PCSI
Room Ballroom South - Session PCSI-WeM2
Spin Transport and Spintronics

Moderator: Ezekiel Johnston-Halperin, The Ohio State University

11:00am **PCSI-WeM2-31 Direct Visualization of Electronic Transport in a Quantum Anomalous Hall Insulator***, **Katja Nowack**,* Cornell University **INVITED**

A quantum anomalous Hall (QAH) insulator is characterized by quantized Hall and vanishing longitudinal resistances at zero magnetic field that are protected against local perturbations and independent of sample details. This insensitivity makes the microscopic details of the local current distribution inaccessible to global transport measurements. Accordingly, the current distributions that give rise to the transport quantization are unknown. Here, I will discuss how we use magnetic imaging to directly visualize the transport current in the QAH regime [1]. As we tune through the QAH plateau by electrostatic gating, we clearly identify a regime in which the sample transports current primarily in the bulk rather than along the edges. Furthermore, we observe a local response of the equilibrium magnetization to electrostatic gating, whose spatial structure is strongly correlated with the observed current density. Combined, these measurements are consistent with the current flowing through incompressible regions whose spatial structure can change throughout the QAH regime.

At sufficiently high currents in the QAH regime and generally outside the QAH regime, we observe a weak response of the magnetization to the applied current. We show that this response can be explained by current-induced heating of the electrons. Effectively this allows us to image local dissipation in the QAH regime. As an example, I will show images of hot-spots localized in the corners of the electrical contacts through which the transport current enters our devices.

[1] Ferguson, G.M. *et al.* Direct visualization of electronic transport in a quantum anomalous Hall insulator. *Nat. Mater.* 22, 1100–1105 (2023).

Acknowledgments: Work at Cornell University was primarily supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering, under award DE-SC0015947. Sample synthesis and fabrication at Penn State was supported by the Penn State 2DCC-MIP under NSF Grant Nos. DMR-1539916 and DMR-2039351.

11:40am **PCSI-WeM2-39 Magneto-Optical Detection of the Orbital Hall Effect in Chromium***, **Igor Lyalin**, R. Kawakami,* The Ohio State University

The Hall effect was discovered by a PhD student Edwin Hall and his advisor Henry Rowland in 1879. Since then, the family of Hall effects has grown considerably. The anomalous Hall effect, integer and fractional quantum Hall effects, spin Hall effect, quantum anomalous Hall effect are fundamental physics phenomena of great importance. The orbital Hall effect (OHE) with giant orbital Hall conductivities has recently been theoretically predicted [1-4], however its direct observation is a challenge. Here, we report the magneto-optical detection of current-induced orbital accumulation at the surface of a light 3d transition metal, Cr. The orbital polarization is in-plane, transverse to the current direction, and scales linearly with current density, fully consistent with the orbital Hall effect. Comparing the thickness-dependent magneto-optical measurements with ab initio calculations, we estimate an orbital diffusion length in Cr of 6.6±0.6 nm. Along with Choi et al. study of the OHE in Ti [5], our work [6] provides strong evidence for the OHE. The detection of the orbital Hall effect in light metals can have important consequences for future spintronics applications that could utilize orbital currents rather than spin currents.

11:45am **PCSI-WeM2-40 Temperature Dependent Study of Na_XSi_{136} Type II Si Clathrate Spin Dynamics***, **Joseph Briggs**, Y. Liu, S. Saiter, A. Faricy, C. Burns, C. Taylor, M. Singh, R. Collins, C. Koh,* Colorado School of Mines

We report the temperature dependence of relaxation time (T_1) and phase memory (T_M) of Na dopants in type II Si clathrate films utilizing electron paramagnetic resonance (EPR). There is a rich history directed at understanding defect properties i---n conventional diamond Si motivated by its dominant position in the microelectronics industry. Type II Si clathrates represent an alternative crystal structure to diamond Si. This cage-like inclusion compound is made up of a Si lattice with interstitial “guests” situated inside the cages. Our recent advances have allowed the synthesis of Na guest, type II Si clathrate films with low enough Na concentration for the Na to be considered a dopant and the spin dynamics of isolated Na donors to be investigated.[1]

EPR gives insight into the electron spin dynamics of the Na donors and their placement and interactions within the Si cages. The naturally occurring Na isotope, ^{23}Na, has nuclear spin 3/2 with the EPR spectrum exhibiting four hyperfine l----ines associated with the interaction of the electron and nuclear spins. Hyperfine features associated with Na atoms in neighboring cages, clustered Na, and interactions with ^{29}Si isotopes on the cage, are also observed.[2] Pulsed-EPR spectra exhibit clear spin echo signals with T_1 times in the hundreds of microseconds at temperatures near 7 K, and T_M times above a microsecond. The effects of various parameters (i.e. temperature, magnetic field center, Na concentration) on the relaxation time and phase memory are reported. The relaxation time exhibits thermally activated behavior from 6-14K suggesting an Orbach relaxation pathway. Strong similarities and important differences between the spin dynamics of Na in clathrate and P in diamond Si will be discussed along with Na’s potential to function as a qubit in quantum applications. This work was supported by National Science Foundation award #2114569.

[1] Y. Liu et al., Appl. Phys. Rev., **8,** 4(2021).

[2] W. K. Schenken et al., Phys. Rev. B, **101**, 24(2020).

11:50am **PCSI-WeM2-41 Spin-orbit coupling in InGaAs random and digital alloy quantum wells***, **Jason Dong**,* University of California at Santa Barbara*; Y. Gul,* University College London, UK*; A. Engel, C. Dempsey,* University of California at Santa Barbara*; T. van Schijndel,* University of California Santa Barbara*; M. Pepper,* University College London, UK*; C. Palmstrøm,* University of California at Santa Barbara

InGaAs two dimensional electron gases (2DEGs) have high spin-orbit coupling, making them potentially useful for spintronics [1] and topological quantum computing applications [2,3]. With increasing In concentration, InGaAs quantum wells will have lower effective masses, higher spin-orbit coupling, and higher g-factors than GaAs quantum wells [4]. Digital alloying, or growing the ternary as a superlattice,is an alternative to growing ternary III-V as a random alloy. However, the effect of digital alloying on the spin-orbit coupling in semiconductor quantum wells is not understood. Digital alloy quantum wells can potentially enhance the Rashba spin-orbit coupling by forming asymmetric interfaces with the barrier layers.Here, we use molecular beam epitaxy and magnetotransport to the role of random and digital alloying of the spin-orbit coupling of InGaAs quantum wells.

We report the growth of high electron mobility $In_{0.81}Ga_{0.19}As$ quantum wells grown as a random and a digital alloy. From low temperature magnetotransport (2 K), the electron mobility of the random alloy quantum well is in excess of 450,000 cm^2/Vs and the electron mobility of the digital alloy quantum well is in excess of 540,000 cm^2/Vs. The spin-orbit coupling of the quantum wells is extracted from fits to the weak localization in the magnetotransport data and will be presented. We will also discuss the role of interfaces on the differences in the spin-orbit coupling observed in the random and digital alloy quantum wells.

References

[1] *Appl. Phys. Lett.* **56**, 665 (1990)

[2] *Phys. Rev. Lett.* **105**, 077001 (2010)

[3] *Phys. Rev. Lett.* **105**, 177002 (2010)

[4] *Electron. Lett.* **37**(7), 464 (2001)

11:55am **PCSI-WeM2-42 Screw Dislocations-Based Spin Valves***, **Finley Haines**, E. Renteria, M. Debasu, F. Cavallo,* University of New Mexico

We fabricated and characterized a vertical spin valve (VSV) based on single-crystalline Si nanomembranes (NMs) engineered with 2D arrays of screw dislocations (SDs) throughout their thickness. The device includes a bottom soft ferromagnetic contact (NiFe), Si NMs, and a top hard ferromagnetic contact (Co). Based on previously reported theoretical calculations, we expect that the operation of the VSV relies on the coherent transport of spin-polarization through SDs [1]. The first step in the fabrication of the VSV is patterning a 220 nm-thick Si NM into a 2D array of pixels with lateral sizes in the range of 200-400 �m. At this stage of the process, the NM is bonded to a SiO2-coated bulk Si substrate. Si pixels are released in place by selective etching of the SiO2 layer. An adhesive stamp removes the pixels from the original substrate and transfers them onto a second array of patterned pixels at a controlled twist angle, Ψ. The twisted NM pairs are then annealed at 1000-1200 °C in N2 atmosphere to grow the SDs. Annealed NMs are finally transferred to a bulk substrate coated with NiFe.

A dielectric barrier and a Co/Au top contact are fabricated using conventional top-down processes. The coercivity of the ferromagnetic films used for the contacts is extracted from measured magnetization curves on a Quantum Design Magnetic Properties Measurement System 3 (QD-MPMS3). Magneto-transport measurements characterize the resistance of the VSV at different magnitudes of magnetic induction (B). We observe a change in resistance at B corresponding to the measured coercivity of NiFe. The estimated magnetoresistance ratio, $MR(\%)=(R_{AP}-R_P)/R_P$ is -0.38 % at 300 K. No change in resistance was measured for VSVs based on Si NM that did not include SDs, suggesting that the line defects are responsible for the probed MR at 300K.

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