Magnetic Interfaces and Nanostructures
Room: 6 - Session MI-WeM

Topological Insulators and Rashba
Moderator: M. Donath, Muenster University, Germany, E. Vescovo, Brookhaven National Laboratory

8:00am **MI-WeM1 UP or DOWN? Rashba-type Spin Structures in *sp*- and *d*-derived Surface States Below and Beyond the Fermi Level**, ***M. Donath**, S.D. Stolwijk, A. Zumbülte, S.N.P. Wissing, Ch. Langenkämper, A.B. Schmidt, P. Krüger,* Muenster University, Germany*, K. Miyamoto, K. Shimada, A. Kimura,* Hiroshima University, Japan*, K. Sakamoto,* Chiba University, Japan*, R.C. Hatch, P. Hofmann*, Aarhus University, Denmark

Rashba-type spin splittings in the surface electronic structure of heavy elements and topological insulators are a hot topic of today's research in condensed matter physics. The interest is guided by possible applications of these materials in spintronic devices, in which the electron spin is used as an information carrier.

In this talk, I will present several experimental studies of surface states of different origin and with distinct spin configurations. At W(110), a spin-polarized Dirac-cone-like surface state with *d* character was identified, which appears below the Fermi level in a spin-orbit-induced symmetry gap of the projected bulk-band structure [1]. At Tl/Si(111), an unoccupied surface state with a spin-dependent energy splitting of more the 0.5 eV exhibits a distinct spin structure around the K point, leading to almost complete spin polarization at the Fermi level. Furthermore, the spin-dependent unoccupied electron states of the topological insulator Bi_2Se_3(111) were studied as a function of different preparation conditions. Making combined use of direct and inverse photoemission, we were able to characterize the electronic states below and beyond the Fermi level.

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

8:20am **MI-WeM2 Scanning Tunneling Spectroscopy of Topological Insulators' Electrically Tunable Electronic Structure**, *N. Levy,* Center for Nanoscale Sci. and Tech. / NIST*, T. Zhang,* Center for Nanoscale Sci. and Tech. / NIST and Maryland NanoCenter / Univ. of Maryland*, **J. Ha***, Center for Nanoscale Sci. and Tech. / NIST and Seoul National Univ., Korea*, Y. Kuk,* Seoul National Univ., Republic of Korea*, J.A. Stroscio*, Center for Nanoscale Sci. and Tech. / NIST

Three-dimensional (3D) topological insulators (TI) are a new state of matter with a bulk band gap but topologically protected gapless surface states. These protected surface states are massless helical Dirac fermions which are predicted to host many striking quantum phenomena [1]. Angle resolved photoemission spectroscopy (ARPES) and scanning tunneling microscopy (STM) measurements confirmed the existence of these surface states and their helical spin structure [1]. All the 3D TI materials to date have an initial doping level which places the Dirac point away from the Fermi level. Initial studies used chemical doping to align the surface states within the bulk band gap. A preferable method to realize the host of new phenomena in TI materials is to electrically tune the carrier density using the field effect from a gate electrode, as demonstrated in three terminal transport experiments [2]. However, the combination of local probe studies with samples containing low defect concentrations and a tunable carrier density remains a challenge, due to the chemical reactivity of the TI surfaces which precludes ex-situ fabrication and processing of the unprotected films.

In this talk we present new results on atomically flat Bi_2Se_3 and Sb_2Te_3 films grown on $SrTiO_3$ substrates using Molecular Beam Epitaxy (MBE). $SrTiO_3$ has a very large dielectric constant of $\sim 10^4$ at 4 K [3], allowing tuning of the TI Dirac point and carrier density even with a relatively thick dielectric of 100 μm. The $SrTiO_3$ substrates were pre-patterned with platinum electrodes and mounted in specially designed sample holders, allowing us to *in-situ* control the carrier density with a back gate on *in-situ* grown films, avoiding any *ex-situ* post processing of the samples. As a result, we are able to continuously change the carrier density and observe the local electronic structure of pristine grown TI films. Initial measurements at 5 K are focused on very thin films of 2 to 10 quintuple layers. Scanning tunneling spectroscopy measurements of the thin film's surface electronic structure allow us to study the gate's efficiency *vs.* local film thickness in a single sample. We find that the efficiency of gating the top surface state's electronic structure depends on the film thickness, with a decreasing efficiency for thicker films. In addition, we observe substantial differences in gating between Bi_2Se_3 and Sb_2Te_3.We will discuss these results and models of the gating of carriers in the bottom and top surface states through the bulk films at different bulk carrier densities.

[1] Rev. Mod. Phys. **82** 3045 (2010)

[2] Nano Lett., **10 (12)**, 5032 (2010)

[3] Phys. Rev. B **19**, 3593–3602 (1979)

11:20am **MI-WeM11 Scanning Tunneling Microscopy Observation of the Superconducting Gap in $Cu_xBi_2Se_3$**, ***J. Ha***, Center for Nanoscale Sci. and Tech. / NIST and Seoul National Univ.*, N. Levy,* Center for Nanoscale Sci. and Tech. / NIST*, T. Zhang,* Center for Nanoscale Sci. and Tech. / NIST and Maryland NanoCenter / Univ. of Maryland*, R.L. Kallaher, F. Sharifi, A.A. Talin,* Center for Nanoscale Sci. and Tech. / NIST*, Y. Kuk,* Seoul National Univ., Republic of Korea*, J.A. Stroscio*, Center for Nanoscale Sci. and Tech. / NIST

The discovery of topological insulators has triggered the search for new topological states of matter. A topological superconductor is one such state, characterized by the existence of an unconventional superconducting gap in the bulk, and gapless Andreev bound states on the surface. Recently, Cu intercalated Bi_2Se_3 ($Cu_xBi_2Se_3$) was found to be superconducting with $T_C \approx 3.8$ K [1], and is considered a prime candidate for topological superconductivity due to its peculiar band structure and strong spin-orbit coupling. A recent point contact measurement observed zero-bias conductance peaks, claiming these as evidence of surface Andreev bound states, and angle resolved photoemission spectroscopy has revealed the preservation of the topological surface states at the Fermi level [2, 3]. However, direct measurement of the superconducting gap in this material has not been reported.

In this work, we use an ultra-low temperature scanning tunneling microscope [4] to investigate the superconducting properties of a cleaved $Cu_xBi_2Se_3$ bulk crystal. The crystal was synthesized by electrochemical intercalation of Cu atoms into a previously synthesized Bi_2Se_3 crystal. We observe a superconducting gap in scanning tunneling spectroscopy (STS) measurements. We estimate the size of the gap to be 0.35 meV from a preliminary BCS fit of the superconducting gap. STS measurements under a magnetic field show a complete suppression of the superconducting gap at a critical field of ≈ 1.5 T. Significant inhomogeneity is observed in the material with spatial variations of the superconducting gap. We will discuss these observations in the context of current theories of topological superconductors.

[1] Y. S. Hor *et al.*, Phys. Rev. Lett. 104, 057001 (2010)

[2] L. A. Wray *et al.*, Nat. Phys. 6, 855–859 (2010)

[3] S. Sasaki *et al.*, Phys. Rev. Lett. 107, 217001 (2011)

[4] Y. J. Song *et al.*, Rev. Sci. Instrum. 81, 121101 (2010)

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