Electron Transport in Low Dimensional Materials Focus Topic
Room: 209 - Session ET+EM+SS-MoM

Quantum Transport: From 0- to 2-Dimensions
Moderator: A.-P. Li, Oak Ridge National Laboratory, K. Varga, Vanderbilt University

8:20am **ET+EM+SS-MoM1 Charge and Spin Transports at Surfaces of Strong Spin-Orbit-Coupling Materials**, ***S. Hasegawa***, *T. Hirahara*, University of Tokyo, Japan **INVITED**

Transports of charge as well as spin at crystal surfaces are now intensively studied by various kinds of experiments. Surface electronic states are generally decoupled from the bulk states and therefore intrinsically low-dimensional. Furthermore, space-inversion symmetry is broken down at crystal surfaces; one side of the surface is empty vacuum while other side is full of electrons in the crystal. These effects provide rich physics of transport, especially on surfaces of strong spin-orbit-coupling (SOC) materials. The surface-state bands are known to be spin-split of such strong SOC crystals such as Bi and Bi alloys, which is called by Rashba effect [1-4]. Similar effect is observed on a special kind of materials called topological insulators such as BiSb, BiSe, and BiTe alloys. Some of them have spin-split Dirac-cone type surface-state bands. This implies that spin-polarized current will flow at the surfaces of such materials.

In my presentation, by using samples of pure Bi [1-4], BiSb [5], BiSe [6,7], and BiTe, I will show that the surface-state bands are really spin-split and the Dirac-cone conductivity is directly measured by microscopic four-point probe method. An on-going project to detect the spin-polarization of surface current by using magnetic tips in a four-tip STM will be also introduced.

[1] T. Hirahara, et al., Phys. Rev. Lett. 97, 146803 (2006).

[2] T. Hirahara, et al., Phys. Rev. B 76,153305 (2007).

[3] T. Hirahara, et al., Appl. Phys. Lett. 91, 202106 (2007).

[4] T Hirahara, et al., New J. Phys. 10, 083038 (2008).

[5] T .Hirahara, et al., Phys. Rev. B81, 165422 (2010).

[6] Y. Sakamoto, et al., Phys. Rev. B81, 165432 (2010).

[7] T. Hirahara, et al., Phys. Rev. B82, 155309 (2010).

9:00am **ET+EM+SS-MoM3 Electron Transport in Ferroelectric Domains and Walls**, ***A. Baddorf***, Oak Ridge National Laboratory **INVITED**

Ferroelectric tunneling, where electron transport is controlled by the polarization state, has recently been realized in a number of experiments. Polarization-controlled transport effects have been detected in tunnel junctions, thin films, single crystals and at domain walls. Yet, little analysis of data has undertaken to determine the transport mechanisms and their interaction with ferroelectric fields and domain boundaries involved in switching. We present seminal experimental observations of transport in thin films of $Pb(Zr_{0.2}Ti_{0.8})O_3$ (PZT) and $BiFeO_3$ (BFO). Earlier we have shown that both materials exhibit pronounced polarization-controlled electroresistance [1]. Temperature and voltage dependence of currents are not well fit by any one standard model. Instead a transition between surface and bulk limiting effects is observed. Upon close inspection, I-V curves exhibit a reproducible region of negative differential conductance associated with ferroelectric switching. Although this anomaly may originate from extrinsic processes, e.g. due to oxygen vacancies or charge injection, we have carried out a series of control experiments on PZT films that unequivocally connect variation of conductance with the size of the polarization domain in the plane of the surface. The I-V anomaly therefore originates from significant conductivity of the domain wall and a relatively slow expansion of the domain following polarization switching. However, our results do not imply simply that transport is through domain walls, but further that nanoscale domains formed by switching have fundamentally different conduction behavior [2]. We suggest that domains formed by tip-applied bias have curved walls and are consequently charged, modifying adjacent material much as charge accumulation modifies a semiconductor. Engineering the ferroelectric domain size produces a tunable conductance reminiscent of analogue memristors, providing a quasi-continuous spectrum of non-volatile resistive states, even though the PZT polarization itself is bistable. Ferroic memristive behavior, which based on our measurements is likely to be universal to ferroic semiconductors, is a striking departure from the conventional picture of discrete electron transport states in ferroelectrics.

Research was conducted at the Center for Nanophase Materials Sciences and sponsored by the Division of Scientific User Facilities, U.S. Department of Energy.

[1] P. Maksymovych et al., Science 324 (1421) 2009.

[2] P. Maksymovych et al., submitted.

9:40am **ET+EM+SS-MoM5 Electronic Instabilities, Fluctuations, and Transport in Epitaxial Nanowires**, ***H.H. Weitering***, University of Tennessee and Oak Ridge National Laboratory **INVITED**

Quantum transport is at the heart of nanoscience and marries a fundamental law of nature — quantum mechanics — with applied electrical engineering and emerging materials technologies. Ultimately, nanoscale electronic devices will contain networks of wires whose cross sections will be so small as to represent one-dimensional conductors with novel transport properties. We have fabricated exceptionally long and uniform YSi_2 nanowires via self-assembly of yttrium atoms on Si(001). The wire widths are quantized in odd multiples of the Si substrate lattice constant. The thinnest wires represent one of the closest realizations of the isolated Peierls chain, exhibiting van Hove type singularities in the one-dimensional density of states and charge order fluctuations below 150 K. Conduction through individual nanowires follows an inverse Arrhenius behavior, indicative of thermally-assisted tunneling of small polarons between defect centers. Quantitative analysis of individual wire resistances, probe resistances, and negative differential resistances of nanowire networks indicates significant electronic interwire coupling below 150 K. The long-range coupling mechanism involves the dielectric polarization of the substrate, which induces current blockades in neighboring conduction channels.

This work is sponsored by the NIH/NHGRI and was partially conducted at the Center for Nanophase Materials Sciences, which is sponsored at Oak Ridge National Laboratory by the Office of Basic Energy Sciences, U.S. Department of Energy

10:40am **ET+EM+SS-MoM8 Grain Boundary Resistivity in Copper Nanowires**, ***T.H. Kim***, POSTECH, South Korea **INVITED**

The reliable choice of the interconnect materials in current integrated circuits is copper because of its higher electrical conductivity and improved stability against electromigration among all possible candidates. However, as the width of interconnects is approaching a mean free path of the electrons, the resistivity of copper interconnects is known to increase dramatically. Typically, this increase in the resistivity of the narrow interconnect is attributed to enhanced sequential scattering of electrons from defect planes such as either grain boundaries (GB) or other surfaces/interfaces. But, it is very challenging to distinguish which scattering factor is dominant over others in such a small scale.

To answer such a fundamental question, theorists developed semi-empirical methods and the relative contribution of various electron scattering mechanisms has been understood largely by relying on the semi-empirical methods based on the theories of Fuchs-Sondheimer and Mayadas-Shatzkes. The direct measurements of the resistance of individual GBs have been surprisingly lacking mainly due to technical difficulty to access single GBs in a nanowire that could not be realized by conventional fabrication methods using a fixed electrical contacts. Recently, Y. Kitaoka *et al.* have observed a resistance change along a damascene Cu interconnect wire with four-probe scanning microscope. They successfully separated the GB scattering effect from other scattering sources; however, the direct correlation between the GB structure and the specific GB resistivity remained unclear.

Here we present the direct measurement of individual GB resistances and the critical role of GB structure in the increased resistivity in copper nanowires with a four-probe scanning tunneling microscope. The resistances of high symmetry coincidence GBs are then calculated using a first-principle method, which confirms that the coincidence GBs have orders of magnitude smaller resistance than those measured at the high-angle random GBs. As well, to explain high resistivity of random GBs, we used free-electron-with-random-point-scatterer (FERPS) model. In the FERPS model, we derived that the specific GB resistivity of random GB is independent of the specific structures of random GB such as orientation and is determined entirely by the Fermi wavelength of the bulk.

This research was conducted at the Center for Nanophase Materials Sciences, which is sponsored at Oak Ridge National Laboratory by the Office of Basic Energy Sciences, U.S. Department of Energy.

11:20am **ET+EM+SS-MoM10 Tunable Coulomb Blockade and Giant Coulomb Blockade Magnetoresistance in a Double Quantum Dot System**, ***X.-G. Zhang***, Oak Ridge National Laboratory, *T. Xiang*, Chinese Academy of Sciences

We propose a Hubbard model to describe the tunneling effect of electrons in a double quantum dot system connected in the parallel circuit configuration to electrodes. The change in the interdot coupling is shown to dramatically influence the Coulomb blockade properties. For magnetic double dots, the interdot coupling can be tuned by the external magnetic field, leading to a giant Coulomb blockade magnetoresistance. Possible detection of this effect in organic systems is discussed.

This research was conducted at the Center for Nanophase Materials Sciences, which is sponsored at Oak Ridge National Laboratory by the Office of Basic Energy Sciences, U.S. Department of Energy.

11:40am **ET+EM+SS-MoM11 Quantum Transport in Crossbar Devices**, ***B. Cook***, *P. Dignard*, *K. Varga*, Vanderbilt University

Electronic devices with crossbar geometries have recently been fabricated with nanoscale features (Zhong. et al, Science Vol. 302). Consisting of a two dimensional grid, devices have been formed with a variety of components including carbon nanotubes and semiconductor nanowires. These devices are assumed to operate classically, but as the dimensions of the device shrink consideration of quantum effects becomes necessary. We consider a single junction between two wires up to a four by four grid of wires. Through a series of calculations with atomistic first-principles, tight-binding and analytic models of multi-terminal devices we demonstrate the presence of unique behavior, such as interference effects, not present in classical models. It is expected that exploitation of these effects will useful in the creation of circuit components.

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