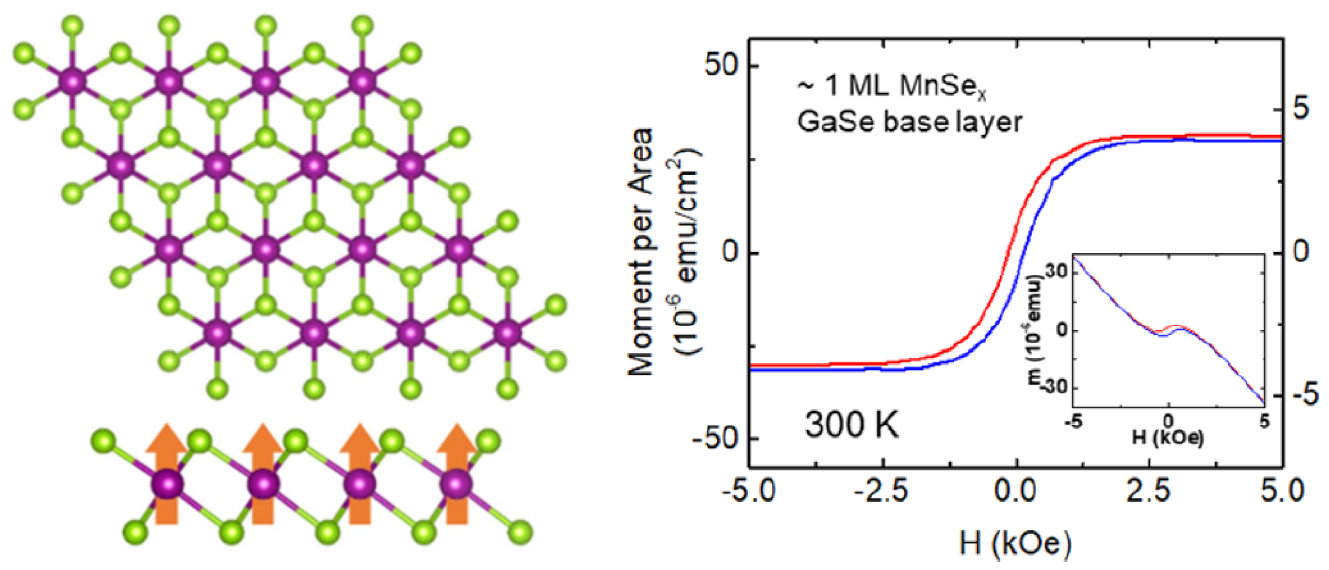
The Kawakami Group

Spintronics, Magnetism, Topological Materials, 2D Materials, and Quantum Point Defects

Room Temperature 2D Magnets

We have developed one of the first room-temperature 2D magnets, monolayer $MnSe_2$, by molecular beam epitaxy.

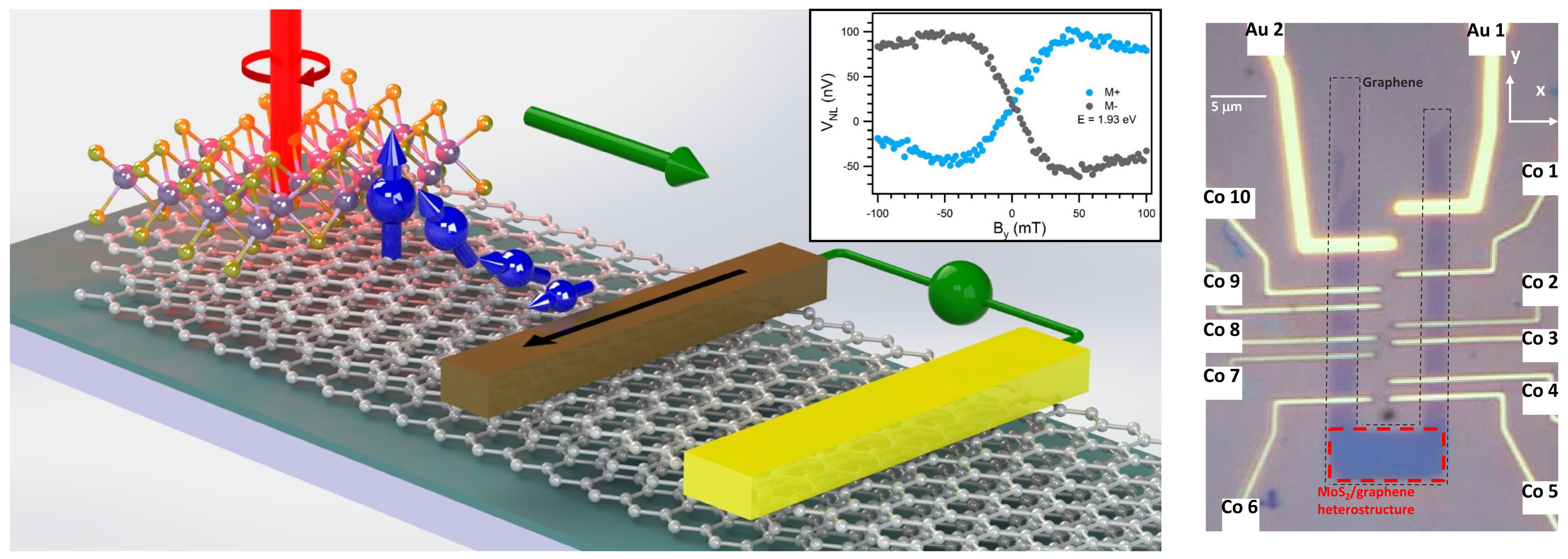


(Left) A top and side view of 1T-$MnSe_2$. Arrows indicate the magnetic moments on the Mn atoms. (Right) A magnetic hysteresis loop taken with SQUID magnetometry demonstrates the ferromagnetic nature of ~1 monolayer $MnSe_x$

D. J. O'Hara, T. Zhu, A. H. Trout, A. S. Ahmed, Y. K. Luo, C. H. Lee, M. R. Brenner, S. Rajan, J. A. Gupta, D. W. McComb, R. K. Kawakami, Room Temperature Intrinsic Ferromagnetism in Epitaxial Manganese Selenide Films in the Monolayer Limit., Nano Lett. 18, 3125 (2018).

Optospintronics and Spin Transport in 2D Materials

2D materials offer a unique system where different materials can be easily stacked into heterostructures in which their behaviors can complement each other. We showed for the first time that the opto-valley selection rules of transition metal dichalcogenides (TMDs) could be leveraged to optically inject spins into graphene, a high spin conductivity material.

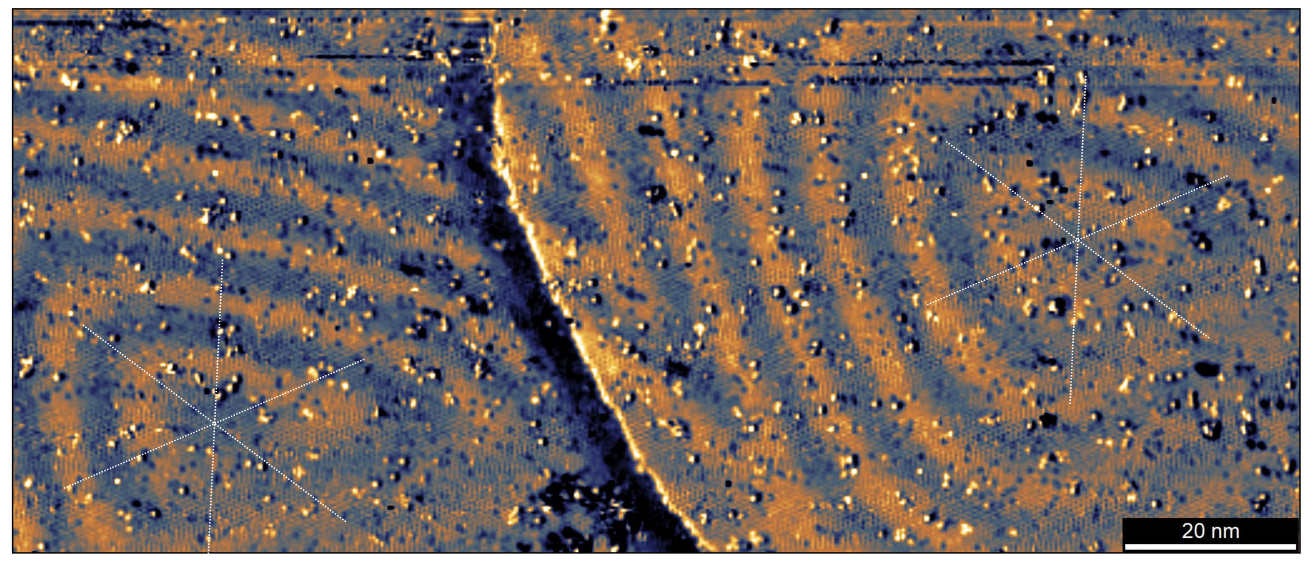


(Left) Optical-pump and electrical detection experiment of spin transfer from monolayer MoS_2 to graphene. (Right) Image of a MoS_2/graphene spin valve device.

Y. K. Luo, J. Xu, T. Zhu, G. Wu, E. J. McCormick, M. R. Neupane, and R. K. Kawakami, "Optovalleytronic spin injection in monolayer MoS_2/few-layer graphene hybrid spin valves," Nano Letters 17, 3877 (2017).

Atomic-Scale Magnetic Skyrmions

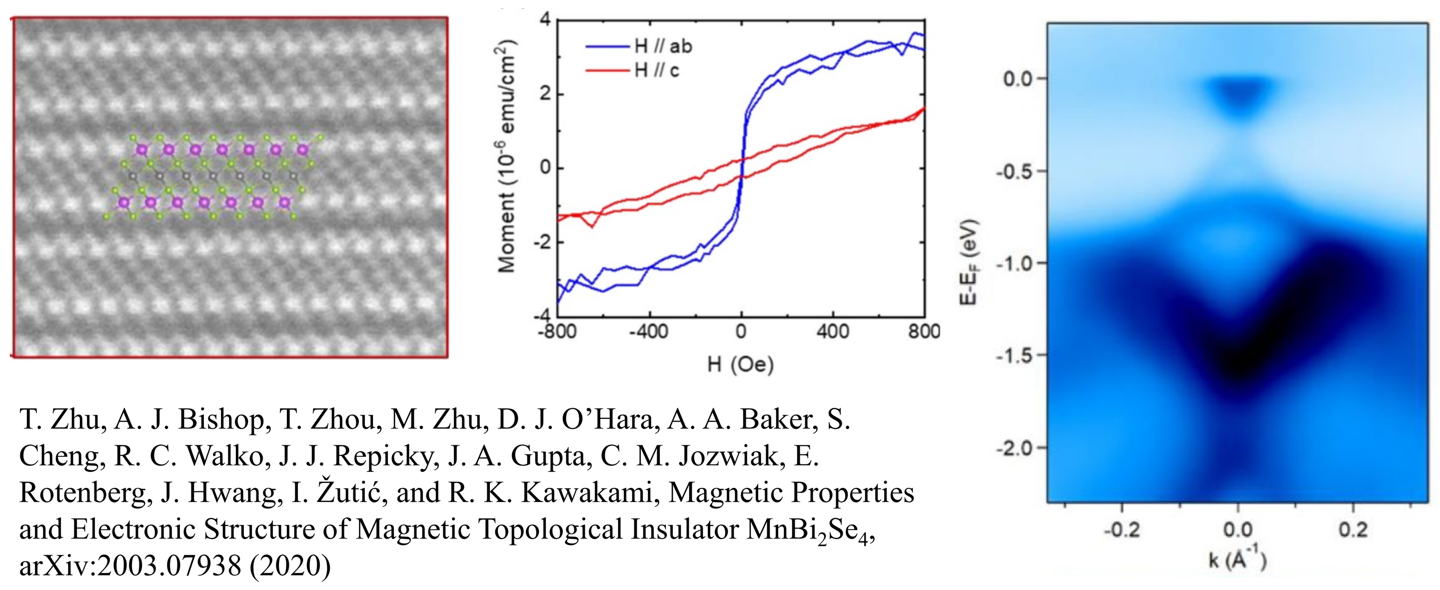
Magnetic materials with broken structural inversion symmetry have a spin-spin interaction that causes the magnetic moments to twist, leading to magnetic textures such as extended helices and localized Skyrmions.



Here, we utilize molecular beam epitaxy to grow films of MnGe, a magnetic material with broken inversion symmetry, and image the atomic-scale structure and magnetism with spin-polarized scanning tunneling microscopy (SPSTM). This reveals nanometer-scale helices and Skyrmions.

Magnetic Topological Materials

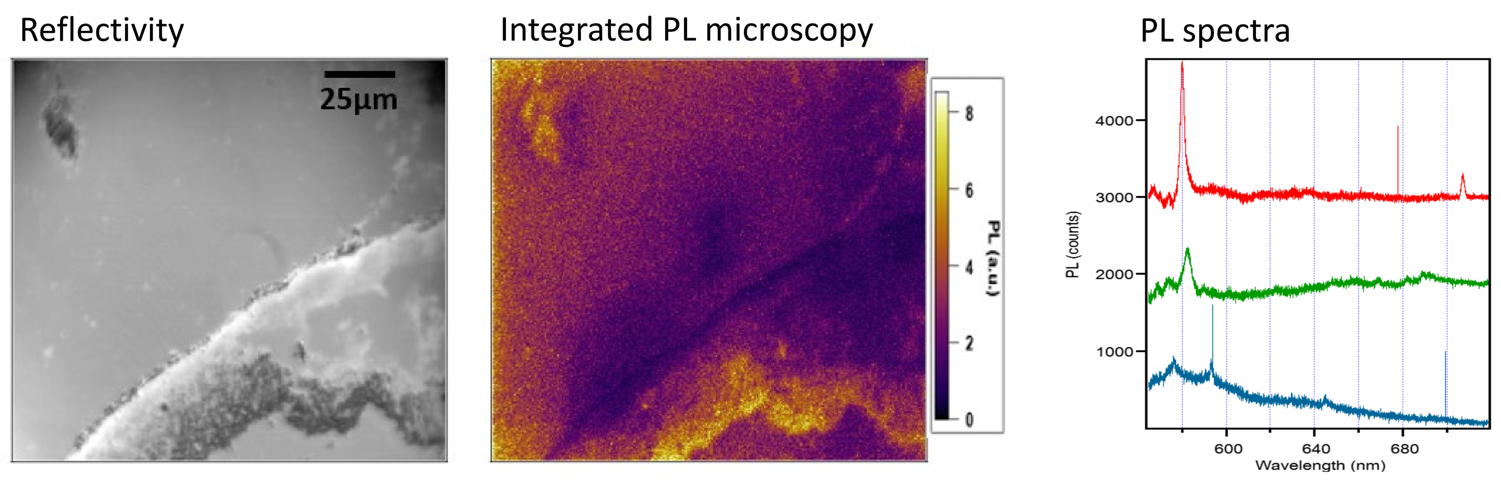
New topological states are predicted when introducing magnetism into topological materials. Using non-equilibrium MBE, we are the first to synthesize multilayer $MnBi_2Se_4$, a metastable magnetic topological insulator that does not exist as a bulk material. This is a layered antiferromagnet (left: TEM image) with in-plane magnetic moments (center: SQUID loops) and topological surface states measured by angle-resolved photoemission spectroscopy (right: ARPES).



T. Zhu, A. J. Bishop, T. Zhou, M. Zhu, D. J. O'Hara, A. A. Baker, S. Cheng, R. C. Walko, J. J. Repicky, J. A. Gupta, C. M. Jozwiak, E. Rotenberg, J. Hwang, I. Žutić, and R. K. Kawakami, Magnetic Properties and Electronic Structure of Magnetic Topological Insulator $MnBi_2Se_4$, arXiv:2003.07938 (2020)

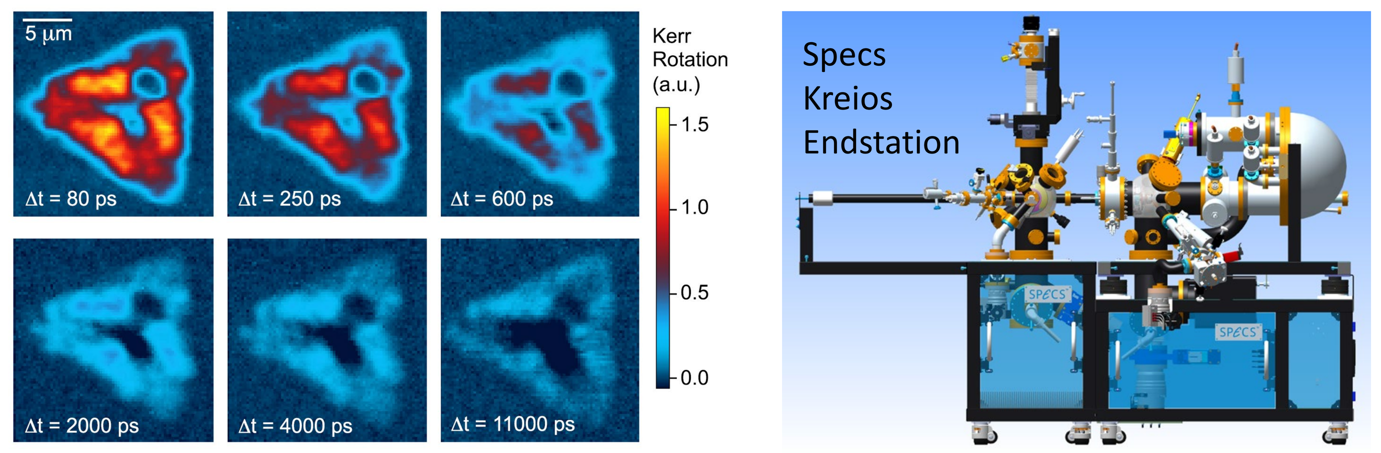
Spin Qubits and Single-Photon Emitters for Quantum Information Science

Point defects implanted into crystalline materials are an exciting new platform for single spin qubits and single photon emitters. We utilize standard annealing techniques, along with argon sputtering and MBE, to create tailored point defect emitters in hexagonal boron nitride (hBN), a 2D insulator. The van der Waals nature of hBN means these emitters can also be easily integrated into heterostructures with other 2D or 3D materials, where their behavior can be tuned by local electric or magnetic fields.



(Left) Reflectivity image of drop-cast hBN flakes on Si/SiO_2 substrate. (Center) Photoluminescence (PL) map of the same region. Bright locations indicate strong PL. (Right) PL spectra from select locations on the hBN. Bright narrow peaks such as in the red curve are characteristic of single photon emitters.

Ultrafast Magnetooptics & Time-Resolved ARPES



(Left) We have utilized all-optical time-resolved Kerr rotation to image the dynamics of valley-spin polarization in 2D semiconductor WS_2. (Right) As part of the NSF NEXUS (National Extreme Ultrafast Science) Facility, we are developing time-resolved micro-ARPES (Angle-Resolved Photoemission Spectroscopy) to measure the dynamics of band structure and the electron and hole populations for even more direct measurements of valley-spin dynamics.

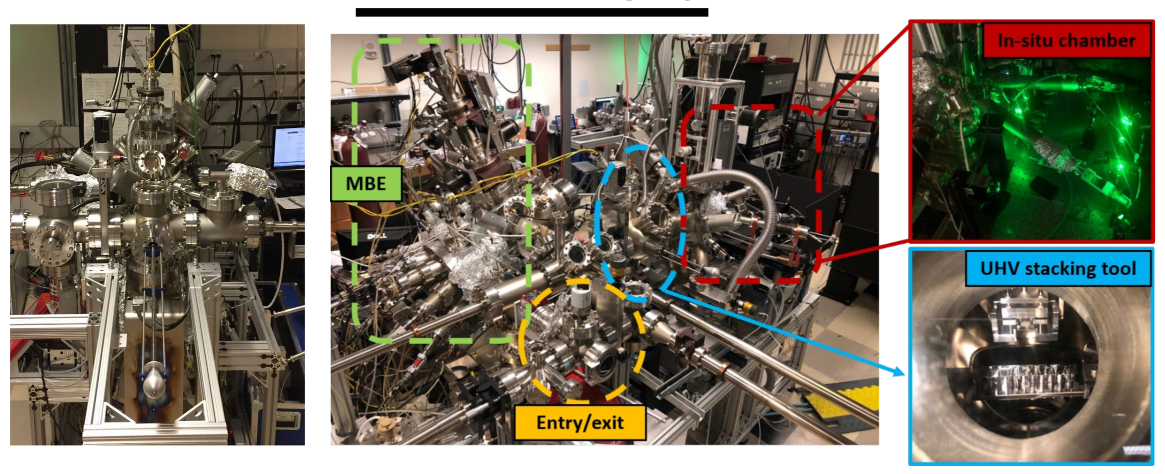
E. J. McCormick, M. J. Newburger, Y. K. Luo, K. M. McCreary, S. Singh, I. B. Martin, E. Cichewicz, J., B. T. Jonker, and R. K. Kawakami, Imaging spin dynamics in monolayer WS_2 by time-resolved Kerr rotation microscopy, 2D Mater. 5, 011010 (2018).

Facilities

Optics Lab

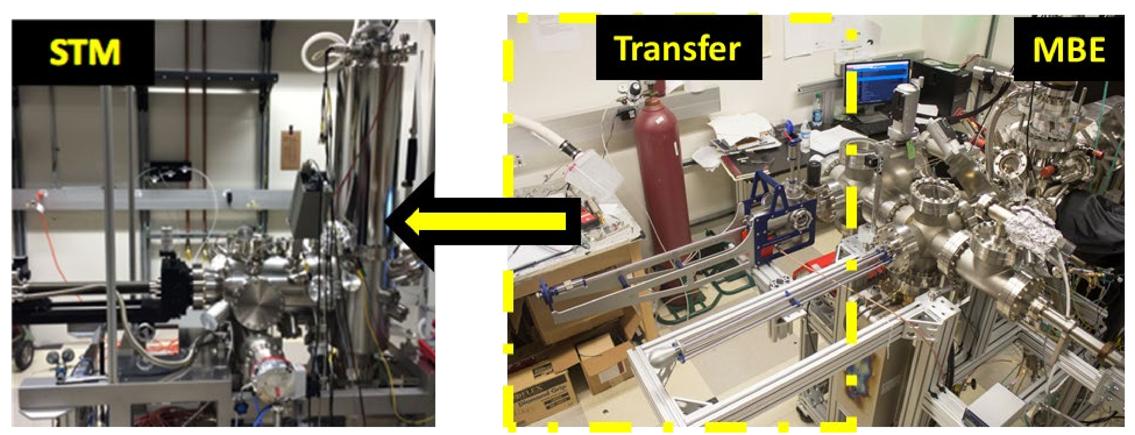
- 2 pulsed lasers and multiple diode lasers allow for multiple optics experiments including MOKE, time-resolved Kerr rotation, photoconductivity, and photoluminescence
- 3 optical cryostations allow for low temp and high magnetic field measurements of devices and materials

MBE Lab



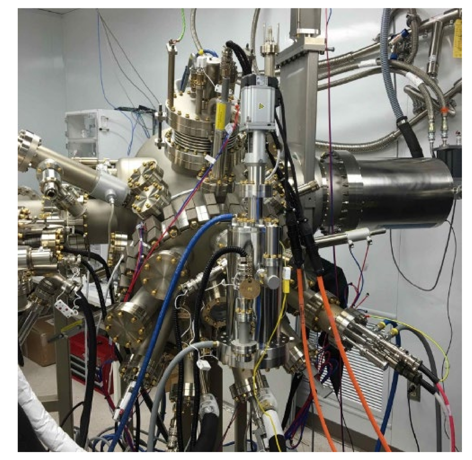
- 2 MBE chambers provide high quality growth of novel materials including oxides, ferrites, Skyrmion materials, Dirac semimetals, and doped insulators
- A connected UHV stacking tool integrates 2D materials with ultraclean interfaces of MBE materials while optics allow for in-situ photoluminescence of point defects

STM Lab



- A spin-polarized STM lets us image atomic structure, as well as magnetic behavior and edge or surface states in MBE grown materials (SPSTM is run jointly with the Gupta group)
- A UHV suitcase lets us transport materials from growth chambers around campus to the STM without contamination of their surface

2D MBE



- A Veeco 930 MBE chamber in the cleanroom of Dreese labs allows for the growth of 2D materials including transition metal dichalcogenides and 2D magnets, as well as topological insulators.
- Using the UHV suitcase, these materials can be integrated with our other growth systems