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Physics of Emergent Materials Workshop

The Ohio State University

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The Center for Emergent Materials at The Ohio State University is a Materials Research Science and Engineering Center (MRSEC) funded by the National Science Foundation (NSF), one of 23 nationwide. The MRSEC program funds teams of researchers from different disciplines to work collaboratively on materials research in order to address fundamental problems in science and engineering. By working in teams, called Interdisciplinary Research Groups (IRG), the researchers at CEM tackle scientific problems that are too large and complex for a scientist working alone to solve.

Research

- Spin-Orbit Coupling in Correlated Materials: Novel Phases and Phenomena, lays the foundations for magnetic and topological phenomena in 4d and 5d oxides by discovering and developing new paradigms and guiding principles enabled by SOC and correlations. Highlights include the discovery of topological states in compounds containing 4d and 5d ions, predictions of novel magnetism enabled by intersite hopping, and new understanding of exchange coupling between 5d and 3d ions.
- Control of 2D Electronic Structure and 1D Interfaces by Surface Patterning of Group-IV Graphane Analogues is developing new 2D materials and heterostructures that are tunable by surface modification and proximity effects to achieve robust topological states and atomic-scale spin manipulation. Highlights include tuning electronic structure and spin-orbit effects in 2D materials via chemistry, atomic-scale patterning of lateral heterostructures, and ultrafast imaging of spin dynamics.
- Nonlinear Interactions between Spin Flux and Engineered Magnetic Textures seeks to engineer magnetic textures to explore novel magnetic dynamics and excitation, with high-efficiency spin transport, and new regimes to manipulate spin flux. Highlights include high quality insulating magnets and spatially textured hyperfine fields.

Outreach & Professional Development

- Local primary and secondary school partnerships to enhance STEM learning in non-traditional ways through programs like Breakfast of Science Champions, Scientific Thinkers, and Math Science Partnership Program.
- Undergrads from community colleges, national universities receive authentic research experiences.
- Graduate students, postdocs participate in technical & professional workshops for career development.
- Physics Masters-to-PhD Bridge program, which CEM was vital in establishing, strives to enhance the diversity of talented applicants and prepare them to succeed in a physics PhD program.

Industry & Collaborations

- Robust national and international collaborations like IFW-Dresden in Germany, Iowa State, University of Tennessee, Case Western, UCLA and UC Berkeley, to name a few.
- Industrial and commercial collaborations with companies such as Lake Shore Cryotronics; HGST, a Western Digital company; IBM Research- Almaden; Traycer Systems, Inc. and Entrotech Inc. improve both partners' ability to translate technologies from the lab to the commercial sector.

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Workshop Schedule

Tuesday, May 23rd

9:00 - 9:45 am	PREM Introduction to CEM (CEM internal advisory council), Smith Seminar Room
9:45 - 11:00 am	CEM Research Overview Poster Session for PREM, Atrium
11:00 - Noon	NSL lab tours, meet in Atrium
Noon - 1:30 pm	Lunch, walk off-campus
1:30 - 5:00 pm	Research Lab Tours and Research Discussions, locations on handout
5:00 - 5:45 pm	Welcome and CEM Overview (Chris Hammel), Smith Seminar Room
5:45 - 6:00 pm	Student Poster Setup, Atrium
6:00 - 7:30 pm	Evening Reception, Atrium

Wednesday, May 24th in PRB Smith Seminar Room

8:00 - 8:45 am	Breakfast	
8:45 - 9:00 am	Announcements	
9:00 - 10:30 am	Nandini Trivedi: Tutorial 1 - Spin-orbit Coupling (notes available)	
10:30 - 11:00 am	Coffee break	
11:00 - 11:30 am	Jack Brangham: Antiferromagnetic Spin Transport in NiO and Spin-to-Charge…	Chair:
11:30 - Noon	Chi Zhang: Spin-Orbit Torque Control of Dipole Field-Localized Spin Wave…	S. Singh
Noon - 1:30 pm	Lunch	
1:30 - 3:00 pm	Jos Heremans: Tutorial 2 - Irreversible Thermodynamics and Transport (notes available)	
3:00 - 3:30 pm	Coffee Break and Group Photo	
3:30 - 4:00 pm	Arati Prakash: Spin Seebeck physics: Effect of temperature Gradients in YIG	Chair:
4:00 - 4:30 pm	Koen Vandaele: Spin Seebeck effect in bulk nanocomposites	T. McCormick
4:30 - 6:30 pm	Poster Session	
6:30 - 8:00 pm	Dinner	

Thursday, May 25th in PRB Smith Seminar Room

8:00 - 8:45am	Breakfast	
8:45 - 9:00 am	Announcements	
9:00 - 10:30 am	Nandini Trivedi: Tutorial 3 - Topology in Band Structures (notes available)	
10:30 - 11:00 am	Coffee break	
11:00 - 11:30 am	Bryan D. Esser: Correlating Microstructure & Magnetic Structures in Skyrmion…	Chair:
11:30 – Noon	Maxx Arguilla: Adventures of Tin in 2D: Electronic & Magnetic Materials Based…	V.Bhallamudi
Noon - 1:30 pm	Lunch	
1:30 - 2:00 pm	Yunqiu (Kelly) Luo: Opto-Valleytronic Spin Injection in MoS2/Graphene Hybrid…	Chair:
2:00 - 2:30 pm	Carola Purser: Nanoscale Sensing & Magnetic Resonance Spectroscopy Using...	T. Hazra
2:30 - 3:00 pm	Kyusung Hwang: TBA	
3:00 - 3:30 pm	Coffee and closing remarks	
3:30 - 4:30 pm	Brainstorming future research directions	

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Presentation Abstracts

Maxx Arguilla Adventures of Tin in 2D: Electronic & Magnetic Materials Based on 2D Honeycomb Sn Lattice

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 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 BaSn2, 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 BaSn2 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's 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's 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 ASn2As2 (A= Na, Sr and Eu) structure that exhibits anisotropic carrier type (p-type out-of-plane and n-type in-plane) transport in NaSn2As2, Dirac semi-metallic behavior in SrSn2As2 and anisotropic magnetism, with anti-ferromagnetic coupling out-of-plane and ferromagnetic coupling in-plane, in EuSn2As2. Overall, the creation of these novel materials beyond graphene allows for the discovery of novel electronic and spintronic phenomena, properties and applications in 2D.

Jack Brangham Antiferromagnetic Spin Transport in NiO and Spin-to-Charge Conversion in Au

The generation, propagation, and detection of spin currents are of intense interest in the field of spintronics. Spin current generation by FMR spin pumping using Y3Fe5O12 (YIG) and spin current detection by the inverse spin Hall effect (ISHE) in metals such as Au and Pt have been well studied. This is due to YIG's exceptionally low damping and insulating behavior, the high conductive and stability of Au, and the large spin Hall angle of Pt. However there have been conflicting reports for the spin Hall angle in Au, so we investigated the thickness dependence of the spin Hall angle in Au and found films less than 10 nm showed in a significantly larger spin Hall angle than thicker films, potentially explaining the previously inconsistent reports. Additionally, our group showed that the ISHE voltages are significantly enhanced by adding a thin intermediate layer of an antiferromagnet (AFM) between Pt and YIG at room temperature [1, 2]. Recent theoretical work predicts a mechanism for this enhancement as well as the temperature dependence of the ISHE voltages of metal/AFM/YIG trilayers [3]. The predictions show a maximum in the ISHE voltages for these systems near the magnetic phase transition temperature of the AFM. Here we present experimental results showing the temperature dependence for Pt/AFM/YIG structures with various AFMs. 1. H. L. Wang, et. al., Phys. Rev. Lett. 132, 097202 (2014). 2. H. L. Wang, et. al., Phys. Rev. B 91, 220410(R) (2015). 3. R. Khymyn, et. al., Phys. Rev. B 93, 224421 (2016).

Bryan D. Esser Correlating Microstructure and Magnetic Structures in Skyrmion Materials Using in situ Aberration-Corrected Electron Microscopy

With the evolution of novel magnetic structures such as skyrmions, there exists a need to develop techniques capable of imaging these complex magnetic structures with high spatial resolution. Aberration-corrected electron microscopy with a sub-Angstrom sized probe gives atomic resolution images of thin films and nanometer resolution compositional analysis. In combination with in situ techniques such as Lorentz transmission electron microscopy (LTEM) and differential phase contrast scanning TEM (DPC-STEM), the skyrmion phase diagram can be probed as a function of both temperature and applied magnetic field. Here we show that thin film microstructure plays a significant role in skyrmion lattice formation and evolution in FeGe thin films grown on Si(111). Additionally, we preview promising work with B20 heterostructures for tunable skyrmion properties.

Kyusung Hwang **Title TBA**
Abstract TBA

Yuniqu (Kelly) Luo **Opto-Valleytronic Spin Injection in MoS2/Graphene Hybrid Spin Valves**
Two dimensional (2D) materials provide a unique platform for spintronics and valleytronics due to the ability to combine vastly different functionalities into one vertically-stacked heterostructure, where the strengths of each of the constituent materials can compensate for the weaknesses of the others. Graphene has been demonstrated to be 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 efficiently generated in monolayer transition metal dichalcogenides (TMD) such as MoS2 via absorption of circularly-polarized photons, but lateral spin or valley transport has not been realized at room temperature. In this letter, we fabricate monolayer MoS2/multilayer graphene hybrid spin valves and demonstrate, for the first time, the opto-valleytronic spin injection across a TMD/graphene interface. 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 achieves optical spin injection and lateral spin transport at room temperature in a single device, which paves the way for multifunctional 2D spintronic devices for memory and logic applications.

Arati Prakash **Spin Seebeck physics: Effect of temperature Gradients in YIG**
Temperature-dependent spin Seebeck effect (SSE) data on Pt/YIG (yttrium iron garnet, Y3Fe5O12)/GGG (gadolinium gallium garnet) trilayers are reported for various thicknesses of the YIG films, from 10 nm to 1um, and for a Pt/bulk YIG sample. While the SSE has been studied extensively in recent years, the absence of a thorough experimental understanding and control of the temperature profiles in the multilayered SSE structures has led to disparities in results between various experimental groups. We address this issue by expressing the SSE as the ratio of the electric field due to the inverse spin Hall effect in the Pt films to the heat flux across the Pt/YIG/GGG trilayer which, in fact, corresponds to a thermal spin Seebeck resistivity (SSR). We study our data as a function of the YIG thickness. Results are analyzed within a diffusive model for magnon spin and energy transport.

Carola Purser **Nanoscale Sensing and Magnetic Resonance Spectroscopy Using NV Centers in Diamond**
Nitrogen-vacancy (NV) centers in diamond have been identified as excellent atomic-sized sensors that have been used to measure single electron and proton spins at room temperature. These capabilities make NV centers good candidates for imaging single biological molecules and characterizing spin-based information devices. For most sensing applications, a single NV center must be measured at specific field-matching conditions with the target spins or manipulated with intricate control sequences. However, the Hammel research group at OSU discovered

a novel detection technique that uses simple, continuous-wave excitation of the NV center spins. This detection scheme can be used for broadband, nanoscale detection of ferromagnetic and paramagnetic spin dynamics at room temperature. The first half of this talk will highlight recent developments in the field of NV diamond magnetometry and introduce common detection techniques. In the second half, I will give an overview of on-going research efforts in the Hammel labs with the aim of facilitating future collaborations.

Koen Vandaele **Spin Seebeck effect in bulk nanocomposites**

Here we discuss the spin Seebeck effect (SSE) in nanocomposite samples. Typically, the SSE is observed in metallic thin films deposited onto an insulating ferromagnetic substrate, but their high contact resistant limits their thermoelectric conversion efficiency. Therefore, nanocomposites composed of Ni particles deposited with Pt nanoparticles were synthesized. The obtained Ni-Pt nanocomposites exhibited a contribution of the spin Seebeck effect (SSE) in Pt to the transverse thermopower in Ni, proving that the SSE effect observed in thin film structures can also be obtained in bulk samples.1 This proof of concept provides a pathway for further material design and enhancing the thermoelectric conversion efficiency in nanocomposites.

Further, we discuss the Nerst thermopower in semimetallic bismuth antimony alloys2 based on the antimony content and the use of Bi1-xSbx nanocomposites in SSE experiments.

References

(1) S. R. Boona et al., Nature Communications 7 (2016)

(2) S. Tang and M. S. Dresselhaus, Nano Lett. 12, 2021–2026 (2012)

Chi Zhang **Spin-Orbit Torque Control of Dipole Field-Localized Spin Wave Modes**

Auto-oscillation of a ferromagnet due to spin-orbit torques in response to a dc current is of wide interest as a flexible mechanism for generating controllable high frequency magnetic dynamics. We use localized spin wave modes that are confined by strongly inhomogeneous dipole magnetic field of a nearby micromagnet to manipulate their response to spin-orbit generated spin currents. This provides variable spatial confinement and systematic tuning of magnon spectrum, which offers a new approach to study the impact of multi-mode interactions on auto-oscillations by continuously tuning the spectral separations of dipole field-localized modes. Here we first demonstrate electrical spin-torque ferromagnetic resonance (ST-FMR) detection of well-resolved dipole field-localized modes in a Py/Pt strip. We observe clear damping control, and find that localized modes can be controlled as efficiently as the uniform mode. We further drive localized modes into auto-oscillations with dc current only. We study their characteristic behaviors, and discuss the role of reduced scattering channels.

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Posters

Thaddeus Asel	Electronic Propertes and Defects in Germanane
Beth Bushong	Imaging Spin Dynamics in Monolayer WS2 by Time-Resolved Kerr Rotation Microscopy
Abhilasha Dehankar	Proximity induced novel physics in magnetic nanoparticle (0D) – graphene (2D) interfacial composites
Luis Garcia	Maintenance and Utilization of Supercomputer Cluster for Density Functional Theory
Evgheni Jucov	Structural and Computational Studies of the New Polymorph of Tetracene-TCNQ
Jyoti Katoch	Giant spin-splitting and gap renormalization driven by trions in single-layer WS2/h-BN heterostructures
Kyungmin Lee	TITLE TBA
Jared Leyba	TITLE TBA
Yunqiu (Kelly) Luo	Opto-Valleytronic Spin Injection in MoS2/Graphene Hybrid Spin Valves
Tim McCormick	The theory of thermomagnetic transport in topological Weyl semimetals
Keng-Yuan Meng	Dzyaloshinskii-Moriya interaction at SrRuO3-SrIrO3 bilayer
Carola Purser	Nanometer-scale Spectroscopy of Spin Dynamics Using Nitrogen-Vacancy Centers in Diamond
Jacob Repicky	Title: Novel Surface Reconstruction and Hysteretic Tunneling Spectroscopy on Cr(001)
Billy Romero	Magnetic properties and behaviors of Zn-BTC metal organic framework
Chris Svoboda	Orbital and spin order in spin-orbit coupled d1 and d2 double perovskites
Steven Tjung	Crystalline Hydrogenation of Graphene Grown on Cu(111)
Matthew Warren	TITLE TBA
Daniel Weber	Single Layers of Magnetic Semiconducting RuCl3 – a True 2D Honeycomb Lattice
Jiaxin Wu	Symmetry-enforced quantum spin Hall insulators in Ï€-flux models
Yuanhua Zheng	Thermopower and Anomalous Nernst Coefficients of Binary Ferromagnetic Alloys Fe-Co and Ni-Cr
Tiancong Zhu	Atomic hydrogen induced resonant scattering in bilayer graphene

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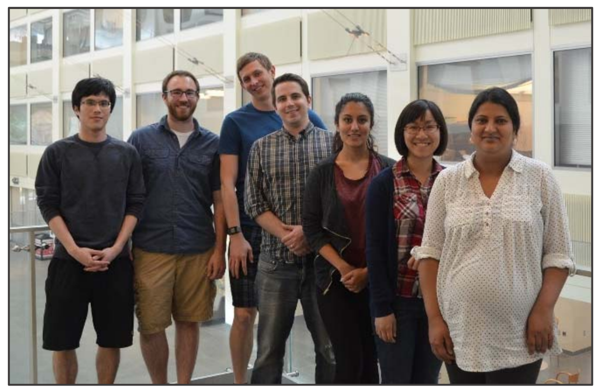
This event was organized by the CEM Internal Advisory Council. The Council was created in 2016 to advise the Center in the interests of students and postdocs. It is open to all students or postdoctoral researchers affiliated in any way with the MRSEC (funding/tuition from the Center is not required). The Council meets to offer input on current and future directions within the MRSEC and receives a budget to spend on its own initiatives or events.

CEM Internal Advisory Council
Dr. Jyoti Katoch (Chair, Postdoc, IRG-2)
Prof. Nandini Trivedi (Faculty Advisor, IRG-1)
Jack Brangham (Graduate Researcher, IRG-3)
Tim McCormick (Graduate Researcher, IRG-1)
Keng Yuan Mark Meng (Graduate Researcher, IRG-3)
Arati Prakash (Graduate Researcher, IRG-3)
Jacob Repicky (Graduate Researcher, IRG-2)
Phuong Tran (Graduate Researcher, IRG-1)



Past Members:
Grady Gambrel (Graduate Researcher, IRG-2)
Jie Xiong (Graduate Researcher, IRG-1)

Your feedback is valued!

Please respond to our workshop survey:

https://osu.az1.qualtrics.com/jfe/form/SV_bO6YKXTyxqUIdel