

Welcome to NU-MSE!

and

*the VPD Group!!*

**We are looking for –**

**A Few  
Proud  
Wo/men**

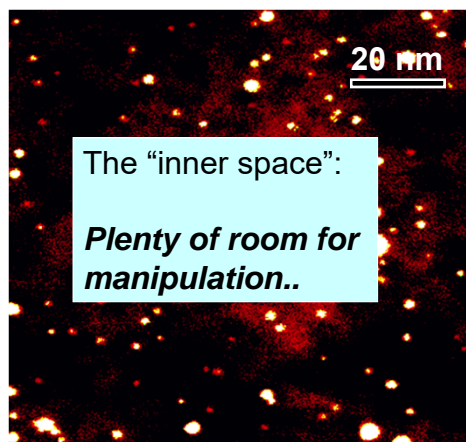


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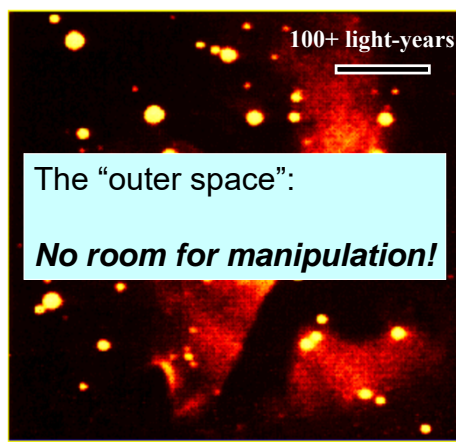
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**Shape, form, pattern, architecture..**

*Transcend disciplines, phenomena, length-scales..*



**Carbon Supported Pt Catalyst**



**M20 Nebula (galaxies) !!**



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**Atomic & Nanoscale Phenomena in Materials:**  
*Electronics, Energy, Health and Advanced Tools/Techniques*

**Vinayak P. Dravid**

*Abraham Harris Chaired Professor , Materials Science & Engineering - McCormick  
Professor of Entrepreneurship (Courtesy), Kellogg School of Management  
Founding Director, NUANCE Center  
Founding Director, SHyNE Resource  
(Foundry Director: Q-FAB: TBA)  
Co-founder International Institute for Nanotechnology (IIN)  
Founding Director, Global McCormick*

*Active Member: CCNE, NSEC/IIN, MRSEC, PS-OC, CLP, CAMI, RHLCCC, EFRC..*

E-mail: [v-dravid@northwestern.edu](mailto:v-dravid@northwestern.edu)

Ph.: (847) 467-1363, Office: 1133 Cook Hall

**Program Assistant:**

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[amy.morgan@northwestern.edu](mailto:amy.morgan@northwestern.edu)

**Student Labs:**

1141-1149 and 1163 Cook Hall (Hard)  
B0560 Silverman Hall (Soft)

<http://www.northwestern.edu/vpdgroup> <http://www.nuance.northwestern.edu>



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**Dravid Group**  
*Seeing & Sensing  
the Invisible*

- Global Leadership in EM
- Regional and National Center of Excellence@
- Integrated Research, Education & Outreach

**Elected Fellowships:**

- AAAS, APS, ACerS, MSA, MRS, RMS

**Recent/Major Awards:**

- MSA Burton, MAS Heinrich Medals
- US-Japan Fulrath Award
- Chinese Academy Lee Huen Award
- Indian Academy – MRS-I & ASM-IIM
- UK - Royal Microscopy Soc. Fellow

- ✓ 480+ publications
- ✓ 24+ patents & IDs
- ✓ Hirsch H-Index >89+
- ➔ One of the highest at NU

**NUANCE**  
Atomic and Nanoscale  
Characterization Experimental Center

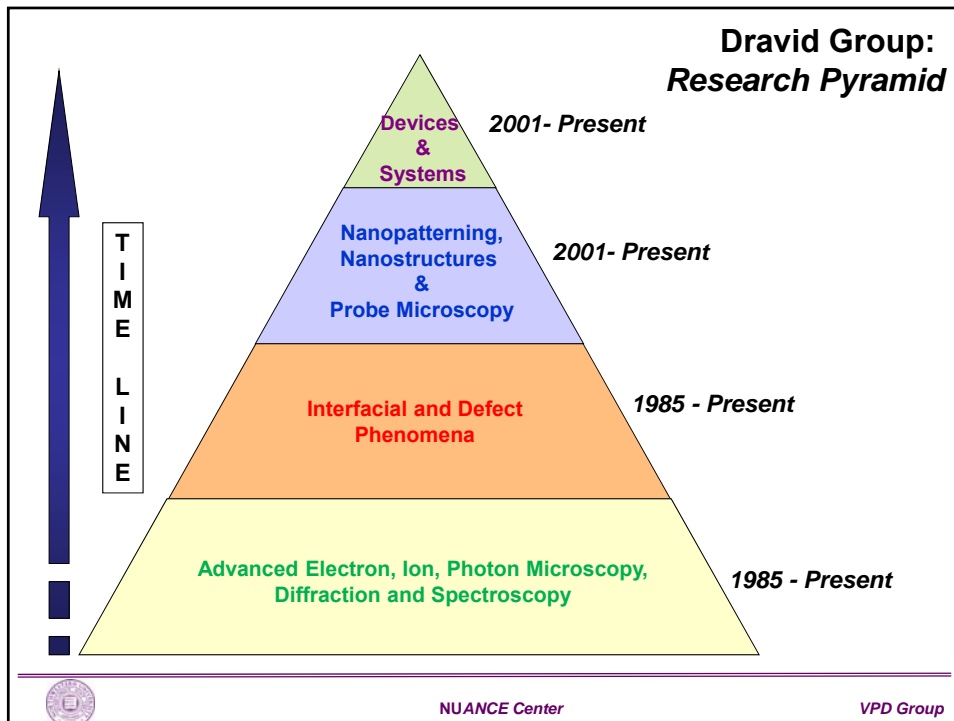
**SHyNE**

Soft and Hybrid Nanotechnology  
Experimental Resource



**MRSEC**  
MATERIALS RESEARCH SCIENCE  
AND ENGINEERING CENTER

**Northwestern**  
EXPLORING INNER SPACE



## VPD Group Academic Philosophy

- Emphasis on BIG picture
- Interdisciplinary, collaborative and “center” exposure
- Seamless integration of research, teaching and outreach
- Emphasis on global and international engagement
- Encouragement for independent and individual creativity
- Emphasis on communication skills
- Bloom’s taxonomy in 21<sup>st</sup> century:
  - *Knowledge, synthesis, analysis, creativity and dissemination*

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## Facts, Figures and Anecdotes

- Money is not a problem (!?!)
- Risk taking and out-of-the-box initiatives are a must!
- Collaboration across disciplines (and overseas) is often the norm!
- Graduate research and teaching awards/honors
  
- ¼ graduates in faculty position (PennState, Florida, France)
- ½ graduates in core industries (GE, Intel, IBM..)
- ¼ graduates in national labs/other industries



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## FAQs..

- **Time for PhD graduation:**
  - ~ 3.5 – 5 years, typical ~ 4.5 yrs
- **Historical graduations..**
  - > ~ 100 “graduates” of VPD group, spanning UGs to Postdocs
  - 40+ full-time PhD graduates,
- **Representative Graduates:**
  - V. Ravikumar, 1996 PhD, GE Global R&D, NY
  - Shelly St. Louis-Weber, 1997 PhD, Head, Intel Phoenix, AZ
  - Beth Dickey, 1998 PhD, Professor, PennState → NC State
  - Sylvie Mao, 2001 postdoc, Professor CRISMAT/CNRS, France
  - Kevin Johnson, 2002 PhD, Senior Manager, Intel Corp., Oregon
  - Lei Fu, 2003 Postdoc, Engineer, AMD, TX
  - Luke Brewer, 2003 PhD, Associate Professor, Naval PostGrad. School, CA
  - Ming Su, 2004 PhD, Assoc. Professor, Univ. Central Florida, FL
  - Suresh D., 2007 PhD, Specialist, Rio Tinto Mining, Singapore
  - N. Alem, 2008 PhD, Asst. Prof., PennState
  - Z. Pan, 2008 PhD, Flextonics, CA, S. Tark, 2009 PhD, Intel Corp., OR,
  - Tao Sun, 2010 PhD, Argonne – APS; Bin Liu, 2012 PhD, Intel Corp, CA,
  - Stan Chou, 2014, PhD, Sandia National Labs.; Shanwei Lin, 2015, Intel Corp.; Jeff Cain, 2017; LBNL/Cal., Eve Hanson, 2018 (Citrione Info.).

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Publications: > 480+  
Hirsch - “h” index: > ~90  
Patents/inventions: > 25



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## VPD Group PhD Open Position Themes: Fall 2018

### 1. Patterning and Architecture in 2-D and 0-D Structures:

- Radial and vertical heterostructures; 2-D + nano composites/assembly
- Magneto-Photo-Transport, correlated phenomena and gas-solid interactions
- Colloidal- and Self-Assembly of 2-D sheets, composites
- Ex-situ & in-situ microscopy and analysis

### 2. Microscopy of Energy Materials: *Thermoelectrics*

- Hierarchical microstructure tailoring
- Novel chalcogenides and multicomponent, dual nanostructuring
- Thermal and charge carrier transport
- In-situ defect and interfacial phenomena; and "structure-property" correlation

### 3. "Soft Microscopy": Microscopy of Nano-Bio-Hybrids

- Electron microscopy for characterizing protein-based architectures: structure & dynamics
- Soft matter imaging and analysis through liquid-cell methodologies
- 3D and 4D characterization of proteins and mega-molecules
- Sparse imaging, dynamic sampling and pattern recognition in imaging

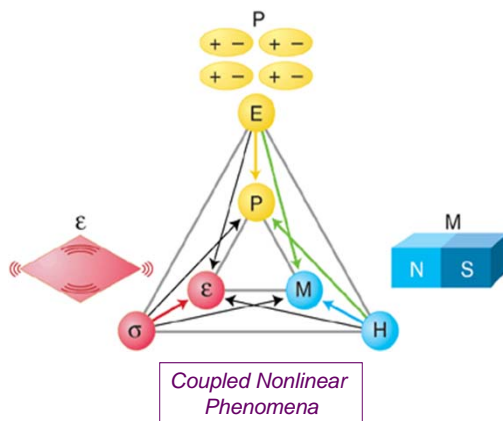
### 4. Misc.. -- unknown unknowns!



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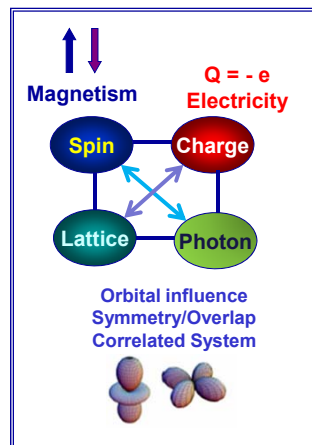
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## Moving Forward *Intellectual Excitement*



**Mixed Anions & Atomically-layered structures**

### Nonlinear Phenomena



*Synthetic approach for creating multilayer architecture for charge-spin-lattice coupling*



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## Positioning, patterning & stacking of (Nano)Structures



?



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## Multifunctional Nanostructures: *Going Beyond Silicon/Electronic Functionalities*

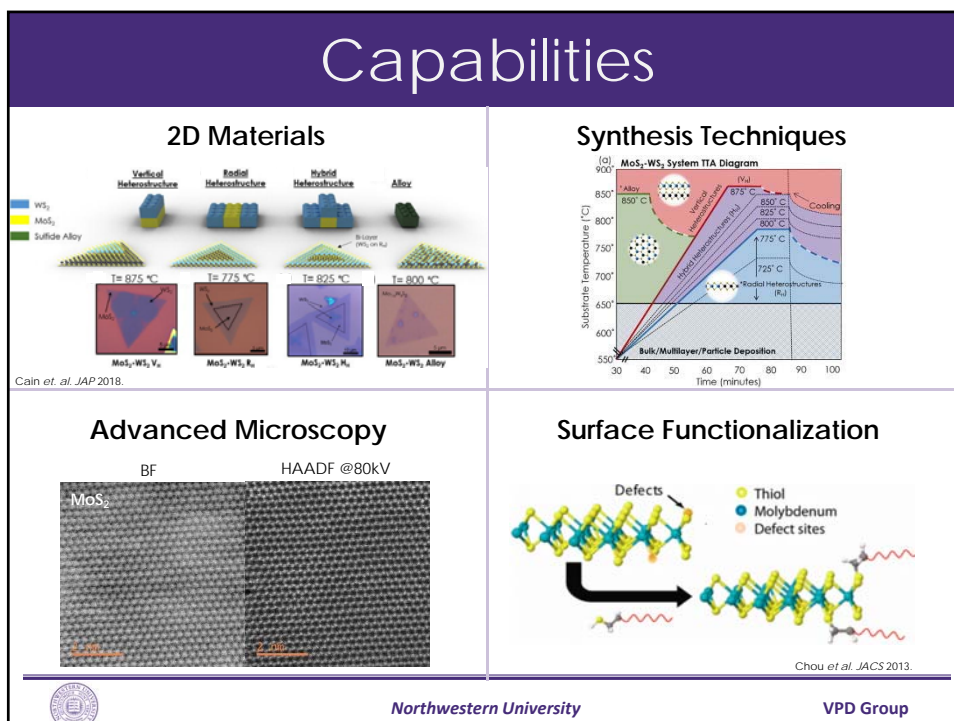
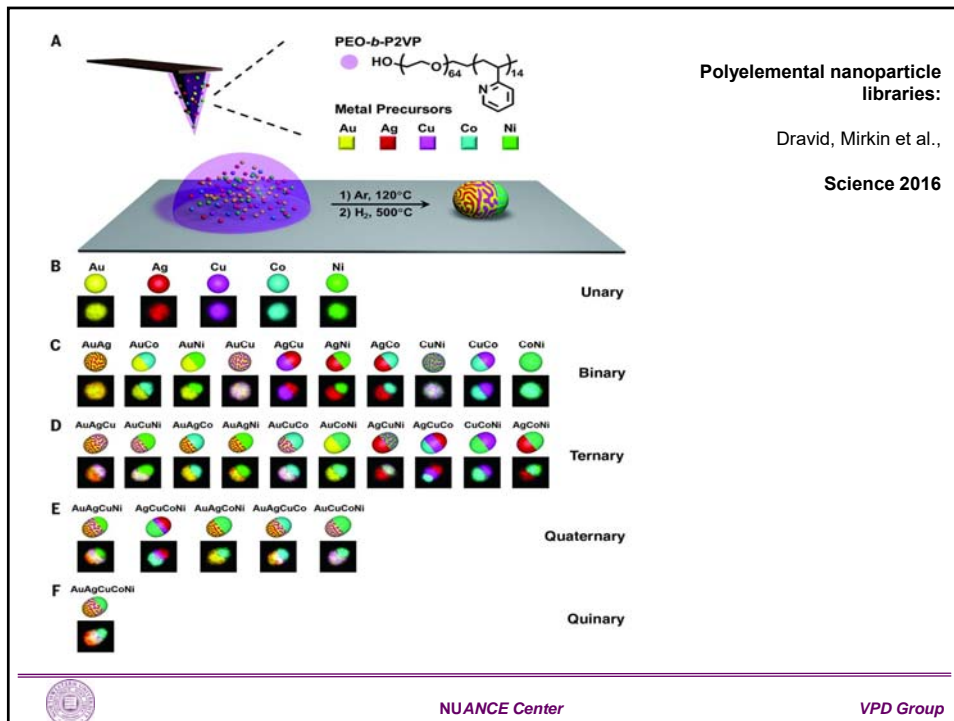


*"We have lots of information technology. We just don't have any information."*



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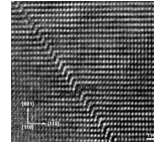
## Future Research Directions:

### Nanopatterning and Assembly:

*Ferroelectric-Ferromagnetics*

*Atomically-layered Halides, Chalcogenides & mixed Anions*

*DNA-NP assemblies*

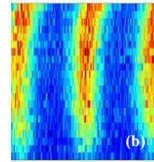


### In-situ EM and x-ray scattering – nucleation, growth & assembly:

*In-situ TEM, energy filtered e-diffraction,*

*RDF and PDF*

*Fluidic-Cell S/TEM*

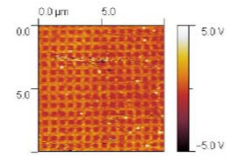


### Localized measurements and coupling phenomena:

*In-situ synchrotron GIWAXS/GISAXS,*

*PFM/MFM*

*Transistors and sensors*



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No..Its wind & geothermal stupid!

Renewable/Alternate Energy

Strategy

Solar it is!

Wrong.. Looks like all Bio-Fuels to me..



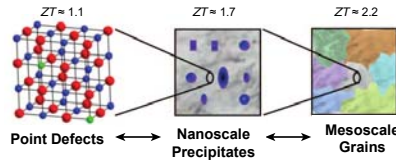
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## Hierarchically Structured Thermoelectrics

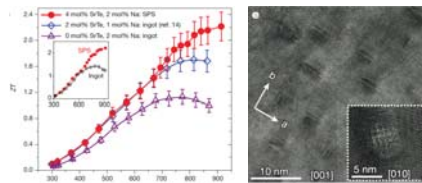
- Thermoelectric materials create an electric potential when exposed to a heat gradient, and could be used to recover waste heat generated whenever energy is utilized in our society



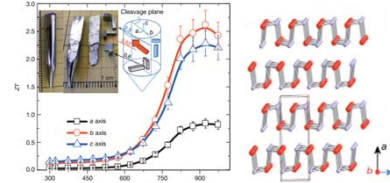
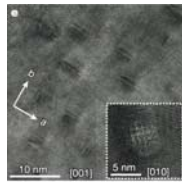
Seebeck Coefficient  $S$ , Electrical Conductivity  $\sigma$ , Thermal Conductivity  $\kappa$

$$ZT \equiv \frac{S^2 \sigma}{\kappa} T$$

- The structure of thermoelectric materials across all length scales has profound effects on thermal conductivity, charge carrier mobility, and thermoelectric performance



Nanostructured PbTe-4% SrTe  $ZT=2.2$



Single Crystal SnSe  $ZT=2.6$

Biswas, K., et al. (2012). *Nature* 489(7416): 414-418.; Lee, Y., et al. (2014). *Nat Commun* 5: 3640.; Zhao, L. D., et al. (2014). *Nature* 508(7496): 373-377.



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## Equine Paintings: *Galloping Horses Before 1878 AD*



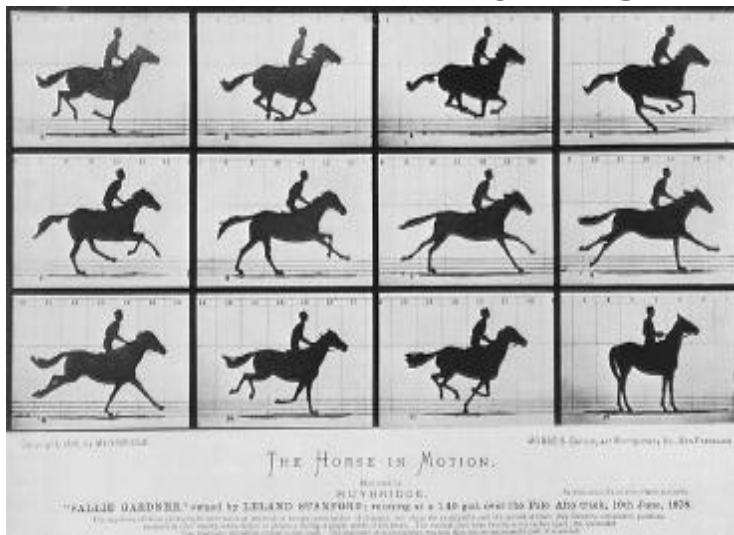
*A picture is worth a thousand words*



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## The Horse in Motion: Muybridge 1878



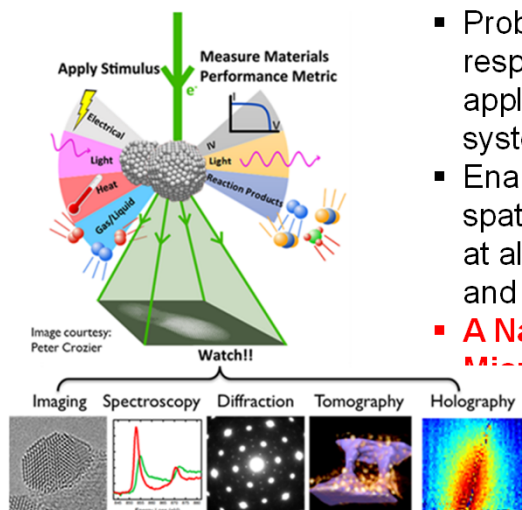
*A video is worth a thousand pictures!*



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## In-situ/operando TEM



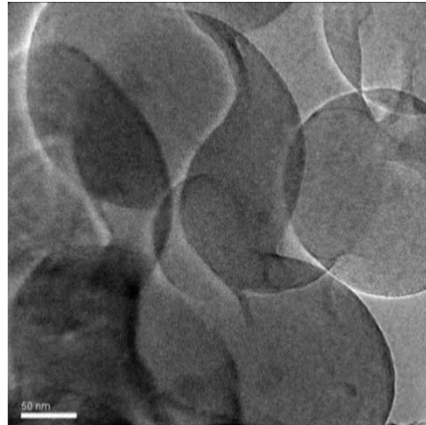
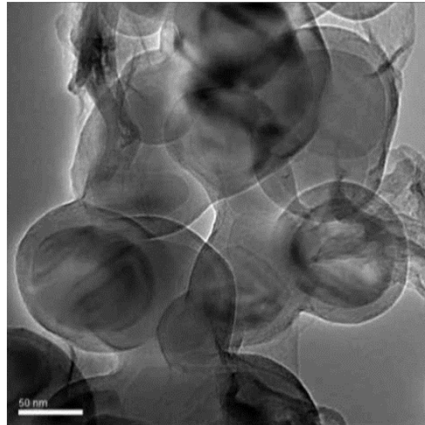
- Probing direct material response to multiple stimuli applied to the nanoscale system.
- Enabling real-time and spatially-resolved observation at all relevant length scales and dimensions.
- **A Nano Lab inside a Microscope!**



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# Lithiation/delithiation process of Graphene-Si spheres

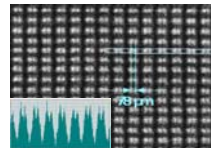


Nature Sci. Rep. 2014



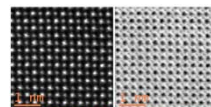
JEOL JEM-ARM200CF S/TEM

- Cold FEG – Flash & Go
- 200 kV acceleration voltage
- Aberration corrected (probe)
- 0.08 nm STEM resolution
- 0.23 nm TEM resolution
- 0.35 eV energy resolution
- Dual SDD EDS detector (1.7sr)
- Simultaneous HAADF/BF/ABF
- Gatan Quantum Dual EELS
- Atomic resolution at 60-200kV
- Gatan OneView CMOS camera

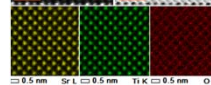


High angle annular dark-field scanning transmission electron microscopy (HAADF-STEM) image of Si specimen showing dumbbell structure along (112) orientation, and demonstrating 78 pm spatial resolution in STEM mode.

Upper row: simultaneously acquired high-angle annular dark-field (HAADF) and annular bright-field (ABF) STEM images of SrTiO<sub>3</sub> specimen indicating atomic columns of Sr, Ti and O.



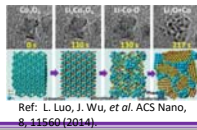
Lower row: EDS maps of Sr, Ti and O from the same sample showing atomically resolved chemical analysis capability.





JEOL JEM-ARM300CF S/TEM

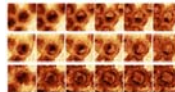
- Cold FEG – Flash & Go
- 300 kV acceleration voltage
- 0.19 nm STEM resolution
- 0.22 nm TEM resolution
- Wide gap pole-piece for *in situ* experiments
- Simultaneous imaging by HAADF/BF/ABF
- Diffractive STEM imaging
- SDD EDS detector
- Gatan OneView-IS camera for fast imaging at 300 fps (1k x 1k) with automated drift correction
- Hummingbird gas holder & gas delivery system
- Compatible with many other *in situ* holders (heating, fluidic, biasing, mechanical straining...)



Ref: L. Luo, J. Wu, et al. ACS Nano, 8, 11560 (2014).



Gas-flow TEM holder can deliver up to 8 pressure-controlled gases (from  $\leq 10^{-7}$  Torr to 1 atm) to an environmental cell, with local specimen heating via an integrated thin film heater with an accurately calibrated temperature sensor.



Co nanoparticle oxidation in 1 bar flowing  $O_2$  from 150°C to 250°C. Ref: H.L. Xin, et al. Microscopy & Microanalysis, 19, 1558 (2013)



Tomography TEM holder allows for large tilt range up to  $\pm 70^\circ$  enabling precise 3D reconstruction. It equips exchangeable tip to accommodate TEM grids, FIB, and atom probe samples.



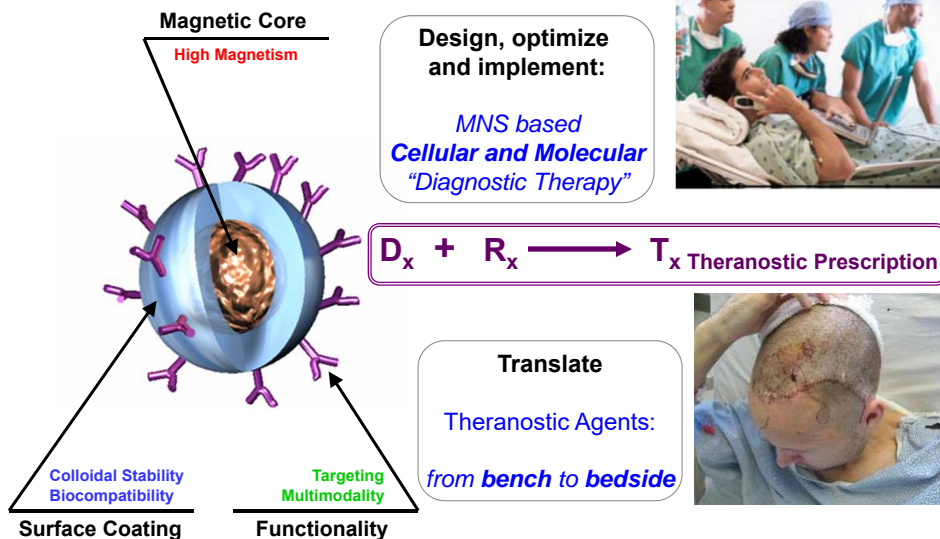
3D reconstruction of Au particle distribution on Si nano-wires. Ref: J. Wu, et al. Journal of Physical Chemistry C, 117, 1059 (2013).



Nanofactory nano-manipulation and electric biasing holder enables *in situ* observation of electrochemical reactions in rechargeable batteries.

Lithiation of  $Co_3O_4$  nanoparticles in real time.

Non-Invasive Theranostics: “Integrated Diagnostic Therapy”



# Magnetic Nanostructures (MNS)

## Synthesis and Characterization

*Thermal Decomposition*  
*MRI Contrast Enhancement*  
*Thermal Activation*

Int. Patent #: WO2009036441-A2,A3 (2009)  
 Inv. Disclosure # NU29172 (2009),  
 NU29169 (2009), NU27101 (2007)  
 ACS Nano, NanoLett, 2017-18

## Biosensing

*MNS/2D Nanocomposite*  
*Non-Invasive Glucose Detection*

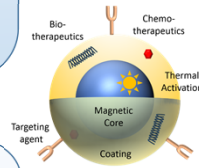
Adv. Mater. (Under Prep)  
 Inv. Disclosure #: NU2017-094 (2017)  
 ACS Appl Mater/Inter; Sensors &  
 Actuators, 2016-18

## Therapy and Diagnostics (Theranostics)

*Cardiovascular Disease*  
 Chem. Mat. (2017),  
 ACS Appl. Mat. Inter (2016)  
 Prov. US Patent #: 62/354,438 (2016)

*Cancer*  
 Nature Nanotech. (Under Prep)  
 Prov. US Patent #: 62/510,468 (2017)

*Alzheimer's Disease*  
 Nat. Nanotech 2015-17,  
 US Patent #: 9,095,629 (2015)

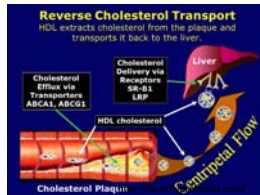


## Tissue Engineering

*Hydrogel-MNS Nanocomposite*  
*Invention Disclosure; 2018*  
*ACS Appl Mater/Inter: 2017-8*

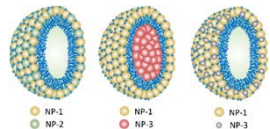
# Theranostic Magnetic Nanostructures (MNS) in Dravid Group

## Cardiovascular Disease Diagnostics and Therapy



HDL-MNS (Non-invasive Imaging + Therapy)  
 Chem. Mat. (2017), ACS Appl. Mat. Inter (2016)  
 Provisional US Patent #: 62/354,438 (2016)

## Lipid Nanoparticle Nanoconstruct

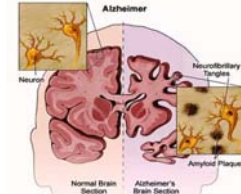


Lipid-MNS Construct: Imaging + Drug Delivery  
 Nature Nanotech. (Under Prep)  
 Provisional US Patent #: 62/510,468 (2017)

Int. Patent: #WO2009036441-A2,A3 (2009)  
 Inv. Disclosure #: NU29172 (2009),  
 NU29169 (2009),  
 NU27101 (2007)

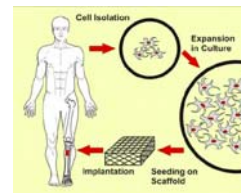


## Alzheimer's Disease: Diagnostics



MNS-Ab (Non Invasive Imaging)  
 Nat. Nanotech (2015)  
 US Patent #: 9,095,629 (2015)

## Tissue Engineering: Diagnostics and Therapy



Hydrogel-MNS: Imaging + Regeneration  
 Invention Disclosure: Under Prep.

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- Radial and vertical heterostructures; 2-D + nano composites/assembly
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- Electron microscopy for characterizing protein-based architectures: structure & dynamics
- Soft matter imaging and analysis through liquid-cell methodologies
- 3D and 4D characterization of proteins and mega-molecules
- Sparse imaging, dynamic sampling and pattern recognition in imaging

### 4. Misc.. -- unknown unknown!



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# Q & A



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