



# Living in a Material World

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UW-Stout

Applied Science Seminar Nov. 20, 2014



# San Francisco, CA





# What is Materials Chemistry?

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- The Chemistry of Solids
  - Relationship between structure and properties of solids
  - Chemical transformations affecting solids
  - Synthesis and processing of solids



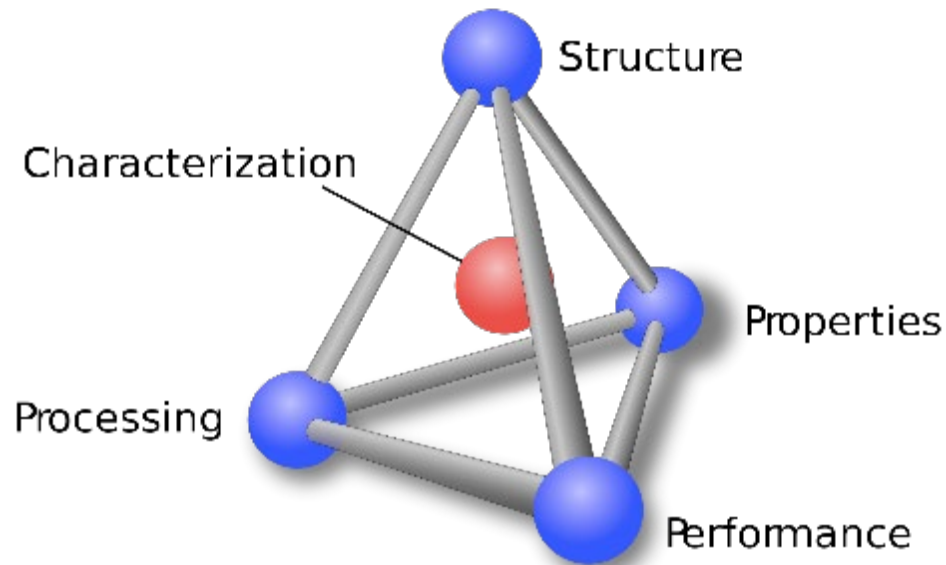
# Materials and Nanoscience

- Structure

  - Property-Performance-Processing-Characterization

- Size

  - Property-Performance-Processing-Characterization





# How Do We Classify Materials?

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- **Metals** – pure metallic elements or mixtures of metallic elements
- **Ceramics** – compounds of metals and non-metals semiconductors are often types of ceramics
- **Polymers** – (Plastics) very large molecules made up of many parts or mers
- **Composites** – materials composed of two or more of the above



# The Elements

## Metals

hydrogen 1 <b>H</b> 1.0079																	helium 2 <b>He</b> 4.0026						
lithium 3 <b>Li</b> 6.941	beryllium 4 <b>Be</b> 9.0122																	boron 5 <b>B</b> 10.811	carbon 6 <b>C</b> 12.011	nitrogen 7 <b>N</b> 14.007	oxygen 8 <b>O</b> 15.999	fluorine 9 <b>F</b> 18.998	neon 10 <b>Ne</b> 20.180
sodium 11 <b>Na</b> 22.990	magnesium 12 <b>Mg</b> 24.305																	aluminum 13 <b>Al</b> 26.982	silicon 14 <b>Si</b> 28.086	phosphorus 15 <b>P</b> 30.974	sulfur 16 <b>S</b> 32.065	chlorine 17 <b>Cl</b> 35.453	argon 18 <b>Ar</b> 39.948
potassium 19 <b>K</b> 39.098	calcium 20 <b>Ca</b> 40.078	scandium 21 <b>Sc</b> 44.956	titanium 22 <b>Ti</b> 47.867	vanadium 23 <b>V</b> 50.942	chromium 24 <b>Cr</b> 51.996	manganese 25 <b>Mn</b> 54.938	iron 26 <b>Fe</b> 55.845	cobalt 27 <b>Co</b> 58.933	nickel 28 <b>Ni</b> 58.693	copper 29 <b>Cu</b> 63.546	zinc 30 <b>Zn</b> 65.39	gallium 31 <b>Ga</b> 69.723	germanium 32 <b>Ge</b> 72.61	arsenic 33 <b>As</b> 74.922	selenium 34 <b>Se</b> 78.96	bromine 35 <b>Br</b> 79.904	krypton 36 <b>Kr</b> 83.80						
rubidium 37 <b>Rb</b> 85.468	strontium 38 <b>Sr</b> 87.62	yttrium 39 <b>Y</b> 88.906	zirconium 40 <b>Zr</b> 91.224	niobium 41 <b>Nb</b> 92.906	molybdenum 42 <b>Mo</b> 95.94	technetium 43 <b>Tc</b> [98]	ruthenium 44 <b>Ru</b> 101.07	rhodium 45 <b>Rh</b> 102.91	palladium 46 <b>Pd</b> 106.42	silver 47 <b>Ag</b> 107.87	cadmium 48 <b>Cd</b> 112.41	indium 49 <b>In</b> 114.82	tin 50 <b>Sn</b> 118.71	antimony 51 <b>Sb</b> 121.76	tellurium 52 <b>Te</b> 127.60	iodine 53 <b>I</b> 126.90	xenon 54 <b>Xe</b> 131.29						
caesium 55 <b>Cs</b> 132.91	barium 56 <b>Ba</b> 137.33	57-70 *	lutetium 71 <b>Lu</b> 174.97	hafnium 72 <b>Hf</b> 178.49	tantalum 73 <b>Ta</b> 180.95	tungsten 74 <b>W</b> 183.84	rhenium 75 <b>Re</b> 186.21	osmium 76 <b>Os</b> 190.23	iridium 77 <b>Ir</b> 192.22	platinum 78 <b>Pt</b> 195.08	gold 79 <b>Au</b> 196.97	mercury 80 <b>Hg</b> 200.59	thallium 81 <b>Tl</b> 204.38	lead 82 <b>Pb</b> 207.2	bismuth 83 <b>Bi</b> 208.98	polonium 84 <b>Po</b> [209]	astatine 85 <b>At</b> [210]	radon 86 <b>Rn</b> [222]					
francium 87 <b>Fr</b> [223]	radium 88 <b>Ra</b> [226]	89-102 * *	lawrencium 103 <b>Lr</b> [262]	rutherfordium 104 <b>Rf</b> [261]	dubnium 105 <b>Db</b> [262]	seaborgium 106 <b>Sg</b> [266]	bohrium 107 <b>Bh</b> [264]	hassium 108 <b>Hs</b> [269]	meitnerium 109 <b>Mt</b> [268]	ununilium 110 <b>Uun</b> [271]	unununium 111 <b>Uuu</b> [272]	ununbium 112 <b>Uub</b> [277]	ununquadium 114 <b>Uuq</b> [289]										

\* Lanthanide series

\*\* Actinide series

lanthanum 57 <b>La</b> 138.91	cerium 58 <b>Ce</b> 140.12	praseodymium 59 <b>Pr</b> 140.91	neodymium 60 <b>Nd</b> 144.24	promethium 61 <b>Pm</b> [145]	samarium 62 <b>Sm</b> 150.36	europium 63 <b>Eu</b> 151.96	gadolinium 64 <b>Gd</b> 157.25	terbium 65 <b>Tb</b> 158.93	dysprosium 66 <b>Dy</b> 162.50	holmium 67 <b>Ho</b> 164.93	erbium 68 <b>Er</b> 167.26	thulium 69 <b>Tm</b> 168.93	ytterbium 70 <b>Yb</b> 173.04
actinium 89 <b>Ac</b> [227]	thorium 90 <b>Th</b> 232.04	protactinium 91 <b>Pa</b> 231.04	uranium 92 <b>U</b> 238.03	neptunium 93 <b>Np</b> [237]	plutonium 94 <b>Pu</b> [244]	americium 95 <b>Am</b> [243]	curium 96 <b>Cm</b> [247]	berkelium 97 <b>Bk</b> [247]	californium 98 <b>Cf</b> [251]	einsteinium 99 <b>Es</b> [252]	fermium 100 <b>Fm</b> [257]	mendelevium 101 <b>Md</b> [258]	nobelium 102 <b>No</b> [259]

# The Elements

## Ceramics

One of These + One of These

hydrogen 1 H 1.0079																	helium 2 He 4.0026						
lithium 3 Li 6.941	beryllium 4 Be 9.0122																	boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
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potassium 19 K 39.098	calcium 20 Ca 40.078	scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80						
rubidium 37 Rb 85.468	strontium 38 Sr 87.62	yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29						
caesium 55 Cs 132.91	barium 56 Ba 137.33	lanthanum 57 La 138.91	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]						
francium 87 Fr [223]	radium 88 Ra [226]	actinium 89 Ac [227]	lutetium 71 Lu 174.97	thorium 90 Th 232.04	protactinium 91 Pa 231.04	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	unnilium 110 Uun [271]	ununium 111 Uuu [272]	unubium 112 Uub [277]	ununquadium 114 Uuq [289]										

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actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]

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# What Makes Materials Differ?

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**Macrostructure**

**Depends on . . .**

**Microstructure**



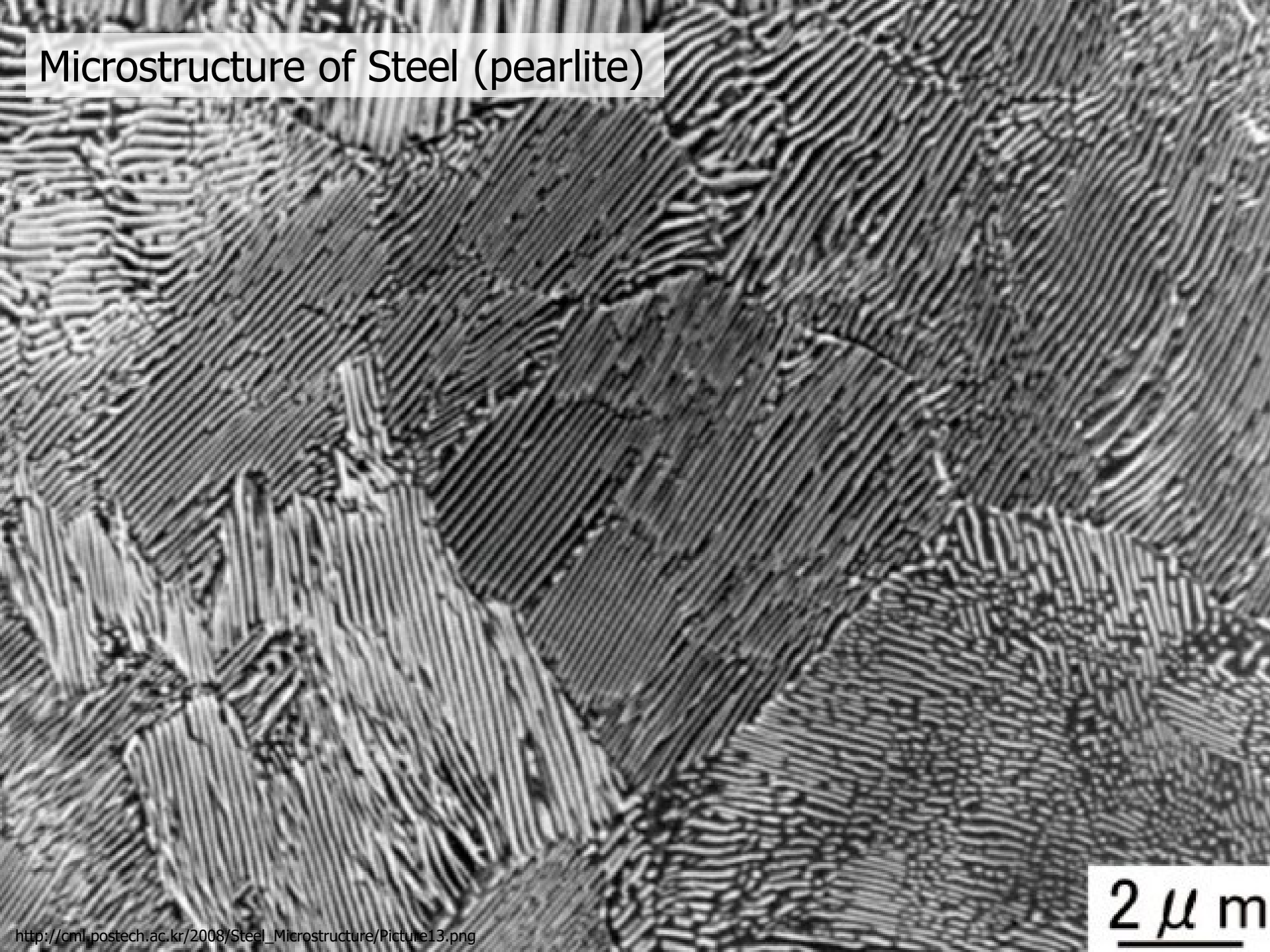
# San Francisco, CA



# Steel I-Beam

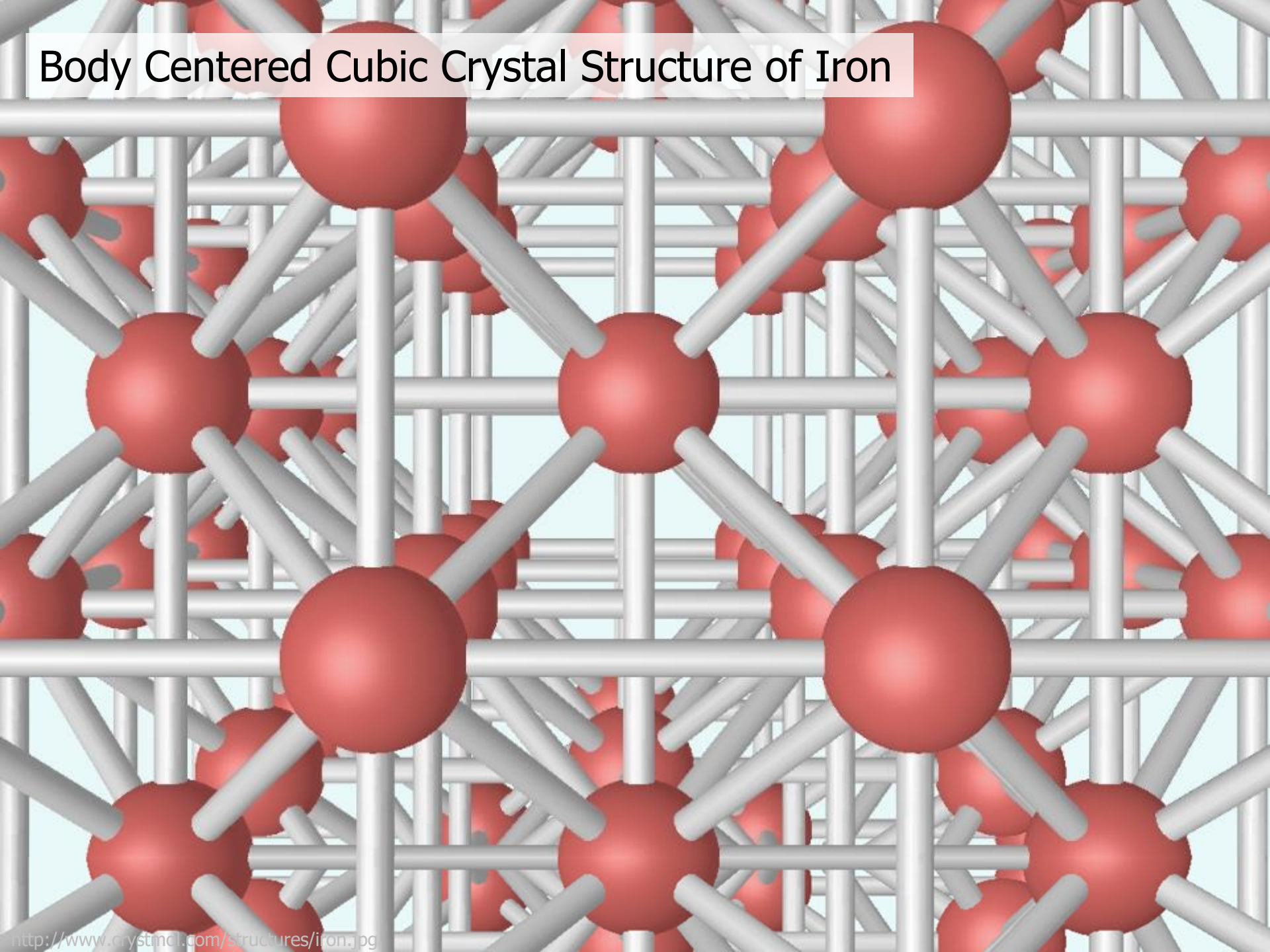


# Microstructure of Steel (pearlite)



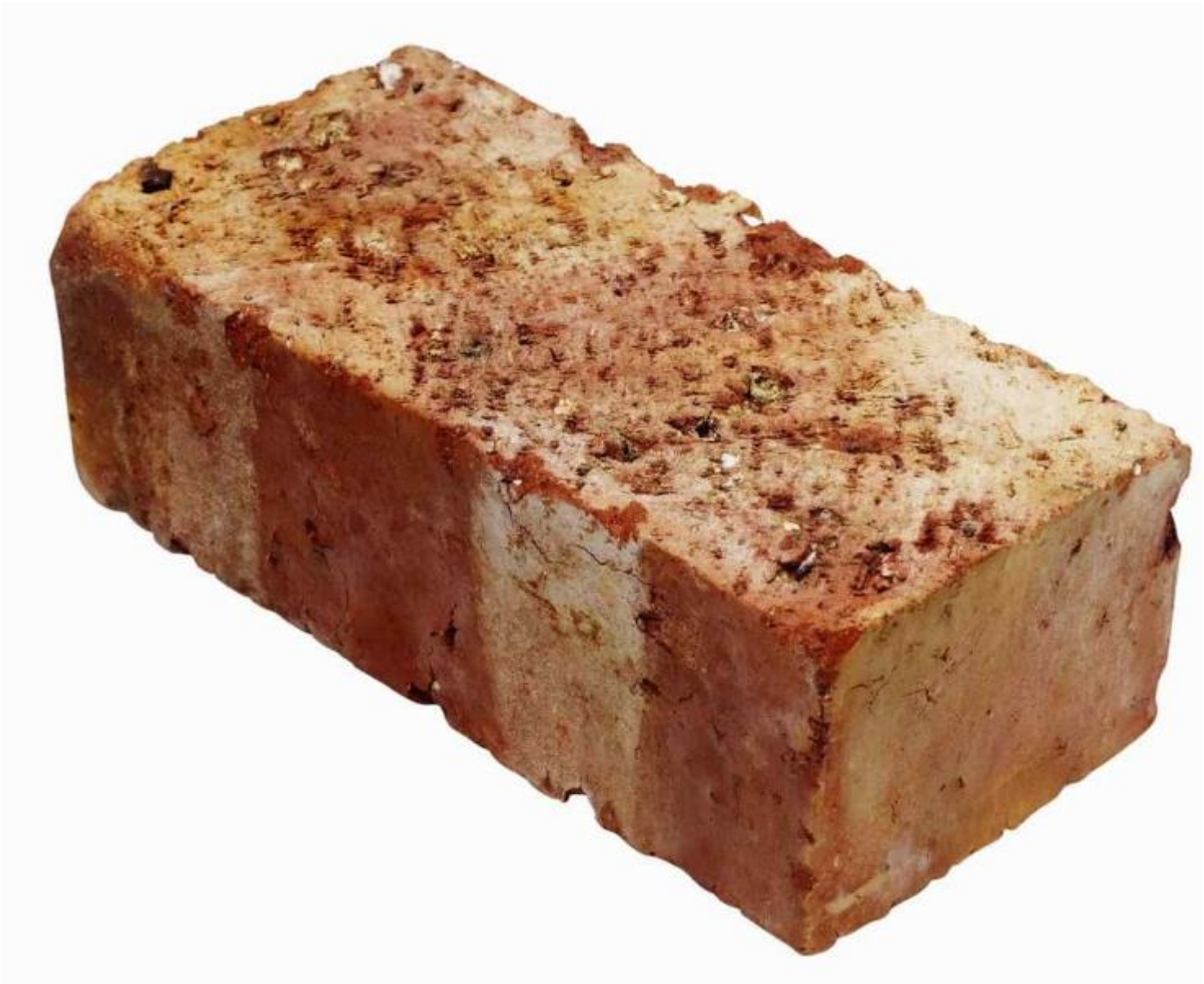
2  $\mu$  m

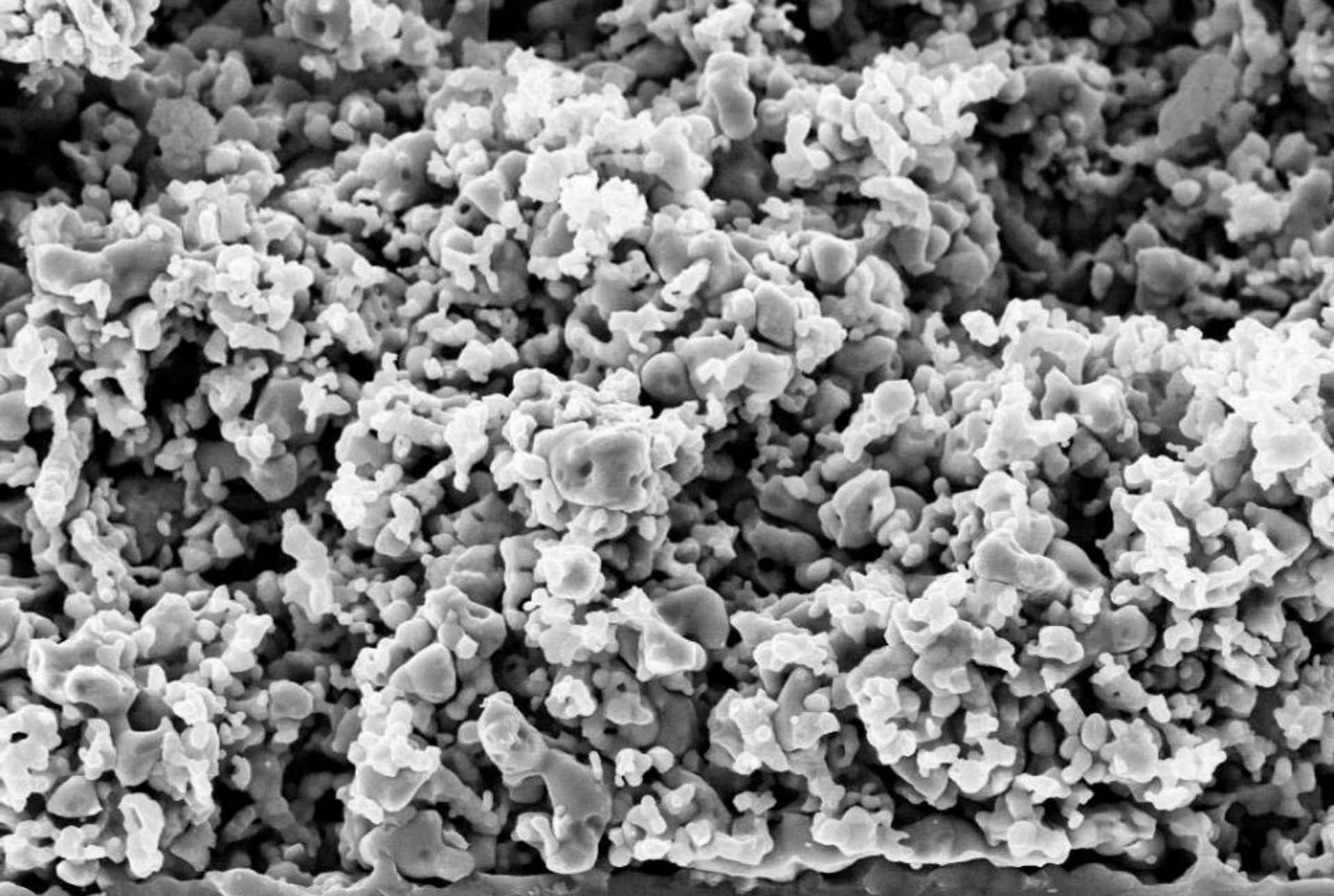
# Body Centered Cubic Crystal Structure of Iron





ENGINEHOUSE  
- N°5 -





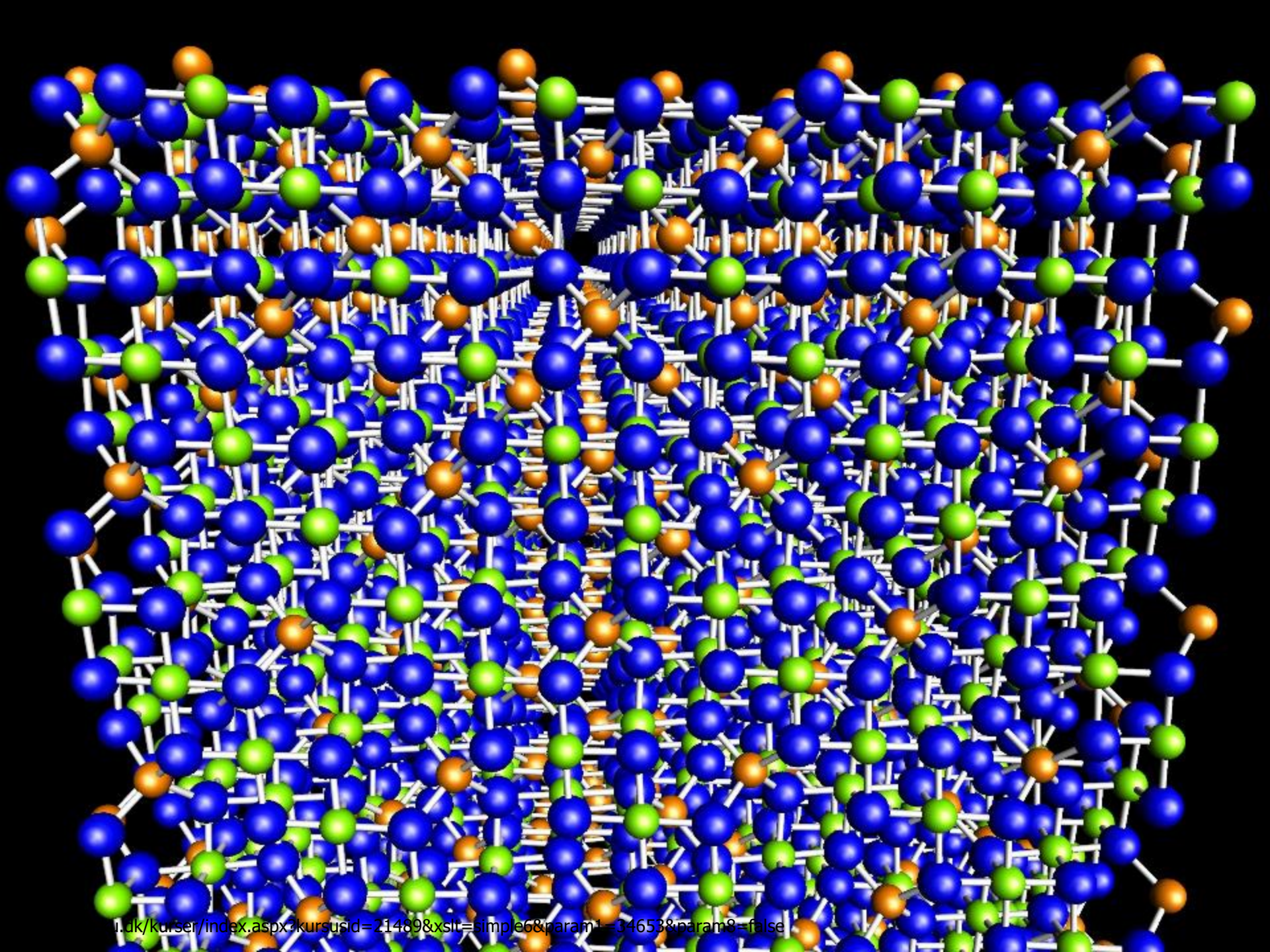
1  $\mu\text{m}$   
|-----|

EHT = 10.00 kV  
WD = 5 mm

Signal A = SE2  
Photo No. = 6497

Date :26 Feb 2003  
Time :17:42:54









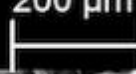
UWO CrossBeam  
Mag = 40 X

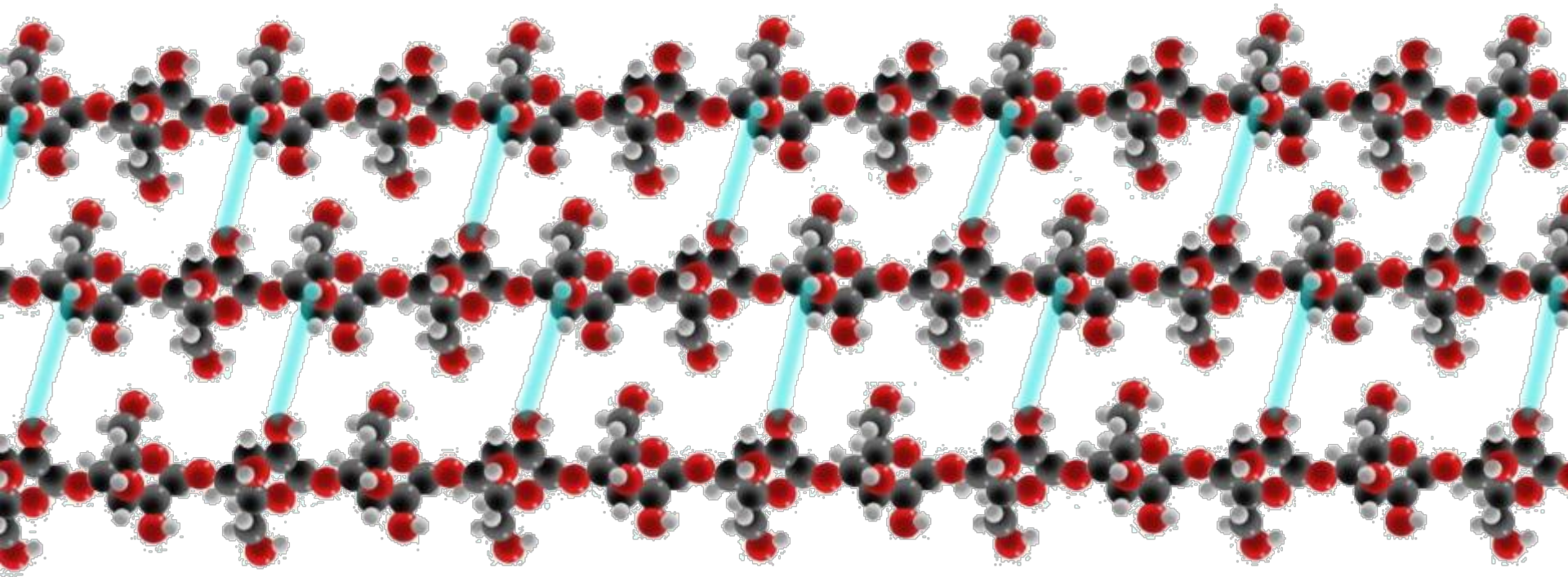
EHT = 5.00 kV  
WD = 15.5 mm

Signal A = SE2  
FIB Imaging = SEM

Date :22 Feb 2013  
Time :13:38:01

200  $\mu$ m

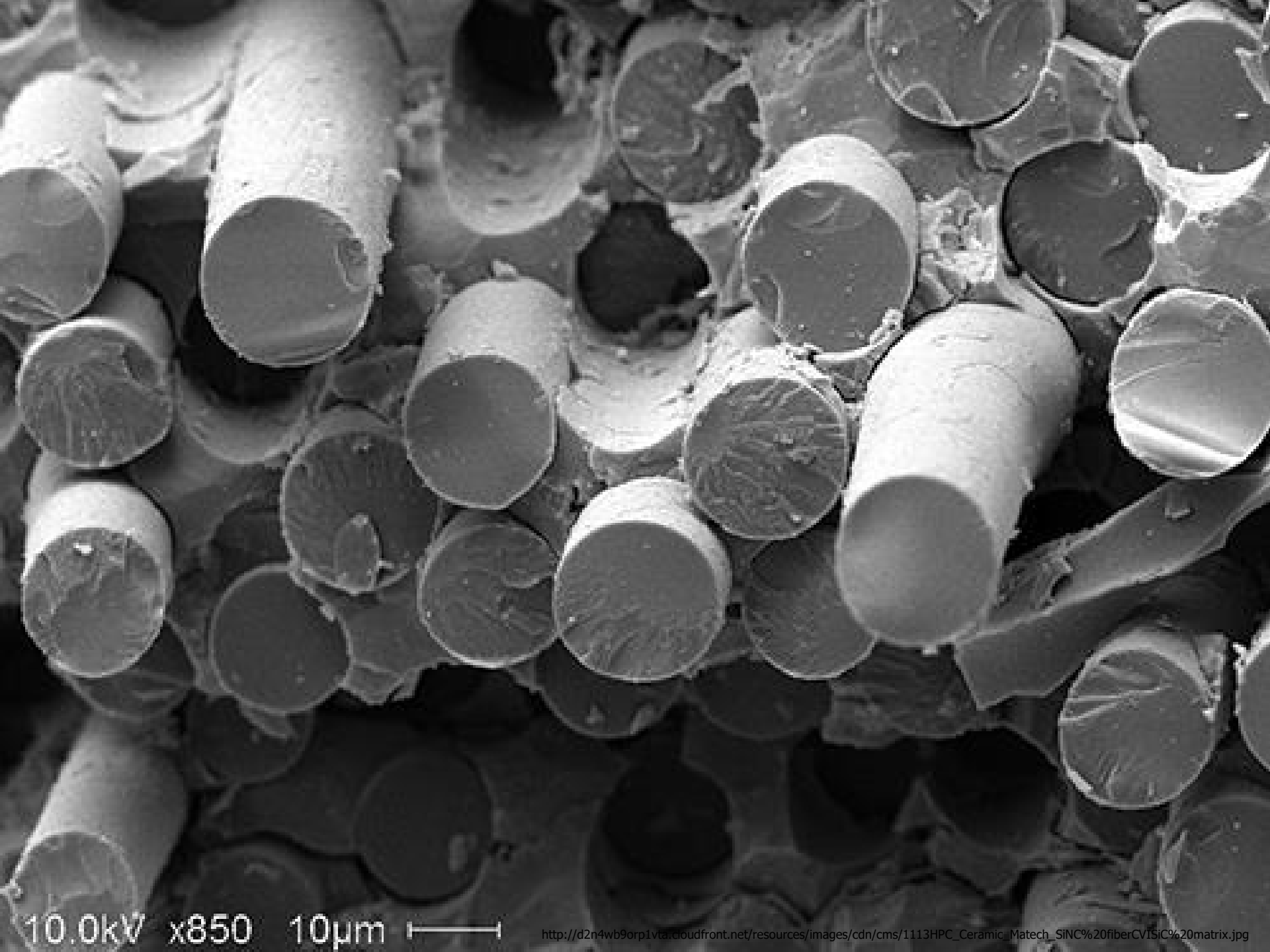






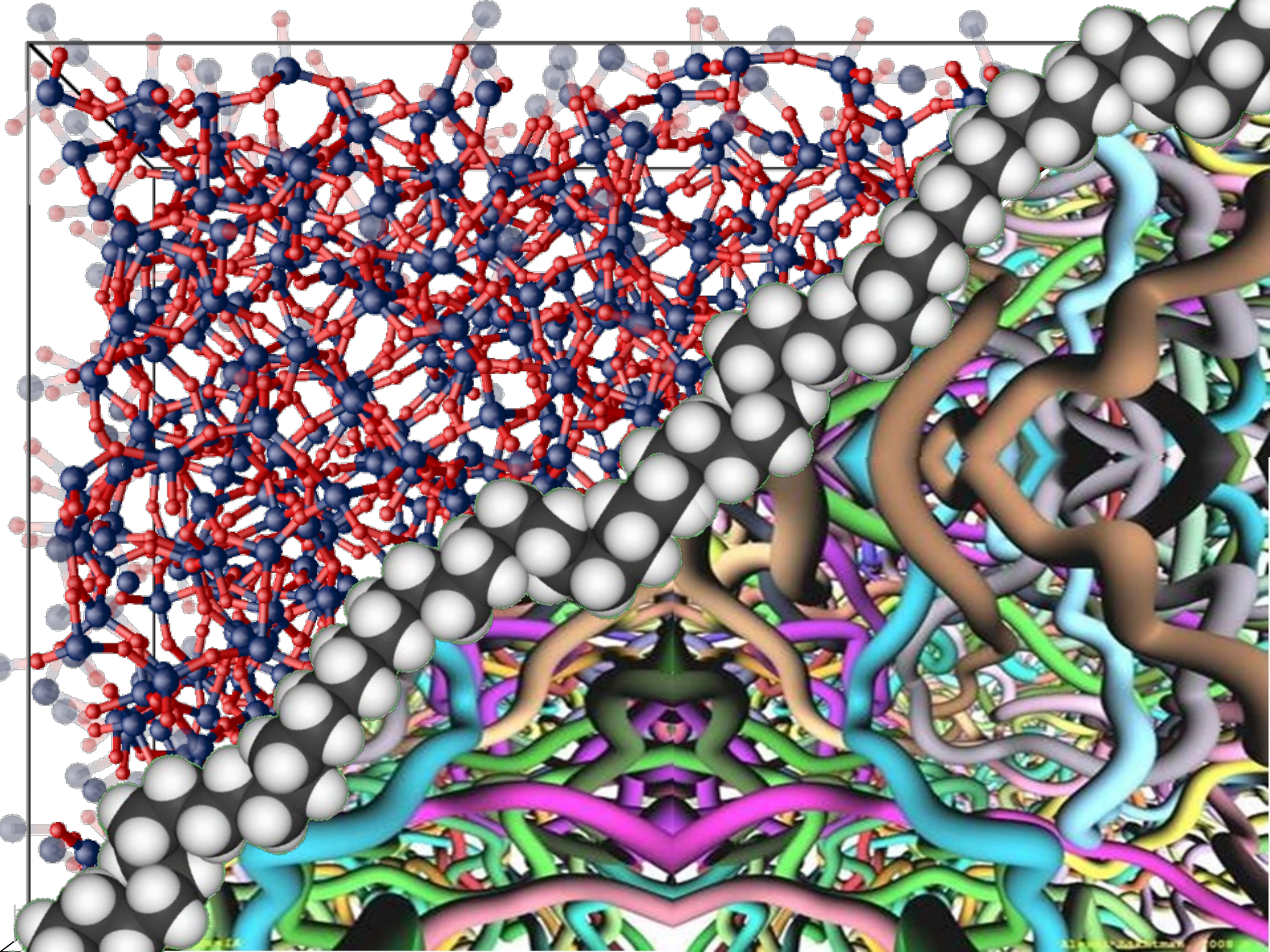


<http://www.boatdesign.net/forums/attachments/materials/50874d1291586763-heat-treated-fiberglass-mat-p1010129.jpg>  
<http://www.easycomposites.co.uk/images/products/large/EF80-Flexible-Epoxy-Resin.jpg>



10.0kV x850 10 $\mu$ m 

[http://d2n4wb9orp1vt.cloudfront.net/resources/images/cdn/cms/1113HPC\\_Ceramic\\_Matech\\_SiNC%20fiberCVISiC%20matrix.jpg](http://d2n4wb9orp1vt.cloudfront.net/resources/images/cdn/cms/1113HPC_Ceramic_Matech_SiNC%20fiberCVISiC%20matrix.jpg)







# Categories of Properties

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- **Mechanical Properties** – deformation of material due to applied force
- **Electrical** – reaction of material to applied electric field
- **Thermal** – reaction of material to applied heat
- **Magnetic** – response of material to applied magnetic field
- **Optical** – response of material to light radiation
- **Deteriorative** – response of material to chemical and environmental stimuli



# Metals



- **Bonding:** Metallic Bonding
- **Structure:** Crystalline Lattice
- **Plusses:** Strong, Tough, Heat Resistant, Weldable
- **Minuses:** Heavy, Prone to Corrosion

# Ceramics



- **Bonding:** Covalent Bonding
- **Structure:** Crystalline Lattice
- **Plusses:** High Compressive Strength,  
Heat Resistant
- **Minuses:** Low Impact Strength



# Polymers



- **Bonding:** Covalent Bonding and Inter-Chain IMFs
- **Structure:** Amorphous and Semi-crystalline
- **Plusses:** Easy to form, recyclable
- **Minuses:** Low Heat Tolerance, Not as Strong



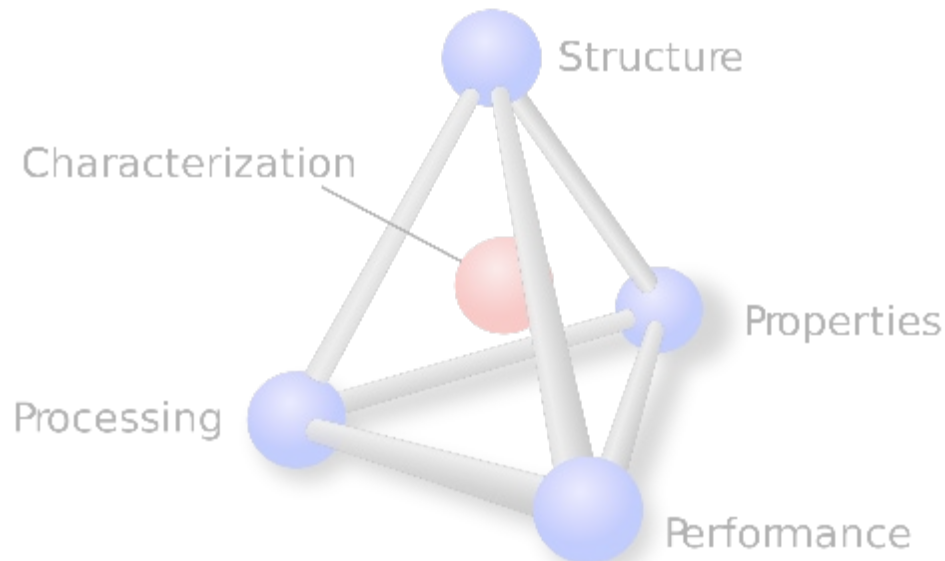
# Materials and Nanoscience

- Structure

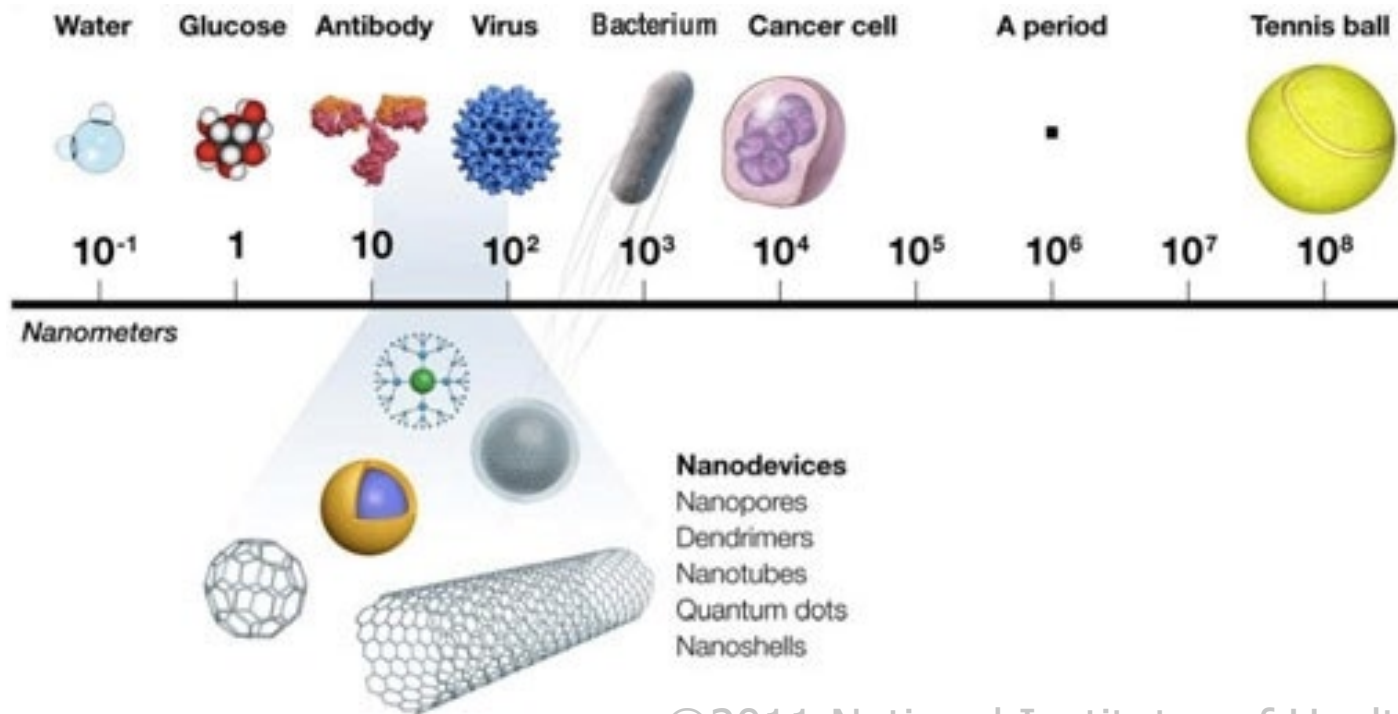
  - Property-Performance-Processing-Characterization

- Size

  - Property-Performance-Processing-Characterization



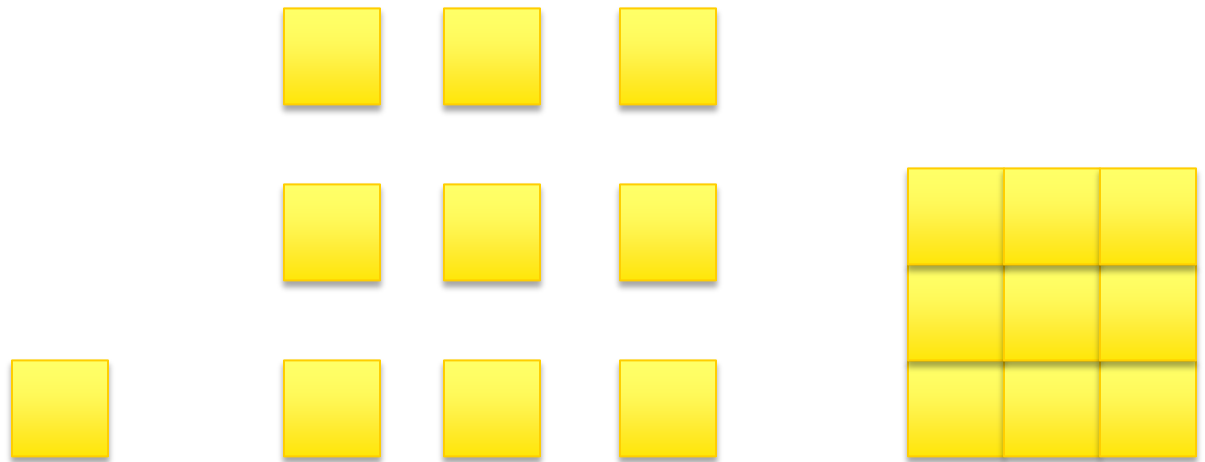
# Size Range



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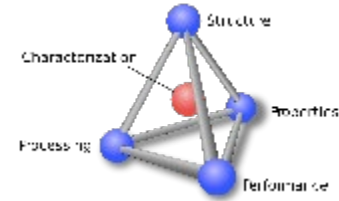


# Surface Area to Volume Ratio



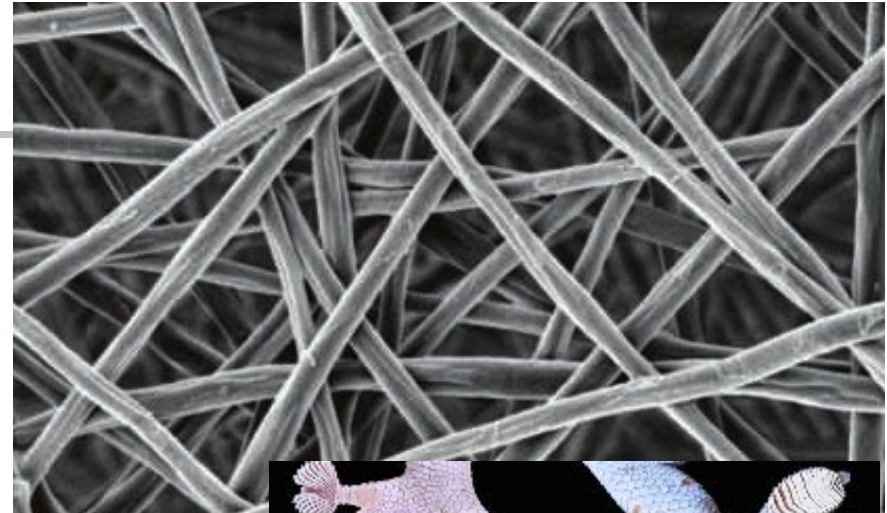
Surface Area (m <sup>2</sup> )	.24	2.2	1.2
Volume (m <sup>3</sup> )	.008	.072	.072
Ratio (m <sup>-1</sup> )	30	30	17





# Surface Area

- Filtration
- Heat dissipation
- Wetting
- Adhesion

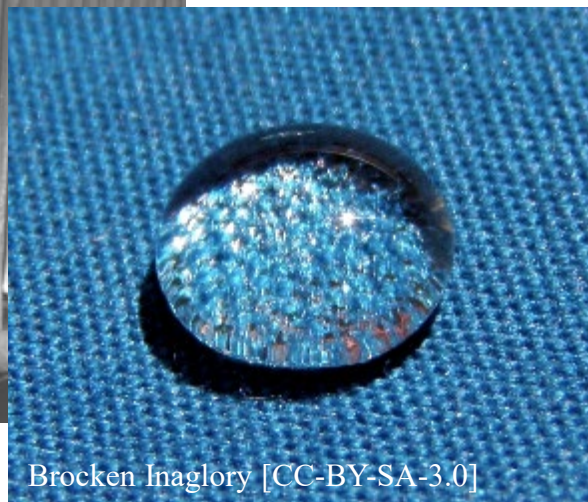
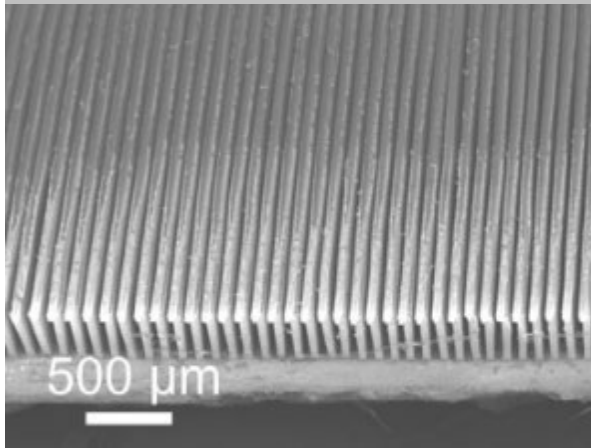


materialsviews.com



gecko feet © 2009 Kellar Autumn

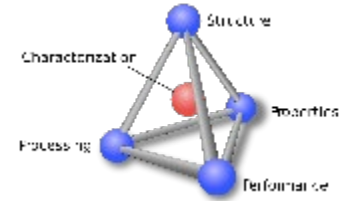
CNT microfins by Dr. Liu, Chalmers U. of Tech.



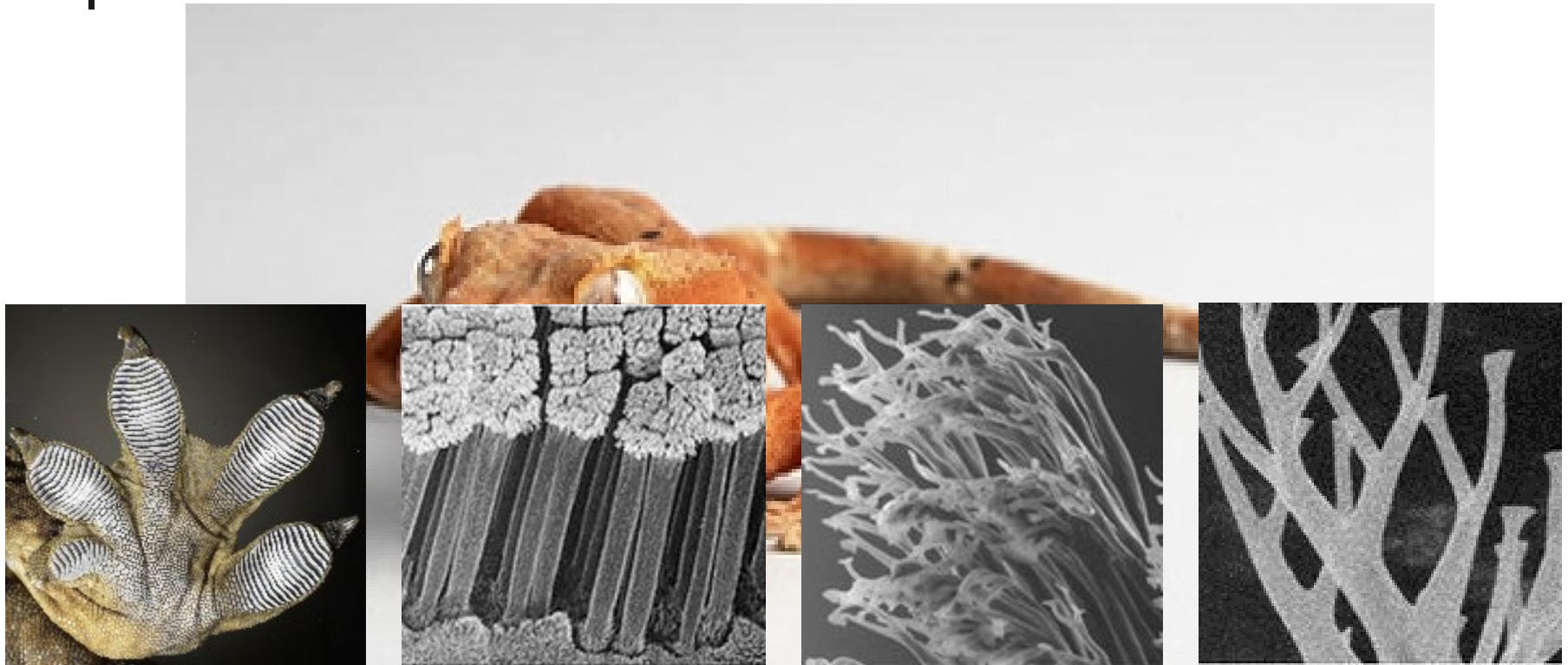
Brocken Inaglory [CC-BY-SA-3.0]





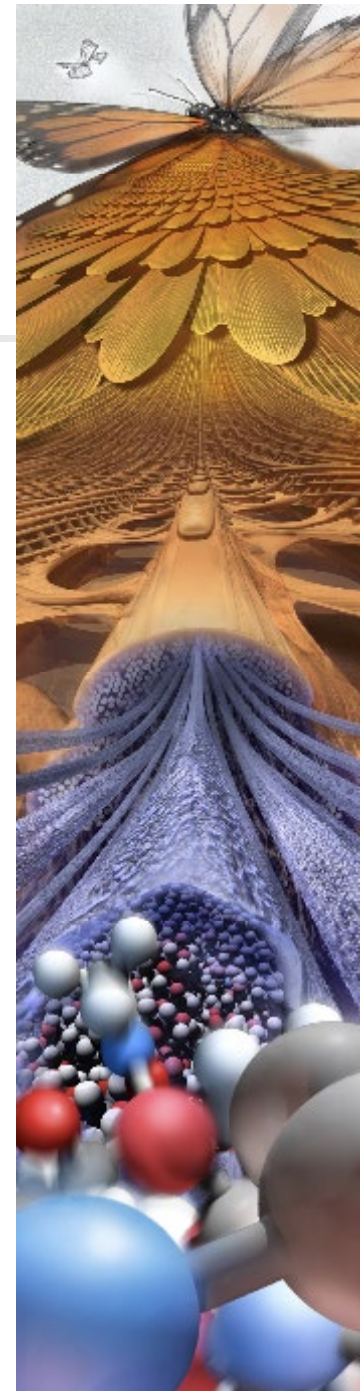


# van der Waals forces

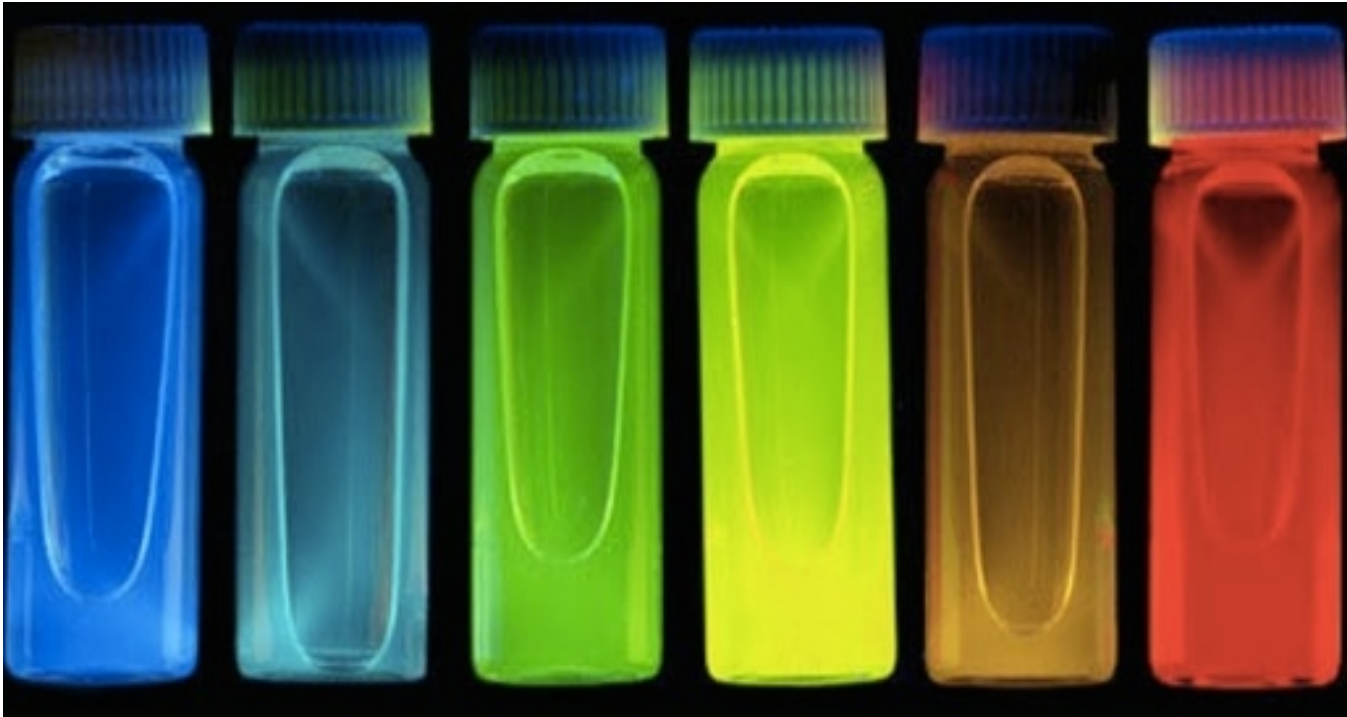




# Blue Morpho Butterfly



# Size Matters



colloidal suspensions of variously-sized quantum dots in inert solvents © Felice Frankel



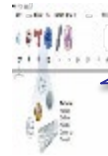
# Medieval Stained Glass



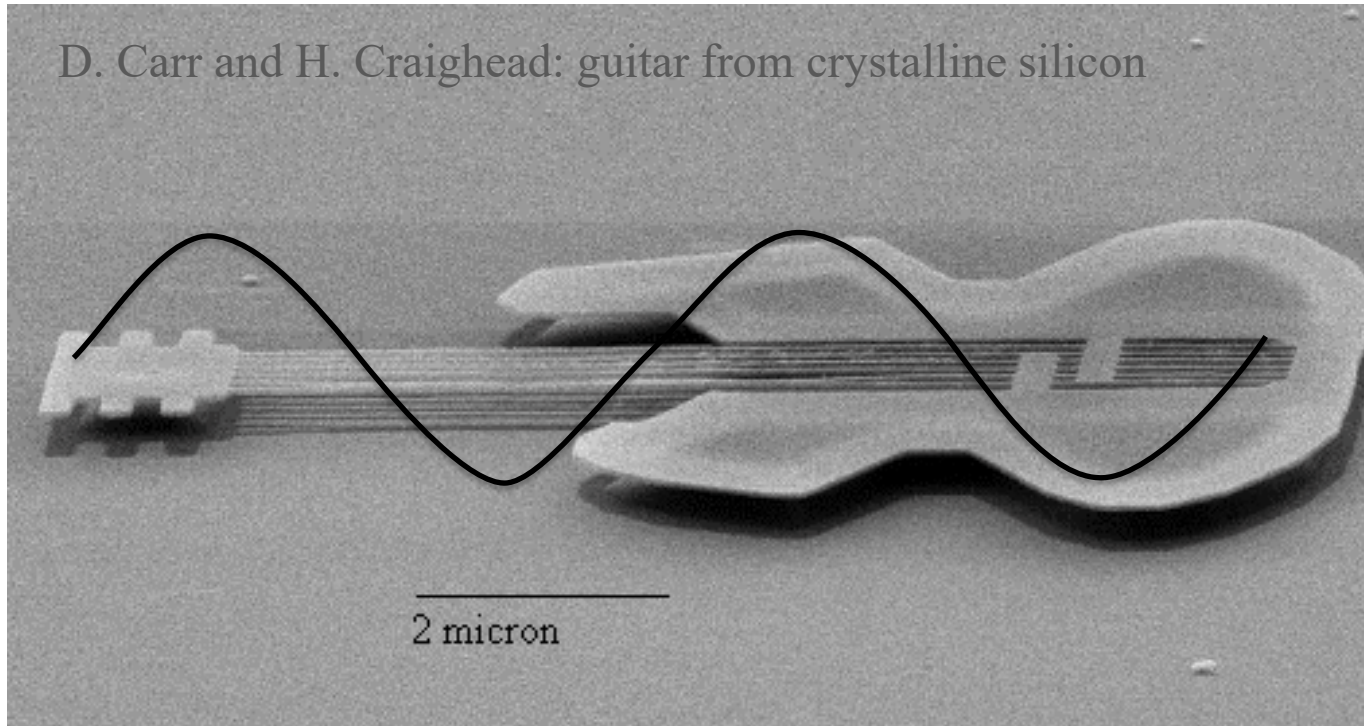
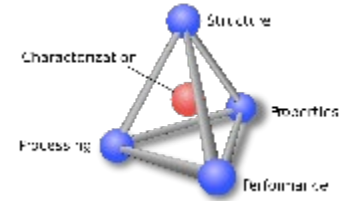
Theodosius Arrives at Ephesus (Scene from the Legend of the Seven Sleepers), ca. 1200–1205. The Cloisters Collection, 1980 (1980.263.4)



# Nano Guitar



Button your  
vacuole, baby!



86 MHz (humans can't hear above 20 kHz)

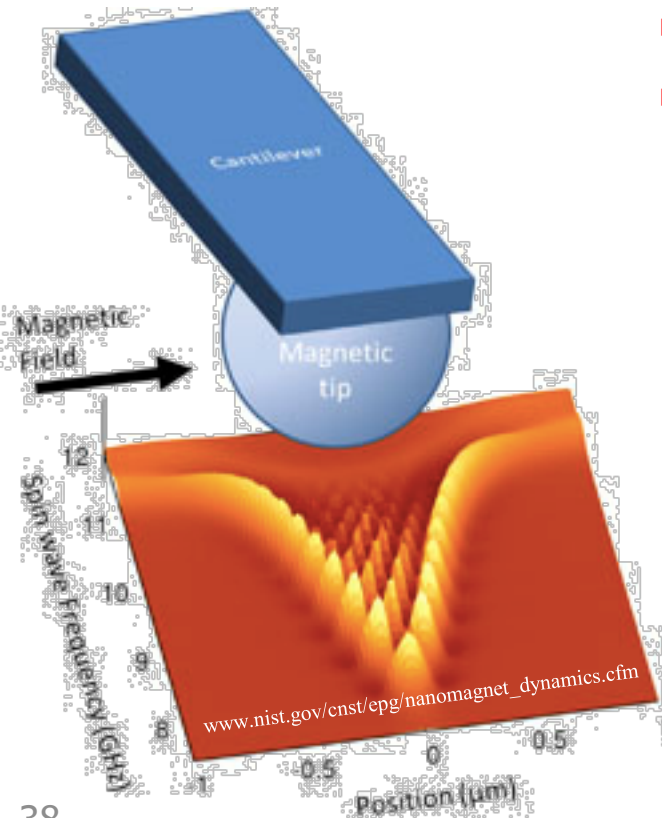


# Nanomagnet Fabrication



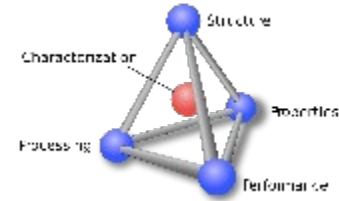
## Hard Disks

- more robust than solid state drives
- current hard disks ( $10^{11}$  bytes)
- Nanomagnet disks ( $>10^{13}$  bytes)



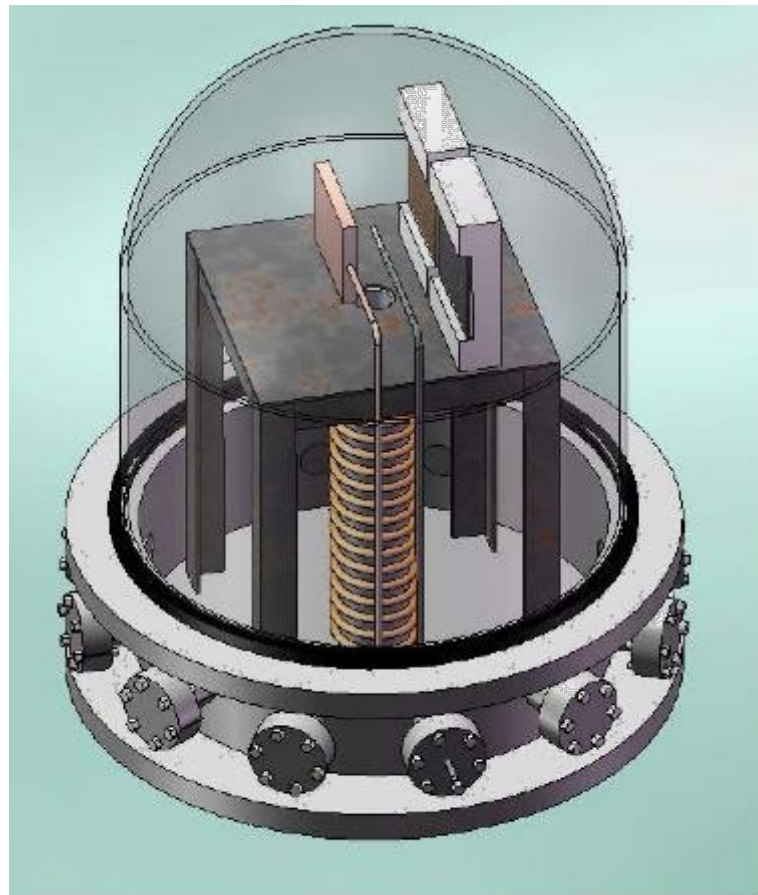
University of California - Davis. (2013, May 20). Iron-platinum alloys could be new-generation hard drives. ScienceDaily.





# Sputter Chamber Construction

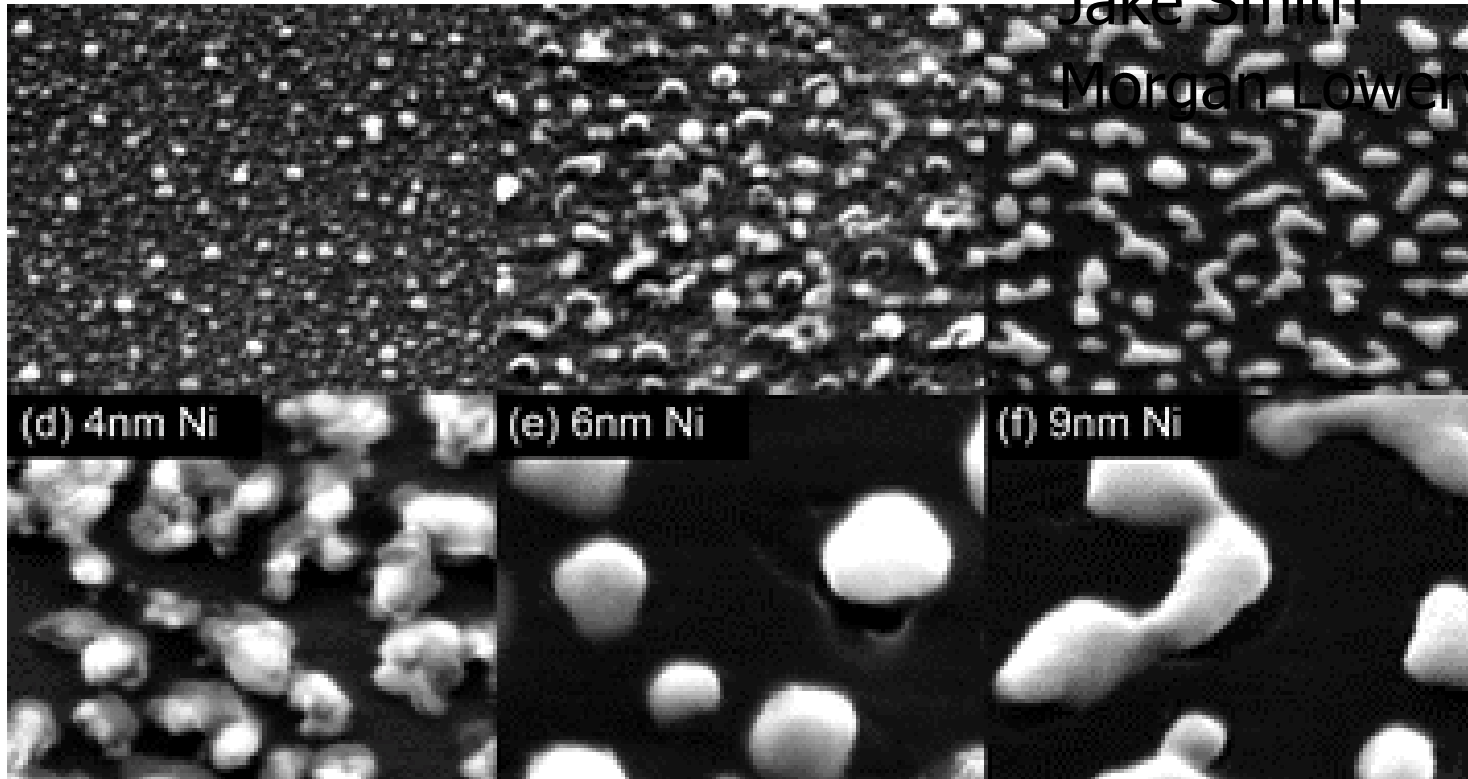
Cody Lang  
Roy Lindsay  
Aaron Forde  
Kirk Coughlin  
Ryan Kraft  
Bill Hahn  
Shawn Kozey  
Jake Smith





# IGC

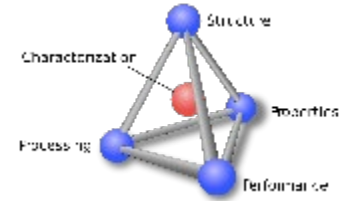
Sarah Voeller  
Aaron Cochran  
Jacob Ferrina  
Shawn Kozey  
Jake Smith  
Morgan Lowery



13 SEM photographs of Ni films with varying thicknesses deposited using magnetron sputtering on 50 nm of SiO<sub>2</sub> after annealing at 750 ° C in 20 Torr of H<sub>2</sub> for ...

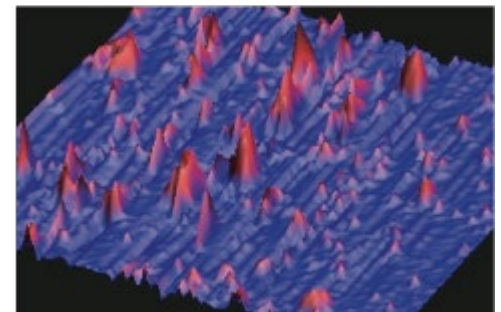
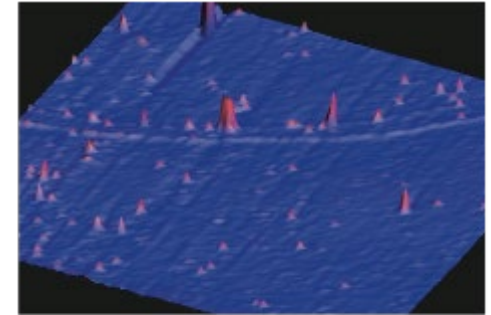
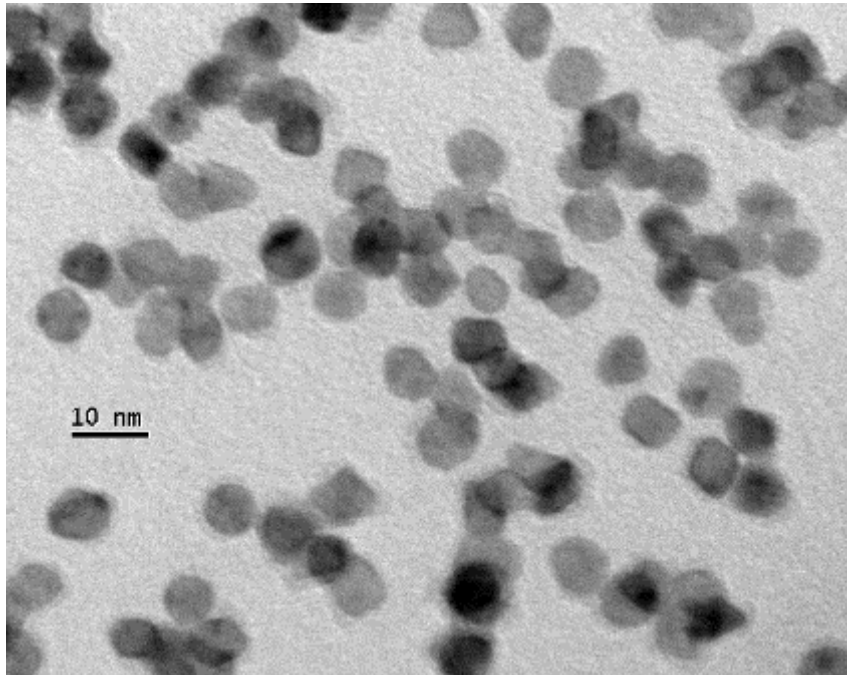


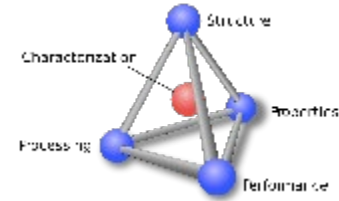




# Nanomagnet Characterization

- AFM
- TEM

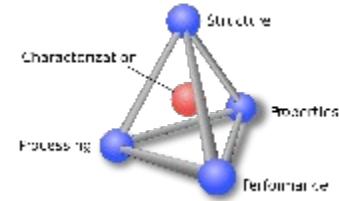




# Quadrupole Mass Spec

- Matt Bouc





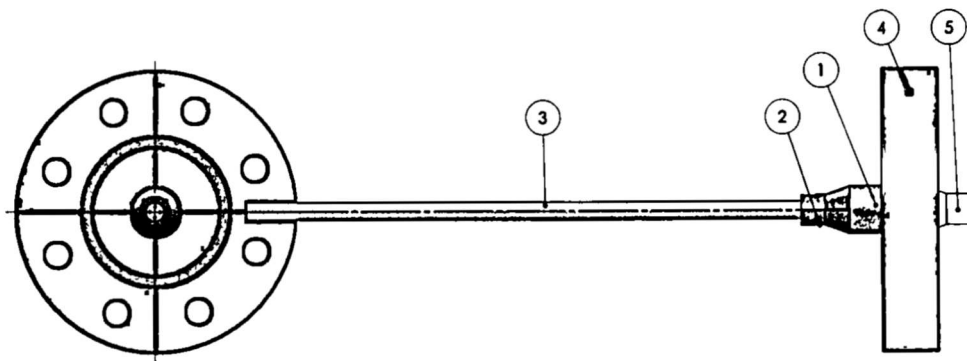
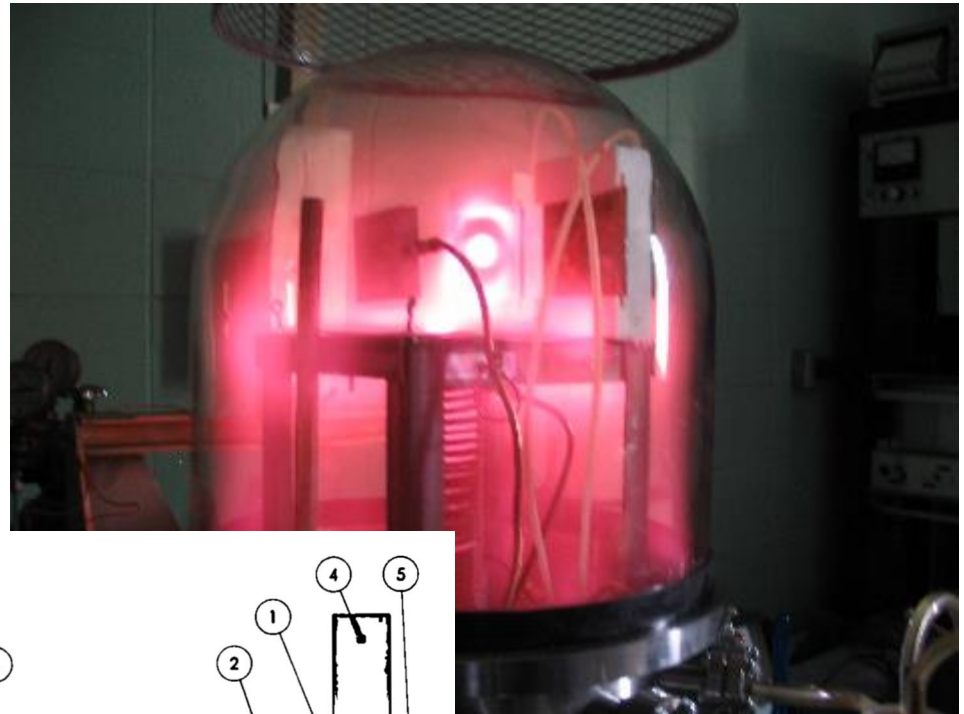
# SEED Chamber Construction

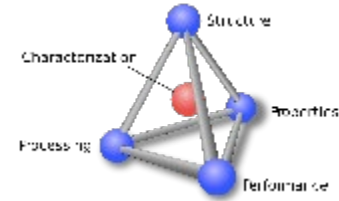
- Bill Hahn
- Joe Pagenkopf
- Matt Bouc



# Plasma Diagnostics

- Langmuir Probe
- Emissive Probe
- Spectroscopy

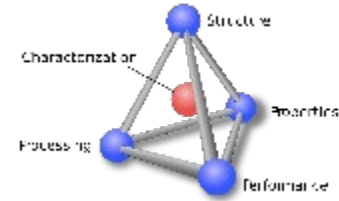




# Physics of Cloud Formation

- Caleb Ryberg

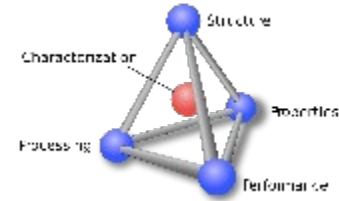




# Indexing Nanomagnets

- Tom Yungbauer
- Chris Buelke
- Kirk Coughlin
- Matt Bouc





# Reverse Engineering in Clean Room

- Take apart a microchip



# Introduction to Nano-Clusters

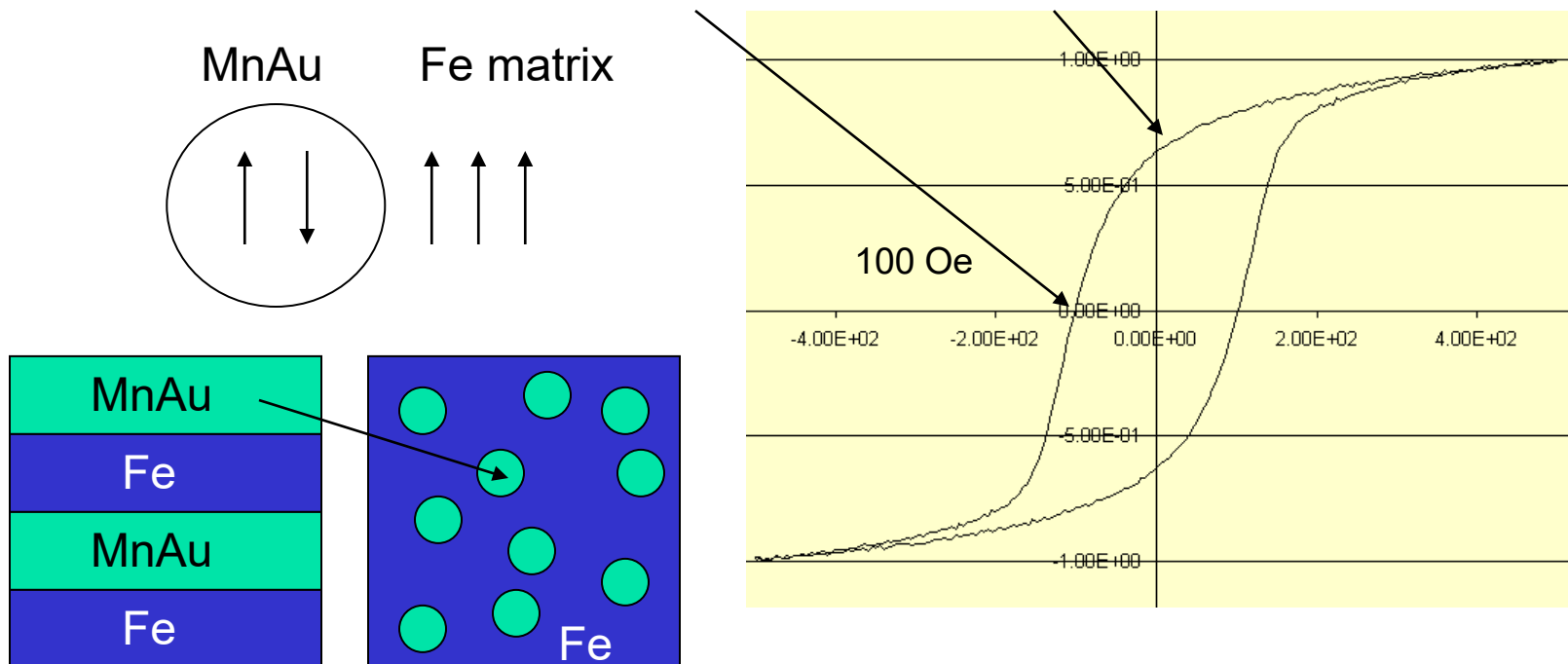
- Current data storage device
  - Hard disc
    - Thin Glass coated with magnetic material
    - Reading/Writing pads
      - Limits size of byte
- Desire for small devices/more data
  - 1950' s hard disks ( $10^6$  bytes)
  - Current hard disks ( $10^{11}$  bytes)
  - Nanomaterial hard disks ?
    - *At least* another factor of 100 increase





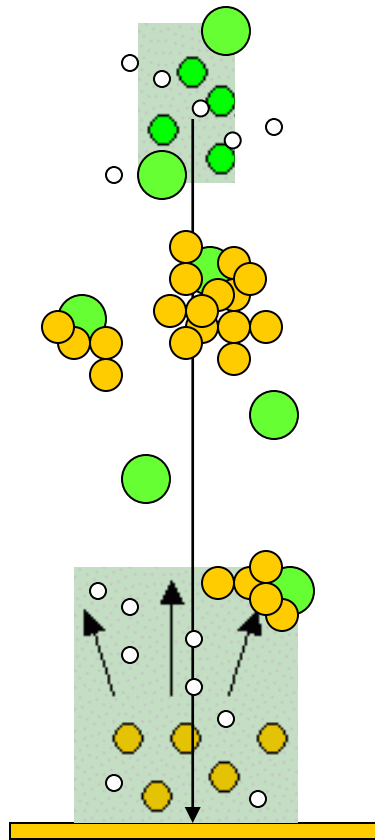
# Nanomaterials Engineering

- Anti-Ferro magnet in Ferromagnetic Matrix
  - Cluster-matrix boundary pins the electron spin
  - High coercivity and Low magnetization



# Gas Phase Aggregation

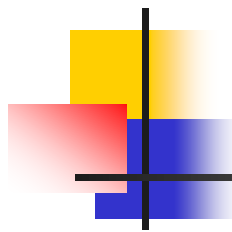
- Electron
- Inert atom
- Inert ion
- Target atom



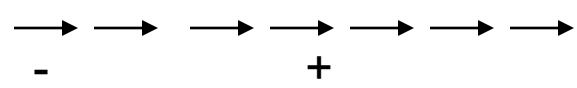
- Proto-Cluster Formation
  - Bombardment by ions
  - Target atom ejection
- Cluster Formation
  - Nucleation of target atoms
  - Anneal to change structure
    - Heating mechanism: *collisions between argon ions & clusters*
- Cluster Density
  - Secondary electron ejection
  - B field confines ejected electrons
  - More ions born!



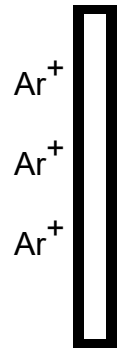
# How a Sputtering Device Works



Pressure Differential



MnAu or Fe Target



Supply gas plate



Substrate

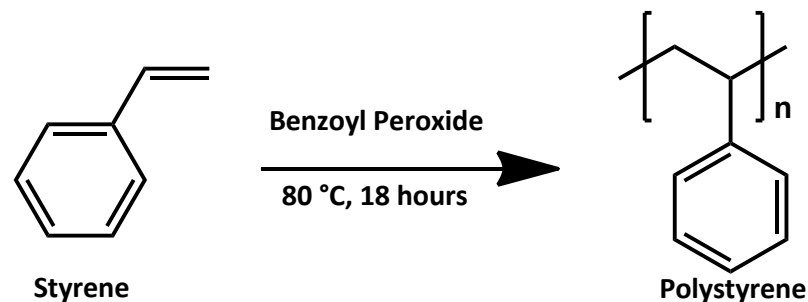


# Ray Research

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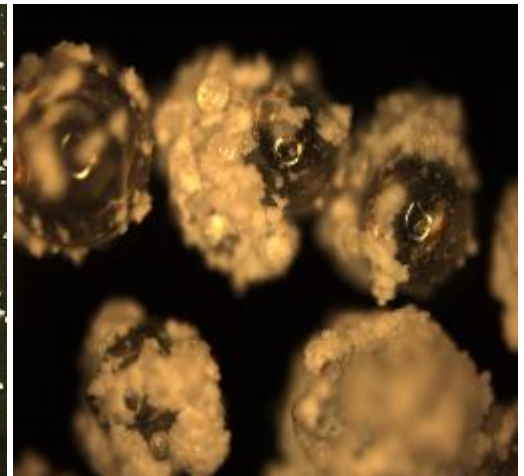
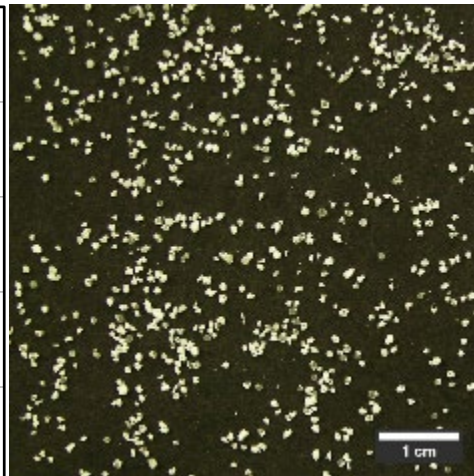
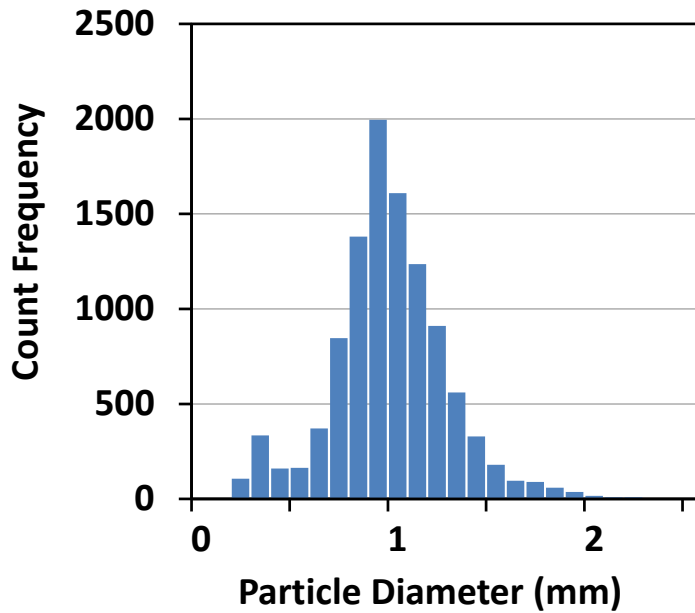
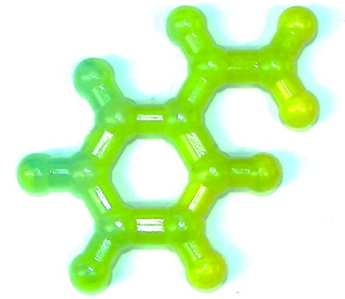


# Suspension Polymerization

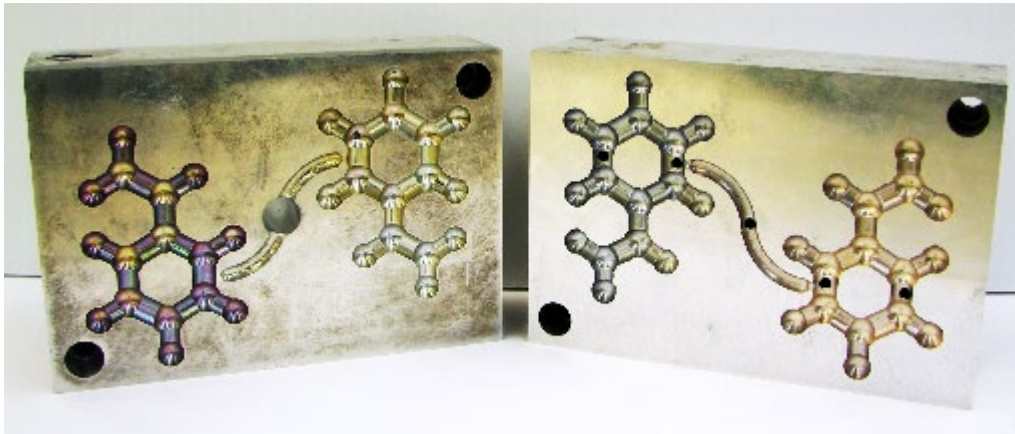


Ingredients	Amount
Water	234 g
5% Polyvinyl Alcohol	26 g
Styrene	88 g
Hexadecane	2 g
Benzoyl Peroxide	0.4 g

# Particle Size Distribution



# Injection Molding



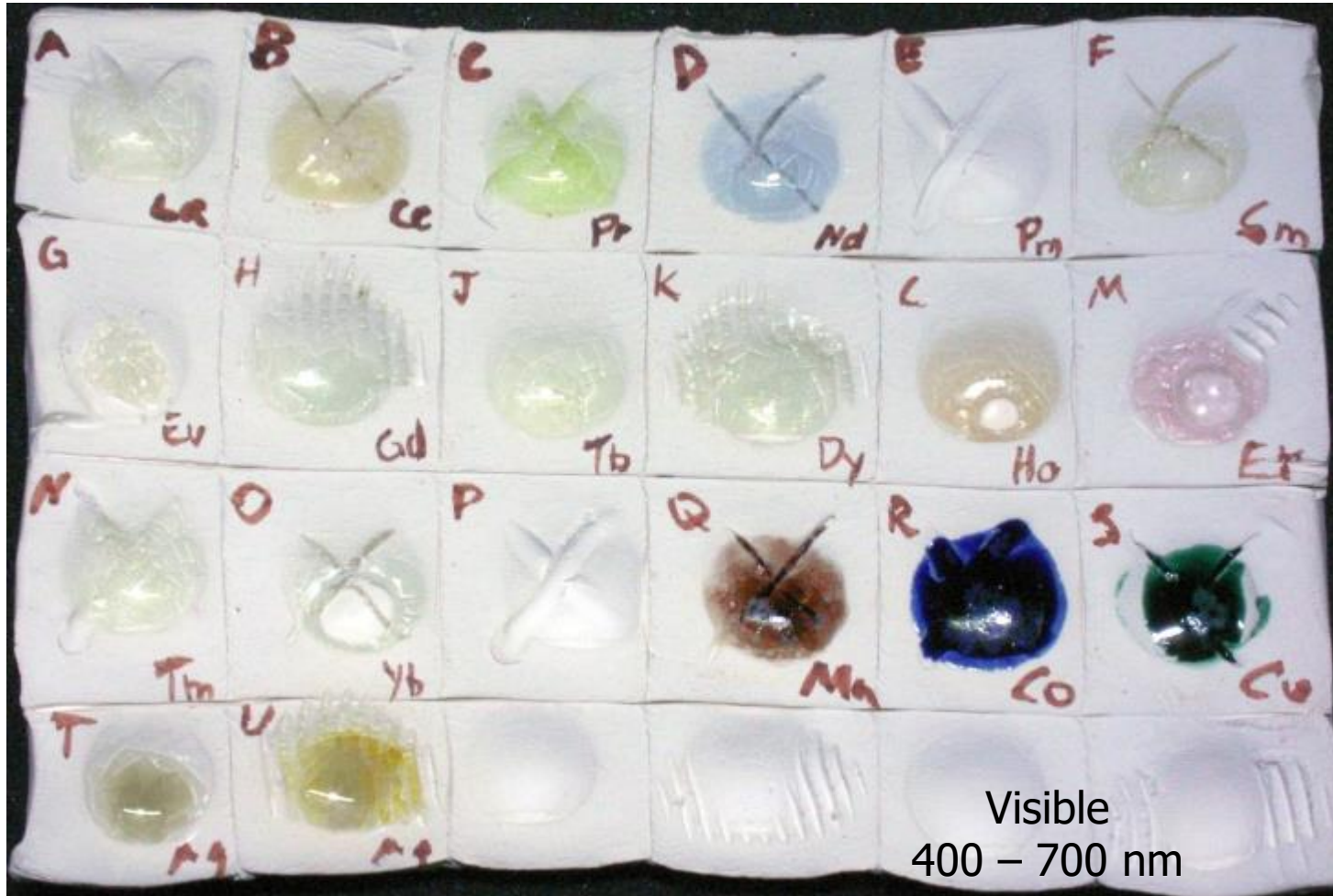
Clayton Barrix  
Dayton Ramirez

# Fluorescent Ceramics





# Fluorescent Ceramics

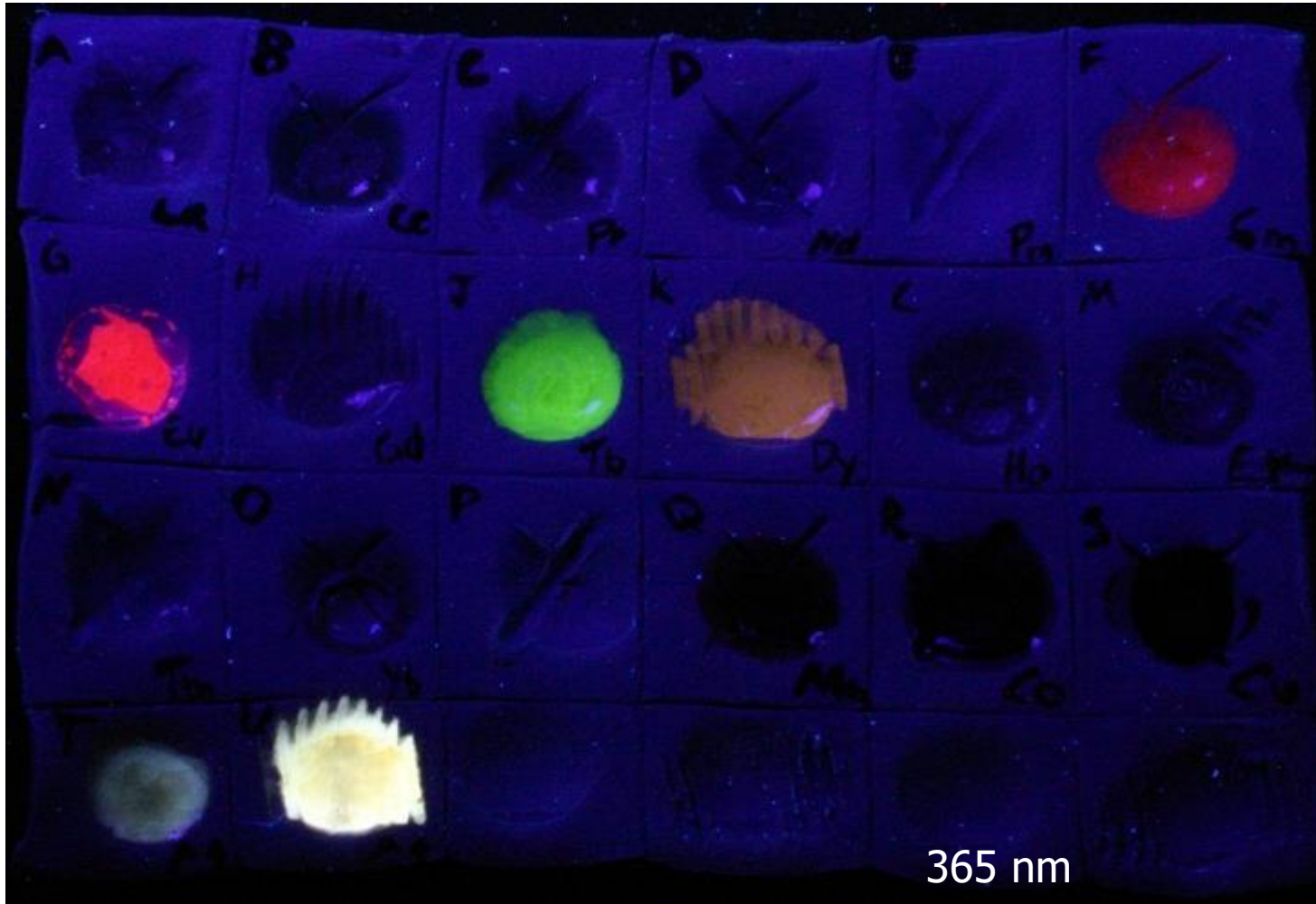


Visible  
400 – 700 nm

Felipe Marra-Mateus



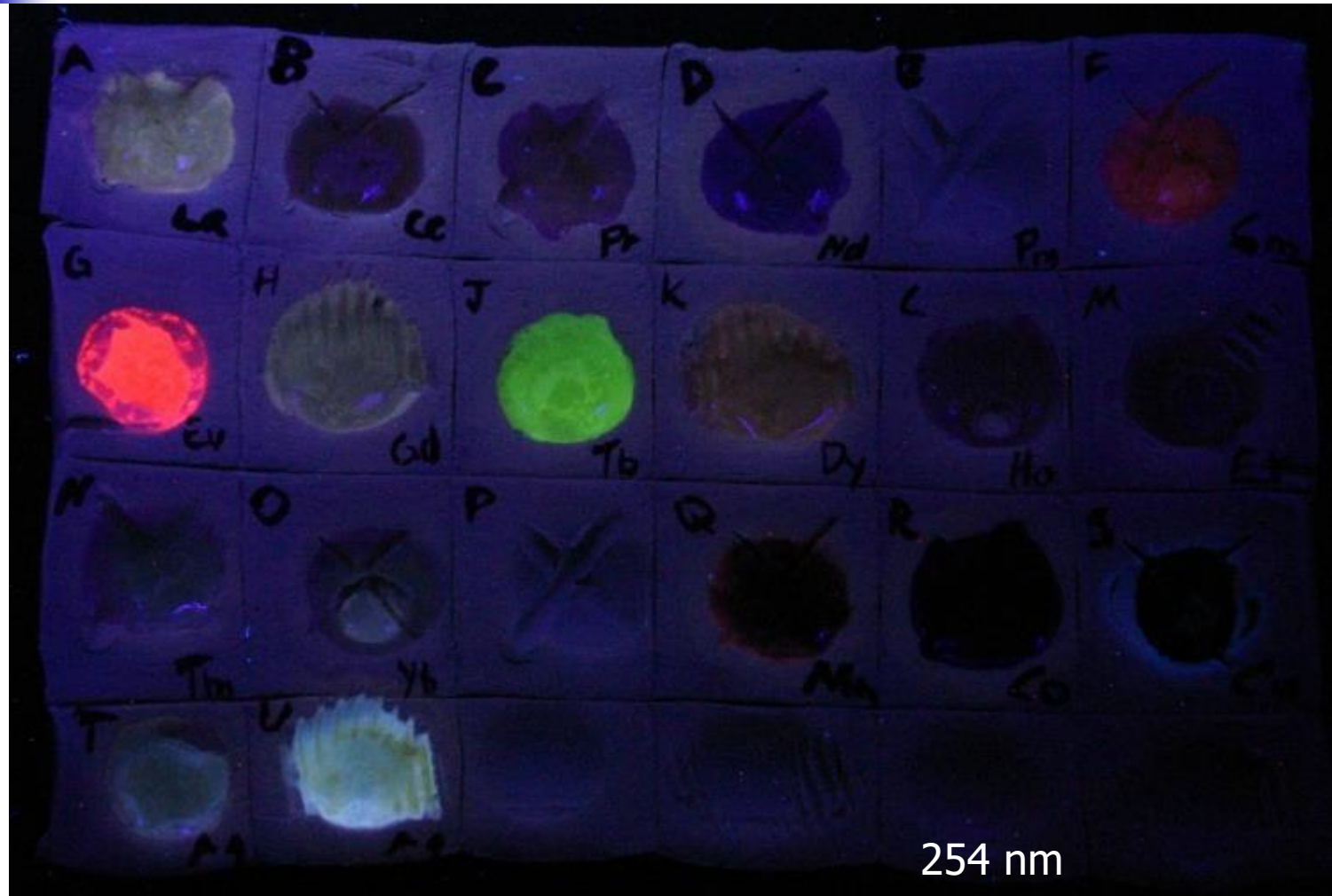
# Fluorescent Ceramics



Felipe Marra-Mateus



# Fluorescent Ceramics



254 nm

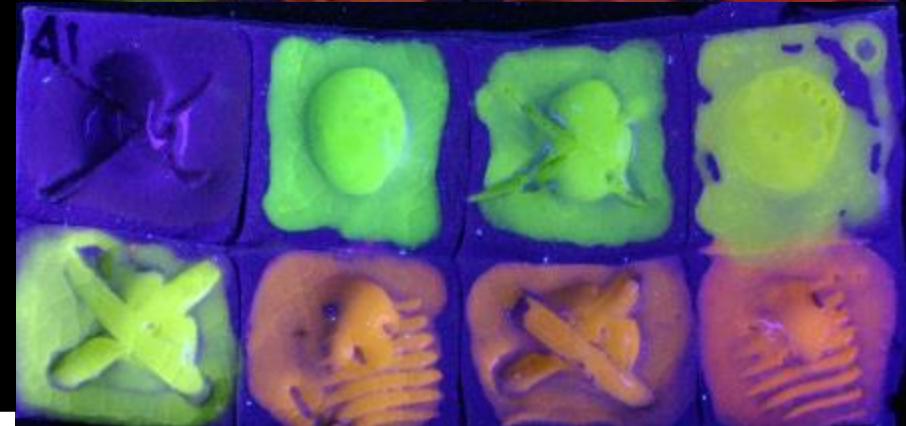
Felipe Marra-Mateus



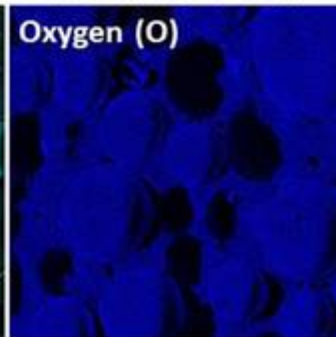
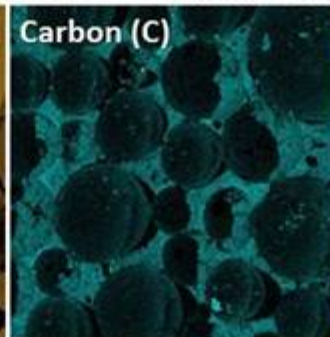
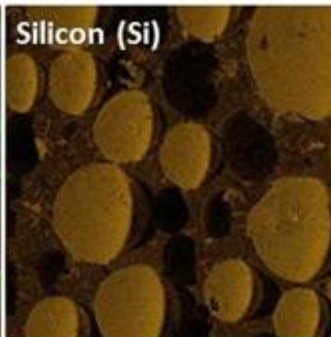
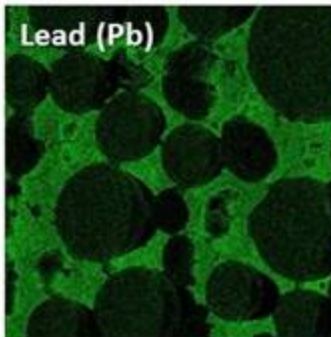
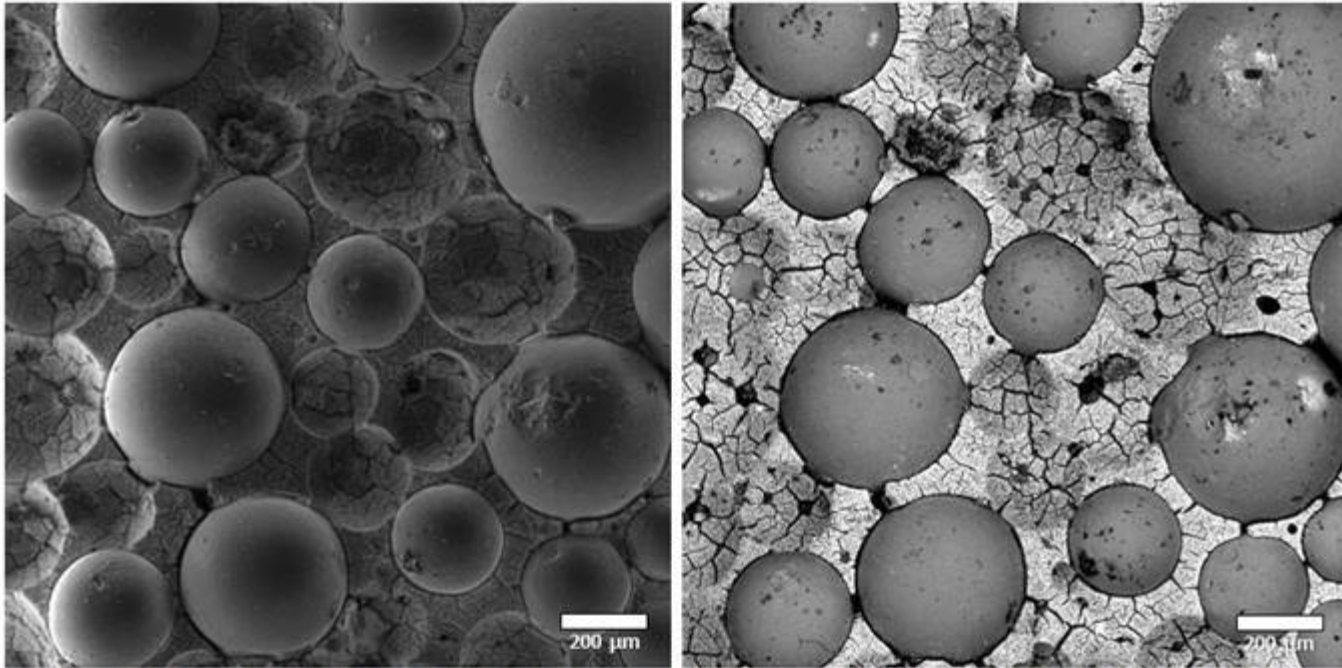
# Fluorescent Ceramics



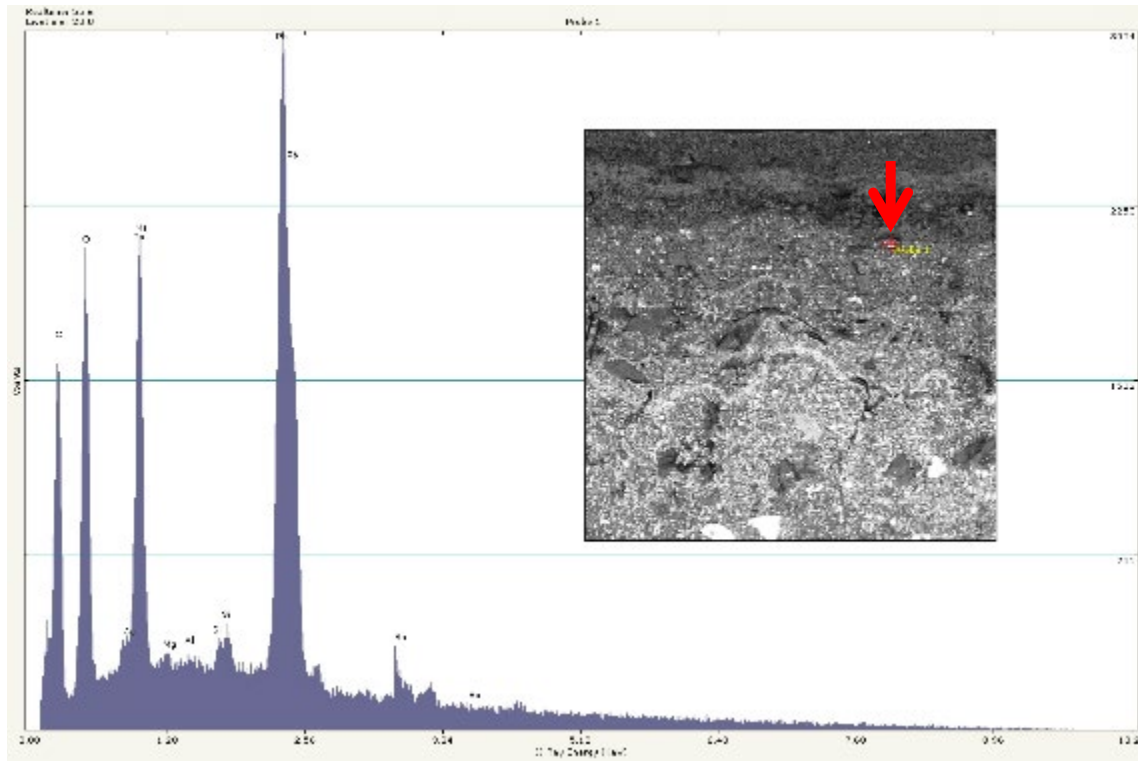
<b>Worthington Control</b>	<b>3.0% Tb 0% Eu</b>	<b>3.0% Tb 0.1% Eu</b>	<b>3.0% Tb 0.3% Eu</b>
<b>3.0% Tb 0.5% Eu</b>	<b>3.0% Tb 0.75% Eu</b>	<b>3.0% Tb 1.0% Eu</b>	<b>3.0% Tb 1.5% Eu</b>



# Lead Analysis

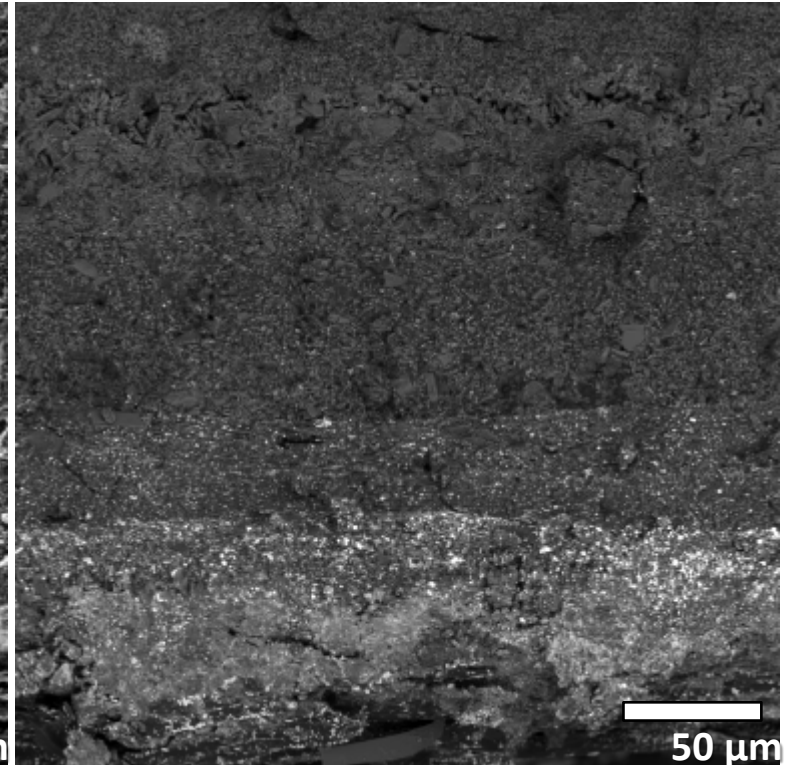
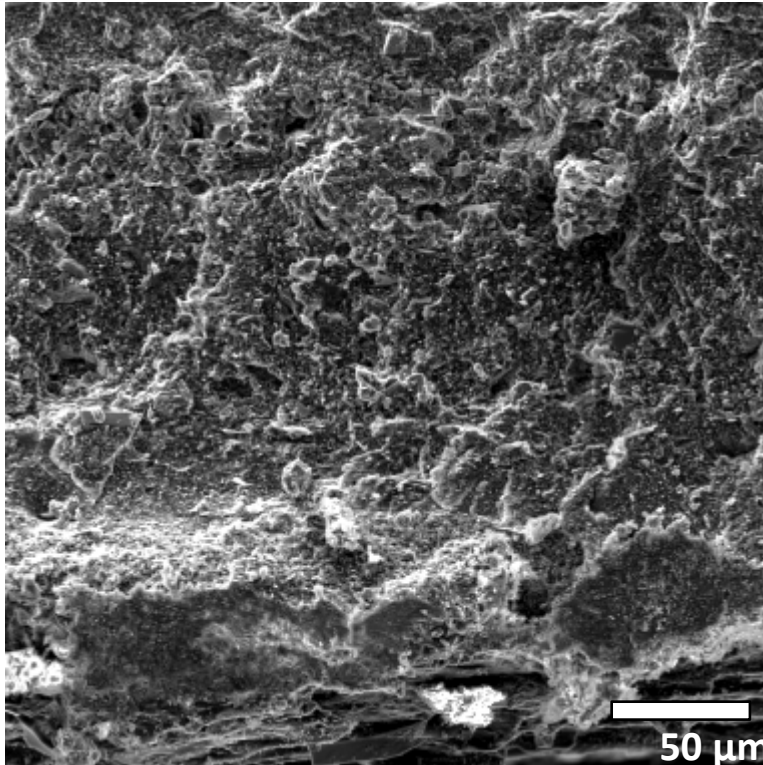


# Lead Analysis



- X-Ray Energy Spectrum produced by probing the paint pigment particle marked with the red arrow with the electron beam and measuring the energies of the resulting emitted x-ray photons.

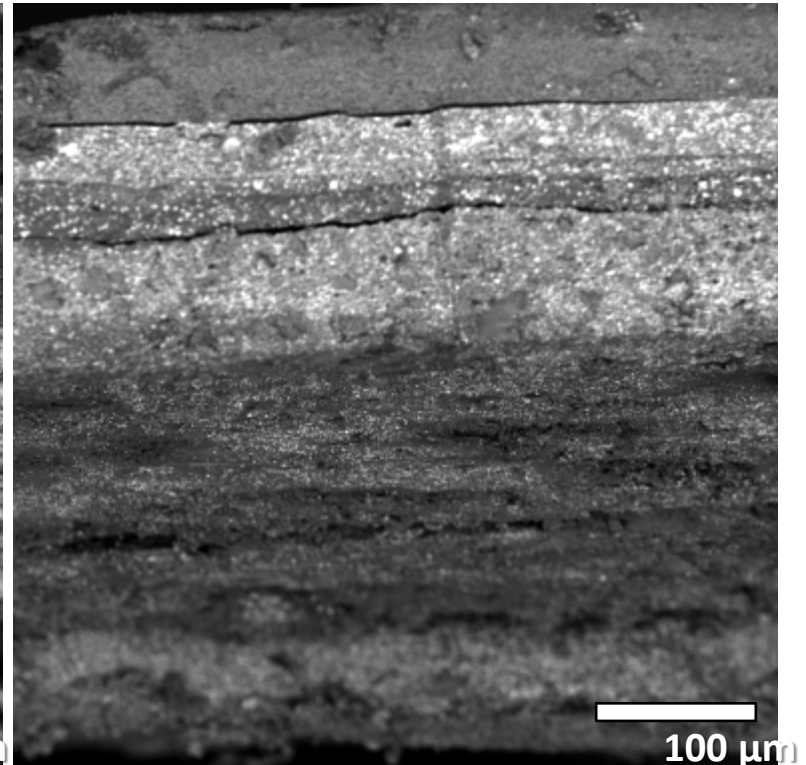
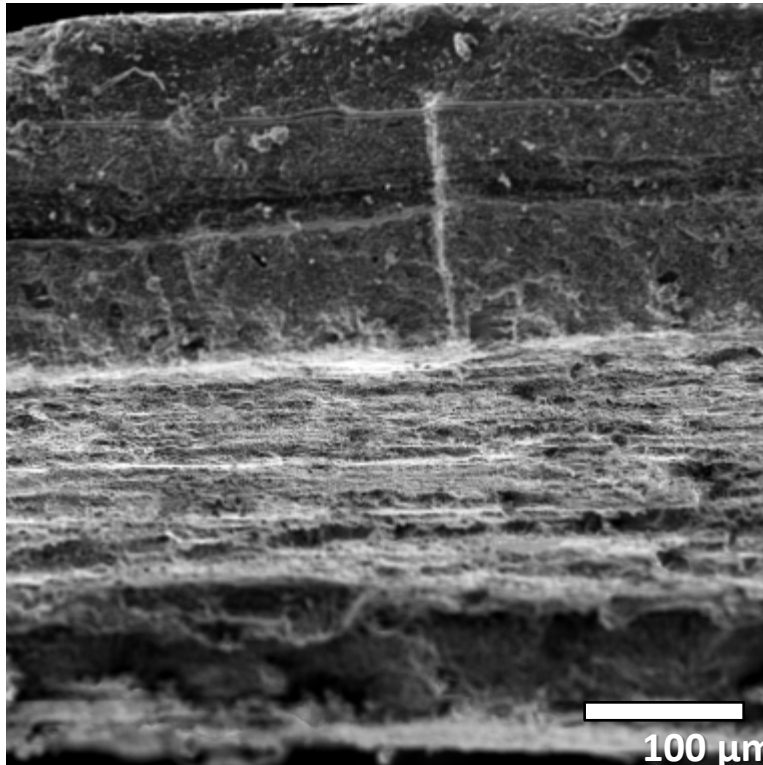
# Lead Analysis



- SEM Micrographs of Sample ER130147D with both (left) secondary electron detection and (right) backscattered electron detection.



# Lead Analysis

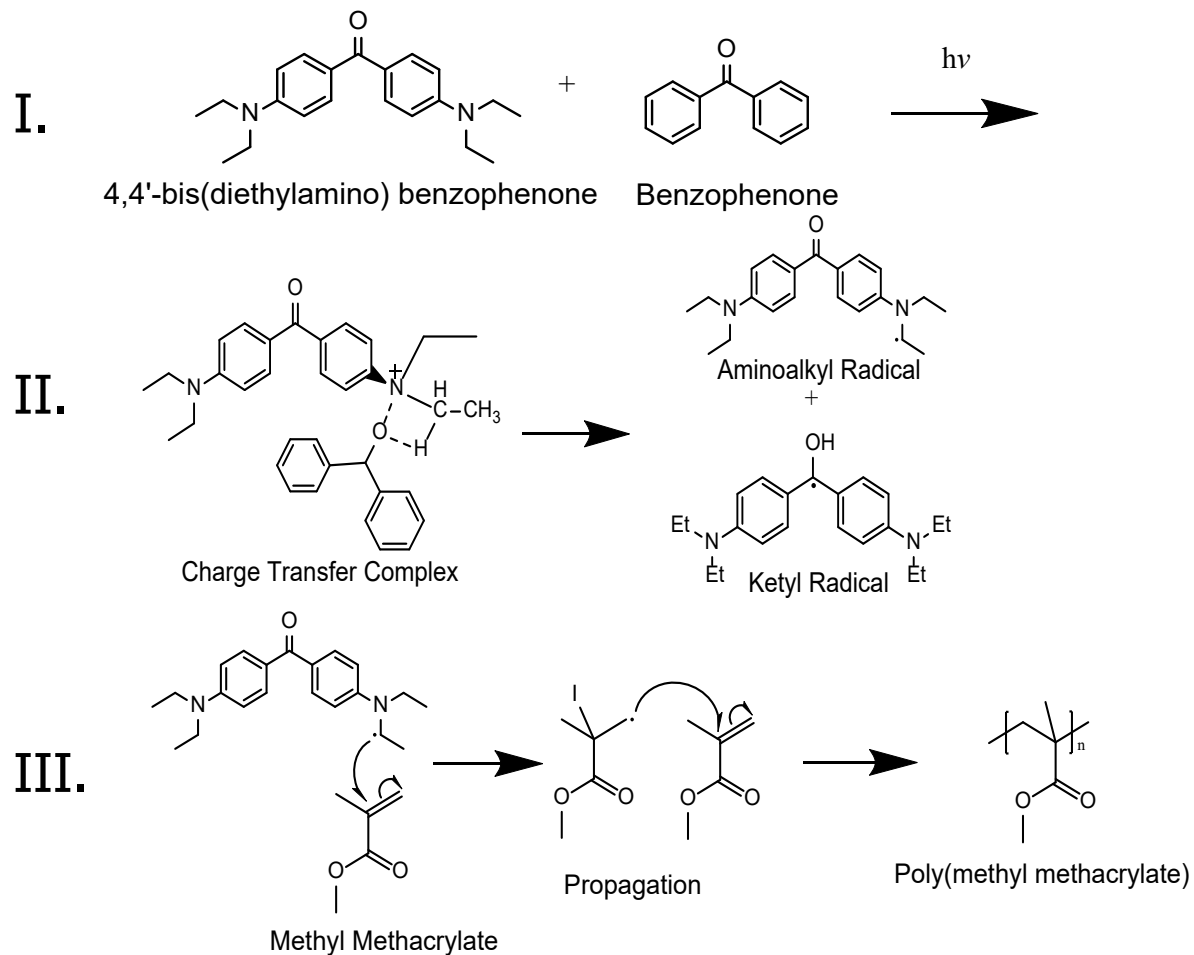


- SEM Micrographs of Sample ER130147G with both (left) secondary electron detection and (right) backscattered electron detection.





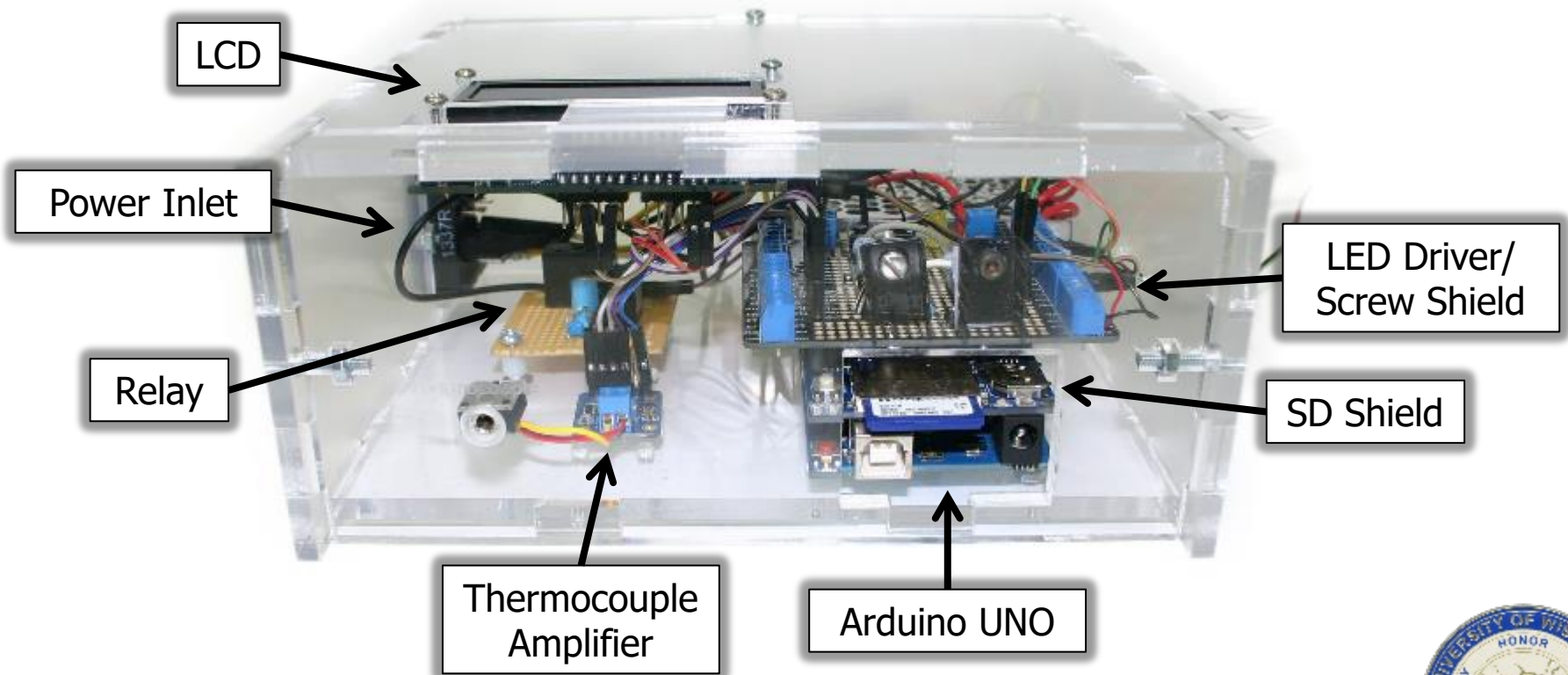
# Photopolymerization



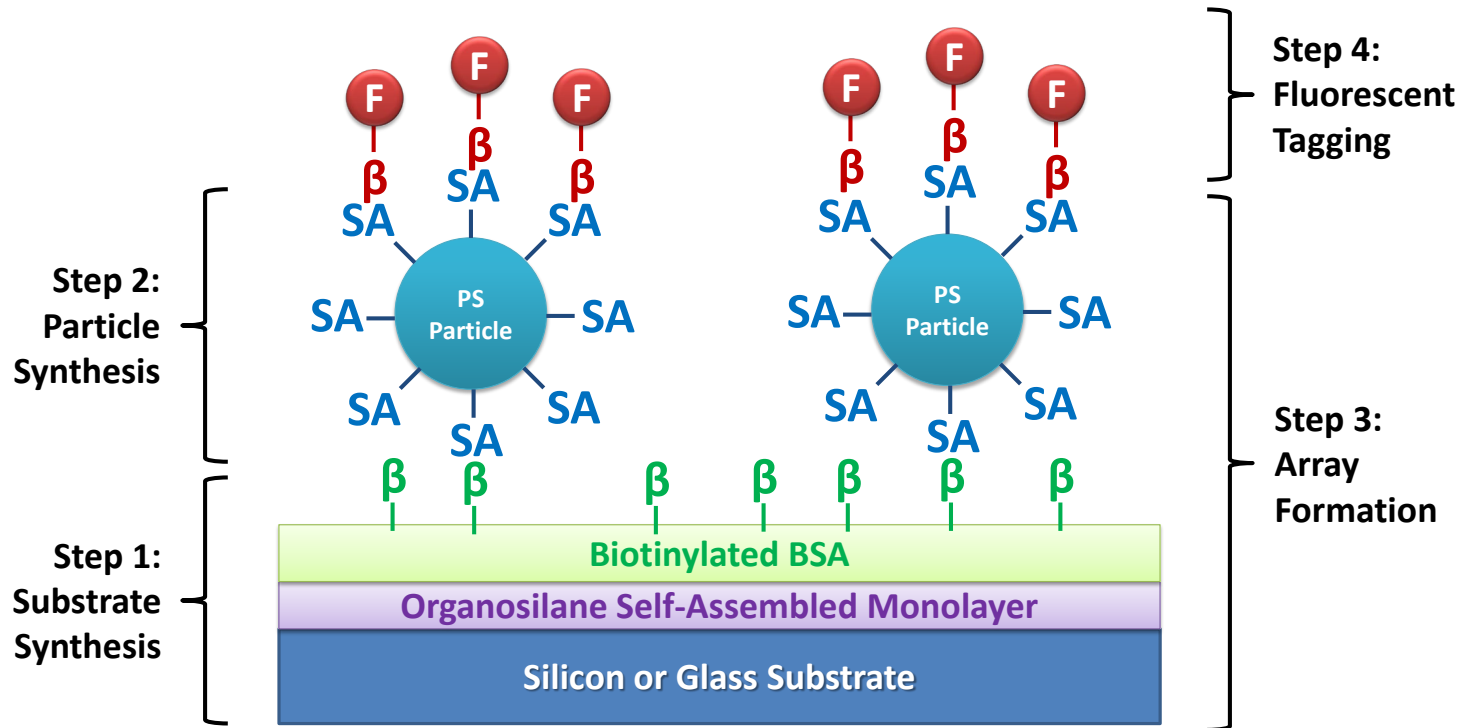
# Photopolymerization



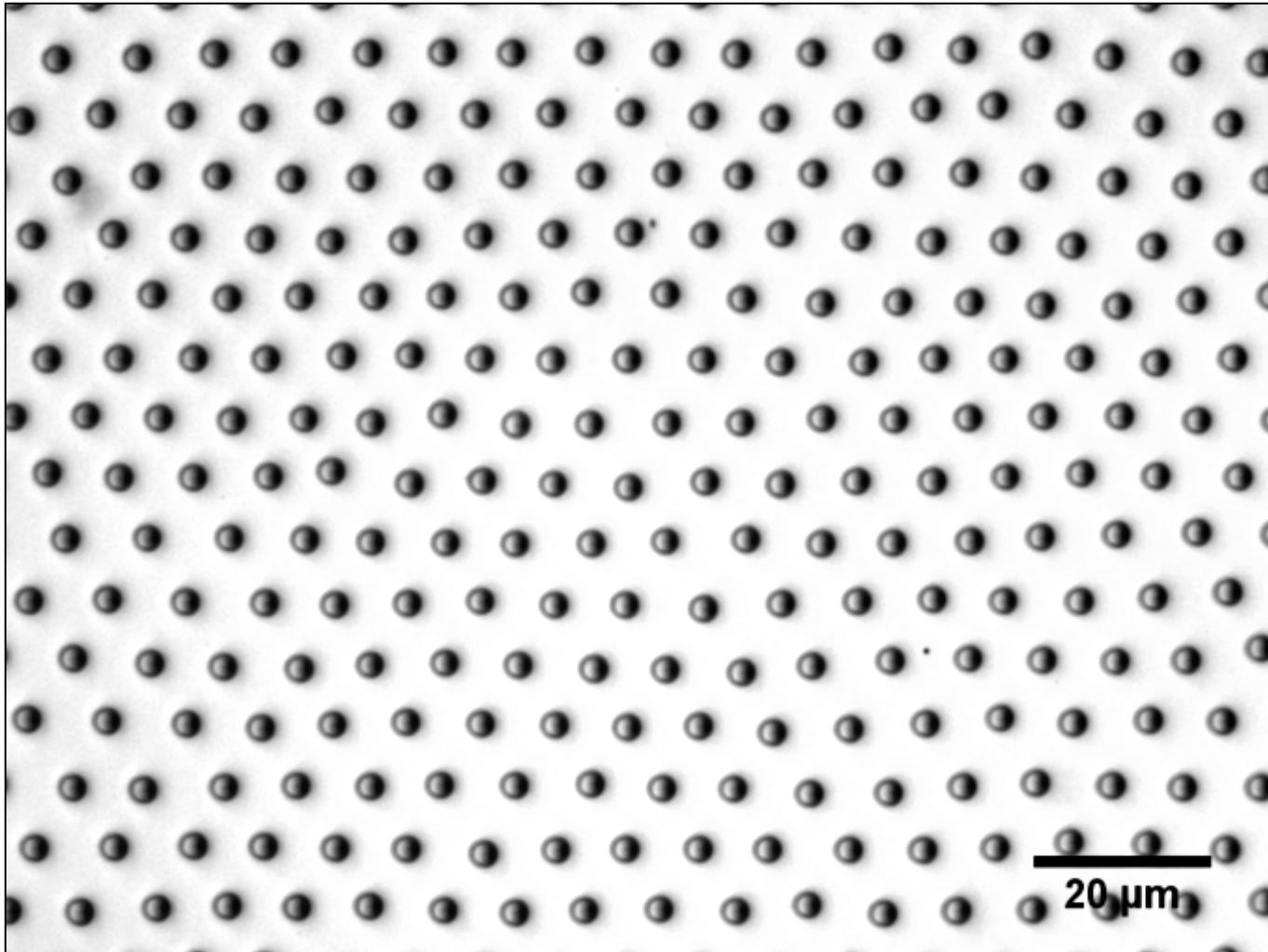
# Photopolymerization



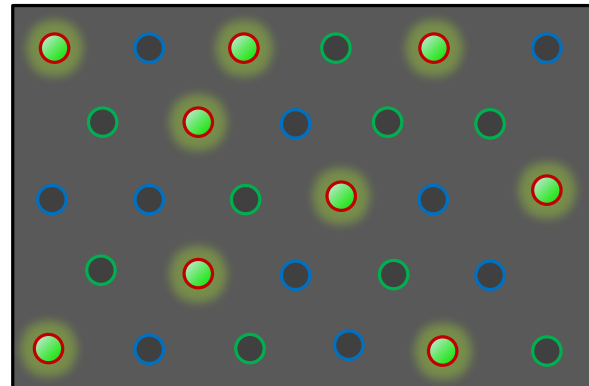
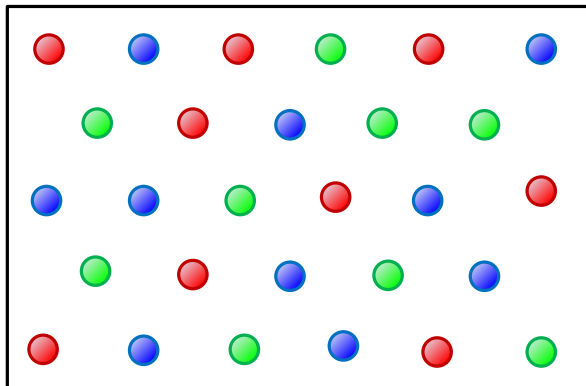
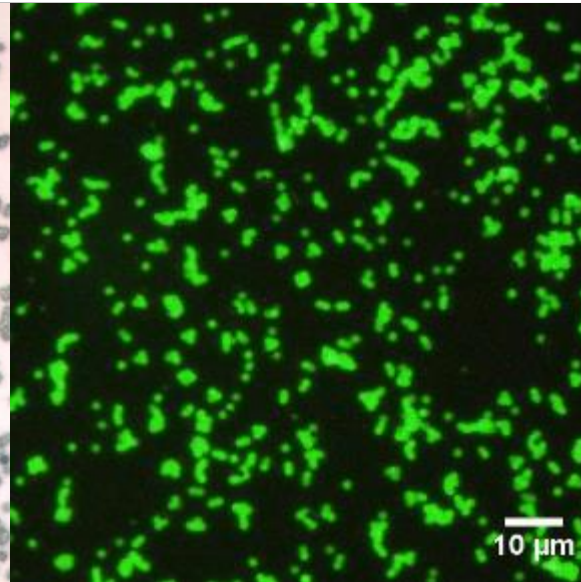
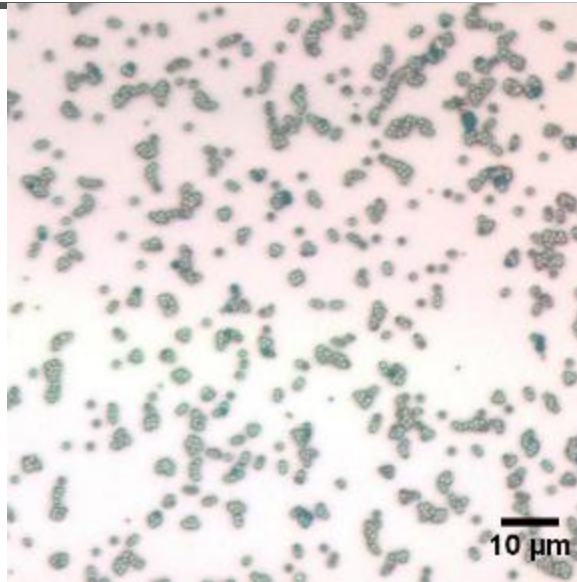
# Bioassay Development



# Bioassay Development



# Bioassay Development



# Acknowledgements



Ellie Raethke, Felipe Marra Mateus, Noah Holzman, Clayton Barrix, Dr. Ray  
at the Spring 2014 STEM EXPO

