Poster Abstracts

Spins, Valleys, and Topological States in 2D and Layered Materials

June 5-8, 2017

- **Poster sessions / Lunch:** **Mon 12:00 – 2:30**
  Tue 12:20 – 2:30
  Wed 12:00 – 2:30

- **Posters stay up all week. Please set up Monday morning.**

- **Poster presenters are encouraged to be available for discussion during poster sessions throughout the week**

- **Poster presenters should stay at their poster for the entire session on their assigned day:**

  - **Monday's Assigned Posters: Odd numbered posters**
  - **Tuesday's Assigned Posters: Even numbered posters**
  - **Wednesday's Assigned Posters: Ad Hoc (extra time for all posters)**

- **Remove posters ~~on Wednesday after the poster session~~ by Thursday 1 pm (updated removal time).**

- **Poster size: (up to) 48" wide x 36" high**

P-01 (Mon)

Broadband Femtosecond Transient Absorption Spectroscopy for CVD MoS_2 Monolayer

Shrouq H. Aleithan[1], Maksim Livshits[2,3], Sudiksha Khadka[1], Jeffrey Rack[2,3], Martin Kordesch[1] and Eric Stinaff[1]*

[1]*Department of Physics and Astronomy, Ohio University*
[2]*Department of Chemistry, Ohio University*
[3]*Department of Chemistry and Chemical Biology, University of New Mexico*

Carrier dynamics in monolayer MoS_2 have been investigated using broadband femtosecond transient absorption spectroscopy (FTAS). A tunable pump pulse was used while a probe pulse of white-light continuum over the spectral range of 350 nm - 800 nm revealed ground and excited state carrier dynamics. For MoS_2 we observe previously reported features related to ground state bleaching along with higher energy features that can be related to states identified as the C and D excitons, which have been reported to arise from band nesting. Interestingly, for pump wavelengths both resonant and non-resonant with the A and B excitons, we observe a broad ground state bleach around 2.9 eV, with decay components similar to A and B. Associating this bleach with the band nesting region between K and Gamma in the band structure indicates significant k-space delocalization and overlap among excitonic wave functions identified as A, B, C, and D. Comparison of time dynamics for all features in resonance and non-resonance excitation is consistent with this finding. The results on these dynamics may prove useful to a greater understanding of the electronic structure of this material.

P-02 (Tue)

Mass Inversion in Graphene by Proximity to Dichalcogenide Monolayer

Abdulrhman Alsharari and Sergio Ulloa

Department of Physics and Astronomy, Ohio University, Athens, Ohio, OH 45701, USA

Heterostructures of graphene (G) and transition metal dichalcogenides (T) create novel 2D systems with exotic properties due to proximity spin-orbit effects, including mass inversion and unique edge states in G-T structures [1]. In multilayers, stacking order and twist are crucial. Using a tight binding formalism we analyze the band structure in terms of the symmetries of the Hamiltonian. We characterize system topology through Berry curvatures, and Chern numbers, and study zigzag edge states to identify and classify different phases. A superstructure of G-G-T is shown to exhibit a massive Dirac band structure at low energy similar to that in TMDs with scaled parameters. An inverted mass gap regime appears in the presence of Rashba spin-orbit coupling. Energy bands of bilayer graphene have a tunable gap via an external gate voltage, which plays an important role in controlling the band dispersion of the G-G-T multilayer at low energy. G-T-G superstructures may preserve mirror symmetry (z to -z), leading to the formation of bands with definite parity +1(-1). These two sets have inverted and parabolic band structures, respectively. Symmetry breaking effects, e.g. mirror symmetry breaking in the presence of a field, is shown to lead to distinct topological phases in the system. Twists in such multilayers generate incommensurate structures that may give rise to interesting physical behavior not present in commensurate structures. Such Moire modulation systems can be described using a continuum model, which enables the investigation of their electronic structure and topology. Contrasting with tight binding results when appropriate, we explore the behavior of gaps and proximitized spin-orbit couplings in the system as function of twist angle and other structural characteristics.

[1] A. M. Alsharari et al., Phys. Rev. B (R) 94, 241106 (2016).

P-03 (Mon)

Synthesis, Structure, and Electronic Properties of Ge Two-Dimensional Materials

Nicholas D. Cultrara and Joshua Goldberger

Department of Chemistry, The Ohio State University

There have been numerous exciting predictions of novel electronic behavior and topological phenomena in two-dimensional group 14 containing materials. Here, we will describe the synthesis, structure, and electronic properties of new classes of group 14 layered materials. First, we show that germanane, a hydrogen-terminated germanium graphane analogue, can be created via the topotactic deintecalation of $CaGe_2$ in acidic solutions, and fully resolved the structure using of synchrotron X-ray diffraction. These structures are determined by the precursor phase and are retained through the topotactic deintercalation process. We show that electronically active dopants such as Ga/As can be incorporated into the precursor $CaGe_2$ layered Zintl phase and are retained in the germanane framework following topotactic deintercalation. These dopants become activated upon exposure to electron rich species, resulting in an increase of conductivity in germanane by orders of magnitude. These materials can be readily exfoliated into few layers, making them promising building blocks for next-generation electronics, spintronics, and topological phases.

P-04 (Tue)

Electrical Control of Spin and Valley Hall Effect in Monolayer WSe_2 Transistors Near Room Temperature

E. Barre,[1*] J. A. Currivan-Incorvia,[1*] S. H. Kim,[2] C. McClellan,[1] E. Pop,[1] H-S. P. Wong,[1] and T. Heinz[2]

[1]*Department of Electrical Engineering, Stanford University, Stanford, California 94305*
[2]*Department of Applied Physics, Stanford University, Stanford, California, 94305*

Semiconducting monolayer transition metal dichalcogenide (TMDC) crystals have evoked much recent interest because of their distinctive spin and valley properties. In particular, they are predicted to exhibit a coupled spin and valley Hall effect (SVHE) [1,2]. In this context, WSe_2 is an attractive system because of its large valence band spin splitting. Lifetimes of spin and valley polarized carrier in monolayer WSe_2 have been measured by pump-probe techniques, yielding values from 0.7 ns to 1 μs at 10 K [3, 4, 5]. Such long lifetimes combined with reasonable mobilities lead to spin-valley accumulation through SVHE that can be directly imaged by a laser probe through the magneto-optic Kerr effect (MOKE). Here we investigate p-type monolayer WSe_2 transistors. We observe distinct spin-valley polarization along the two sides of the FET channel at a temperature of 250 K. The spatial distribution of the spin-valley carrier is imbalance found to be in agreement with a drift-diffusion transport model. Our study complements earlier reports of electrical control of the Valley Hall Effect (VHE) in gated bilayer MoS_2 at 30 K [6] by showing that the SVHE can be observed up to room temperature. Our results demonstrate the robustness of the SVHE effect and the potential for device applications spin-valley effects in this class of materials.

[1] K. F. Mak et al. Science 344, 1489-1492 (2014).
[2] D. Xiao, et al. PRL 108, 196802 (2012).
[3] W. T. Hsu, et al., Nature Commun. 6, 8963 (2015).
[4] X. Song et al., Nano Lett 16, 5010-4 (2016).
[5] J. Kim et al., arXiv:1612.05359 (2016).
[6] J. Lee, et al., Nature Nanotech. 11, 421-425 (2016).

*These authors contributed equally to this work

P-05 (Mon)

Magnetic Indirect Interaction in MoS_2-WS_2 Lateral Heterostructure Interfaces

O. Avalos-Ovando,[1] D. Mastrogiuseppe,[2] S. E. Ulloa[1]

[1]*Department of Physics & Astronomy, and Nanoscale and Quantum Phenomena Institute, Ohio University, Athens, OH 45701, USA*
[2]*Instituto de FÃsica Rosario (CONICET), 2000 Rosario, Argentina*

Heterostructures of different 2D materials such as graphene and transition metal dichalcogenides (TMDs) are being explored for their potential in design of custom-made electronic materials [1]. TMD lateral heterostructures (LHSs) provide carriers with strong spin-orbit coupling and 1D interfacial states with unique optoelectronic properties. In particular, they may allow interesting long-range exchange effects between magnetic impurities (MIs). MIs embedded in a conductor interact indirectly through the charge carriers in the host, via the well-known RKKY interaction. The presence of strong spin-orbit coupling in doped TMDs, has been shown to produce a sizable non-collinear Dzyaloshinskii-Moriya (DM) interaction between MIs [2], which is long ranged when MIs lie on/near the edges of TMD nanoflakes [3]. Here we present a study of the formation of 1D interface states in a MoS_2-WS_2 LHS. We model the LHS via a tight-binding formalism. The properties of zigzag and armchair boundaries are analyzed, demonstrating the formation of interface states. These are strongly localized and hybridized across the interface at midgap energies of both materials. Utilizing full diagonalizations of the structure, we find that the RKKY interaction between MIs located at LHS interfaces is long-ranged and with sizeable DM interaction terms. These numerical results agree with analytical second-order perturbation theory calculations. The interaction is strongly dependent on doping, separation between impurities, and also on whether both impurities are hybridized on the same or on opposite sides of the interface. The combination of long-range and DM interactions leads to helicoidal impurity configurations, resulting in interesting ground state arrangements of MI chains at these interfaces.

[1] K. S. Novoselov et al., Science 353, aac9439 (2016).

[2] F. Parhizgar et al., PRB 87, 125401 (2013); D. Mastrogiuseppe et al., PRB 90, 161403(R) (2014).

[3] O. Ãvalos-Ovando et al., PRB 93, 161404(R) (2016); Ibid. 94, 245429 (2016); arXiv:1607.08553.

P-06 (Tue)

Imaging Spin Dynamics in Monolayer WS_2 by Time-Resolved Kerr Rotation Microscopy

Elizabeth (Bushong) McCormick,[1] Yunqiu (Kelly) Luo,[1] Kathleen McCreary,[2] Michael Newburger,[1] Simranjeet Singh,[1] Berend Jonker,[2] Roland Kawakami[1]

[1]Department of Physics, The Ohio State University
[2]Naval Research Laboratory

Transition metal dichalcogenides (TMDs) are interesting due to their unique band structure with large valley-dependent spin-orbit splittings, Berry curvature, and spin/valley-selective optical selection rules. While these properties make TMDs extremely attractive for spintronics, utilization of these properties in nanoscale devices demands the imaging of spin dynamics. Here, we show spatially-resolved images of spin dynamics in monolayer WS2 using time resolved Kerr rotation (TRKR) microscopy with ~1 micron resolution. We discover a complex spatial dependence of spin density varying within a few microns, with spin lifetimes exceeding 5 ns. We investigate numerous samples with both TRKR microscopy and micro-photoluminescence in order to determine the mechanism behind long spin lifetimes and the transfer of angular momentum to long-lived resident conduction electrons. These results demonstrate high resolution imaging of spin dynamics as a powerful technique for investigating microscopic mechanisms that govern spin-dependent physics of 2D materials, and enable numerous studies of TMDs that are crucial for developing spintronic applications.

P-07 (Mon)

Magneto-Optical Studies of an Atomically Thin Ferromagnetic Semiconductor

Genevieve Clark,[1] Bevin Huang,[1] Efren Navarro-Moratalla,[2] Dahlia Klein,[2] Ran Cheng,[3] Kyle Seyler,[1] Emma Schmidgall,[1] Michael McGuire,[4] David Cobden,[1] Wang Yao,[5] Di Xiao,[3] Pablo Jarillo-Herrero,[2] Xiaodong Xu[1]

[1]University of Washington
[2]Massachusetts Institute of Technology
[3]Carnegie Mellon University
[4]Oak Ridge National Laboratory
[5]University of Hong Kong

Atomically thin van der Waals materials display a broad range of emergent phenomena in the truly two dimensional limit, making them fundamentally fascinating as well as technologically relevant. Ferromagnetic (FM) semiconductors offer simultaneous control over charge and spin ordering, providing a method to electrically control spin-active devices. The combination of these properties in the two dimensional limit could lead to novel materials with potential applications in data storage and computing. However, magnetic properties in an atomically thin material are just beginning to be explored. Recent studies suggest the possible existence of 2D FM semiconductors in single-layer chromium trihalides. Here, we discuss magneto-optical measurements on flakes of chromium triiodide (CrI_3) down to monolayer thickness, to determine its magnetic ordering as a function of layer thickness, magnetic field, and temperature.

P-08 (Tue)

Stacking Change in MoS_2 Bilayer by Interstitial Mo Impurities

Natalia Cortes,[1] Luis Rosales,[1] Pedro Orellana[!], Jhon Gonzalez,[2] Andres Ayuela[2]

[1]Universidad Tacnica Federico, Santa Maria
[2]Centro de Fasica de Materiales (CSIC-UPV/EHU)-Material Physics Center (MPC), Donostia International Physics Center (DIPC)

The electronic properties of MoS_2 nanostructures depend on the number of layers and the stacking type. MoS_2 bulk has an indirect band gap semiconductor, while a monolayer behaves as a direct band gap semiconductor in the range of the visible region. The coupling of two layers of MoS_2 causes attractive physics properties to emerge. For instance, the MoS_2 bilayers under an external electric field, that controls the inversion symmetry, split the spin degeneracy of the valence bands, and tune the orbital magnetic moments. Structurally affecting the stacking in MoS_2 bilayer makes that the band gap size varies, band gap engineering can be developed by strain, and twisting MoS_2 layers affect their electronic properties. The control of MoS_2 bilayer stacking is crucial to new physics with applications in nano-devices.

Under this context, we explore the electronic and structural properties of MoS_2 bilayer using van der Waals density functionals, with a molibdenum atom as intrinsic impurity in different positions within the interlayer region. The electronic levels for the Mo impurity atoms reside in the gap, and split as being in octahedral or tetrahedral crystal fields. We interestingly found that the interstitial Mo impurities change the AA stacking for pristine bilayers to AB. The AB stacking becomes energetically more favorable than the AA one induced by the broadening of the impurity bands. The Mo impurity atoms in the AB stacking are bonding with the Mo neighbors atoms of the MoS_2 layers, forming a Mo trimer. This originates a bonding orbital atomic that causes this energy reduction.

P-09 (Mon)

Probing Spin-Forbidden Dark Excitons in Atomically Thin 2D Semiconductors

Xiaoxiao Zhang,[1] Tony Heinz[1], Ting Cao,[2] Steve G. Louie[2], Zhengguang Lu,[3] Dmitry Smirnov[3], Yu-Chuan Lin,[4] Joshua Robinson[4], Fan Zhang,[5] James Hone[5]

[1]Department of Applied Physics, Stanford University
[2]Department of Physics, University of California, Berkeley
[3]National High Magnetic Field Laboratory, Tallahassee, FL
[4]Department of Materials Science and Engineering, Pennsylvania State University
[5]Department of Mechanical Engineering, Columbia University

Transition metal dichalcogenides in the MX_2 class (M=Mo, W; X=S, Se) have received a lot of attention for its unique optical properties at monolayer limit. Although bright excitons at K/K' valleys have been studied extensively, theory predicts the existence of intrinsic lower-energy dark excitons in some TMDC compounds (e.g., WS_2 and WSe_2), which comes from the expected spin splitting in conduction band. In this talk, I will present two approaches to optically probe the intrinsic lower-lying dark state in WSe_2. First, we demonstrate an indirect identification of these optically dark states by analyzing the temperature dependence of photoluminescence and time-resolved photoluminescence. The bright exciton population shows a thermal activation behavior, matching the expectation of a two-level model with a lower-energy dark state. In the second approach, we directly brightened and characterized this spin-forbidden exciton by applying an in-plane magnetic field. Both the dark exciton and its associated trion were rendered visible in spectrum, providing crucial information for the strength of band splitting and many-body interaction. In addition, much extended emission and valley lifetimes were achieved for these dark excitons.

P-10 (Tue)

Topological, Dirac and Magnetic Materials Based on 2D-Honeycomb Sn Lattices

M. Q. Arguilla,[1] J. Katoch,[2] W. McCulloch,[1] Z. J. Baum, [1] N. D. Cultrara, [1] Y. Wu, [1] R. Kawakami[2] and J. E. Goldberger[1]

[1]Department of Chemistry, The Ohio State University
[2]Department of Physics, The Ohio State University

The discovery of new families of layered 2D crystals that have diverse sets of electronic, optical, and spin-orbit coupling properties, enable the realization of unique physical phenomena, such as dissipationless electron transport in topological insulators, 2D ferromagnetism and extremely high carrier mobilities in Dirac semimetals. Herein, we present three classes of 2D-honeycomb Sn-based layered materials, which possess diverse properties ranging from topological insulators to anisotropic magnets. First, we have synthesized $BaSn_2$, which enabled us to study, for the first time, its electronic structure via angle-resolved photoemission spectroscopy and have proven, both theoretically and experimentally, that $BaSn_2$ is a 3D Z2-type topological insulator. Second, we have shown that the deintercalation of layered Zintl phases (NaSnP, KSnAs and KSnSb) into 2D crystalline organic-functionalized materials is limited by an underlying electrochemical process, wherein the Zintl phase reduces the alkyl halide via a one-electron reduction process which produces organic radicals that amorphize the crystalline framework. By choosing the correct alkyl halide/Zintl phase pair, where the alkyl halide reduction process is more negative in potential than the oxidation process of the Zintl phase, we have created a family of 2D Sn(Ethyl)Pn (Pn = P, As and Sb) phases that have band gaps from 1.3 eV (P) down to 0.2 eV (Sb), putting the Sn(Ethyl)Sb band gap in the regime of a 2D topological insulator. Third, we have created a family of exfoliatable vdW layered Zintl phases based on the ASn_2As_2 (A= Na, Sr and Eu) structure that exhibits temperature-dependent two-carrier (p-type and n-type) transport in $NaSn_2As_2$, Dirac semi-metallic behavior in $SrSn_2As_2$ and anisotropic magnetism, with anti-ferromagnetic coupling out-of-plane and ferromagnetic coupling in-plane, in $EuSn_2As_2$. Overall, the creation of these three unique classes of novel materials beyond graphene opens the doors to the discovery and experimental demonstration of novel electronic and spintronic phenomena, properties and applications in 2D.

P-11 (Mon)

A Hartree-Fock Study of the $\nu = 0$ Quantum Hall State of Monolayer Graphene

Braden Feshami and H. A. Fertig

Department of Physics, Indiana University

Recent experiments involving tilted graphene samples have shown evidence of a continuous phase transition in the $\nu = 0$ quantum Hall bulk state. We present here a simple model that supports such a transition. In addition to a long range SU(4) symmetric Coulomb interaction, we include Hubbard on-site and nearest neighbor interactions with tunable coupling strengths, and perform a self-consistent Hartree-Fock analysis. A large sea of negative energy Landau levels is retained, and is shown to have important qualitative and quantitative effects. Phase diagrams are constructed within the space of physically relevant parameters, yielding results consistent with experimental observation.

P-12 (Tue)

Strong Coupling Between 2D-Material Excitons and Photonic Crystal Cavity Photons

Long Zhang, Rahul Gogna, Hui Deng

Department of Physics, University of Michigan

Cavity exciton-polariton systems integrate strong optical nonlinearities and spontaneous coherence into a semiconductor photonic platform, which has been widely investigated in GaAs systems at helium temperatures. Recently, optically active Van der Waals crystals such as transition-metal dichalcogenides (TMDs) have exhibited strong exciton absorption and large binding energy, making it possible to achieve strong coupling at room temperature. Several groups have reported the observation of strong coupling between TMD excitons and cavity photons by integrating 2D TMDs with Fabry-Perot planar cavities or plasmonic nano arrays. Yet these systems typically have large cavity mode volumes and/or low cavity quality; true strong-coupling regime with well resolved polariton modes is yet to be demonstrated at room temperature. Photonic crystals provide a powerful platform for achieving simultaneously high cavity quality and small mode volume. Integrating 2D TMDs with photonic crystals has led to photon lasing in the weak coupling regime. In this work, we report strong coupling between 2D TMD excitons and photonic crystal cavity photons. Well-resolved polariton splitting was observed in both the angle resolved reflectance and photoluminescence spectra, which unambiguously demonstrates coherent strong coupling between excitons and photons in our device. Strong coupling regime was achieved up to room temperature. The system is promising to achieve polariton lasing without population inversion at room temperature.

P-13 (Mon)

Magnetism and Proximity Effects in Layered Two-Dimensional Materials

Devashish Gopalan, Sergio de la Barrera, Nathan Drucker, Shengwei Jiang, Amanda Haglund, Takashi Taniguchi, Kenji Watanabe, David Mandrus, Kin Fai Mak, Benjamin Hunt

Department of Physics, Carnegie Mellon University

The versatility of layered van der Waals materials has allowed a study of diverse physical phenomena in the two-dimensional limit. Furthermore, by means of proximity effects, one material can acquire the properties of an adjacent material by bringing them in close contact. Despite these advances, magnetism in van der Waals materials has remained largely unexplored. Chromium silicon tritelluride ($CrSiTe_3$) is a layered ferromagnetic semiconductor with a bulk Curie temperature (Tc) of 33 K. Therefore, one can conceivably use $CrSiTe_3$ and the proximity effect to introduce long range magnetic order in graphene, which implicitly has a high mobility. Here, we report on progress in assembling mesoscopic devices of $CrSiTe_3$ as well as proximity devices based on graphene/ $CrSiTe_3$ heterostructures. Results from magneto-transport measurements and Kerr microscopy will be discussed.

P-14 (Tue)

Crystal Growth and Magnetic Properties of Metal Phosphorus Tri-Chalcogenides

Amanda Haglund and David Mandrus

Materials Science and Engineering Department, University of Tennessee

Magnetic semiconducting two-dimensional materials have become of great interest lately due to their potential for various applications, including spintronics. A relatively new addition to this class of materials are the metal phosphorus tri-chalcogenides of the structure MPX_3, that have been predicted to exhibit single layer magnetism. To further understand their unique properties, we have investigated many of the compounds in the family of MPX_3 (M = V, Cr, Mn, Fe, Ni and X = S, Se), and will present their crystal growth methods and characterization.

P-15 (Mon)

Electronic Transport in Osmium-Decorated Graphene

Jamie A. Elias and Erik A. Henriksen

Department of Physics, Washington University in St. Louis

The two-dimensional electron system in graphene is inherently unprotected from the environment, so that the electronic properties can be altered by proximity to substrates or through surface adsorbates. In exploring the impact of various transition metal adatoms, we have recently deposited sub-monolayer coatings of osmium atoms on graphene. Unlike all other metal atoms to date--which generically electron-dope graphene and reduce the mobility--osmium is seen to donate holes and has only a limited effect on the quality of transport. However, the resistance maximum of the Dirac peak shows a rather unusual non-monotonic increase and then decrease with increasing Os coverage. We will present our devices, the experimental setup, and transport measurements in zero and finite magnetic field, and comment on the search for a spin-orbit effect in graphene that may be inherited from Os adatoms.

P-16 (Tue)

Direct Measurement of Discrete Valley and Orbital Quantum Numbers in Bilayer Graphene

B. M. Hunt,[1,2,3] J. I. A. Li,[3] A. A. Zibrov,[4] L. Wang,[3] T. Taniguchi,[5] K. Watanabe,[5] J. Hone,[3] C. R. Dean,[3] M. Zaletel,[4] R. C. Ashoori,[1] A. F. Young[1,4]

[1]Massachusetts Institute of Technology
[2]Carnegie Mellon University
[3]Columbia University
[4]University of California, Santa Barbara
[5]NIMS (Japan)

In the bilayer graphene zero-energy Landau level (ZLL), the degeneracy of cyclotron orbits is augmented by spin, valley, and orbital quantum numbers. Both electronic interactions and single-particle effects lift this degeneracy, but the relative role of these mechanisms has remained elusive. I will discuss a new capacitive measurement of layer polarization that provides the first direct experimental probe of valley and orbital order in bilayer graphene. We discover numerous new phase transitions that occur at partial Landau level filling, allowing us to tightly constrain a model that captures the interplay between single-particle and interaction-induced valley, spin, and orbital anisotropies. The resulting roadmap of symmetry breaking in bilayer graphene paves the way for deterministic engineering of fractional quantum Hall states, while our layer-resolved technique is readily extendable to other two-dimensional materials where layer polarization maps to the valley or spin quantum numbers, providing an essential direct probe that is a prerequisite for manipulating these quantum degrees of freedom.

Reference: B.M. Hunt et al., arXiv:1607.06461

P-17 (Mon)

Theory of Multifarious Quantum Phases and Large Anomalous Hall Effect in Pyrochlore Iridate Thin Films

Kyusung Hwang and Yong Baek Kim

Department of Physics and Centre for Quantum Materials, University of Toronto, Toronto, Ontario M5S 1A7, Canada

We theoretically investigate emergent quantum phases in the thin film geometries of the pyrochore iridates, where a number of exotic quantum ground states are proposed to occur in bulk materials as a result of the interplay between electron correlation and strong spin-orbit coupling. The fate of these bulk phases as well as novel quantum states that may arise only in the thin film platforms, are studied via a theoretical model that allows layer-dependent magnetic structures. It is found that the magnetic order develop in inhomogeneous fashions in the thin film geometries. This leads to a variety of magnetic metal phases with modulated magnetic ordering patterns across different layers. Both the bulk and boundary electronic states in these phases conspire to promote unusual electronic properties. In particular, such phases are akin to the Weyl semimetal phase in the bulk system and they would exhibit an unusually large anomalous Hall effect.

Reference: Scientific Reports 6, Article number: 30017 (2016).

P-18 (Tue)

Two-Dimensional Structural Phase Transition in Few-Layer Group-IV Monochalcogenides

Thaneshwor P. Kaloni and Salvador Barraza-Lopez

Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701, USA

Two-dimensional materials, such as graphene, hexagonal boron nitride, and transition-metal dichalcogenides have a non-degenerate structural ground state, which ensures their stability. However, group-IV monochalcogenide monolayers and bilayers undergo a two-dimensional structural phase transition from a rectangular unit cell to a square unit cell [1,2]. There are two ways to determine the transition temperature. Here, the process that reproduces experimental results [3], and hence is correct will be discussed [4].

References:

[1] M. Mehboudi, A. M. Dorio, W. Zhu, A. van der Zande, H. O. H. Churchill, A. A. Pacheco-Sanjuan, E. O. Harriss, P. Kumar, and S. Barraza-Lopez, Nano Lett. 16, 1704-1712 (2016).

[2] M. Mehboudi, B. M. Fregoso, Y. Yang, W. Zhu, A. van der Zande, J. Ferrer, L. Bellaiche, P. Kumar, and S. Barraza-Lopez, Phys. Rev. Lett. 117, 246802 (2016).

[3] K. Chang, J. Liu, H. Lin, N Wang, K. Zhao, A. Zhang, F. Jin, Y. Zhong, X. Hu, W. Duan, Q. Zhang, L. Fu, Q.-K. Xue, X. Chen, and S.-H. Ji, Science 353, 274-278 (2016).

[4] T. P. Kaloni and S. Barraza-Lopez (in preparation).

P-19 (Mon)

Opto-Valleytronic Spin Injection in MoS_2/Graphene Hybrid Spin Valves

Yunqiu (Kelly) Luo, [1] Jinsong Xu, [1] Tiancong Zhu, [1] Guanzhong Wu, [1] Elizabeth (Bushong) McCormick, [1] Wenbo Zhan, [1] Mahesh R. Neupane,[2] Roland K. Kawakami[1]

[1]*Department of Physics, The Ohio State University*

[2]*Sensors and Electron Device Directorate, Army Research Laboratory*

Two dimensional (2D) materials provide a unique platform for spintronics and valleytronics because vertically-stacked heterostructures offer the potential to combine vastly different functionalities, where the strengths of each can compensate for the weaknesses of the other. On one hand, graphene is an exceptional material for spin transport at room temperature, however it lacks a coupling of the spin and optical degrees of freedom. In contrast, spin/valley polarization can be efficiency generated in monolayer transition metal dichalcogenides (TMD) such as MoS_2 via absorption of circularly-polarized photons, but lateral spin or valley transport has not been realized at room temperature. Here, we fabricate monolayer MoS_2/multilayer graphene hybrid spin valves and demonstrate, for the first time, the opto-valleytronic spin injection across a TMD/graphene interface [1]. We observe that the magnitude and direction of spin polarization is controlled by both helicity and photon energy. In addition, Hanle spin precession measurements confirm optical spin injection, spin transport, and electrical detection up to room temperature. Finally, analysis by a one-dimensional drift-diffusion model quantifies the optically injected spin current and the spin transport parameters. Our results demonstrate a 2D spintronic/valleytronic system that combines the strengths of the constituent materials to achieve optical spin injection and lateral spin transport at room temperature, which paves the way for multifunctional 2D spintronic devices for memory and logic applications.

[1] Yunqiu (Kelly) Luo, et al, Nano Letters (2017) 10.1021/acs.nanolett.7b01393

P-20 (Tue)

Collective Spin Excitations in the 3D Topological Insulator Bi_2Se_3

H.-H. Kung,[1] S. Maiti,[2] X. Wang,[1] S.-W. Cheong[1], D.L. Maslov[2], G. Blumberg[1]

[1]*Department of Physics & Astronomy, Rutgers University*
[2]*Department of Physics, University of Florida*

Chiral spin states such as the surface states of 3D topological insulators are predicted to support odd in time reversal symmetry excitations from inelastic light scattering [1]. However, signal from the surface states is often obscured by bulk contributions. Here, using polarization resolved resonant Raman spectroscopy, we selectively probe the spin excitations from the topological surface states in bulk Bi_2Se_3. We observe the emergence of a collective ``chiral spin mode'' below the particle-hole continuum edge with binding energy of about 30 meV, as the excitation energy is tuned in resonance with the unoccupied surface Dirac cones residing about 1.8 eV above the low energy Dirac cones [2]. The particle-hole continuum arises due to direct transitions from the lower to upper Dirac cone, and therefore exhibits a low energy threshold at about 180 meV imposed by Pauli blocking. The continuum edge thus reflects the Fermi energy in the sample, and is observed in all symmetry channels. In contrast, the spin mode is only present in the A2 representation of the C_{6v} point group, which transforms as a pseudovector and is associated with in-plane spin flip excitations. This spin mode is thus analogous to a magnon, which “peel off” from the continuum at the Brillouin zone center due to finite interaction. Moreover, the spin mode is consistently observed in all studied low carrier concentration Bi_2Se_3 samples and remain undamped by the continuum even at room temperature, consistent with the topological protection expected from the Dirac surface states in this material. Our study thus provides new insights into the manybody interactions and collective spin excitations of the Dirac fermions in 3D topological insulators.

[1] S. Maiti et al., PRB 91, 035106 (2015).

[2] J. A. Sobota et al., PRL 111, 136802 (2013).

P-21 (Mon)

As-Grown Two-Dimensional MoS_2 Based Photodetectors with Naturally Formed Contacts

Sudiksha Khadka, Thushan Wickramasinghe, Miles Lindquist, Ruhi Thorat, Shrouq Aleithan, Martin Kordesch, Eric Stinaff

Department of Physics and Astronomy, Ohio University, Athens, OH 45701

Scalable fabrication of two-dimensional materials-based devices with consistent characteristics remains a significant impediment in the field. Here, we report on as-grown monolayer MoS_2 metal-semiconductor-metal photodetectors produced using a CVD process which results in self-contacted two-dimensional materials-based devices. The photodetectors show high responsivity (~1 A/W) even at a low drain-source voltage (V_{DS}) of 1.5 V and a maximum responsivity of up to 15 A/W when V_{DS} = 4 V with an applied gate voltage of 8 V. The response time of the devices is found to be on the order of 1 μs, an order of magnitude faster than previous reports. These devices demonstrate the potential of this simple, scalable, and reproducible method for creating as-grown two-dimensional materials-based devices with broad implications for basic research and industrial applications.

P-22 (Tue)

Dynamical Spin Injection at Quasi-One Dimensional Ferromagnet/Graphene Interfaces

M. Anguera[1], P. Vayda,[1]G. Kathri[1], E. del Barco[1], S. Singh[1], and B. Özyilmaz[2]

[1]Department of Physics, University of Central Florida, Orlando, Florida 32816, USA
[2]Department of Physics, National University of Singapore, 2 Science Drive 3, Singapore 117542

Graphene is a promising material for spintronics applications given its unique properties. However, an efficient method to generate pure spin currents into this two-dimensional material is required to understand the spin dynamics and mechanisms associated to spin transport in graphene. Recently, we reported the first evidence of spin pumping in ferromagnet/graphene interfaces by studying the damping of the ferromagnet due to presence of graphene. We have extended the original studies towards different device configurations. Here we discuss the effect of the interface on the dynamical damping by studying different stacking orders of graphene and Permalloy layers. Our results confirm that the observed damping is indeed a signature of dynamical spin pumping wherein spin polarized currents are pumped into the graphene from the precessing magnetization of the ferromagnet. In addition, in order to understand the pumping and spin relaxation mechanism in graphene, we performed comparative FMR studies of ferromagnet/Graphene strips buried underneath the central line of a coplanar waveguide such that the whole ferromagnet is excited homogenously by the microwave stimulus. A larger FMR linewidth broadening is observed when the graphene layer protrudes away from the ferromagnet strip, indicating that the spin relaxation in graphene occurs away from the area directly underneath the ferromagnet being excited.

S. Singh, A. Ahmadi, C.T. Cherian, E. R. Mucciolo, E. del Barco, and B. Özyilmaz "Dynamical spin injection at a quasi-one-dimensional ferromagnet-graphene interface" *Appl. Phys. Lett*. 106, 032411 (2015)

P-23 (Mon)

Spin Relaxation in Single and Bilayer Graphene: The Role of Resonant Magnetic Impurities

Denis Kochan, Susanne Irmer, Martin Gmitra, Jaroslav Fabian

Institute for Theoretical Physics, University of Regensburg

We propose that the observed small (100 ps) spin relaxation time in single a bilayer graphene is due to resonant scattering off local magnetic moments. At resonances, magnetic moments behave as spin hot spots: the spin-flip scattering rates are as large as the spin-conserving ones, as long as the exchange interaction strength is greater than the resonance width. We analyze a resonant scattering model due to adatoms in single and also in bilayer graphene, where we particularly discuss resonant characteristics of dimer and nondimer adsorption sites. Opposite to single layer graphene, the measured spin-relaxation rate in the graphene bilayer increases with carrier density. Although it has been commonly argued that a different mechanism must be at play for the two structures, our model explains this behavior rather naturally in terms of different broadening scales for the same underlying resonant processes. Not only do our results using robust and first-principles inspired parameters agree with experiment, they also predict an experimentally testable sharp decrease of the spin-relaxation rate at high carrier densities.

P-24 (Tue)

Transport Spectroscopy of Sublattice-Resolved Resonant Scattering in Hydrogenated Bilayer Graphene

Jyoti Katoch,[1] Tiancong Zhu,[1] Denis Kochan,[2] Simranjeet Singh,[1] Jaroslav Fabian[2] and Roland K. Kawakami[1]

[1]Department of Physics, The Ohio State University
[2]Institute for Theoretical Physics, University of Regensburg

Adatom decoration of the graphene surface is a powerful technique to engineer both its charge and spin related properties. In particular hydrogenation of graphene is interesting due to the possibility of inducing spin orbit coupling, and magnetic moment as well as opening a band gap. Moreover theory also predicts ferromagnetic ordering when hydrogen is adsorbed on the same sublattice. We performed in-situ charge transport study of bilayer graphene devices as a function of successive controlled amount of atomic hydrogen in ultra-high vacuum chamber at low temperatures (20 K). Atomic hydrogen is generated by a thermal gas cracker, and gate dependent resistance of graphene is measured after each atomic hydrogen exposure. On hydrogenation, we observed two additional resistance peaks appear on the electron side of the gate dependent resistance curve. Through DFT calculation and tight binding model, we attribute these two peaks to resonant scattering from hydrogen atoms adsorbed on different sublattices of bilayer graphene. Furthermore, we will discuss the annealing study of the hydrogenated bilayer graphene devices, which indicates the possibility to achieve sublattice selective hydrogenation. Our result provides a reliable method to resolve sublattice-selective hydrogenation on bilayer graphene, which may be the key to realize ferromagnetism in graphene systems with point defects.

P-25 (Mon)

Magnetic Ordering by Topological Surface States

Kyungmin Lee and Nandini Trivedi

Department of Physics, The Ohio State University

A heterostructure of a ferromagnetic insulator and a topological insulator has gained interest as it provides a clean alternative to doping the topological insulator with magnetic adatoms to realize quantum anomalous Hall effect. While the effect of ferromagnetism on the surface fermions of the topological insulator is rather well understood, how the fermions affect the magnetic moments of the ferromagnet is not. Here we theoretically study a bilayer of a ferromagnetic insulator and a three-dimensional topological insulator with surface Dirac fermions. The local magnetic moments influence the fermions to spin-polarize, while the fermions mediate interaction between the local magnetic moments. Such RKKY-like interaction mediated by the fermions with large spin-orbit coupling introduces effective spin-spin interactions with high anisotropy, including Ising, Heisenberg, compass, and Dzyaloshinskii-Moriya types. With self-consistency, we find that large enhancement of ferromagnetic Tc is possible, as well as canting of the magnetic moments at the surface.

P-26 (Tue)

Transition-Metal Doping of MoS_2 Thin Films

Zhen Li,[1] Enzhi Xu,[1] Haoming Liu,[1] Kyungwha Park,[2] Yaroslav Losovyj,[3] Matthew Starr,[1] Madilynn Werbianskyj,[1] Herbert A. Fertig,[1] Shixiong Zhang[1]

[1]Department of Physics, Indiana University
[2]Department of Physics, Virginia Tech
[3]Department of Chemistry, Indiana University

Chemical doping with transition-metal impurities is a promising approach to control and tune the electrical and magnetic properties of two-dimensional transition metal dichalcogenides. Here we demonstrate the versatility of transition-metal doping in monolayer and few-layer MoS_2 through a controlled growth and systematic characterizations of Zn-doped and Cr-doped thin films. Large area, Zn-doped, monolayer MoS_2 films were grown via a one-step chemical vapor deposition approach [1]. Zinc doping of 1-2% was found to suppress the n-type conduction of the pristine MoS_2 and shifts its Fermi level downwards, revealing a p-type nature of the dopant. The dopant stability and impurity states were further studied by density-functional-theory calculations. The electrical properties were strongly influenced by stoichiometry, and a p-type transfer characteristic was eventually achieved by thermal treatment of the Zn-doped film in a sulfur atmosphere. Chromium doping was realized by sulfurization of Cr/MoO_3 multilayers that were pre-deposited on the SiO_2/Si substrate. We will discuss the magnetic properties of Cr-doped films based on the magneto-transport studies and Hall measurements.

[1] Xu et al. Nanoscale, 9, 3576 (2017)

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P-27 (Mon)

Classification and Surface Anomaly of Glide Symmetry Protected Topological Phases in Three Dimensions

Fuyan Lu, Bowen Shi, Yuan-Ming Lu

Department of Physics, The Ohio State University

We study glide protected topological (GSPT) phases of interacting bosons and fermions in three spatial dimensions with certain on-site symmetries. They are crystalline SPT phases, which are distinguished from a trivial product state only in the presence of non-symmorphic glide symmetry. We classify these GSPT phases with various on-site symmetries such as U(1) and time reversal, and show that they can all be understood by stacking and coupling two-dimensional short-range entangled phases in a glide-invariant way. Using such a coupled layer construction we study the anomalous surface topological orders of these GSPT phases, which gap out the two-dimensional surface states without breaking any symmetries. While this framework can be applied to any non-symmorphic SPT phase, we demonstrate it in many examples of GSPT phases including the non-symmorphic topological insulator with “hourglass fermion” surface states.

P-28 (Tue)

Superior Valley Polarization and Coherence of 2s Excitons in Monolayer WSe_2

Shao-Yu Chen,[1] Thomas Goldstein,[1] Jiayue Tong,[1] Jun Yan[1], Takashi Taniguchi,[2] Kenji Watanabe[2]

[1]Department of Physics, University of Massachusetts, Amherst
[2]National Institute of Materials Science, 1-1 Namiki, Tsukuba, Ibaraki 305-0044, Japan

We report the observation of 2s exciton radiative emission from monolayer WSe_2, enabled by hexagonal boron nitride protected high-quality samples. The 2s luminescence is highly robust and persists up to 150K, offering a new quantum entity for manipulating the valley degree of freedom. Remarkably, the 2s exciton displays more superior valley polarization and coherence than 1s, despite being a higher energy excitation with more valley decay channels. This observation demonstrates the importance of the intrinsic Coulomb-exchange-interaction-driven valley-depolarization process, the Maialle-Silva-Sham mechanism, in valley excitons of monolayer transition metal dichalcogenides.

P-29 (Mon)

Non-Collinear RKKY Interaction in Graphene with Rashba Spin-Orbit Coupling

Diego Mastrogiuseppe[1] and Sergio Ulloa[2]

[1]Instituto de FÃsica Rosario (CONICET), 2000 Rosario, Argentina
[2]Department of Physics & Astronomy, and Nanoscale and Quantum Phenomena Institute, Ohio University, Athens, OH 45701

Spintronics is an active current area of research that explores the possibility of transferring information via spins, possibly manipulated by electrical means. As such, spin-orbit interaction (SOI) is an essential mechanism to provide the coupling between magnetic moments and electric fields. Two dimensional materials are particularly suitable for this purpose. Their layers can be manipulated in different ways, including STM techniques, allowing the fabrication of novel devices. It is well known that the intrinsic SOI in graphene is negligible. However, an externally induced SOI with sizable strength, the Rashba SOI, can be effected on graphene [1]. This imparts an interesting character to the current carriers in graphene which may mediate the interaction between magnetic impurities (MIs) embedded in such material.

Here we study the RKKY interaction between MIs in graphene in the presence of Rashba SOI, using the Matsubara Green's function formalism. The RKKY interaction provides a way for magnetic moments to interact indirectly via the electrons in the host. We discuss results for varying SOI strength and graphene Fermi energy, at zero and finite temperatures. At charge neutrality, the interaction has a crossover from an R^{-3} decay with no SOI, to an R^{-2} decay for finite Rashba. The interaction is also shown to have anisotropic components, including in-plane (XY), out-of-plane (Ising), and a sizable twisted Dzyaloshinskii-Moriya (DM) term, which can be tailored by the electron concentration. We find that the amplitude of the interactions decreases slowly with temperature (up to ~100 K), providing experimental significance. We calculate angular dependent factors that modulate the interaction, due to the existence of Dirac points at finite momenta. These factors induce rapid oscillations for different relative orientations of the impurities, including zigzag and armchair.

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P-30 (Tue)

2D Materials for STM Studies

Sara Mueller, Grady Gambrel, Steven Tjung, Justin Young, Jonathan Lewis, Driss Guessous, Joshua Schulter, Ezekiel Johnston-Halperin, Jay Gupta

Department of Physics, The Ohio State University

Many 2D materials have been well studied by optical and transport measurements. Though Scanning Tunneling Microscopy is a natural probe for these “all surface” materials, challenges in surface cleanliness have prevented thorough exploration. Since STM requires a pristine, atomically smooth surface, many groups choose to investigate 2D materials by in-situ exfoliation of bulk crystals. Our work, however, focuses on STM studies of UHV grown group IV materials (graphene, silicene, germanene, stannene), and CVD prepared transition metal dichalcogenides (MoS_2). Results from UHV growth on metal substrates demonstrates a competition between 2D material growth and surface alloying in the germanium and tin systems that depends on substrate temperature. Additionally, tunneling spectroscopy can probe the interaction of the 2D material with its underlying substrate. Future efforts will expand the UHV growth to other elemental 2D materials (antimonene) and 2D insulators (h-BN), as well as investigate substrate choices that lead to van der Waals epitaxy or determine the regime where surface alloying is minimized.

P-31 (Mon)

The Theory of Thermomagnetic Transport in Topological Weyl Semimetals

T. M. McCormick[1], S. J. Watzman[2], Chandra Shekhar[3], Yan Sun[3], Arati Prakash[1], Claudia Felser[3], J. P. Heremans[1,2,4] and N. Trivedi[1]

[1]Department of Physics, The Ohio State University
[2]Department of Mechanical and Aerospace Engineering, The Ohio State University
[3]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany
[4]Department of Materials Science and Engineering, The Ohio State University

In topological Weyl semimetals, the low energy excitations are comprised of linearly dispersing Weyl fermions which act as monopoles of Berry curvature in momentum space and result in topologically protected Fermi arcs on the surfaces. Although Weyl semimetals have been demonstrated to exhibit a variety of novel signatures in electronic transport, thermal transport remains less understood. We report on calculations of thermomagnetic transport in Weyl semimetals. In particular, we calculate the dependence of the Nernst effect and the thermal conductivity on magnetic field and temperature. We identify signatures of Weyl nodes in our bulk transport calculations and predict how topological Fermi arcs can be definitively identified in magnetothermal transport. Our work is applicable to several classes of material realizations of Weyl semimetals. We compare our theoretical results with transport measurements in the Weyl semimetal NbP.

P-32 (Tue)

Palladium Diselenide, a New 2D Semiconductor with Tunable Bandgaps and High Mobility for Electronics

Akinola Oyedele[1,2]*, Shize Yang[3], Liangbo Liang[2], Alexander A Puretzky[2], Chris Rouleau[2], Bobby G. Sumpter[2], David B. Geohegan[2], Kai Xiao

[1]*Bredesen Center for Interdisciplinary and Graduate Education, University of Tennessee*
[2]*Center for Nanophase Materials Sciences, Oak Ridge National Laboratory*
[3]*Materials Science and Technology Division, Oak Ridge National Laboratory*

The emergence of two-dimensional (2D) materials in the past decade has enabled the realization of ultra-thin electronic devices with broad-range of applications such as transistors, photodetectors, and chemical sensors. Here, we present a promising 2D candidate, palladium diselenide, belonging to group 10 transition metal dichalcogenides, which shows strong interlayer interactions. Thus, the 2D $PdSe_2$ crystals exhibit a wide band gap variation from ~0.2 (bulk) to ~1.3 eV (monolayer). Few layer $PdSe_2$ FET device shows an excellent carrier mobility of ~ 176 cm^2/Vs with a on/off ratio as high as 10^6. Most importantly, the device is stable in ambient condition, and displays metal-insulator transition in few-layer systems. The unique characteristics exhibited by this material will spark interest making it a promising candidate for 2D electronics.

P-33 (Mon)

Room Temperature Ferromagnetism in MBE-grown van der Waals Magnets

Dante J. O'Hara,[1] Amanda Hanks,[2] Adam S. Ahmed,[3] Choong Hee Lee,[4] Mark R. Brenner,[4] Siddharth Rajan,[4] David W. McComb,[5] Roland K. Kawakami[1,3]

[1]*Program in Materials Science and Engineering, University of California, Riverside*
[2]*Department of Materials Science and Engineering, The Ohio State University*
[3]*Department of Physics, The Ohio State University*
[4]*Department of Electrical and Computer Engineering, The Ohio State University*
[5]*Center for Electron Microscopy and Analysis, The Ohio State University*

Two-dimensional (2D) materials have generated a lot of interest in the scientific community due to their high tunability via surface sensitivity, strain, thickness, and exposure to external fields. Since the discovery of graphene, researchers have explored different classes of 2D materials to discover new physical phenomena and to improve the industrial capability of electronic, photonic and magnetic devices. Recently, there has been a bigger challenge to develop a 2D material that is ferromagnetic at room temperature, which is useful for magnetic memory applications. In this work, we report room temperature ferromagnetism in monolayer $MnSe_2$ grown by molecular beam epitaxy on GaSe/GaAs(111) substrates. This discovery opens the possibility for a tunable room temperature spintronic device using a 2D ferromagnetic material.

P-34 (Tue)

Uniform Wafer-Scale Growth of Stencil Templated, High-Quality Monolayer MoS_2

Ethel Perez-Hoyos,[1] Justin Young,[1] Michael Chilote,[1] Matthew Barone,[1,2] Sara Mueller,[1] Roland Kawakami,[1] Ezekiel Johnston-Halperin[1]

[1]Department of Physics, The Ohio State University
[2]Department of Physics, University of Virginia

With the widespread interest in transition metal dichalcogenides and the recent focus on two-dimensional (2D) vertically stacked heterostructures, a need for an inexpensive and reliable method of producing clean, high-quality, patterned 2D materials has emerged. Here, we report on a templated MoS_2 growth technique by metal sulfurization where Mo is deposited through a SiN stencil onto highly-crystalline sapphire substrates. After sulfurization, the resulting MoS_2 films are shown to be high-quality with thicknesses that can be tuned layer-by-layer "down to a single layer" through manipulation of the initial Mo deposition time. The quality of these films is confirmed through scanning electron and atomic force microscopies as well as Raman and photoluminescence spectroscopy. This facile growth technique results in templated, high-quality MoS_2 films with centimeter-scale uniformity, feature sizes down to 100 nm, and offers both a means to easily probe MoS_2 growth dynamics and a route to 2D stacked heterostructures with arbitrary geometry and pristine interfaces. We will discuss potential applications of this novel growth technique for the development of TMD heterostructures and alloys.

P-35 (Mon)

Confinement and Transmission in Graphene Quantum Wires and Wave Guides Formed by Strain

D. Zhai,[1] Y. Wu,[2] C. Pan,[2] B. Cheng,[2] T. Taniguchi,[3] K. Watanabe,[3] N. Sandler,[1] and M. Bockrath[2,4]

[1]Department of Physics and Astronomy, Ohio University, Athens
[2]Department of Physics and Astronomy, University of California, Riverside
[3]Advanced Materials Laboratory, National Institute for Materials Science, Japan
[4]Department of Physics, The Ohio State University, Columbus

The effects of strain on the electronic and transport properties of graphene have triggered intensive theoretical investigations, which showed that graphene valley filters might be achieved by strain engineering. However, little experimental progress has been made in implementing these ideas. Here, we report transport studies of graphene on top of hexagonal boron nitride, with out-of-plane strained folds. Differential conductance measurements across the linear strained region reveal distinct transport regimes as the gate voltage is changed. In some samples, Coulomb blockade diamonds -characteristic of quantum dot behavior- are observed, while others show Fabry-Perot interferences with higher transmission. The data is consistent with results from a Dirac model including pseudo-magnetic fields produced by a strained Gaussian fold. Theoretical results for the dependence of transport properties on the geometric parameters of the fold, as well as on the incident energy and angle of carriers, for both types of samples are presented. These devices constitute the first step towards a practical realization of valley filters with graphene. Further implications for valley polarization properties of transmitted currents are discussed.

P-36 (Tue)

Van der Waals Stacking Induced Topological Phase Transition in Layered Ternary Transition Metal Chalcogenides

Hua Wang and Xiaofeng Qian

Department of Materials Science and Engineering, Texas A&M University

Electronic materials with nontrivial band topology hold great promise for realizing novel devices with low power consumption and heat dissipation. Here using first-principles approach, we go beyond binary transition metal dichalcogenides, and predict that a class of layered ternary transition metal chalcogenides (TTMC) $MM'Te_4$ exhibits dual topological characteristics: quantum spin Hall insulators in their 2D monolayers and topological Weyl semimetals in their 3D noncentrosymmetric crystals upon van der Waals (vdW) stacking. Remarkably, by tuning the vdW spacing, one can create and annihilate Weyl fermions, and realize the transition between Type-I and Type-II Weyl fermions. In addition, the ternary nature of TTMCs offers greater tunability of electronic structure by controlling different stoichiometry and valence charges. TTMCs, therefore, could be an ideal materials system for exploring quantum spin Hall effect and topological phase transition, and may open up new avenues for both two-dimensional and topological materials research.

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Nano Letters 17, 467-475 (2017)
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P-37 (Mon)

Magnetic Impurity States for Topological Crystalline Insulators

Sahinur Reja,[1] Herbert A. Fertig,[1] Shixiong Zhang,[1] and Luis Brey[2]

[1]*Department of Physics, Indiana University*
[2]*Instituto de Ciencia de Materiales de Madrid, CSIC, 28049 Cantoblanco, Spain*

Topological crystalline insulators (TCI's) are a class of materials which can support non-trivial band topology protected by crystalline symmetry. Using analytic and numerical methods, we study the effect of bulk magnetic impurities on a model of (Sn,Pb)Te alloys which are believed to be TCI's in their topological state. When the Fermi energy is in a bulk gap, gapless surface states are occupied. Their energies are affected by the magnetic ordering on the surface, particularly when it breaks the mirror symmetry. Focusing on the (111) surface, which supports four independent surface Dirac cones (each associated with one of the four L points of the bulk spectrum), we derive the surface states and their coupling to the magnetic moments. Ordering of the moments on the surface opens gaps in the surface spectra, with gap sizes depending on the orientations of the magnetic moments relative to the different L directions in the bulk. This leads to ferromagnetic ordering with magnetization direction sensitive to the doping of the system. In particular we find a transition from a state with a two-fold easy axis to one with six degenerate minima as a function of the surface state filling. Computations of the spin stiffness confirm the linear stability of these states. Possible experimental signatures of these magnetic orderings and transitions among them are discussed.

P-38 (Tue)

Spin-Orbit Coupling Effects and Molecule Adsorption on MoS_2

Tomas Rojas and Sergio E. Ulloa

Department of Physics and Astronomy, Ohio University

Adsorption of molecules on transition metal dichalcogenides (TMDs) such as MoS_2 has opened a number of interesting possibilities in the study of hybrid 2D materials. Gas sensors using layered materials take advantage of the high surface to volume ratio, producing sizable optical and electrical signatures [1]. Similarly, optically addressable molecules (such as azobenzene derivatives) provide an opportunity to controllably gate the TMD materials [2]. In order to better understand and control these hybrid systems, one needs to gain insights into the role of charge transfer and local deformations that are produced by the adsorption of different species.

We have performed first-principles calculations of nitrogen monoxide (NO) and ammonia (NH_3) molecules adsorbed on a MoS_2 monolayer. We use Quantum Espresso with appropriate van der Waals functionals to provide realistic fully-relaxed hybrid structures. Our calculations include spin-orbit interaction, which is sizable in these materials and yet has been neglected in previous studies of similar systems [3]. We aim to describe the adsorption process and resulting local modification to the TMD structure. These molecules are found to have a donor or acceptor character in the TMD which depends on the spin-orbit interaction. We will describe the observed structures and possible observable signatures in optics and/or transport.

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P-39 (Mon)

Universal Fluctuations in Floquet Topological Insulators at Low Frequencies

Martin Rodriguez-Vega and Babak Seradjeh

Department of Physics, Indiana University

We study theoretically the low-frequency regime of Floquet topological insulators. Specifically, we consider a periodically-driven one-dimensional Su-Schrieffer-Heeger (SSH) model, for which we calculate analytically and numerically the quasi-energy spectrum. We study the behavior of the quasi-energy gap as a function of drive frequency and other parameters and self-similar spectral patterns. We also study the topological phase transitions, finding that they are present for arbitrarily small frequencies. We obtain the topological invariants as a function of the system's parameters, and compare with the explicit calculation of localized edge states for systems with open boundary conditions. Finally, we discuss the relevance of our results for the understanding of the long-time adiabatic limit in Floquet systems.

P-40 (Tue)

Effects of Graphene on Sinterability of Al-Zn Based Powder

Haris Rudianto,[1] Sergio Scudinob,[1,2] and Ivo Dlouhya[3]

[1]Department of Mechanical Engineering, Gunadarma University, Depok, West Java, Indonesia
[2]Powder Metallurgy Laboratory, Leibniz Institute, Dresden, Germany
[3]Institute of Materials Science and Engineerin, Brno University of Technology, Technicka 2893/2 Brno, Czech Republic

This research is mainly focused on how to disperse graphene on aluminum powder. Mechanical alloying with 10:1 ball to powder ratio was used to disperse graphene particles on aluminum powder for 10 hours under argon gas. Consentration of graphene was varied from 0.5 to 5wt%. Premix Al-5.5Zn-2.5Mg-0.5Cu was used as matrix. Hot compaction followed by hot extrusion was used for consolidation. It seems that agglomeration is still a problem of dispersion of carbon based materials reinforced metal matrix especially higher concentration of reinforcement particles. This agglomeration will lead to lower density of bulk aluminum. Aluminum carbide (Al_4C_3) was found as a result reaction between graphene and aluminum during consolidation. This compound has important role as bridge to transport tension from matrix to graphene which gave improved mechanical properties.

P-41 (Mon)

Integration of Crystalline Tunnel Barriers onto Graphene: Giant Spin Accumulations and Nanosecond Spin Relaxation Times

Simranjeet Singh[1], Jyoti Katoch[1], Tiancong Zhu[1], Ryan Wu[2], Adam Ahmed[1], Jinsong Xu[1], Cheng Tan[3], Walid Amamou[4], Andre Mkhoyan[2], James Hone[3], and Roland Kawakami[1,4]

[1]Department of Physics, The Ohio State University
[2]Department of Chemical Engineering and Materials Science, University of Minnesota
[3]Mechanical Engineering Department, Columbia University
[4]Materials Science and Engineering, University of California, Riverside

Graphene has shown a great potential for spintronics due to its record-keeping long spin lifetime and spin diffusion length at room temperature. To exploit graphene as a spin channel material for next generation spintronic devices, one needs to inject a high density spin current with suitable tunnel barrier. In graphene spintronics, it has been a challenge to grow a crystalline and robust tunnel barrier, which can withstand large current density and further be used for efficient electrical spin injection. In this work, we experimentally demonstrate giant spin accumulation in graphene lateral spin valves with SrO tunnel barrier. The SrO has been show to grow atomic flat and crystalline with (001) orientation on graphene surface. By measuring non-local DC voltage signals in graphene lateral spin valves (which are directly related to the magnitude of pure spin current), nonlocal spin signals as large as 2 mV are observed at room temperature. These are the highest values reported for graphene. The high spin accumulation observed using SrO tunnel barriers also puts graphene on the roadmap for exploring the possibility of achieving a non-local magnetization switching due to the spin torque from electrically injected spins.

We will also discuss the spin transport in single layer graphene using atomic sheets of hexagonal boron nitride (h-BN) as a tunnel barrier for spin injection. While h-BN is expected to be favorable for spin injection, previous experimental studies have been unable to achieve spin relaxation times in the nanosecond regime, suggesting potential problems originating from the contacts. Here, we investigate spin relaxation in graphene spin valves with h-BN barriers and observe room temperature spin lifetimes in excess of a nanosecond, which provides experimental confirmation that h-BN is indeed a good barrier material for spin injection into graphene. By carrying out measurements with different thicknesses of h-BN, we show that few layer h-BN is a better choice than monolayer for achieving high non-local spin signals and longer spin relaxation times in graphene.

P-42 (Tue)

Valley-Polarized Exciton-Polaritons in a Single-Layer Semiconductor

Yen-Jung Chen,[1] Teodor K. Stanev,[1] Nathaniel P. Stern,[1] Jeffrey D. Cain,[2] Vinayak P. Dravid[2]

[1]Department of Physics and Astronomy, Northwestern University
[2]Department of Materials Science and Engineering, Northwestern University

Single-layer transition metal dichalcogenides (TMDs) are two-dimensional (2D) semiconductors with direct bandgaps and strong excitonic effects, making them promising candidates for strong light-matter interactions [1]. When these materials are embedded into a planar microcavity, interaction of excitons with enhanced photon fields leads to coherent light-matter quasiparticles called exciton-polaritons [2, 3]. While exciton-polaritons are well-understood in traditional semiconductors, TMDs have a richer intrinsic bandstructure that can impart new degrees of freedom that have not yet been exploited in polaritonics. Due to the broken inversion symmetry and the strong spin-orbit coupling, the TMD direct bandgap consists of two degenerate valleys that can be selectively excited by circularly polarized light. Here, we report valley-polarized exciton-polaritons in monolayer MoS_2 embedded in a dielectric microcavity [4]. The polarized emission, Rabi splitting, and spectral anti-crossing of these quasiparticles demonstrate valley polarization in the strong coupling regime. Temperature-dependent measurements show that the polarization dynamics of these valley-sensitive light-matter quasiparticles are highly dependent on the cavity properties, which can be explained by modeling intervalley depolarization in the cavity. The importance of the intervalley and cavity decay channels distinguishes valley-polarized TMD exciton-polaritons from traditional 2D polariton spinor gases, which lack the topologically separate spin-coupled valleys. The ability to access distinct light-matter quasiparticles with potential for intervalley coherence and non-trivial Berry curvature that can be manipulated by microcavity engineering opens new possibilities for polaritonics.

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P-43 (Mon)

Long-Lived Hole Spin/Valley Polarization Probed by Kerr Rotation in Monolayer WSe_2

Xinlin Song[1], Saien Xie[2], Kibum Kang[3], Jiwoong Park[3,4] and Vanessa Sih[5]

[1]*Applied Physics Program, University of Michigan*
[2]*School of Applied and Engineering Physics, Cornell University*
[3]*Department of Chemistry and Chemical Biology, Cornell University*
[4]*Kavli Institute at Cornell for Nanoscale Science*
[5]*Department of Physics, University of Michigan*

Time-resolved Kerr rotation measurements were performed on monolayer tungsten diselenide (WSe_2) grown by metal-organic chemical vapor deposition (MOCVD). A long-lived Kerr rotation signal (approximately 80 ns) was observed at 10 K. The origin of the long-lived Kerr rotation signal is attributed to the hole spin/valley polarization in WSe_2. Due to the transfer of spin polarization from photoexcited carriers to resident carriers, the hole spin/ valley polarization time is not limited by the photo-recombination time (in picosecond scale). Moreover, spatial inversion symmetry breaking and strong spin-orbit coupling results in spin-valley interlocking, which causes hole inter-valley and intra-valley scattering unlikely to happen. In addition to the long lifetime, the hole spin/ valley polarization is robust to a transverse magnetic field up to 300 mT. No spin precession was observed, which is due to spin-orbit spin stabilization. Temperature-dependent photoluminescence (PL) measurements were also done. Free exciton emission and localized exciton emission were observed in the PL spectrum. Wavelength-dependent Kerr rotation measurements showed that only light with energy close to the free exciton emission energy can generate hole polarization even when the free exciton emission is absent at low temperature.

P-44 (Tue)

Robust Spin Transport Through a Graphene Quantum Hall Antiferromagnet

Petr Stepanov[1, 2]*, Shi Che[1, 2*], Dmitry Shcherbakov[1, 2], Jiawei Yang[1, 2], Kevin Thilahar[1], Greyson Voigt[1], Marc W. Bockrath[1, 2], Dmitry Smirnov[3], Kenji Watanabe[4], Takashi Taniguchi[4], Roger Lake[5], Yafis Barlas[1, 5], Allan H. MacDonald[6], Chun Ning Lau[1, 2]

[1]Department of Physics, The Ohio State University
[2]Department of Physics and Astronomy, University of California, Riverside
[3]National High Magnetic Field Laboratory, Tallahassee, FL
[4]National Institute for Materials Science, 1-1 Namiki Tsukuba Ibaraki 305-0044 Japan
[5]Department of Electrical and Computer Engineering, University of California, Riverside
[6]Department of Physics, University of Texas at Austin

An important goal in spintronics is to establish mechanisms that minimize dissipation in the devices that are to exhibit the action of spin currents. In magnetic insulators the easy plane ordered spin currents can be carried dissipationless in the form of spin-supercurrents. Spin superfluidity transport has been theoretically predicted in a graphene quantum Hall insulator [1]. Here we report on the first experimental demonstration of the robust spin-current transport through graphene anti-ferromagnet insulator (AFMI) in the quantum Hall regime. The charge neutrality point (CNP) forms canted anti-ferromagnet (CAF) in the ground state that effectively serves as AFMI for spin currents propagation. By utilizing quantum Hall (QH) edge modes as injector, filters and detector we find large non-local signal across 5 μm long graphene CAF region. Our work demonstrates robust spin transport through AFMI in graphene and shows that QH states can serve as a powerful tool for fundamental studies of ferromagnet and anti-ferromagnet spintronics.

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*These authors contributed equally to this work.

P-45 (Mon)

Orbital and Spin Order in Spin-Orbit Coupled d1 and d2 Double Perovskites

Christopher Svoboda, Mohit Randeria, Nandini Trivedi

Department of Physics, The Ohio State University

We consider strongly spin-orbit coupled double perovskites $A_2BB'O_6$ with B' magnetic ions in either d1 or d2 electronic configuration and non-magnetic B ions. We provide insights into several experimental puzzles, such as the predominance of ferromagnetism in d1 versus antiferromagnetism in d2 systems, the appearance of negative Curie-Weiss temperatures for ferromagnetic materials, and the size of effective magnetic moments. We develop and solve a microscopic model with both spin and orbital degrees of freedom within the Mott insulating regime at finite temperature using mean field theory. The interplay between anisotropic orbital degrees of freedom and spin-orbit coupling results in complex ground states in both d1 and d2 systems. We show that the ordering of orbital degrees of freedom in d1 systems results in coplanar canted ferromagnetic and 4-sublattice antiferromagnetic structures. In d2 systems we find additional colinear antiferromagnetic and ferromagnetic phases not appearing in d1 systems. At finite temperatures, we find that orbital ordering driven by both superexchange and Coulomb interactions may occur at much higher temperatures compared to magnetic order and leads to distinct deviations from Curie-Weiss law.

P-46 (Tue)

Electrical Control of Spin-Valley Photocurrents in a Monolayer Semiconductor

Lei Liu, Erik Lenferink, Nathaniel P. Stern

Department of Physics and Astronomy, Northwestern University

In a monolayer transition metal dichalcogenide (TMDC) that lacks structural inversion symmetry, valley-contrasting optical selection rules enable the creation of a population imbalance between the two valleys with an external polarized optical field [1]. As the two valleys exhibit contrasting Berry curvature, these monolayer materials offer new mechanisms for manipulating carrier transport and optical phenomena governed by the conversion between light and excitons. Utilizing the circular photogalvanic effect, the generation of a spin-valley-polarized photocurrent has been demonstrated in monolayer TMDC devices [2-4], but continuous tuning of this polarized photocurrent so far has remained largely unexplored. Here we discuss the feasibility of tuning spin-valley photocurrent magnitude by purely electrical means. In a monolayer MoS_2 device, we are able to modulate the magnitude by 500% with a lateral electric field, and effectively turn the polarization on and off with a gating voltage. The efficient electrical tuning of spin-valley photocurrent opens new possibilities for manipulating valley index by local electric methods and exploiting valley-polarized photocurrents in monolayer semiconductor devices.

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P-47 (Mon)

Above 400 K Perpendicular Ferromagnetic Phase in a Topological Insulator

Chi Tang,[1] Cui-Zu Chang,[2] Gejian Zhao,[3] Yawen Liu,[1] Zilong Jiang,[1] Chao-Xing Liu,[2] Martha R. McCartney,[3] David J. Smith,[3] Tingyong Chen,[3] Jagadeesh S. Moodera,[4] Jing Shi[1]

[1]Department of Physics and Astronomy, University of California, Riverside
[2]Department of Physics, Pennsylvania State University
[3]Department of Physics, Arizona State University
[4]Bitter Magnet Laboratory, Massachusetts Institute of Technology

The quantum anomalous Hall effect (QAHE) observed in magnetic topological insulators (TI), an outcome of time reversal symmetry broken surface states, exhibits many exotic properties. However, a major obstacle towards high temperature QAHE is the low Curie temperature in the disordered magnetically doped TI systems. Here we report a study on heterostructures of TI and magnetic insulator in which the magnetic insulator, namely thulium iron garnet or TIG, has perpendicular magnetic anisotropy. At the TIG/TI interface, TIG magnetizes the surface states of the TI film by exchange coupling, as revealed by the anomalous Hall effect (AHE). We demonstrate that squared AHE hysteresis loops persist well above room temperature. The interface proximity induced high-temperature ferromagnetism in topological insulators opens up new possibilities for the realization of QAHE at high temperatures.

P-48 (Tue)

Spin Field Effect Transistor in h-BN/Graphene/h-BN Heterostructure with One-Dimensional Contact

Jinsong Xu,[1] Simranjeet Singh,[1] Jyoti Katoch,[1] Guanzhong Wu,[1] Roland K. Kawakami[1]

[1]*Department of Physics, The Ohio State University, Columbus, OH 43210, USA*

Graphene is a very active research field of spintronics because of its long spin diffusion length and spin relaxation time. Very recently, Yan *et al*. reported a two-dimensional spin field effect transistor (FET) based on graphene/MoS_2 heterostructure through tuning spin absorption by electrical backgate. Here, we presented a different approach to realize spin FET in graphene. For the first time, we observed non-local spin transport signal in h-BN/graphene/h-BN heterostructure with one-dimensional contact. Moreover, the spin signal is not only strongly modulated but also changes polarity when applying electrical backgate, which is possibly due to the proximity effect at the one-dimensional interface between graphene and cobalt contact. This opens a new way to the future development of graphene spin FET.

P-49 (Mon)

Plasmon Response of Graphene Nanoribbons

Farhad Karimi and Irena Knezevic

Electrical and Computer Engineering, University of Wisconsin-Madison

In good conductors, electrons can oscillate collectively in response to an external electromagnetic field, producing surface plasmon polaritons (plasmons for short). Plasmons are able to confine the electromagnetic energy below the diffraction limit, which makes them a promising approach to shrink the size of photonic circuits. Among the plasmonic materials, graphene offers interesting plasmonic properties, e.g., plasmon resonances within the terahertz to mid-infrared range as well as plasmon-resonance tunability. However, in graphene on a substrate, the plasmon propagation length is on the order of tens to hundreds of nanometers. One way to improve the plasmon propagation length is nanostructuring. Supported graphene nanoribbons (GNRs) provide a less dissipative environment for plasmons, yet, they retain almost the same interesting plasmonic features as graphene. We show that, in supported GNRs, surface optical-phonon scattering, which is an inelastic and anisotropic scattering mechanism, is very important, so the relaxation-time approximation fails to accurately capture plasmon damping in GNRs.

Here, we calculate the linear optical response in GNRs via a self-consistent- field approach within the Markovian master equation formalism (SCF-MMEF). The SCF-MMEF is able to capture several concurrent scattering mechanisms. We calculate the dielectric function, the loss function, consequently the plasmon response in GNRs, and show that in supported (3N+2)-aGNRs, plasmons can propagate up to a micron, at least an order of magnitude longer than in other types of GNRs. Also, we calculate the plasmon distribution in GNRs. In aGNRs, plasmons are distributed almost uniformly along the width of the ribbon; in zGNRs, because of the strong electron-electron interaction, plasmons are spin polarized and are accumulated near the edges.

P-50 (Tue)

Strong Proximity-Induced Rashba Spin-Orbit Coupling in Graphene/Single-Layer Transition Metal Dichalcogenide Heterostructures

Bowen Yang,[1] Mark Lohmann,[1] David Barroso,[2] Ingrid Liao,[2] Takashi Taniguchi,[3] Kenji Watanabe,[3] Ludwig Bartels,[4] and Jing Shi[1]

[1]*Department of Physics and Astronomy, University of California, Riverside*
[2]*Materials Science and Engineering, University of California, Riverside*
[3]*National Institute for Materials Science, Japan*
[4]*Department of Chemistry, University of California, Riverside*

Despite its extremely weak intrinsic spin-orbit coupling (SOC), graphene can acquire considerable SOC by hybridizing the wave functions of its pi-electrons and foreign heavy adatoms or other atomically layered materials containing heavy atoms such as transition metal dichalcogenides (TMD). In the latter approach, both Rashba and Zeeman-like SOC can be induced by proximity coupling, but the strength should highly depend on the physical distance between them. Here we demonstrate strong induced Rashba SOC in graphene that is proximity coupled with a large sheet (> 50 um) of monolayer TMD (e.g. MoS_2 and WSe_2) grown by chemical vapor deposition (CVD). Graphene/TMD heterostructures are fabricated with a pickup-transfer technique utilizing hexagonal boron nitride (h-BN), which ensures intimate contact and thus leads to strong interfacial interaction between graphene and TMD, as evidenced by quenched photoluminescence in TMD. Consequently, strong induced SOC emerges, which is manifested in the pronounced weak anti-localization (WAL) effect in graphene magnetoresistance. We find that the spin relaxation rate extracted from the WAL analysis varies linearly with the momentum relaxation time, indicating a dominant Dyakonov-Perel (DP) spin relaxation mechanism from the induced Rashba SOC interaction. Our analysis yields the Rashba SOC energy to be approximately 1.5 meV in graphene/WSe_2 and 0.9 meV in graphene/MoS_2. Our work opens up the possibility of tailoring strong Rashba interaction in graphene with CVD grown single-layer TMD to realize novel quantum states such as the quantized anomalous Hall state for spintronic device applications.

P-51 (Mon)

Magnetic Proximity Effect in Pt/$CoFe_2O_4$ Bilayers

Walid Amamou,[1] Igor Pinchuk,[2] Amanda Hanks,[3] Robert Williams[4], Wolfgang Windl,[3] David McComb,[4] Roland Kawakami[1,2]

[1]Materials Science and Engineering, University of California, Riverside
[2]Department of Physics, The Ohio State University
[3]Department of Materials Science and Engineering, The Ohio State University
[4]Center for Electron Microscopy and Analysis, The Ohio State University

Introducing magnetic ordering into intrinsically non-magnetic systems is a promising way to manipulate spin currents in the next generation of 2D spintronic devices. In our work, we study induced magnetic moments inside a 1.7 nm Pt layer deposited on a ferromagnetic insulator $CoFe_2O_4$ using molecular beam epitaxy (MBE). Through angle-dependent magnetoresistance measurements, we confirm the presence of a magnetized Pt layer in contact with $CoFe_2O_4$. Studies of Hall resistivity, insertion of Cu spacers and DFT calculations provide additional evidence for MPE. The observation of MPE in Pt/CFO goes against the conventional wisdom and opens the door to the using the family of spinel ferrites for MPE and spin manipulation via proximity exchange fields.

P-52 (Tue)

Examining the Weak Localization and Weak Anti-Localization in Correlated Semimetallic $SrIrO_3$ Thin Films

Le Zhang, Xiaozhe Zhang, Xuanyuan Jiang, Xiaoshan Xu, Xia Hong

Department of Physics and Astronomy, University of Nebraska, Lincoln

We have studied the weak localization (WL) and weak anti-localization (WAL) effects in epitaxial $SrIrO_3$ (SIO) thin films to probe the electron correlation and spin-orbit coupling (SOC). We deposited 1.6 - 30 nm SIO thin films on $SrTiO_3$ (001) substrates via off-axis RF magnetron sputtering, with c-axis (pseudo-cubic) growth and atomically smooth surfaces achieved. Resistance of the films shows a moderate decrease with decreasing temperature. Modeling the Hall effect result with the two-carrier model and assuming equal electron- and hole-densities, we extracted a carrier density of $\sim 10^{19}$ - 10^{20} cm^{-3} and comparable electron and hole mobility of ~100 cm^2/Vs. For films below 10 nm, we observed a slight resistance upturn at low temperature, which can be attributed to WL. The low temperature magnetoconductance (MC) (2 K - 5 K) shows a transition from WAL to WL. By fitting the MC with the Maekawa-Fukuyama model, we extracted the inelastic dephasing time and spin relaxation time. While the inelastic field shows linear temperature dependence, suggesting electron-electron interaction as the phase breaking mechanism, the spin relaxation field exhibits quadratic temperature dependence. We also explore the effect of carrier doping on the spin relaxation time using the electric field effect approach.

P-53 (Mon)

Topological Dirac Semimetal Na_3Bi Thin Films Grown By Molecular Beam Epitaxy

Igor Pinchuk,[1] Guanzhong Wu,[1] Adam Ahmed,[1] Tadj Asel,[1] Andrew Franson,[1] Tiancong Zhu,[1] Kaifei Kang,[2] Amanda Hanks,[3] Fuyan Lu,[1] Yuan-Ming Lu,[1] Len Brillson,[1,4] Ezekiel Johnston-Halperin,[1] Jay Gupta,[1] Jie Shan,[2] David McComb,[5] Roland Kawakami[1]

[1]Department of Physics, The Ohio State University
[2]Department of Physics, Pennsylvania State University
[3]Department of Materials Science and Engineering, The Ohio State University
[4]Department of Electrical and Computer Engineering, The Ohio State University
[5]Center for Electron Microscopy and Analysis, The Ohio State University

Topological Dirac semimetals are three dimensional materials with Dirac dispersion within the bulk and Fermi arcs on the surface. The spin degree of freedom is locked to the momentum due to strong spin-orbit coupling, which suppresses backscattering for higher mobility and makes these materials potentially interesting for spintronics. Furthermore, quantum size effects in thin films are predicted to have dramatic impact on the topological properties. Here, we report the growth and characterization of Na_3Bi, a topological Dirac semimetal, using molecular beam epitaxy (MBE). Because Na_3Bi is known to quickly oxidize, we employ an air-free sample handling system where samples can be transferred among MBE systems, x-ray photoelectron spectroscopy (XPS), scanning tunneling microscopy (STM), glove boxes for transport and encapsulation, and cathodoluminescence spectroscopy using an ultrahigh vacuum (UHV) suitcase.