National Science Foundation
MRSEC
Materials Research Science and Engineering Centers

I-MRSEC

The Illinois Materials Research Science and Engineering Center (I-MRSEC)

Major Accomplishments, Sept. 2017 – Dec. 2020

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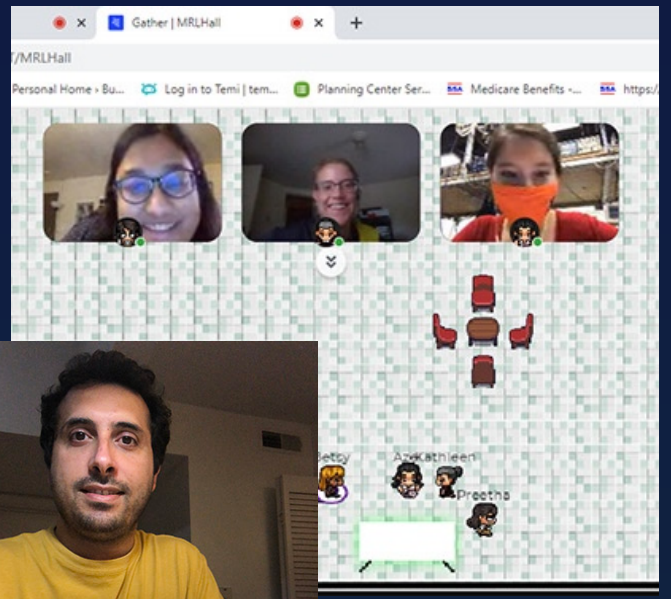
The I-MRSEC

- 2 IRGs
  AFM Metals, Deformed 2D
- 26 PIs from 7 departments
- 58 graduate students
- 19 postdocs
- 10 undergraduates + 10 REUs

- > 100 publications
- 9 new major facilities
- 11 Seed PIs
- Weekly events: IRG meeting, seminars, training, social



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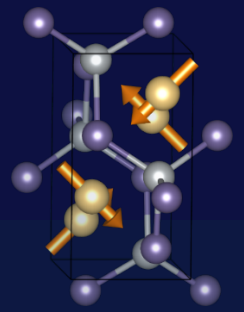
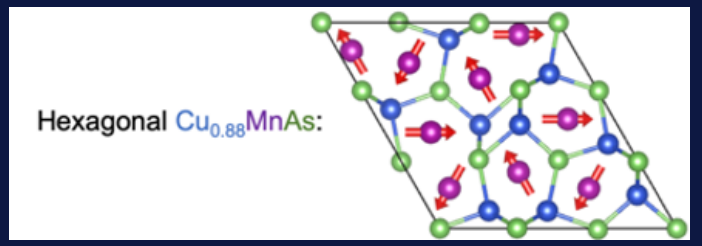
IRG1: Metallic Antiferromagnetic Materials: Ultrafast Charge, Lattice, and Magnetization Dynamics



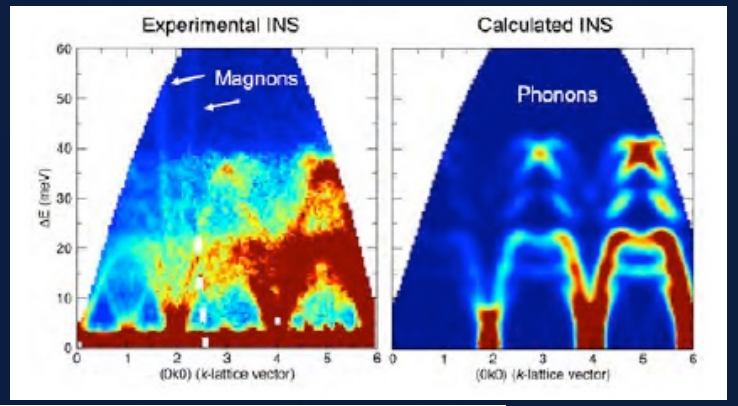
Goal: Determine the magnetic, optical, electronic, and phononic couplings that underlie fundamental limits on the control of magnetic order and dynamics

- Explained the non-collinear magnetic structure of *h*-$Cu_{0.88}MnAs$
- Connected the magneto-optic response and the magnetic structure of collinear and non-collinear metallic antiferromagnets
- Showed that spin-orbit torques may originate from magnetic spin Hall effects
- Revealed a fundamental connection between antiferromagnetism and topology, and applied to magnetoresistance of FeRh

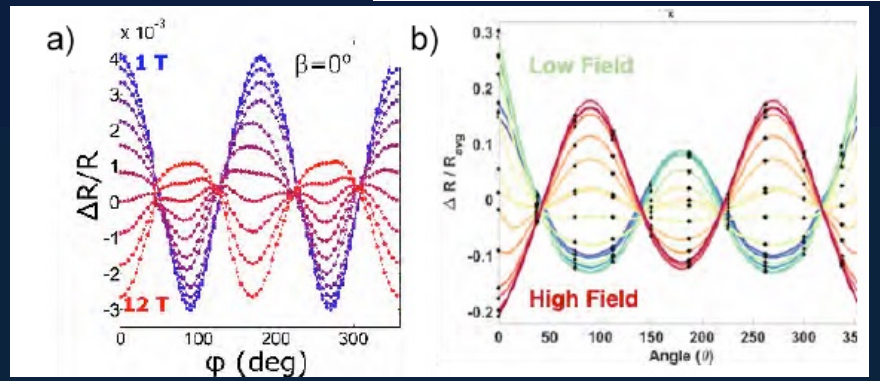


Phys Rev B **102,** 064415 (2020)

Phys Rev Mat **4**, 114416 (2020)



Submitted (2021)



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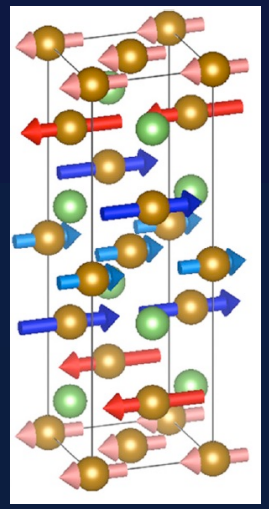
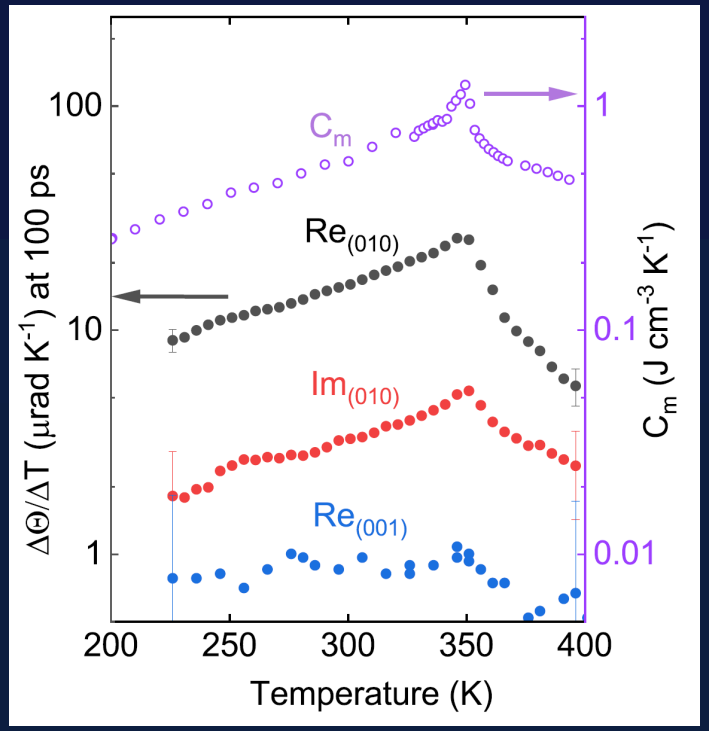
Ultrafast magneto-optic response of the metallic antiferromagnet Fe_2As



- **Shoemaker** synthesized single crystals of tetragonal Fe_2As with easy-plane magnetic structure (left)
- **Cahill** measured the heat capacities and ultrafast magneto-optic response.
- **Schleife** performed first principles density functional theory calculations of heat capacities of electrons, phonons, and magnons

- Counter to conventional wisdom, the magneto-optic effects are largest perpendicular to the Neel vector.
- The transient optical response follows the magnetic heat capacity (right), indicating the importance of exchange interactions to the optical constants.



K. Yang, et al. Phys. Rev. Mat. **3** 124408 (2019)

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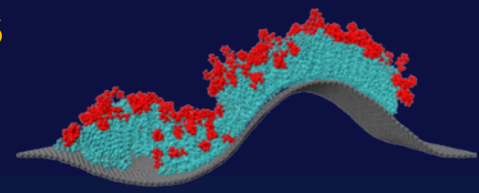
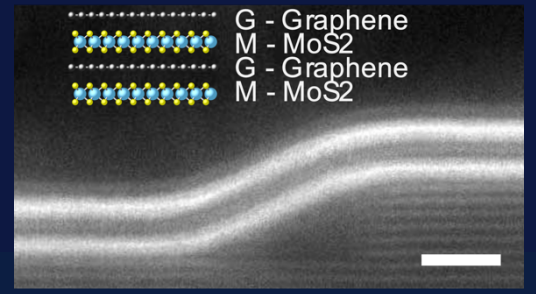
IRG2: Active Interfaces Between Highly-Deformable Nanomaterials



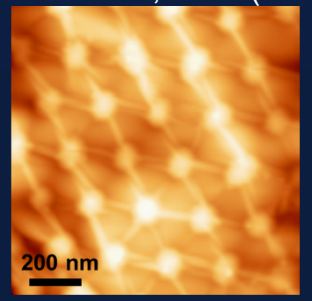
Goal: Advance fundamental understanding of how functional properties of nanomaterials and bio-interfaces are tuned by large multi-scale deformations

- Resolved the mechanism of out of plane bending in 2D multilayers and heterostructures.
- Engineered 3D morphology of 2D multilayers atop pliable substrates from nanoscale folds to micro-scale wrinkles.
- Showed induced quantum states with 3D superlattice templates.
- Elucidated the effect of inhomogeneous strain on the opto-electronic response of 2D membranes.
- Demonstrated strain-resilient electronics from crumpled 2D heterostructures.
- Demonstrated that crumpled graphene FET-based biosensors have 10^4x enhanced sensitivity.
- Demonstrated morphology driven self-assembly of nanoparticles and cells on wrinkled 2D materials.

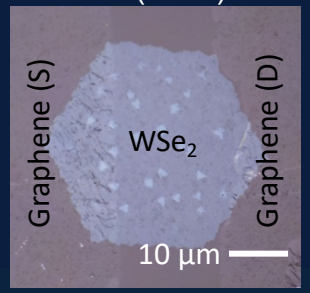
Advanced Materials (2021) In Press.



Nano Lett. 18, 2098 (2018)



ACS AMI 12 43 48910 (2020)



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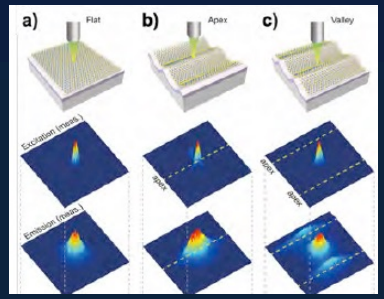

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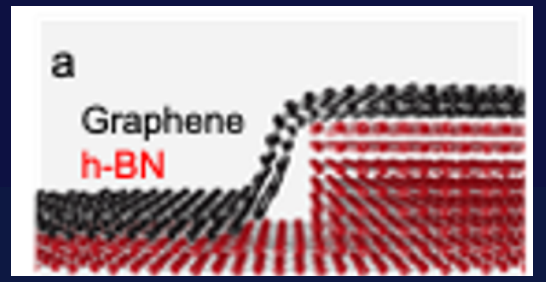
IRG2 Highlight 1

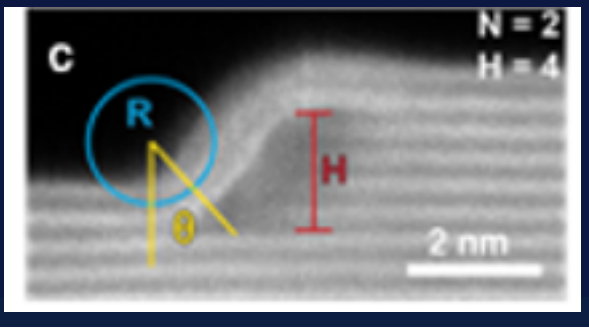
Slip-mediated bending in graphene and 2D heterostructures

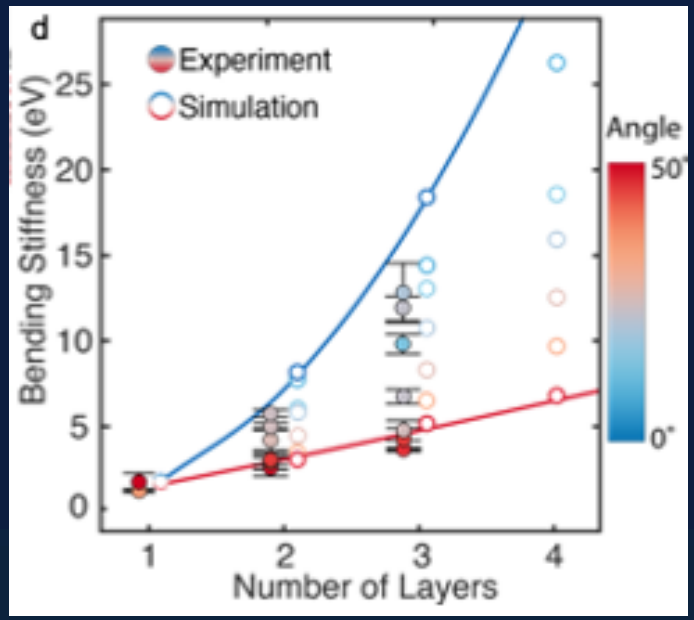
- **Van der Zande** fabricated heterostructures with systematically varying curvature & alignment
- **Huang** used atomic scale imaging
- **Ertekin** performed first principles density functional theory

- Directly measured the bending stiffness of graphene & 2D heterostructures.
- Showed 2D materials can be orders of magnitude softer than previously thought

- Discovered a slip-mediated model of bending that:
  - Unifies a decade of disagreeing results
  - Allows prediction & design of stiffness of arbitrary heterostructures







E. Han et al., Nature Materials 19, 305-309 (2019)
J. Yu et al. Advanced Materials (2021) In Press (superlubric bending)

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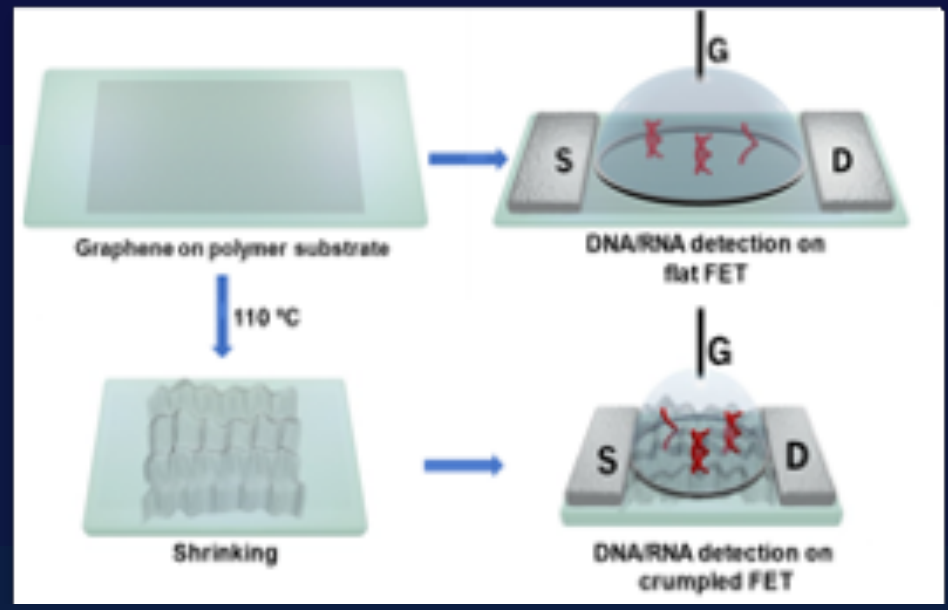
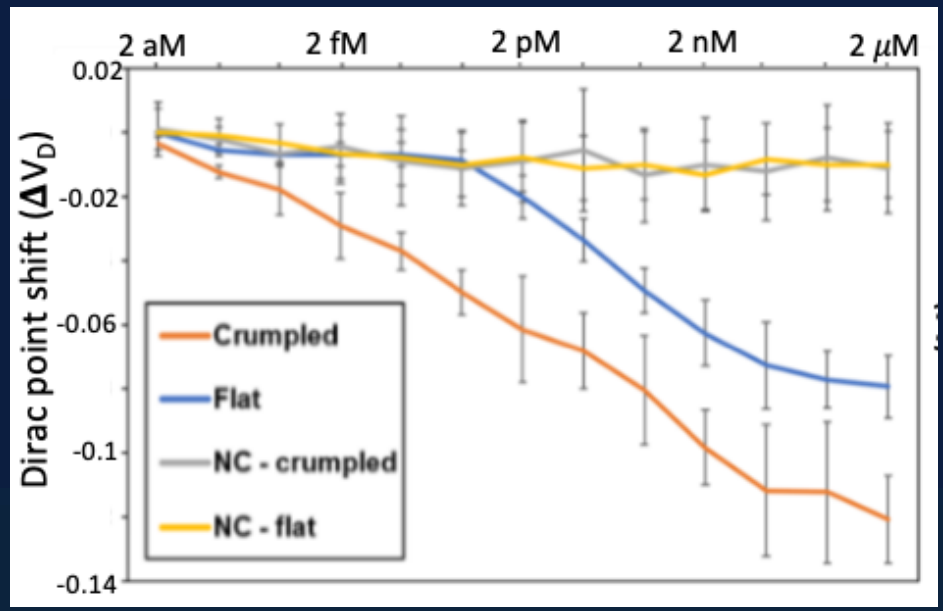
Enhanced label free sensing in crumpled graphene biosensors

Biosensors can identify biomarkers for diseases at early stages

- **Nam & Van der Zande** fabricated crumpled FET devices
- **Bashir** performed bio-sensing
- **Aluru** performed density functional theory& MD simulations

- Demonstrated label free sensing of nucleic acids DNA & RNA using crumpled graphene FETs
- Crumpled devices show 10^4x enhancement in sensitivity, measuring down to 18 molecules on mm-scale channels.
- Expanding technology to diagnose COVID 19.





M. T. Hwang, M. Heiranian et al. *Nature Communications* ***11*** *1453* (2020)

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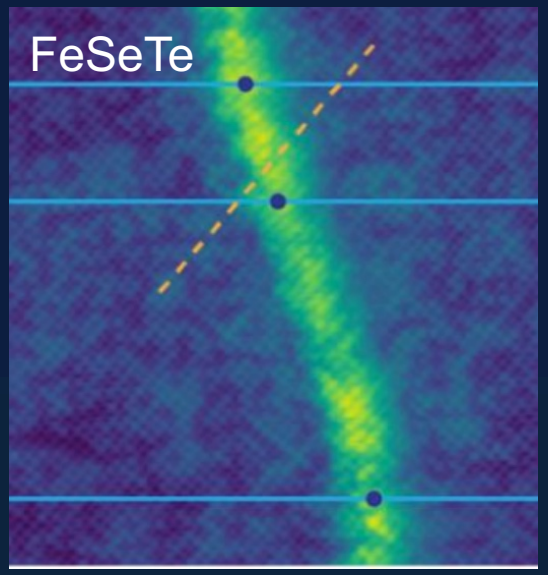
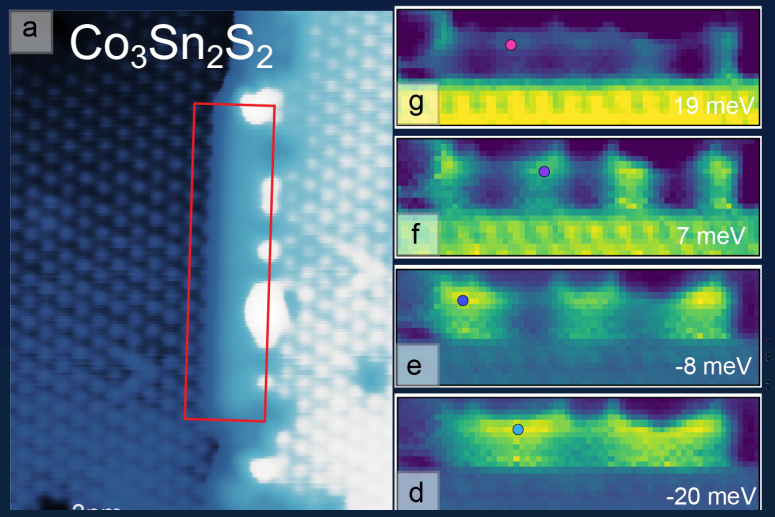
Superseed : Higher Order Topological Insulators (HOTI)

Goal: The goal is to explore electronic solid-state realizations of higher order topological phases using transport and tunneling probes.

- Established Bi and $Bi_{0.92}Sb_{0.08}$ as a HOTI in a joint experiment/theory effort
- Observed chiral edge modes on magnetic Weyl semimetal $Co_3Sn_2S_2$
- Discovered propagating Majorana modes at crystalline domain walls of FeSeTe
- Predicted and modeled new HOTI phenomena
- 10 manuscripts published (incl. with REU student) + 6 under review

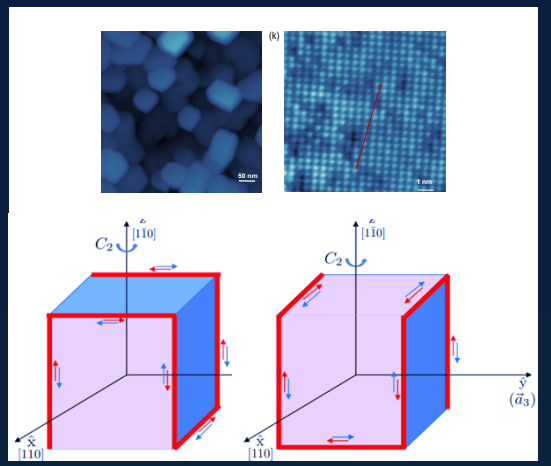


Science 367, 104-108 (2020)



Under review (2021)

Bismuth/BiSb



Under review (2021)

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Superseed Highlight 1

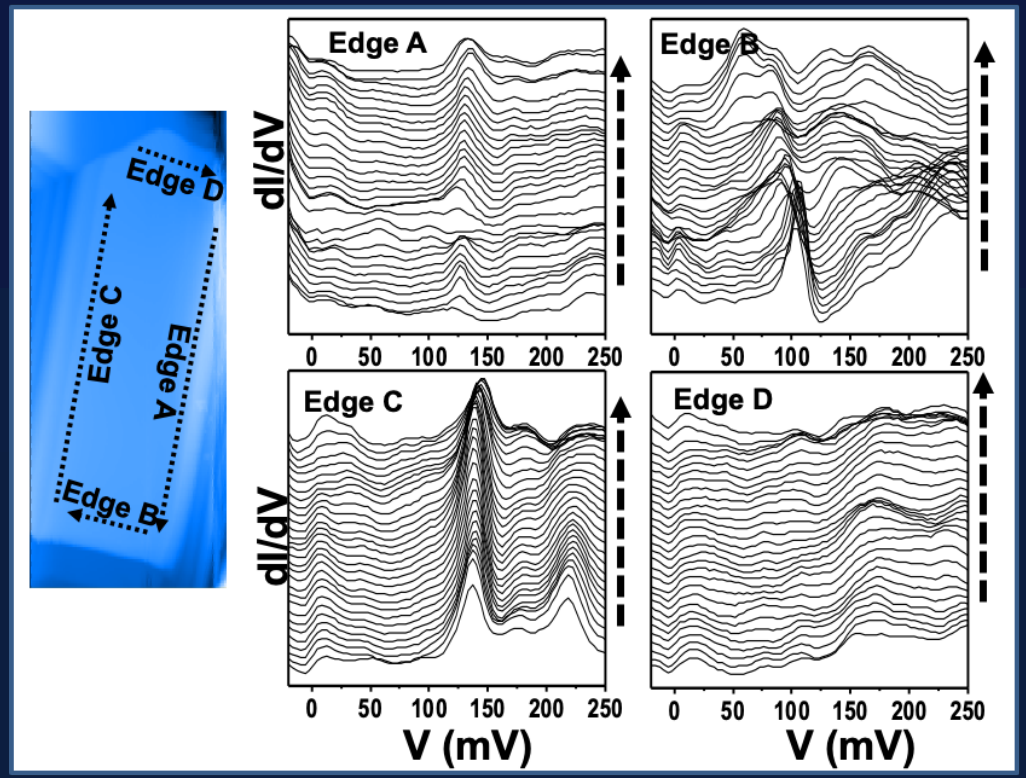
Identification of Bi and BiSb as Higher Order Topological Insulators

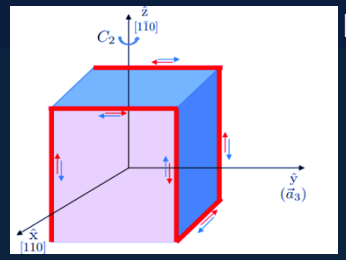
Despite more than a decade of study, the topological classification of Bi and BiSb has long been under debate

- **Madhavan group** grew Bi and BiSb MBE films and characterized them with AFM and STM.
- **Hughes group** provided theoretical support
- **Van Harlingen group** performed transport

As shown in the figure, we find localized hinge states on *only three* of four edges of the 110 islands, which can be explained only by higher order topology.

This work shows unambiguously that Bi and $Bi_{0.92}Sb_{0.08}$ are higher order topological insulators with hinge states





L. Agarwaal et.al, under review Nature Communications

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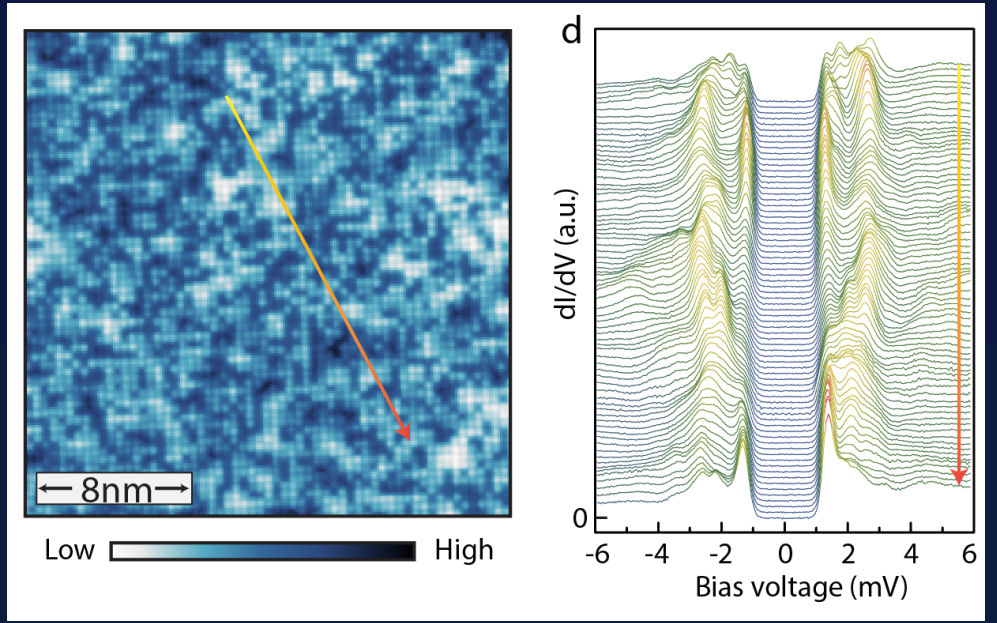
Discovery of propagating Majorana modes at a domain wall

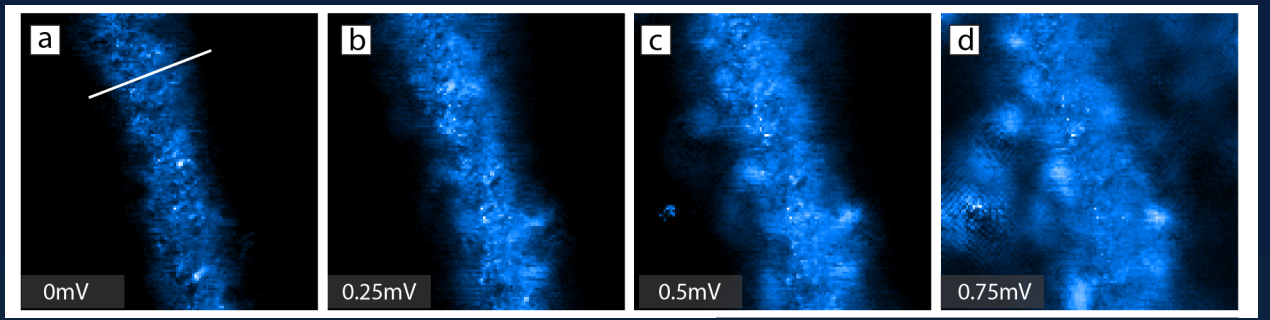
Majorana zero modes have been previously observed in FeSeTe as localized zero bias states in vortex cores

- **Madhavan** group performed STM measurements and **Hughes** modeled the system and analyzed the data

We discovered that propagating helical Majorana modes appear on crystal defects that act like superconducting domain walls

This may be the first observation of helical propagating Majorana fermions





Z. Wang et.a.l, Science 367, 104-108 (2020)

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New I-MRSEC Shared Facilities

Optical parametric oscillator (OPO) pump-probe system, installed Dec. 2018
- In shared laser facility, enables new measurements of magnetization dynamics

Integrated assembly, fabrication, and characterization system, installed Fall 2018
- For creating high quality interfaces between 2D materials

Multi-target sputter deposition system, installed in Winter 2018
- For magnetic materials deposition

Campus cluster nodes
- Shared high-performance computing cluster

Teslatron 300mK measurement system with 12T magnet & rotator, arriving Feb. 2021
- Critical for fast-throughput measurements

Quantum Diamond Microscope, ordered Oct. 2020
- ultra-sensitive NV center magnetometry, for imaging AF domains

Czochralski melter, ordered Nov. 2020
- For growing rare-earth intermetallics (MnIr, $CeMn_2Si_2$, …)

Tip-enhanced Raman and photoluminescence spectrocopy, ordered Dec. 2020
- Spatial mapping of local strain and chemistry in nanomaterials

Opticool 7T split-coil magnet, ordered Jan. 2021
- For low T, high magnetic field THz spectroscopy

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I-MRSEC Education and Outreach Accomplishments

- 31 undergraduates received advanced materials research experience and training through the REU program (2018-2020)
- Developed Musical Magnetism middle school program
- Implemented materials science programming in Spanish-language science at local K-5 dual language schools, reaching hundreds of students and family members
- Created web-streamed series “Musical Magnetism,” with a combined over 700 views of the episodes, plus screened at a Science Art film festival and at the 2019 MMM Meeting.
- Bi-annual communication training for materials community
- Integrated evaluation plan, with completed mid-term Center survey
- Lead materials research lab response to Ed/Out opportunities (MRL Open House, community college project, industry collabs)

88% of faculty have participated in outreach activities

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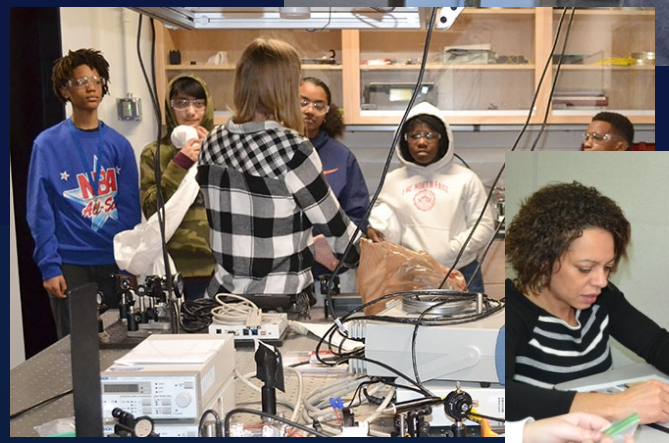
Education Highlight

I-MRSEC Musical Magnetism Program

- An 8-week middle school outreach program developed by the I-MRSEC (Spring 2019 led by 6 I-MRSEC faculty, 3 postdocs, and 13 students)
- Combines materials science demos and music, with students creating song lyrics with a science theme.
- Program components include hands-on lessons; a visit to Materials Research Lab; final presentations of songs or videos
- Reached over 80 7th and 8th graders at local minority-serving public school, and will run virtually starting in February 2021.
- Spring 2021 will feature guest visit by 2019 MRSEC REU student who choreographed a tap dance about her research project on magnetism (part of an Outreach Seed project)



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The program formed centerpiece of Mason's 2020 TED talk (> 425,000 views)

I-MRSEC Diversity Accomplishments

Active and Pro-active recruitment and retention activities at all levels

	I-MRSEC REU		Grad		Postdocs		Faculty	
	URM	Women	URM	Women	URM	Women	URM	Women
I-MRSEC	62%	48%	7%	31%	7%	33%	7%	35%
College of Eng.			5%	22%			7%	17%

- Recruited 5 postdocs from groups underrepresented in science
- Recruited 3 URM grad students, creating new MRSEC and campus fellowships to support URM students.
- K-12 outreach efforts are implemented in local schools with high populations of URM students.
- Regular recruiting at conferences such as National Society of Black Physicists, Emerging Researchers National, and SACNAS.
- Regular activities to maintain welcoming and inclusive climate
- "Go-to" program in college for education, outreach, diversity. Example: Led college #shutdownSTEM discussion and implemented antiracism discussion group for multiple campus departments and units.

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Illinois MRSEC

Funded by NSF DMR-1720633
"Which supports fundamental research across disciplines, that benefits society"

Thank you!