, University of Tennessee, *I. Kravchenko*, Oak Ridge National Laboratory, *J.Y. Yi, G.X. Cao*, University of Tennessee, *J. Howe*, Oak Ridge National Laboratory, *D.G. Mandrus*, University of Tennessee, *Z. Gai*, Oak Ridge National Laboratory

Magnetic skyrmion, a vortex-like spin-swirling object recently observed in chiral-lattice magnets, are of great interest to future spin-electronic related data storage and other information technology applications. We report that single crystal helimagnetic MnSi nanowires could be synthesized in large amounts via SiO2 thin film assisted chemical vapor deposition comparing to previous reports, SiO2 plays an important role in controlling amount of diffusing Si to achieve relative low supersaturation ratio. Growth process is controlled so as to find the optimized parameters. Based on that, a temperature-time-distance growth phase diagram is plotted. The ac and DC magnetic properties of MnSi nanowires reveal the persistent of the helimagnetic and skyrmion magnetic ordering in the one-dimensional wires. Devices are fabricated via photolithography and e-beam lithography. Transport properties of this single wire device are measured.

11:40am **MI-MoM11 Epitaxial Growth, Transport, and Electronic Structure of Half Heusler Compounds: CoTiSb, NiTiSn, and Ni_2TiSn/NiTiSn Nanocomposite Films**, ***J.K. Kawasaki***, UCSB, *L.M. Johansson*, Lund University, Sweden, *J. Shabani, A. Rice*, UCSB, *M. Hjort, R. Timm*, Lund University, Sweden, *B.D. Schultz*, UCSB, *T. Balasubramanian, A. Mikkelsen*, Lund University, Sweden, *C.J. Palmstrom*, UCSB

The Half Heuslers are an attractive family of compounds for high temperature thermoelectrics, and recently there has been renewed interest in these compounds since some are proposed to be topological insulators. We report the epitaxial growth, transport, and angle resolved photoemission spectroscopy (ARPES) measurements of epitaxial films of the Half Heusler compounds CoTiSb and NiTiSn. Both belong to the subset of Half Heuslers with 18 valence electrons per formula unit that are predicted to be trivial insulators despite being composed entirely of metallic components. Here the CoTiSb and NiTiSn films were grown by molecular beam epitaxy on lattice matched InAlAs/InP (001) and (111), or on MgO (001), respectively. The films are epitaxial and single crystalline, as measured by reflection high-energy electron diffraction, low energy electron diffraction, and X-ray diffraction. Both CoTiSb and NiTiSn films also show surface reconstructions that vary with anneal temperature.

For the CoTiSb, scanning tunnelling spectroscopy and temperature-dependent transport measurements reveal that the films are insulating, with unintentionally doped carrier concentrations and mobilities comparable to that of highly doped conventional compound semiconductors ($n = 10^{18}$ cm^{-3} and $\mu = 500$ cm^2/Vs at 300 K). The CoTiSb films also show a peak in the low temperature (1.8-10 K) magnetoresistance that may result from localization or some other mechanism. ARPES measurements reveal that CoTiSb is a bulk insulator but has surface states within the band gap.

Stoichiometric NiTiSn films also show semiconducting-like transport. Additionally, composites of Full Heusler Ni_2TiSn inclusions within a Half Heusler NiTiSn matrix have been grown by codeposition with excess Ni. Despite the large lattice mismatch (2.9%) between the Ni_2TiSn and NiTiSn, the $Ni_{1+\delta}TiSn$ films remain epitaxial for compositions in excess of $\delta > 50\%$. These Half Heusler / Full Heusler nanocomposites show promise for phonon scattering in thermoelectric applications.

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