Northwestern | McCORMICK SCHOOL OF ENGINEERING

MATERIALS SCIENCE & ENGINEERING

# Dravid Research Group

## *Interdisciplinary Atomic and Nanoscale Phenomena in Advanced Materials*

NUANCE Atomic and Nanoscale Characterization Experimental Center

http://vpd.ms.northwestern.edu

## Low-Dimensional Materials

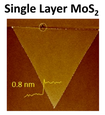
### *Two-Dimensional Materials*

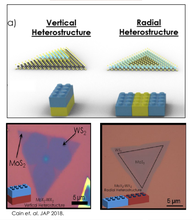
*NSF-DMR*

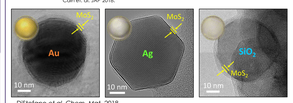

Akshay Murthy, Jennifer DiStefano, Matthew Cheng;
Dr. Yuan Li, Dr. Poya Yasei, Dr. Qing Tu
Collaborators: Profs. M. Kanatzidis, C. Wolverton, K. Aydin, N. Stern, V. Chandrasekhar, M. Grayson, Jiwoong Park (U. Chicago)


**Synthesis**

Single Layer $MoS_2$




DiStefano et al. Chem. Mat. 2018

**Platforms**

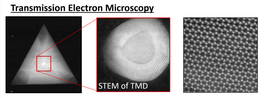
- We focus on chemical vapor deposition to synthesize various 2D materials, including transition metal dichalcogenides ($MoS_2$, $WS_2$, $WSe_2$, $MoSe_2$) .

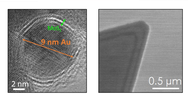
**Structures**

- Radial and vertical heterostructures
- Core-shell nanocomposites
- Substrate engineering

**Fundamental Characterization**

Transmission Electron Microscopy

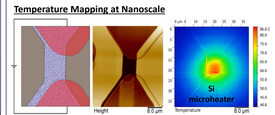




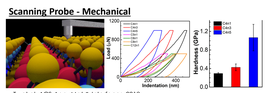


Temperature Mapping at Nanoscale




Shekhawat et al. ACS Nano 2018

Scanning Probe - Mechanical

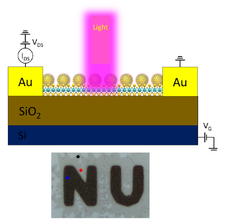



Tu et al. ACS App. Mat & Interfaces. 2018

**Common Techniques**

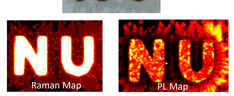
- We employ advanced characterization to obtain a mechanistic understanding of nucleation and growth of TMDs, conduct defect analysis, and answer similar scientific questions.
- Techniques include: Electron Microscopy, Atomic Force Microscopy, Raman Spectroscopy, Photoluminescence Spectroscopy

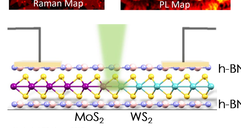
**Applications**









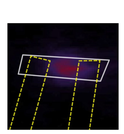

Li et al. ACS Nano 2017
Murthy et al. Nano Letters 2018

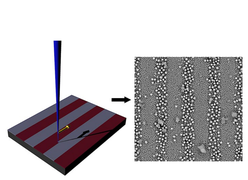
**Electronic Devices**

- Charge transfer dynamics at heterostructure interfaces

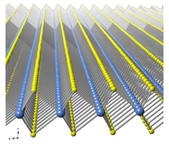
**Optoelectronic/ Photonic Devices**

- Enhanced photodetection via plasmonic architectures

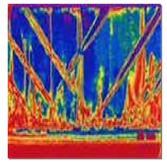




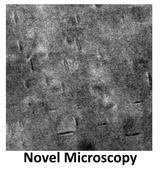
Synthesis, Patterning & Microscopy of Nanostructures



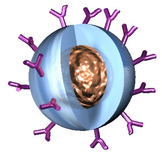
Low-dimensional Materials



Interfaces and Defect Phenomena



Novel Microscopy & Analysis



Multifunctional Nanostructures for Biomedical Imaging & Targeted Therapeutics

## Advanced Microscopy and Nano-Bio Hybrids

### *MNS: Synthesis, Patterning & Applications*

*NU-NTU Nanomat. Inst. (NNIN)*

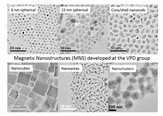

Dr. Vikas Nandwana, Chamille Lescott


**Size** (4-40 nm)

**Composition** $MFe_2O_4$(M=Fe, Co, Mn, Zn)

**Morphology** Spherical, rod, cubic, cluster, core/shell

**Coating** PEG, Silica, Lipid, Protein



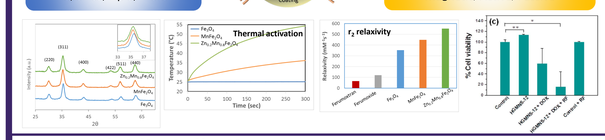


**Diagnostic Imaging** Enhanced MRI Contrast

**Therapy** Thermal Activation, Chemo, Bio

**Functionalization** Biocompatibility, Biodistribution, Pharmacokinetics

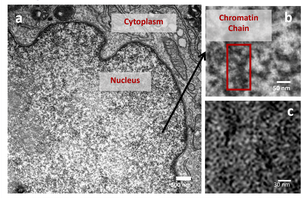
**Targeting** Magnetic, Active, Passive




### *Microscopy of Soft Structures*

*AFOSR, DOD-AFRL C-ABN*


Kelly Parker, Yue Li, Eric Roth, Dr. Reiner Bleher

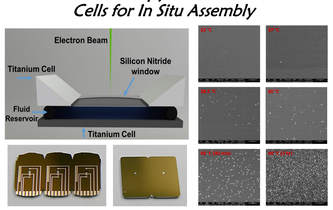

a) High angle annular dark field (HAADF) STEM image of cell nucleus and cytoplasm, with selective DNA staining. b) Magnified image showing chromatin chain. c) Slice from z-stack after tomography reconstruction. d) HAADF STEM and e) bright field TEM of spherical nucleic acids, with ring structure likely indicating DNA staining.


### *In-situ Fluidic Cell Microscopy*

*AFOSR, DOD-AFRL C-ABN*

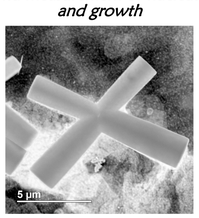

Dr. Ben Myers, Will Kellogg
Collaborators: Drs. Nigel Browning and Layla Medhi


*Electron Microscopy with MEMS Fluidic Cells for In Situ Assembly*

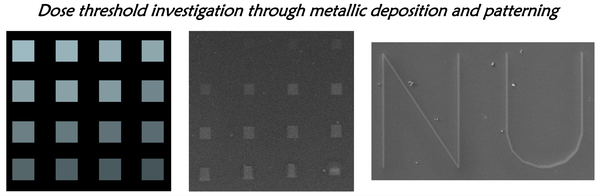



B.D. Myers, Q.-Y. Lin et al., *Microsc. Microanal.* 22 (S3), 764-765 (2016)

*In-situ measurement of nucleation and growth*




*Dose threshold investigation through metallic deposition and patterning*

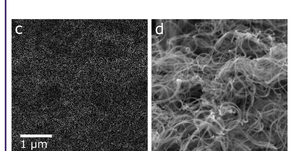


### *Dynamics of Hybrid/Soft/Biological Structures*

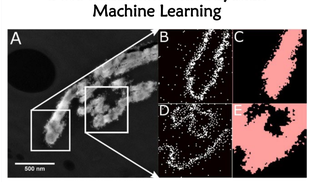
*DOD-AFRL C-ABN*


Karl Hujsak, Dr. Ben Myers, Will Kellogg, Dr. Jinsong Wu, Dr. Reiner Bleher

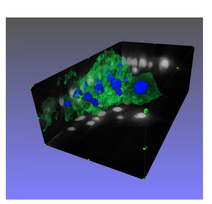

- Next generation microscopes need to image faster, at a higher resolution and with a lower electron dose
- Answering questions about hybrid materials by developing new tools and techniques for imaging in three dimensions and in novel environment




Dose Reduction with Bayesian Machine Learning




'Smart' analytical imaging using machine learning to investigate novel systems



3D Structure of Polymer Grafted Nanoparticle Films for Aerospace Materials

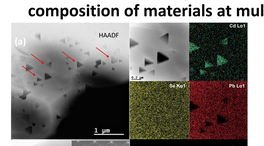
## Functional Imaging

### *Hierarchically Architectured Thermoelectric Materials*

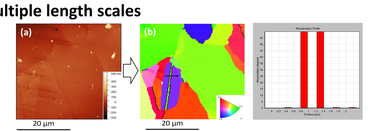
*DOE-BES*


Xiaomi Zhang, Jann Grovogui, Songting Cai
Collaborators: Profs. M. Kanatzidis, C. Wolverton, J. Snyder

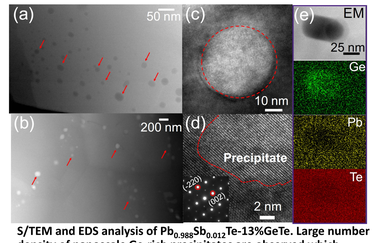

- Design high performance thermoelectric materials via band engineering and microstructure tailoring
- Utilize S/TEM techniques to understand the microstructure and chemical composition of materials at multiple length scales




S/TEM analysis of PbSe-10%Cd. Decent amount of triangular shape CdSe precipitates are observed, super-structured interface appears to compensate the lattice misfit




AFM height profile and EBSD mapping reveal the grain structure and the exact misorientation between specified regions



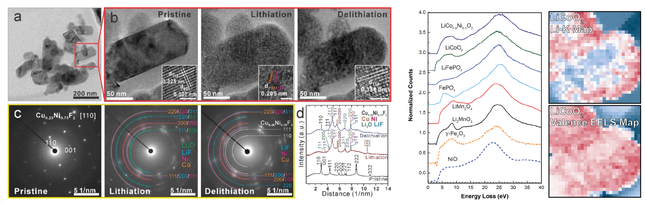

S/TEM and EDS analysis of $Pb_{0.988}Sb_{0.012}Te$-13%GeTe. Large number density of nanoscale Ge-rich precipitates are observed which decrease the thermal conductivity

### *Nanostructured Electrodes for $Li^+$- Ion Batteries and Beyond*

*DOE-BES-EFRC*


Fernando Castro, Cesar Villa, Dr. Yaobin Xu, Dr. Jinsong Wu
Collaborators: Profs. M. Bedzyk, C. Wolverton, C. Johnson (ANL) , P. Fenter (ANL)


- Study electrode nanoscale structure and composition evolution to its electrochemical properties and battery performance
- Correlate S/TEM imaging and spectroscopy data with X-Ray and DFT analysis




In-Situ TEM studies observe lithiation and delithiation of $Cu_xNi_{1-x}F_2$ to understand sources of capacity fade

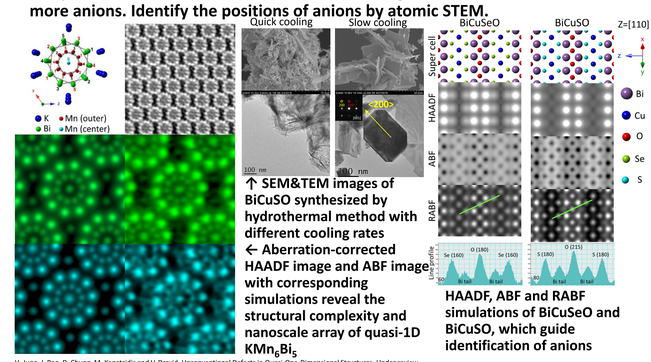
Valence EELS spectroscopy and spectrum imaging of common electrode materials

### *Functional heteroanionic materials*

*NSF-DMR; NSF-ECCS*


Dr. Hee Joon Jung, Chi Zhang
Collaborators: Profs. M. Kanatzidis, K. Poeppelmeier, S. Haile


- Understand, design, and tune heteroanionic materials for wide application.
- S/TEM techniques utilized to study the structure and composition of new compounds, to determine the distribution and degree of order-disorder of two or more anions. Identify the positions of anions by atomic STEM.




↑ SEM&TEM images of BiCuSO synthesized by hydrothermal method with different cooling rates
← Aberration-corrected HAADF image and ABF image with corresponding simulations reveal the structural complexity and nanoscale array of quasi-1D $KMn_6Bi_5$

HAADF, ABF and RABF simulations of BiCuSeO and BiCuSO, which guide identification of anions

H. Jung, J. Bao, D. Chung, M. Kanatzidis and V. Dravid. Unconventional Defects in Quasi-One-Dimensional Structures. Under review.