## PCSI
## Room Canyon/Sugarloaf - Session PCSI-1TuM
## Magnetism

**Moderator:** Michael Flatté, University of Iowa

8:30am **PCSI-1TuM-1 Quantum Microscopy of Nanoscale Materials and Devices***, **Christian Degen,*** ETH Zurich, Switzerland **INVITED**

Diamond nanoprobes with single engineered NV centers allow enhancing scanning probe microscopy with quantum metrology. In this talk, I will introduce the basic concepts and technology of diamond nanoprobes, and give illustrative examples of applications in nanoscale imaging of magnetism and currents.

+ Author for correspondence: degenc@ethz.ch

9:10am **PCSI-1TuM-9 UPGRADED: Mechanical Control of Valley Magnetization and Berry Curvature Dipole in Monolayer $MoS_2$***, **Joolee Son,*** Ajou University, Republic of Korea*; K Kim,* Pohang University of Science and Technology, Republic of Korea*; Y Ahn,* Ajou University, Republic of Korea*; H Lee,* Pohang University of Science and Technology, Republic of Korea*; J Lee,* Ajou University, Republic of Korea

Atomically thin honeycomb crystals have recently emerged as promising platforms to investigate electron's valley degree of freedom for the development of functional valley-based devices. Electron control by valley index has been demonstrated using electrical, optical and magnetic means, owing to the opposite signs of the Berry curvature between two valley centers. Here we report a different kind of valley-based electron control that is based on the Berry curvature dipole. We demonstrate the generation of net valley magnetization under an in-plane electric field, regulated by the strain-induced modification of the Berry curvature distribution, which produces the Berry curvature dipole. The generation of valley magnetization is optically detected by using the Kerr rotation microscopy on monolayer $MoS_2$ embedded in flexible van der Waals heterostructures as functions of tunable strain. The measured valley magnetization is well explained by the calculated values of the strain-induced Berry curvature dipole. Our work demonstrates strain as a new functionality for potential novel flexomagnetic and valley information processing devices using monolayer TMD materials.

9:30am **PCSI-1TuM-13 Room Temperature Ferromagnetic Monolayer MnGaN-2D Investigated by Spin-polarized Scanning Tunneling Microscopy/ Spectroscopy and First-principles Density Functional Theory***, Y Ma, T Erickson,* Nanoscale & Quantum Phenomena Institute*; K Meng, F Yang,* The Ohio State University*; D Hunt, A Barral, V Ferrari,* CAC-CNEA, Argentina*; **A.R. Smith,*** Nanoscale & Quantum Phenomena Institute

Development of spintronic applications based on semiconductor materials combined with magnetic dopants has been a topic of great interest for many years. More recently has been the rapid growth of interest in 2-dimensional materials with both semi-conductive and/or magnetic properties. We have reported the direct observation of the room-temperature ferromagnetism for MnGaN-2D using spin-polarized scanning tunneling microscopy and spectroscopy combined with firstprinciples calculations.[1] This 2D material is directly grown on the surface of N-polar GaN(0001) using molecular beam epitaxy and consists of 1/3 ML of Mn atoms incorporated into the surface Ga adlayer and forming a √3 x √3 - *R*30° structure as seen in Fig. 1.

Density functional theory shows that this monolayer structure has *perpendicular* magnetic anisotropy with a highly spin-polarized and spin-split manganese density of states. We verify the magnetic properties using SQUID magnetometry. In addition, we explore changes in the energy of the Mn peak DOS as seen in tunneling spectroscopy and discover theoretically that it is caused by surface strain. Different models, including isotropic, anisotropic, and defect-induced strain models are explored, and it is concluded that the Mn-N bond length is the critical parameter. The local strain is then directly observed in atomic scale STM images as a non-Gaussian distribution of lattice parameters, and disordering is seen in the 2D pair correlation as well. This strain may be the effect of the manner in which the surface is prepared, thus opening the possibility of atomic-scale engineering of magnetic anisotropy.


[1] Y. Ma, A.V. Chinchore, A.R. Smith, M.A. Barral, and V. Ferrari, *Nano Letters* **18**, 158 (2018).


+ Author for correspondence: smitha2@ohio.edu

9:35am **PCSI-1TuM-14 UPGRADED: Local Exchange Resonance in DC Magnetoresistance of Spin-Polarized Current Through a Dopant***, **Stephen McMillan,*** University of Iowa*; N Harmon,* University of Evansville*; M Flatté,* University of Iowa

Components for quantum information processing and quantum sensing require localized spin-coherent states. These states can be realized in isolated magnetic dopants embedded in a non-magnetic semiconducting host. A critical requirement for utilizing a dopant-based system is an understanding of how the complex host environment influences the coherent spin dynamics at an individual site. In this work we consider the dc magnetoresistance through a spin-1/2 dopant that is addressed by a spin-polarized scanning tunneling microscope (SP-STM) and exchange coupled to an inert spin-1/2 center [1]. The stochastic Liouville formalism is employed to calculate the current through the individual dopant. We predict a substantial increase in resistance at finite magnetic fields due to the formation of a non-trivial bottleneck in the spin-correlated transport. Resonance between the Zeeman and exchange coupling leads to a cancelation in the coherent evolution of the dopant spin resulting in an on-site polarization opposing that of the SP-STM. This feature provides a precise method for measuring the dopant exchange coupling to a nearby electronic spin and by direct analog hyperfine coupling in the presence of nuclear spins. This technique does not require the use of ac electric or magnetic fields and is sensitive to exchange or hyperfine energies well below the thermal energy of the system.


[1] S.R. McMillan, N.J. Harmon, M.E. Flatté, [https://arxiv.org/abs/1907.05509] **[cond-mat.mes-hall]**


+ Author for correspondence: Stephen.mcmillan7@gmail.com

9:55am **PCSI-1TuM-18 Room Temperature Ferromagnetism in GaSb Thin Films Doped with Mn***, A Pulzara Mora, **Camilo Andres Pulzara Mora,*** Universidad Nacional de Colombia, Colombia

The design and development of Hall Effect magnetic field sensors with III-V semiconductor materials and magnetic alloys (Mn) is a current topic - due to its applications in different branches of physics like spintronics. Semiconductor materials such as GaSb are important because of their applications in modern Nano-electronics, infrared emitting lasers with a 0.7 eV bandgap and especially in photovoltaic systems and their optical response to wavelengths longer than silicon-based solar cells [1][2]. When the Mn is introduced in the matrix of these semiconductors, we have new opportunities in the context of spintronics, owing that in the alloys the spatial distribution of electrons and holes can be controlled easily, resulting in the magnetic properties of these materials.

The structural, electrical and magnetic properties of GaSbMn thin films were studied. The samples were grown by Magnetron Sputtering on heated Si (111) substrates. In order to incorporate Mn in low concentrations in the GaSb matrix, the substrate temperatures were varied from 300°C to 400°C. X-ray diffraction patterns show that they have a polycrystalline structure. We find that at 300°C GaSbMn grows as a smooth, phase-pure film, whereas at higher temperatures (400°C) the films become increasingly rough, but more crystalline with segregated MnSb and Mn impurities, shown also by Scanning Electron Microscopy. High temperature SQUID magnetometry measures Curie temperatures of 350 K for the film grown at 300°C, and above 500K for 400°C. The GaSbMn exhibits a well-defined magnetic hysteresis loop above room temperature. These loops show that the superparamagnetic (or weak ferromagnetic) behavior of the GaSbMn layers depends on the Mn content. Magnetotransport measurements show well developed anomalous Hall effect (AHE) hysteresis loops that persist up to room temperature. This result shows that the magnetic properties are very sensitive to experimental parameters such as working pressure and growth temperature [3][4].


[1] H. Luo, *Elsevier*, vol. 20, no. 3–4, pp. 338–345, 2004.

[2] R. Bernal-correa, Momento, no. 51, pp. 31–44, 2015

[3] M. R. Islam, Cryst. Res. Technol. 43, No. 10, 1091 – 1096 (2008).

[4] Z.C. Feng, J. Appl. Phys. 68, 5363 (1990).


10:00am **PCSI-1TuM-19 Magnetotransport Studies in Hybrid 2D/0D Nanostructures***, **Ethel Perez-Hoyos,** Y Luo, A Dehankar, J Xu, D Pharis, J Winter, R Kawakami, E Johnston-Halperin,* The Ohio State University

We introduce a device fabrication strategy that takes advantage of stacking techniques developed for van der Waals heterostructures to construct hybrid 2D/0D composite magnetic nanostructures, with potential application in the study of spin and charge disorder as well as magnetic-proximity effects. The structures in this study are comprised of superparamagnetic iron oxide nanoparticles (SPIONs) and monolayer graphene. The SPIONs are deposited first using a Langmuir-Blodgett technique, yielding rafts of highly ordered nanoparticles. Characterization via magnetic force microscopy (MFM) reveals magnetic order at multiple length scales and SQUID magnetometry identifies both glassy antiferromagnetic and ferromagnetic response. Single graphene monolayers are mechanically stacked on the SPIONs layer, and characterized via low temperature magneto-transport. Initial measurements show good electron mobility in the graphene layer and indications of exchange coupling between the graphene and the SPIONs layer.

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