

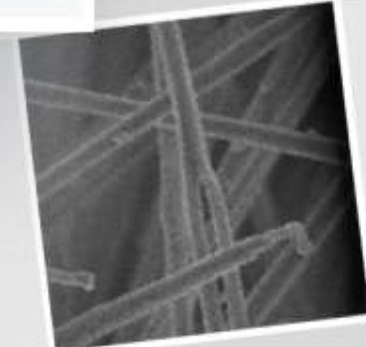

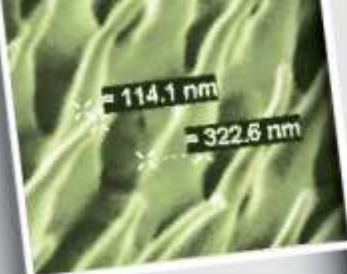


Building College-University
Partnerships for Nanotechnology
Workforce Development

Fundamentals of Metrology and Characterization for Nanotechnology

September 27, 2013

The webinar will begin at 1pm Eastern Time



= 40.89 nm

**Perform an audio check by going to
Tools > Audio > Audio Setup Wizard**

File Edit View Tools Window Help

AUDIO & VIDEO

NetWorks Admin

Talk

Video

PARTICIPANTS

NetWorks A...
Moderator

MAIN ROOM (3)

NetWorks Admin
Moderator (You)

mike mac

mike pc #2

CHAT

- You joined the Main Room. (12:33 PM) -

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Room

Moderators

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NACK

Building College-University
Partnerships for Nanotechnology
Workforce Development

Fundamentals of Metrology and
Characterization for Nanotechnology

September 27, 2013

Whiteboard

AUDIO & VIDEO



NetWorks Admin

Talk Video

PARTICIPANTS

NetWorks A...
Moderator

MAIN ROOM (3)

NetWorks Admin
Moderator (You)

mike mac

mike pc #2

Participant
Box

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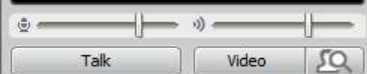
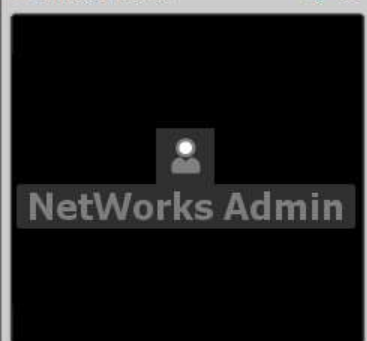
Load Content Record

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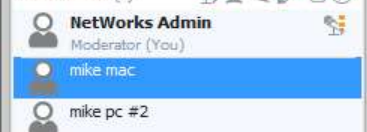
NACK Building College-University Partnerships for Nanotechnology Workforce Development

Fundamentals of Metrology and Characterization for Nanotechnology

September 27, 2013



MAIN ROOM (3)



- You joined the Main Room. (12:33 PM) -
- Your chat permission has been enabled. (12:33 PM) -

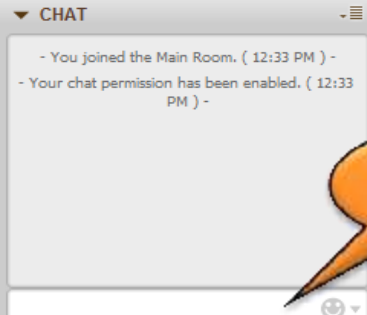
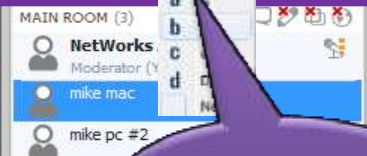
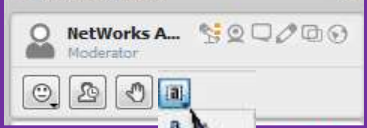
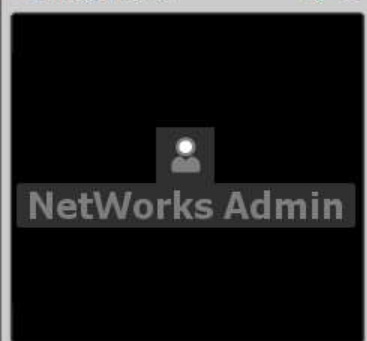
Chat Box



Fundamentals of Metrology and Characterization for Nanotechnology

September 27, 2013

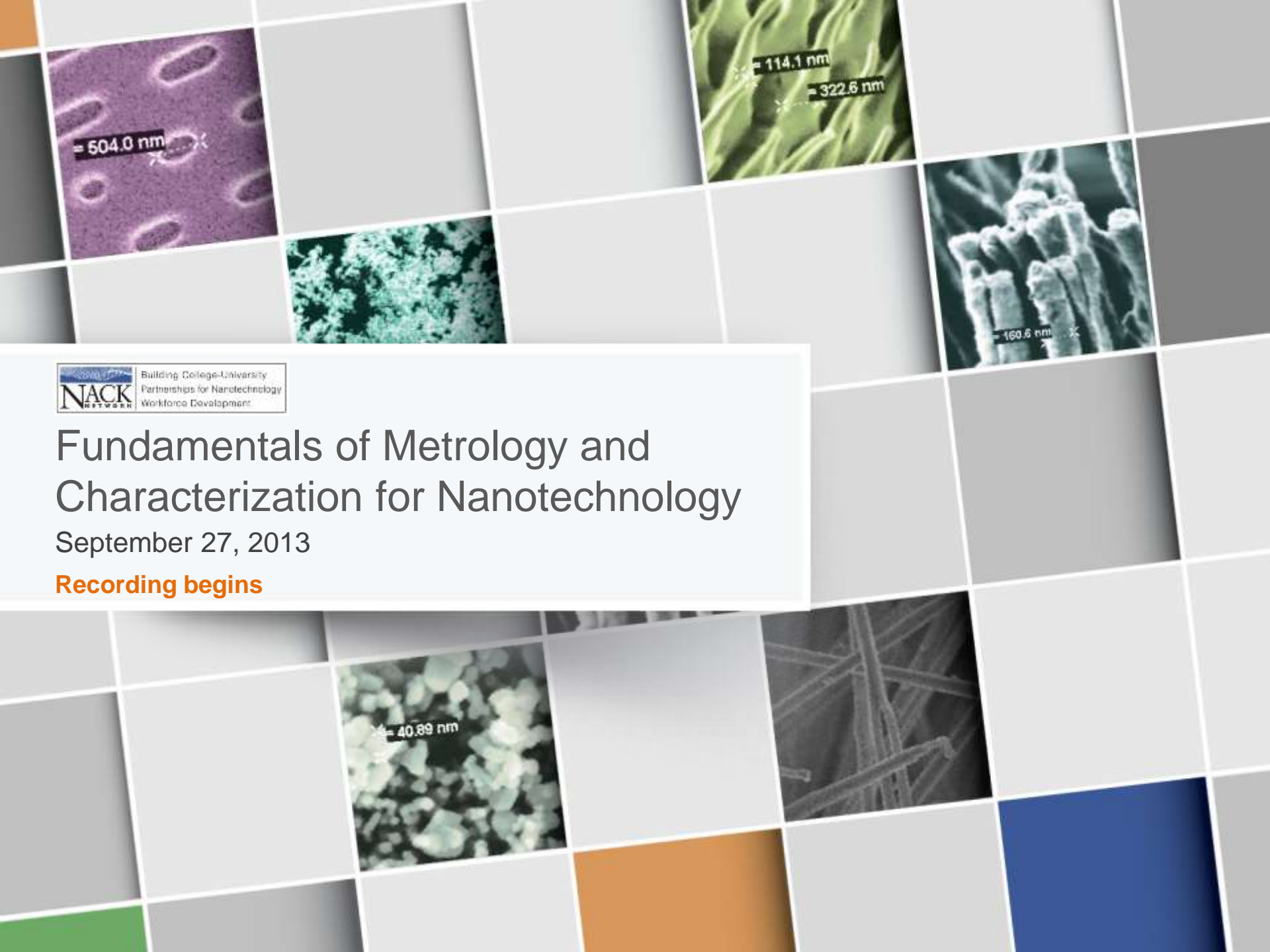
Send Questions
and Message
Here



Fundamentals of Metrology and Characterization for Nanotechnology

September 27, 2013

Not
here!



Building College-University
Partnerships for Nanotechnology
Workforce Development

Fundamentals of Metrology and Characterization for Nanotechnology

September 27, 2013

Recording begins

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The NACK Network, established at the Pennsylvania State College of Engineering, and funded in part by a grant from the National Science Foundation.



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Welcome to NACK's Webinar



Today's Presenter:

Dr. Diane Hickey-Davis

Ph.D., Industry

NanoScience Instruments



Giovanni, Student



Mike Davis,
2-yr Administrator

Moderator: Mike Lesiecki



Poll Question –

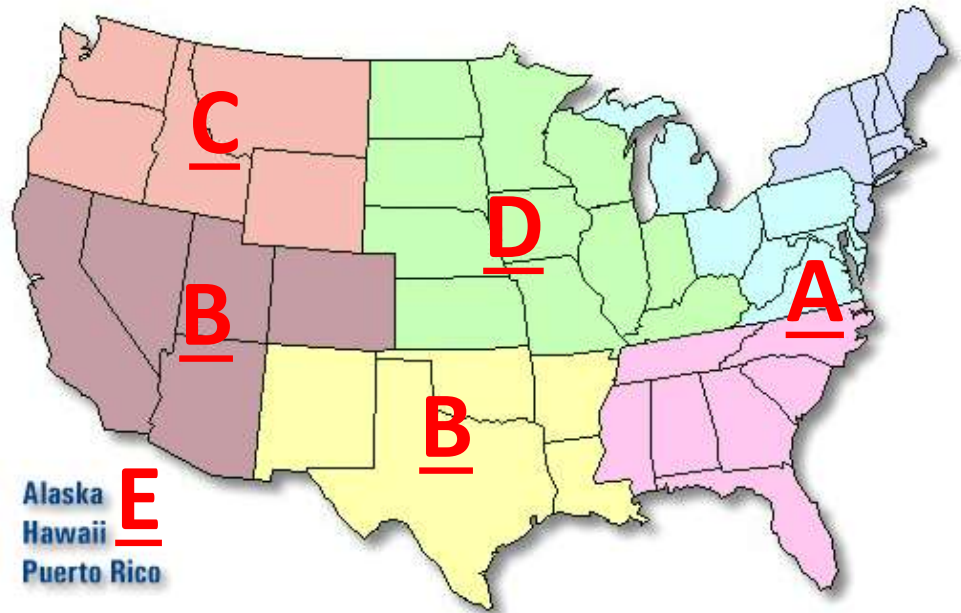
Who is here today?

- A. Educator – 2yr or 4yr institution
- B. Educator – Primary or Secondary
- C. Administrator – Any
- D. Student
- E. Industry

Poll Question –

Which region on the map do you live/work?

- A. East Coast
- B. South West
- C. North West
- D. Mid-West
- E. Extra-continental



In today's webinar:

- How do we see what we can't see?
- Five **common** nanotech instruments
- For each, I'll cover:
 - What it does
 - How it works
 - Where it's used in Industry
 - What subjects you can teach with it
 - What skills your students can learn from it

The Scale of Things – Nanometers and More

Things Natural



Dust mite
200 μm

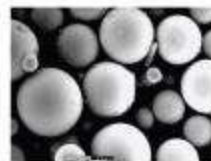


Human hair
~ 60-120 μm wide

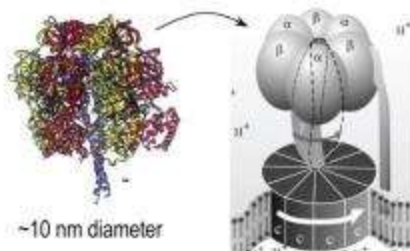
Red blood cells
(~7-8 μm)



Ant
~ 5 mm



Fly ash
~ 10-20 μm



~10 nm diameter

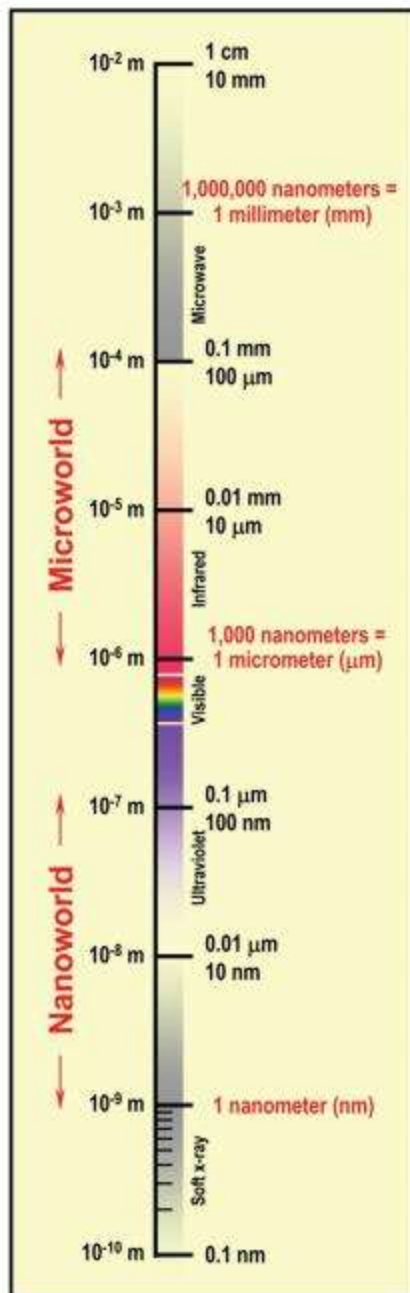
ATP synthase



DNA
~2-1/2 nm diameter



Atoms of silicon
spacing 0.078 nm



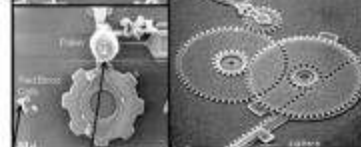
Things Manmade



Head of a pin
1-2 mm

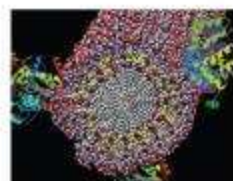


MicroElectroMechanical (MEMS) devices
10 -100 μm wide

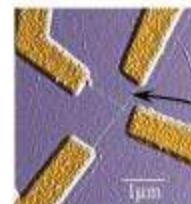


Pollen grain
Red blood cells

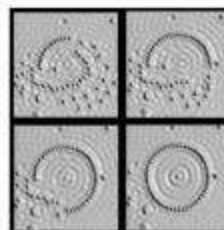
Zone plate x-ray "lens"
Outer ring spacing ~35 nm



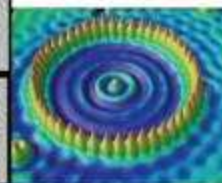
Self-assembled,
Nature-inspired structure
Many 10s of nm



Nanotube electrode



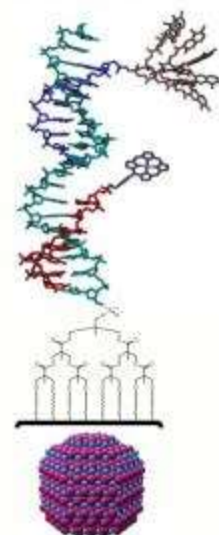
Quantum corral of 48 iron atoms on copper surface
positioned one at a time with an STM tip
Corral diameter 14 nm



Carbon nanotube
~1.3 nm diameter

Carbon buckyball
~1 nm diameter

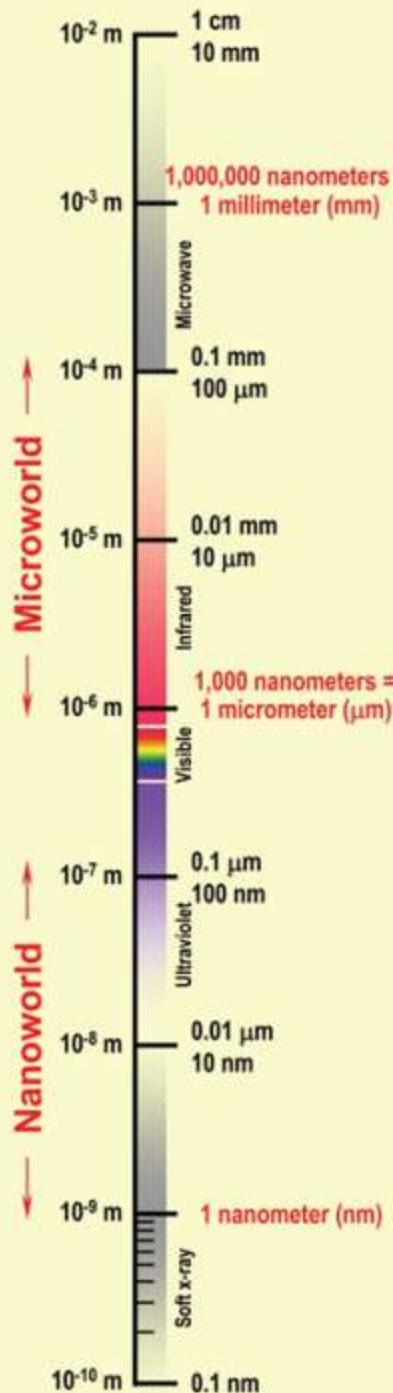
The Challenge



Fabricate and combine nanoscale building blocks to make useful devices, e.g., a photosynthetic reaction center with integral semiconductor storage.

Five Microscopes

to fit the scale of things



3D Optical

Wavelength of Light



Scanning Electron (SEM)

Wavelength of Electron



Atomic Force (AFM)

Atomic Force



Transmission Electron (TEM)

Electron interaction
through a material



Scanning Tunneling (STM)

Quantum Force

Poll Question –

Do you use any instrumentation in your teaching?

- A. None
- B. Yes, Optical Microscope
- C. Yes, Electron Microscope
- D. Yes, Force Microscope
- E. Yes, many of the above and others, too!



Poll Question –



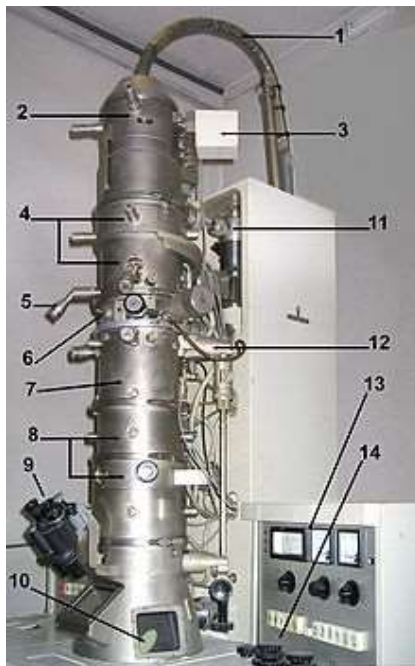
Gas Chromatography with Mass Spectral Detector is the instrument of choice for fire debris analysis.

What's your biggest concern when considering using or buying equipment / instruments in the classroom?

- A. The students would break it. Heck, I might break it!
- B. I don't know what it does, therefore I don't know why I'd want it.
- C. It's not a useful skill for my students to learn.
- D. I don't know how to integrate it into the subject.
- E. It won't get used. It will collect dust.
- F. *(Write your answer in the chat box)* It looks boring, for example ...

Common fears about instruments

- What is it **used** for?
 - [industry]
- Would it be useful for my students to **learn**?
 - [educational benefit]
- **What do I do with it** once I've got it?
 - [content]
- Will it collect **dust**?
 - [45 min class period; too complicated?; needs expensive replacement parts?]

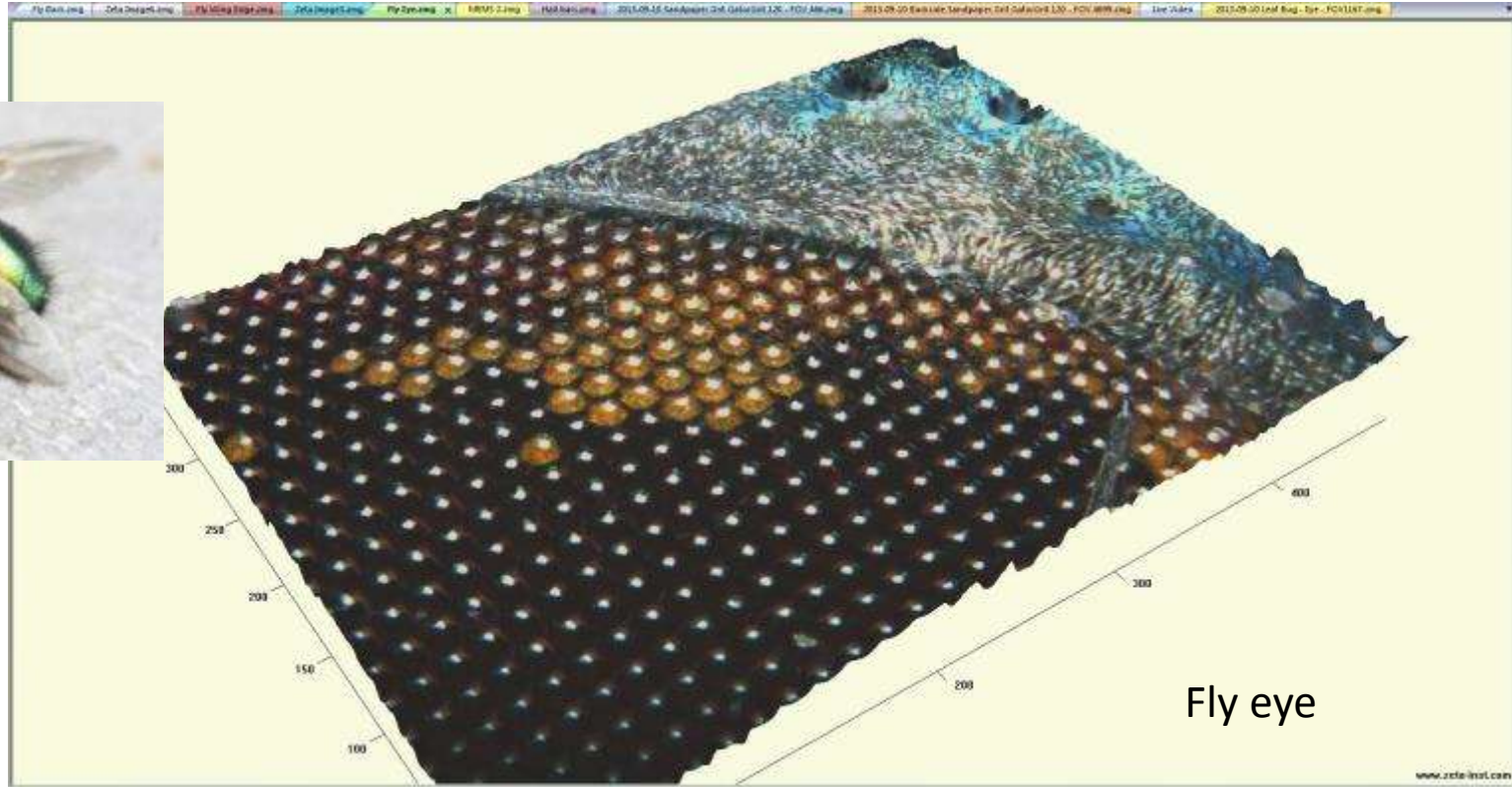


Today: Alleviate Fears and Provide Info

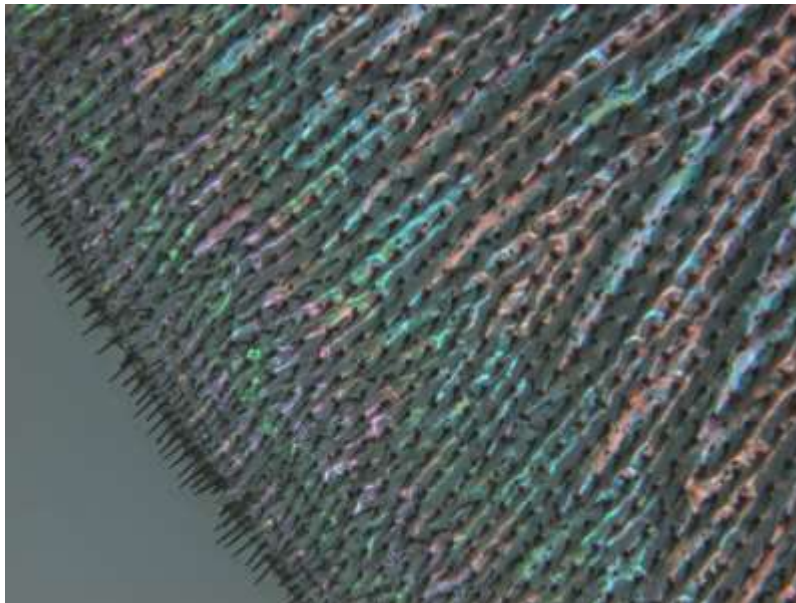
With each instrument, I'll try to communicate:

- What it **does**.
- How it **works**, on a high level.
- **Where** it's used.
- What **subjects** can be taught with it.
- What skills your students can **learn** from it. (*this is subjective*)

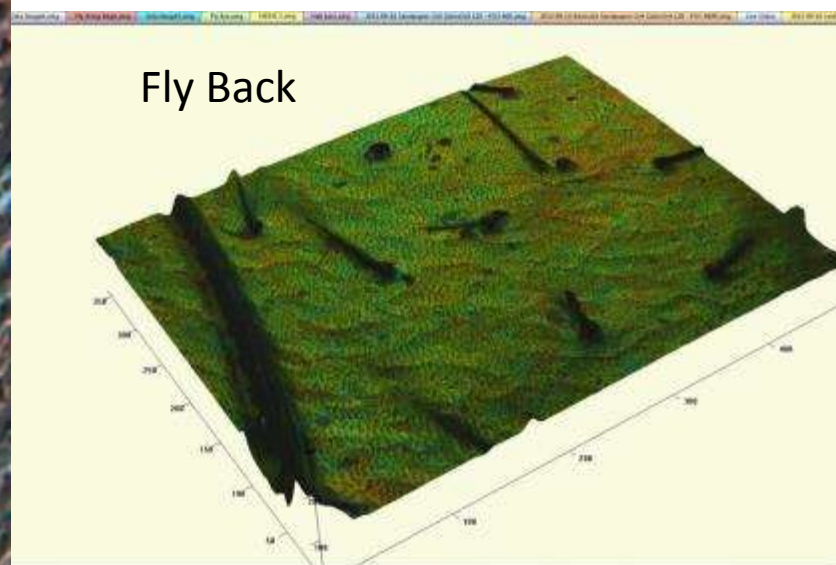
Optical 3D Microscope



Fly Wing -
Edge



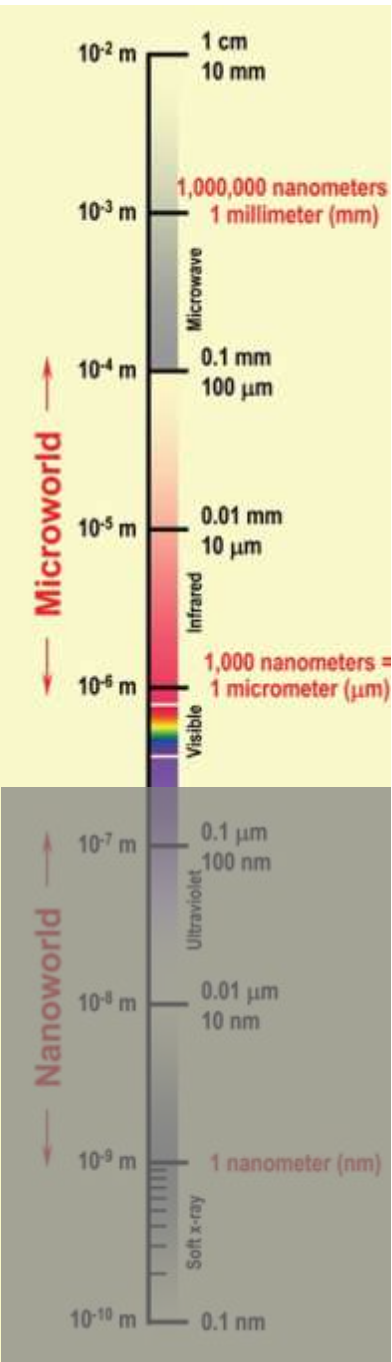
Fly Back



Optical Microscope

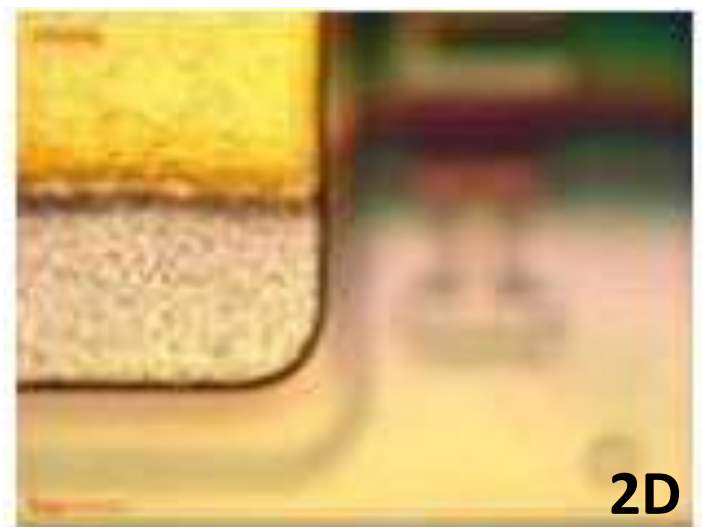
Optical microscopy is ubiquitous in almost any scientific, medical or manufacturing quality environment.

- **What does it do?**
 - It adds a third dimension (3D) to viewing samples, and adds quantitative measurement data.
- **How does it work?**
 - Taking 'slices' of optical images, it reconstructs the focal planes into a 3D image.
- **Where is it used?**
 - Industries: Semiconductor, Manufacturing, Medical devices.
 - Areas: Quality Control, Quality Assurance, Engineering design, Failure Analysis, etc.
- **What subjects can be taught with it?**
 - Integrates easily with Biology, Earth sciences, and the description of the optics for physics.
- **What skills can be taught?**

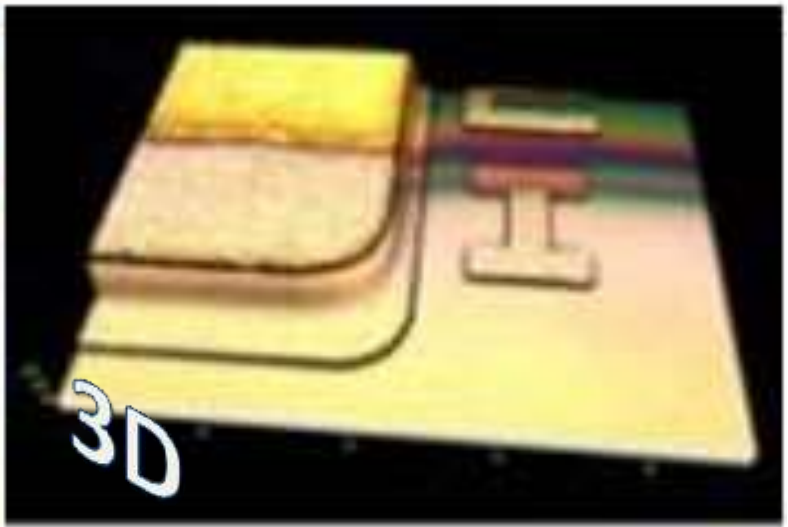
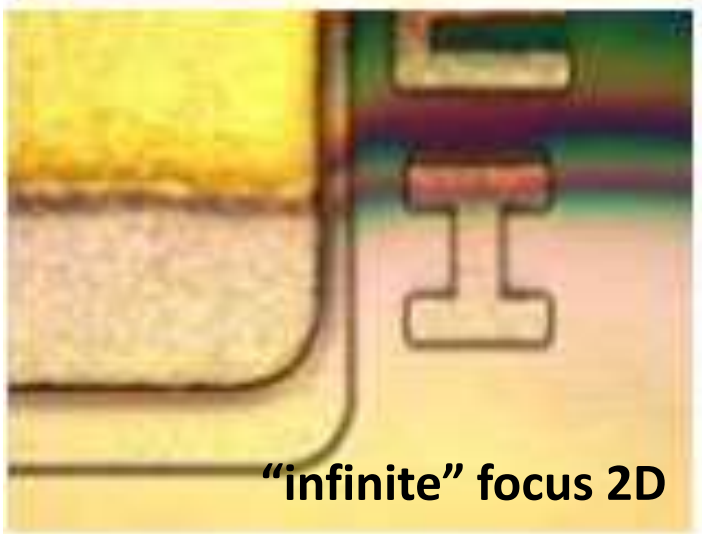


Optical metrology is widely used in:

- **high-tech manufacturing,**
- **quality control, and**
- **failure analysis.**



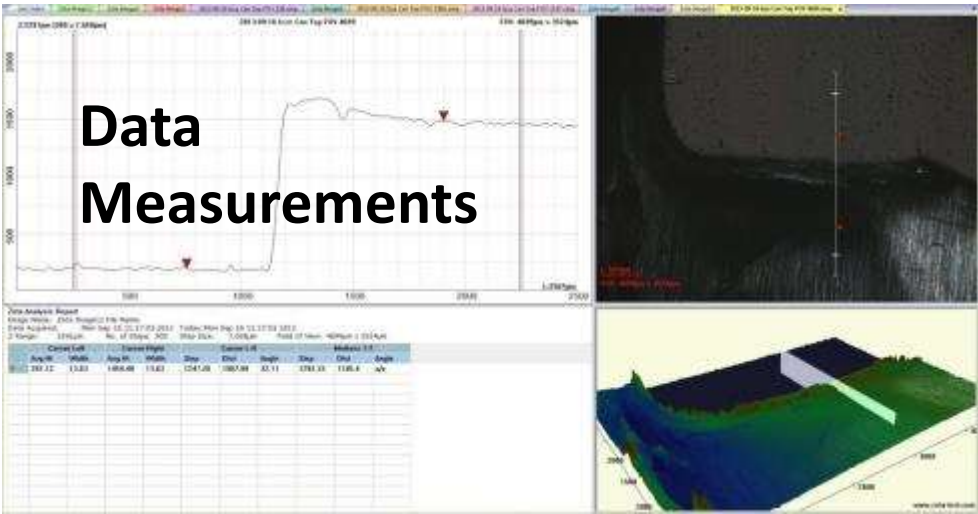
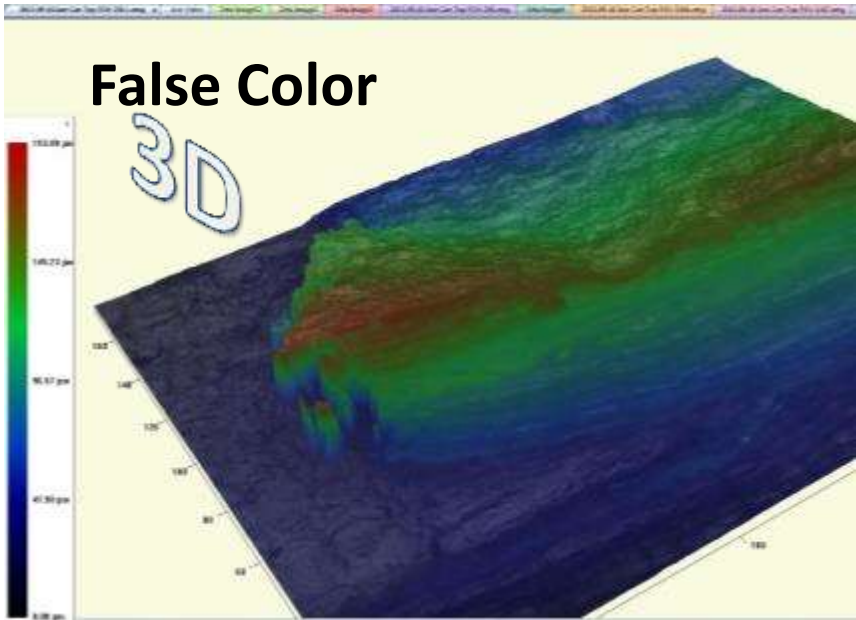
A 3rd Dimension for Microscopy



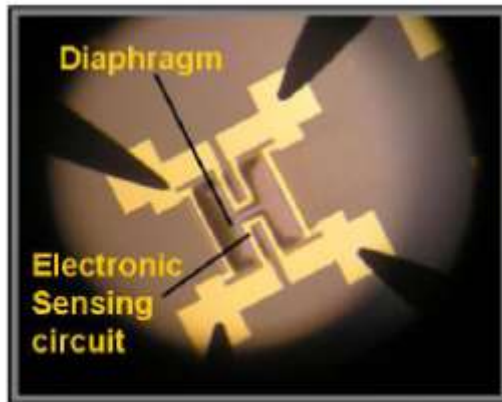
Failure Analysis – Metal Parts



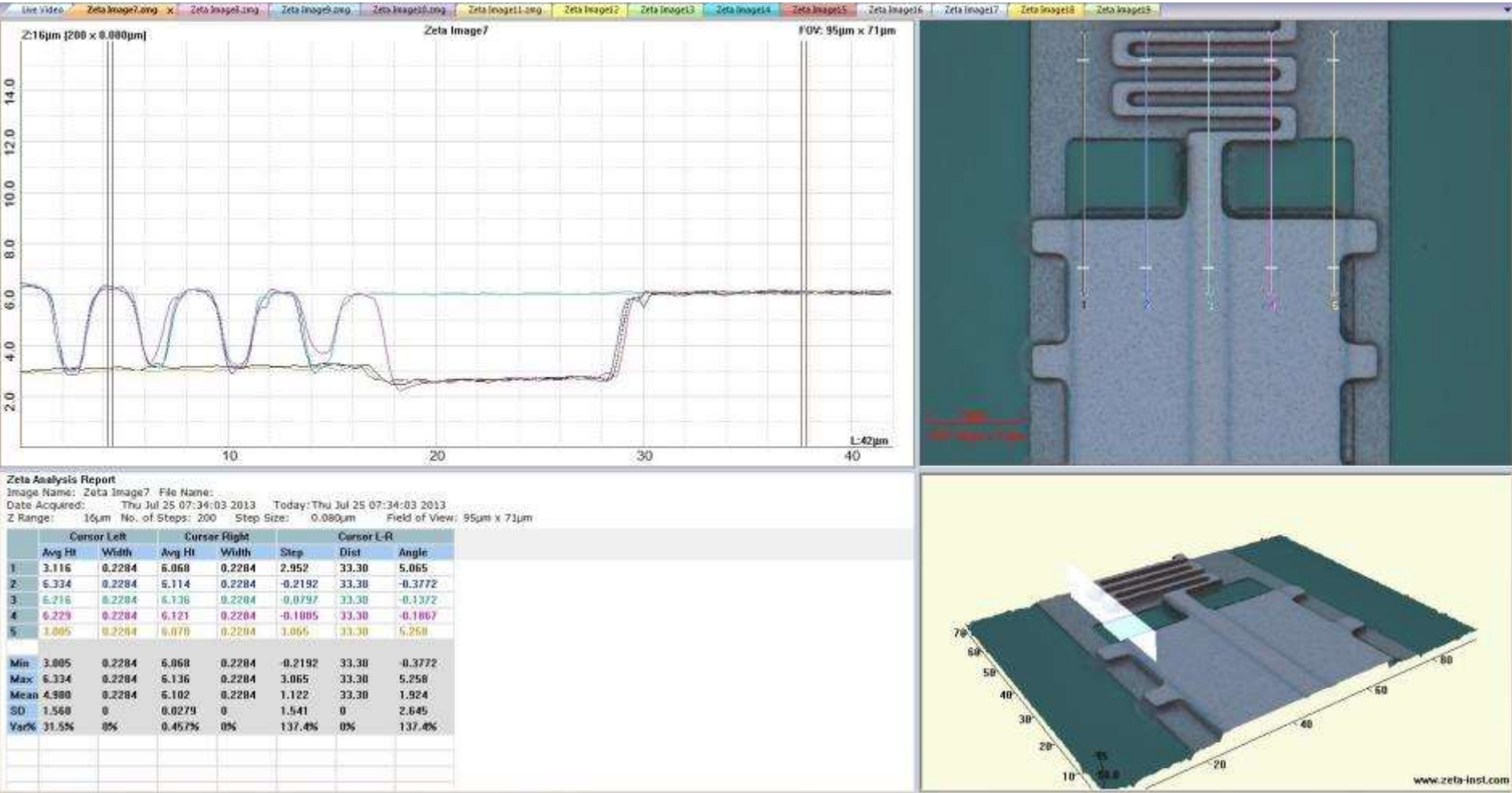
Failure Analysis – Metal Parts

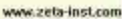


Failure Analysis – Semiconductor Parts



MEMS Fabrication – Argonne National Lab





From the Optical Microscope ...



Ant
~ 5 mm





Lisa Del Muro @lisa_delmuro

28 Aug

got a WOW as soon as class moved the sample from the optical to SEM. one student asked why image in black/white :)

pic.twitter.com/j1Q1EAXET8

Retweeted by shreya

Hide photo

Reply

Retweeted

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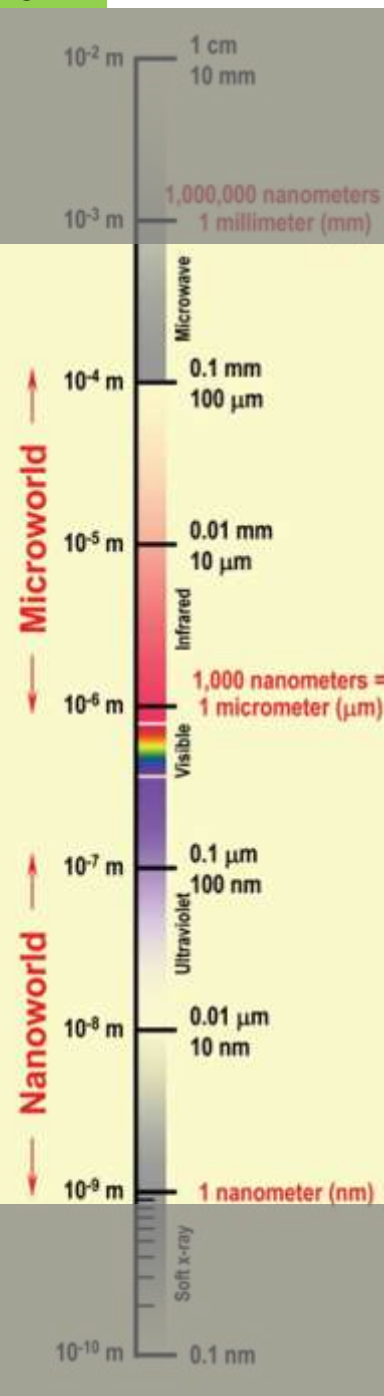


1
RETWEET



12:22 PM · 28 Aug 13 · Details

Flag media



Scanning Electron Microscope

- What does it do?
 - Let's let Abby, from the TV Show NCIS, explain...
- How it works, on a high level.
- Where it's used.
- What subjects can be taught with it.
- What skills your students can learn from it. (*this is subjective*)

NCIS' "Abby" – explaining the SEM

<http://www.youtube.com/watch?v=W4HnH6Ar6pw>

Five Microscopes

to fit the scale of things



3D Optical
Profiler



Scanning
Electron (SEM)



Atomic Force
(AFM)



Transmission
Electron (TEM)

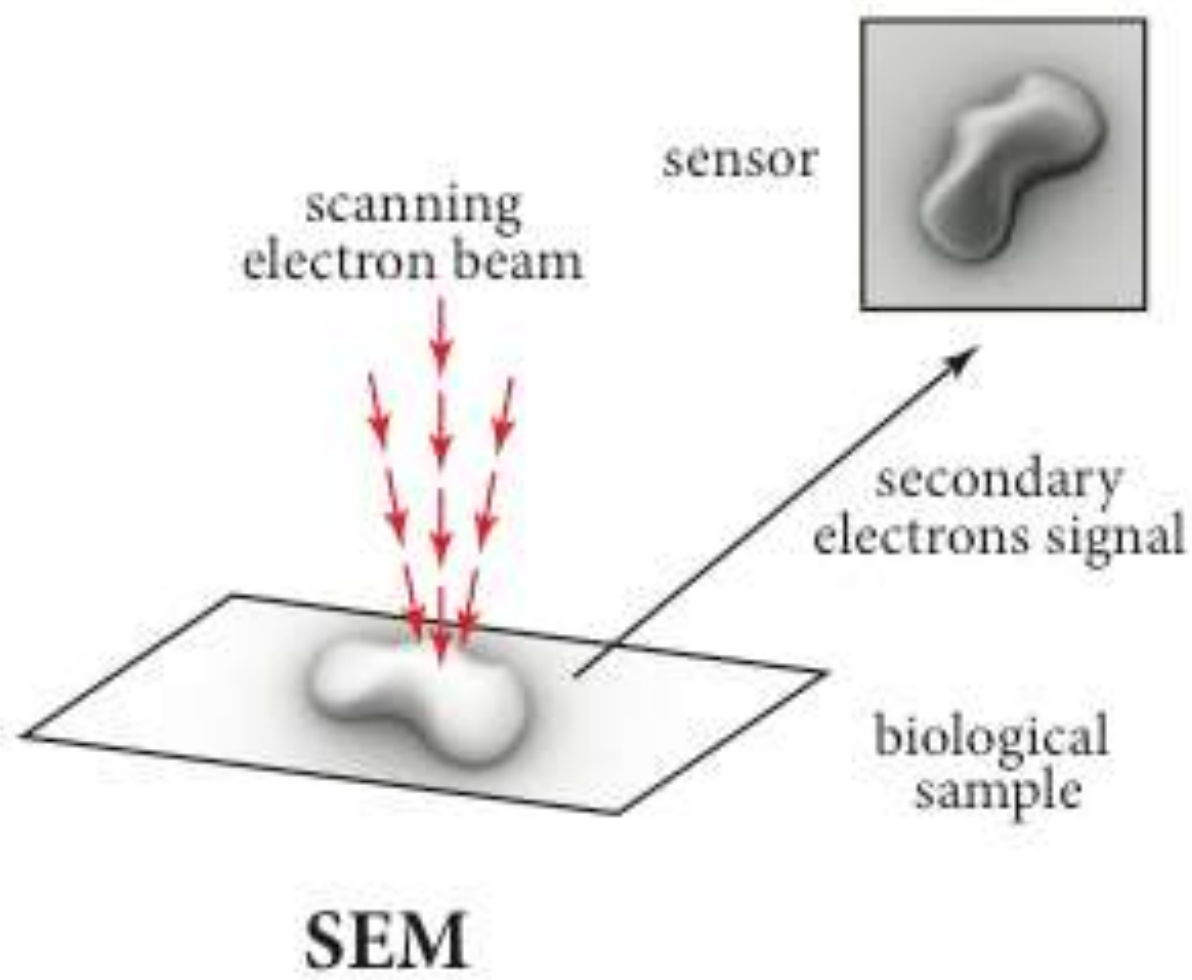


Scanning
Tunneling (STM)

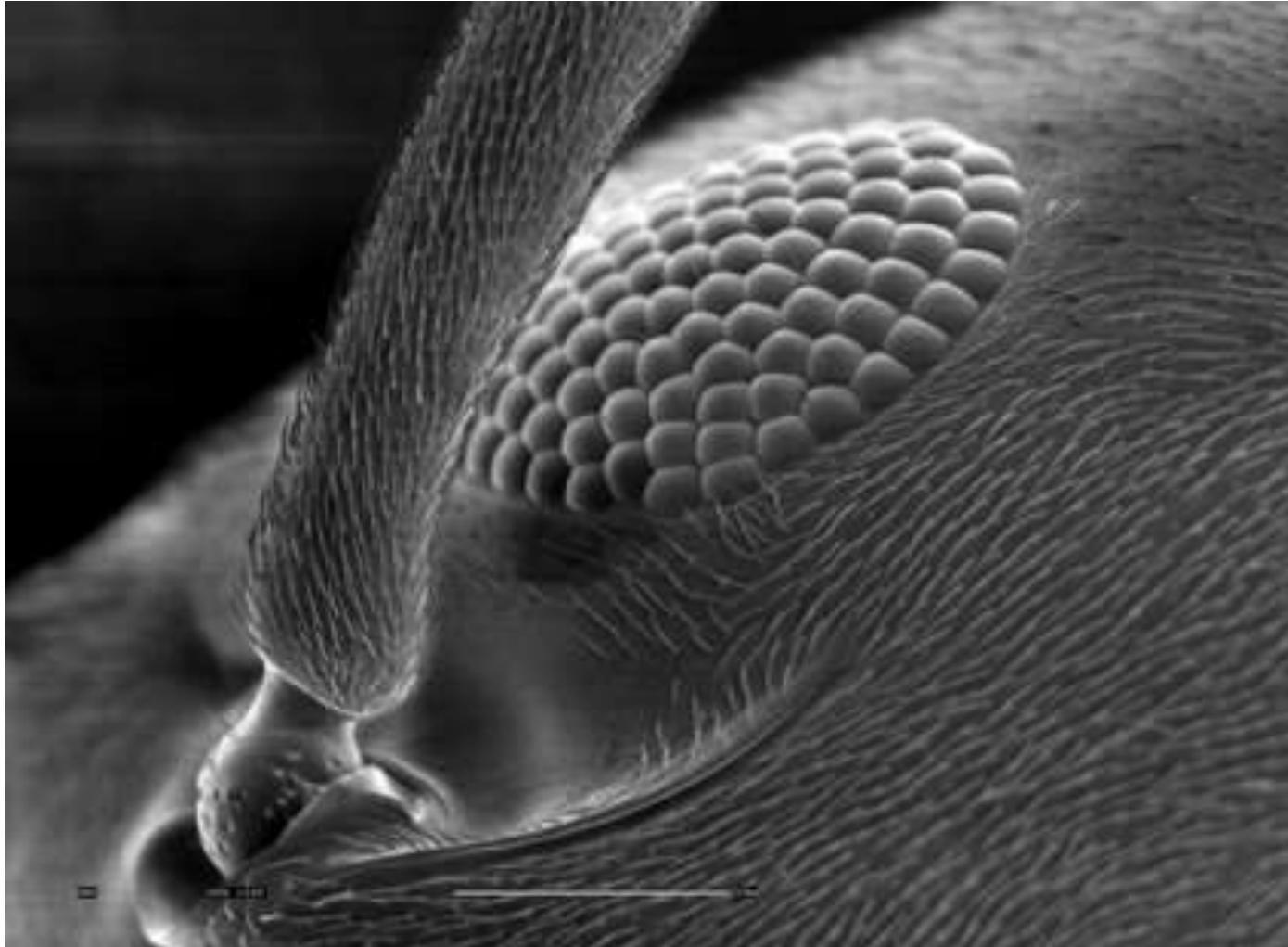
Scanning Electron Microscope

- What it does.
- How it works, on a high level.
- Where is it used?
- What subjects can be taught with it.
- What skills your students can learn from it. (*this is subjective*)

How it works



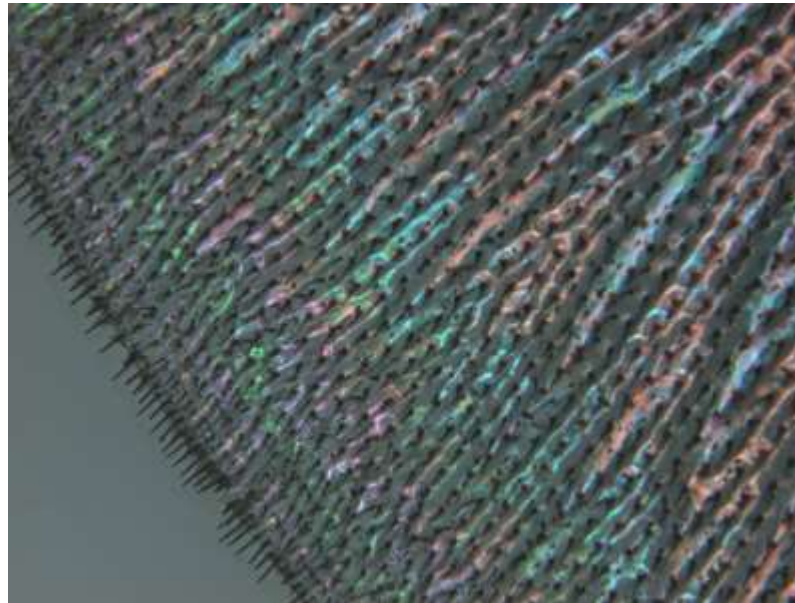
Why is it black and white?





Think,
think,
think.

Color on the
Optical
Microscope
...
Hmmmm...

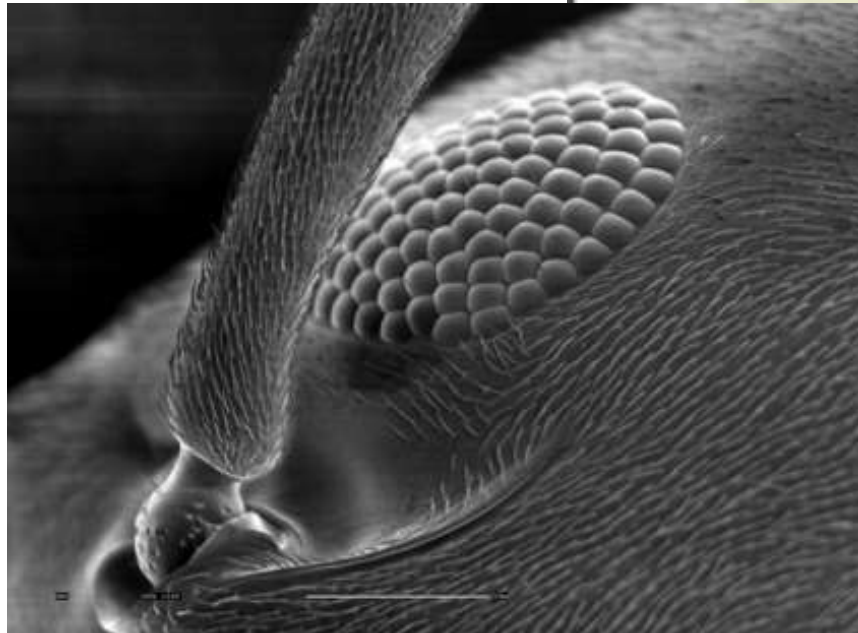


Fly Wing - Edge



Fly Back

No color on the
electron microscope?



How does color work
again?



Lisa Del Muro @lisa_delmuro

28 Aug

got a WOW as soon as class moved the sample from the optical to SEM. one student asked why image in black/white :)

pic.twitter.com/j1Q1EAXET8

Retweeted by shreya

Hide photo

Reply

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1

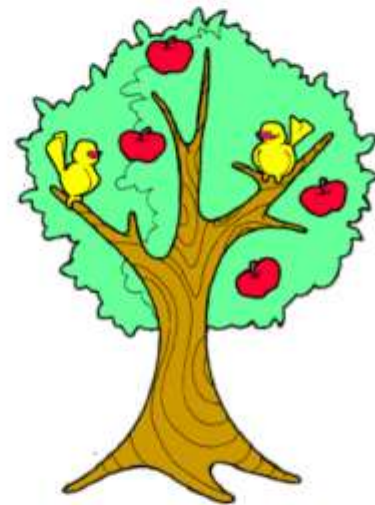
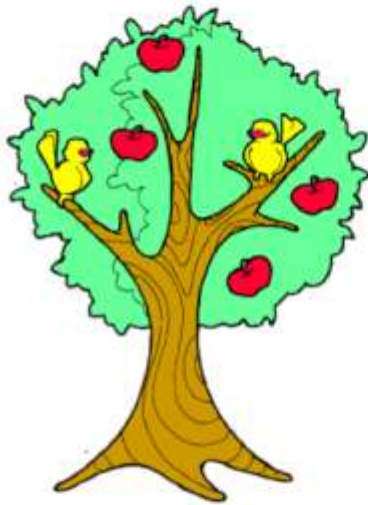
RETWEET



12:22 PM - 28 Aug 13 · Details

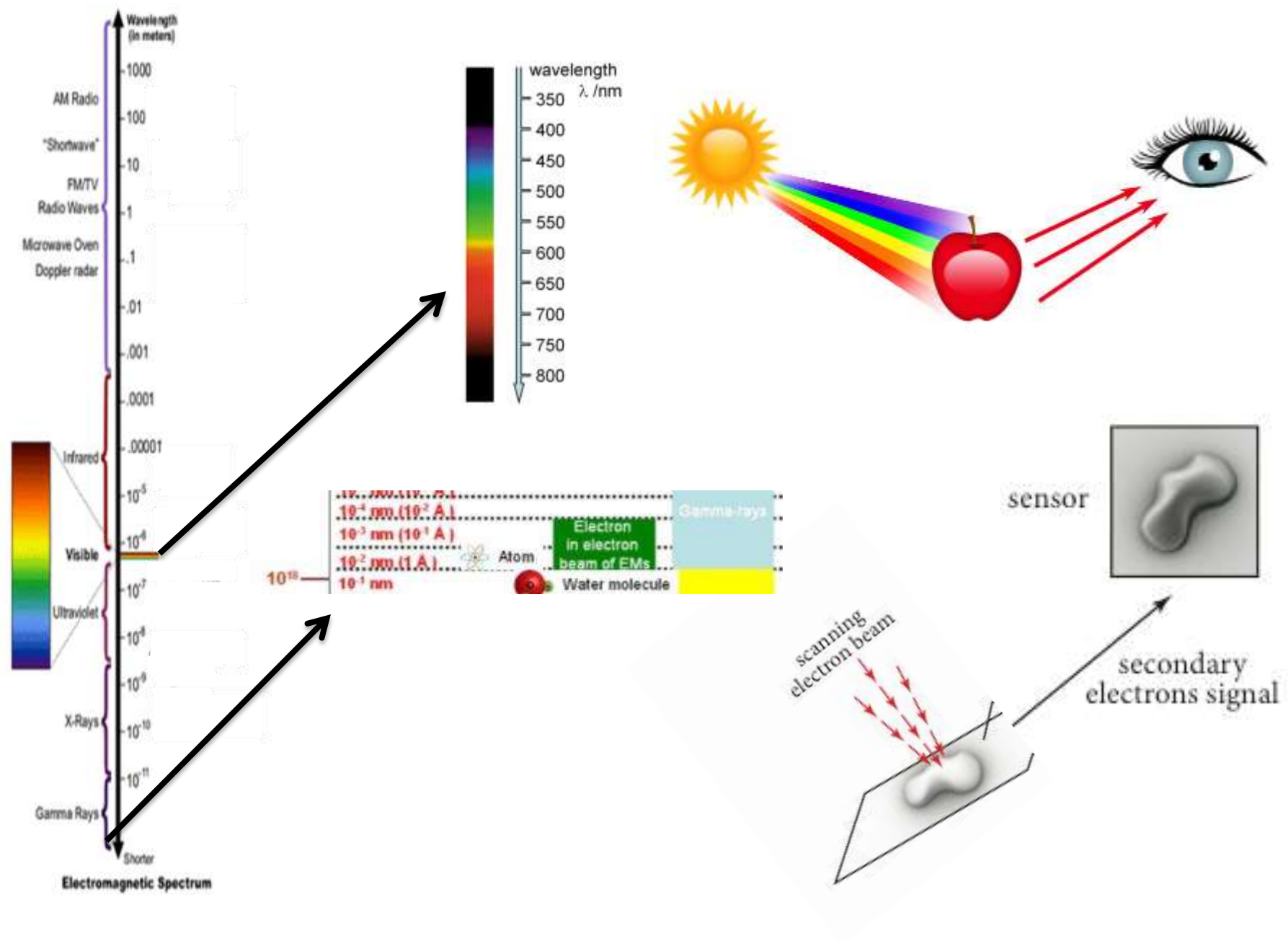
Flag media

Why Does an Apple Look Red?



Title your paper, and record each of your observations.

SEM – How it works, described visually



Well,
technically...

In EMs, the kinetic energy (eV) gained by an electron as it is accelerated in the electron gun is equal to the electron's drop in potential energy (V_0). Therefore, we have,

$$eV_0 = m_0 v^2 / 2 \text{ ----- [4787a]}$$

where,

v -- The electron velocity,

m_0 -- The electron rest mass.

Based on Newtonian theory, the relation between the wavelength (λ) of a particle (e.g. electron here), moving at a velocity, v , is given by the de Broglie wave equation:

$$\lambda = h / m_0 v \text{ ----- [4787b.a]}$$

$$= h / (2m_0 eV_0)^{1/2} \text{ ----- [4787b.b]}$$

where,

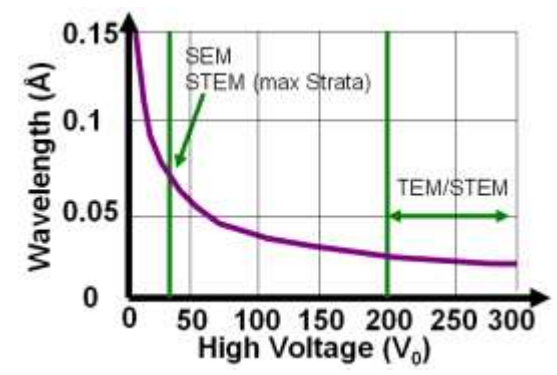
h -- The [Planck's constant](#).

Because the accelerated electrons have a speed of approximately light speed (c), they should be treated using relativistic quantum mechanics, which are important in electron microscopy since the electrons are typically accelerated to potentials of 30 to 400 keV (about half the speed of light). By introducing the correction for relativistic effects, the wavelength is given by,

$$\lambda = h / \left[2m_0 eV_0 \left(1 + eV_0 / 2m_0 c^2 \right) \right]^{1/2}$$

The wavelength of the electrons is dramatically decreased with increase of the acceleration voltage; therefore, the spatial resolution of the microscopes is significantly improved. Note that, in electron microscopy it is normally sufficient only to replace the mass and wavelength of the electrons with the corresponding relativistic values [1]. Therefore, the relation between λ and V_0 can be given by,

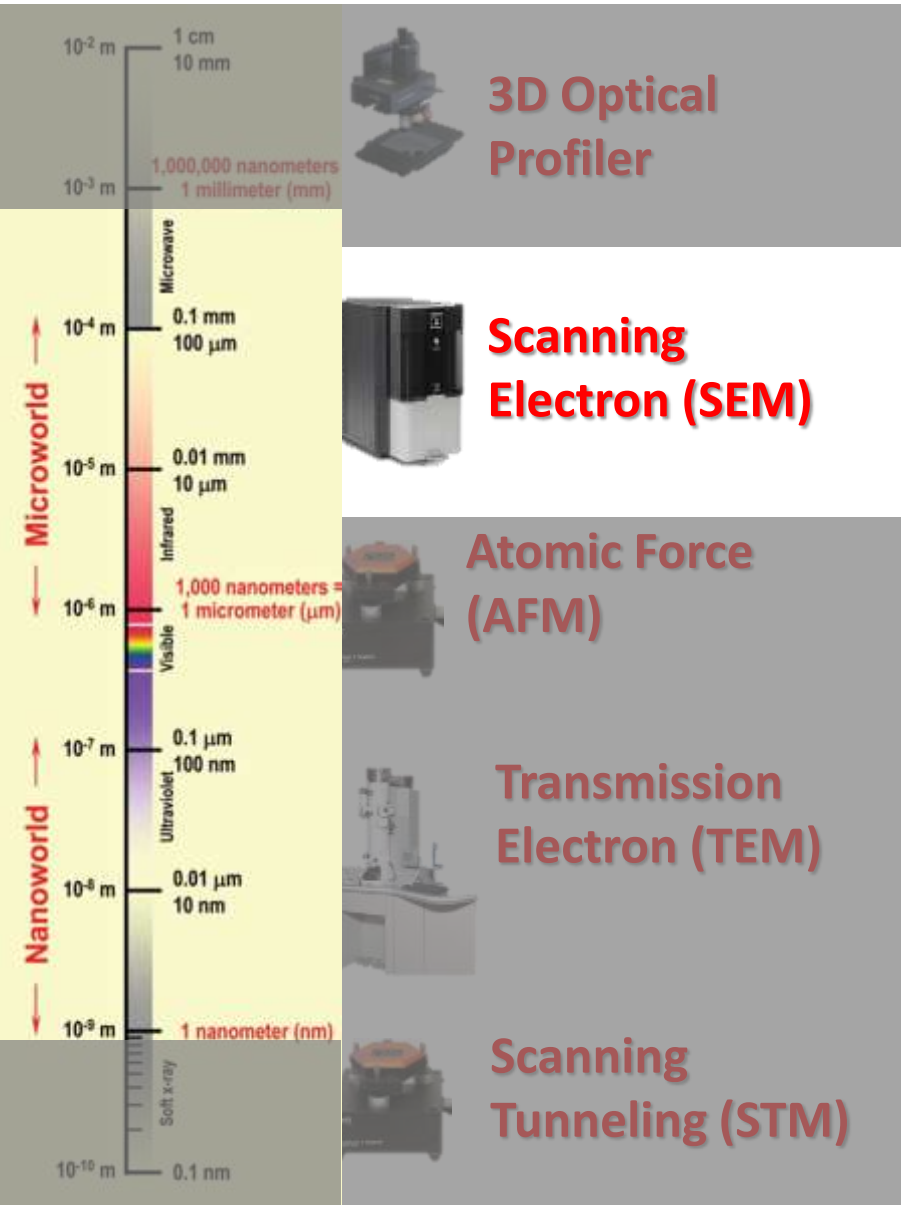
$$\lambda = \frac{1.23}{\sqrt{V_0 + 10^{-6} V_0^2}} \text{ nm}$$



Five Microscopes

to fit the scale of things

Scanning Electron Microscope



3D Optical Profiler

Scanning Electron (SEM)

Atomic Force (AFM)

Transmission Electron (TEM)

Scanning Tunneling (STM)

- What it does.
- How it works, on a high level.
- **Where is it used?**
 - Scanning Electron Microscopy is used in virtually every high technology and scientific area.
 - Additionally, there is a strong focus on including SEM in forensic analysis, as depicted here...
- What subjects can be taught with it.
- What skills your students can learn from it. (*this is subjective*)

CSI NY

<http://www.youtube.com/watch?v=dWe65XWsqHY>

SEM in Education

Then....



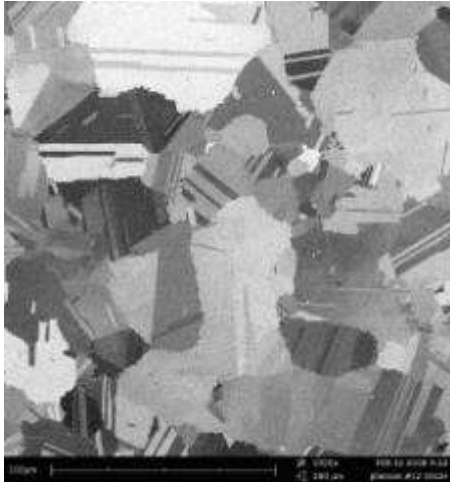
.... And Now...

Phenom SEM and Students

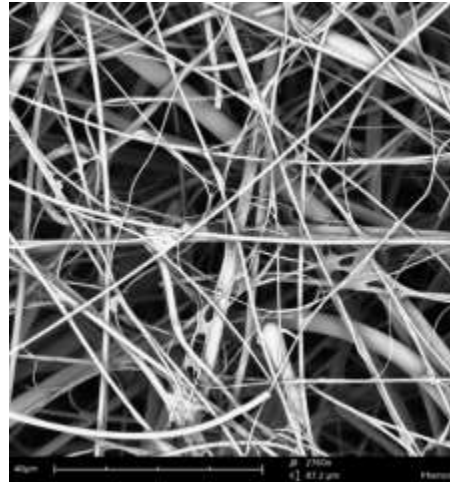


<http://www.youtube.com/watch?v=OyrVL-Dy5RY>

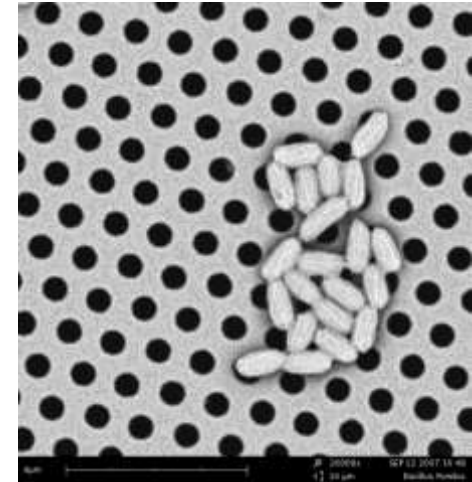
Where SEM is used in industry:



Aerospace: nickel-base superalloy



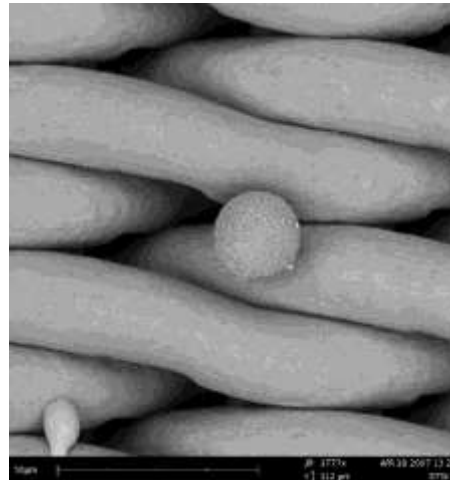
Consumer Goods: hepa filter



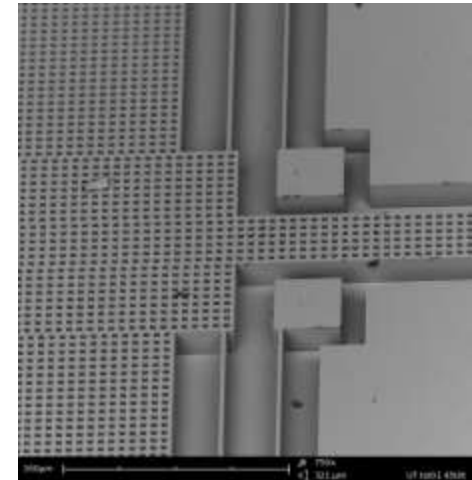
Medical: bacteria



Pharmaceutical: powder compound



Industrial: metal filter



Semiconductor: micro structure (MEMS)

Also, colored SEM images can be used as art:

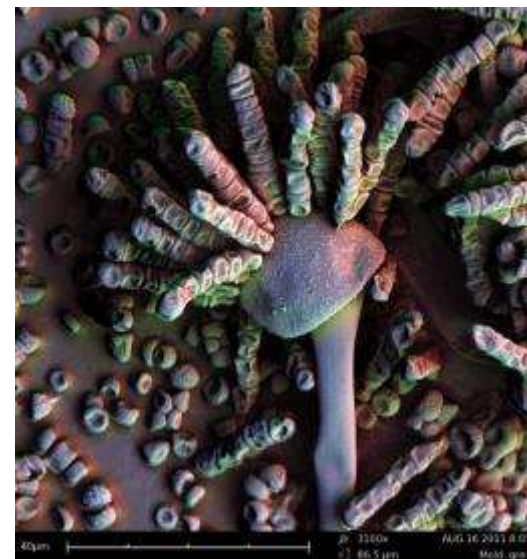
Fly mouth



Penny



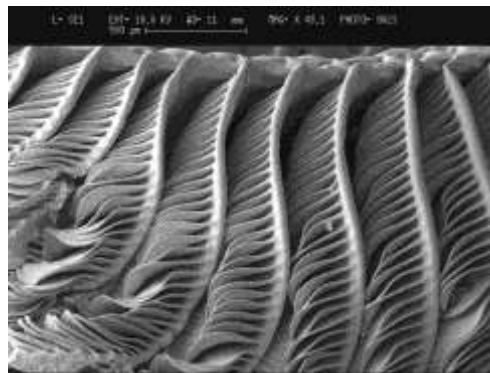
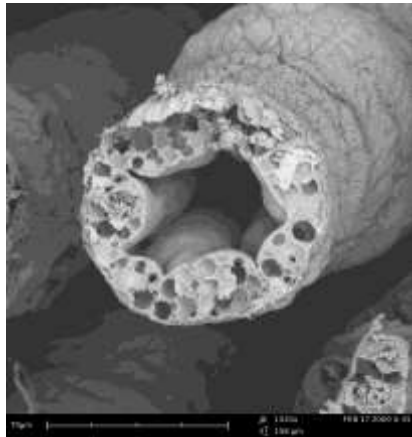
Green Mold



Used in teaching, for example: Occidental College



*"We love the (SEM)." –Dr. Gary Martin,
Biology Professor @ Occidental College*



Courses taught with the SEM:

- Introductory Biology
- Upper division Invertebrate biology

Other activities:

- Student research
- Book chapters
- Publications

Another example: Western New England University



“This instrument enriches our program and helps students get interested and excited about science.” –Dr. Robert Gettens, BioEngineering Professor @ WNE College



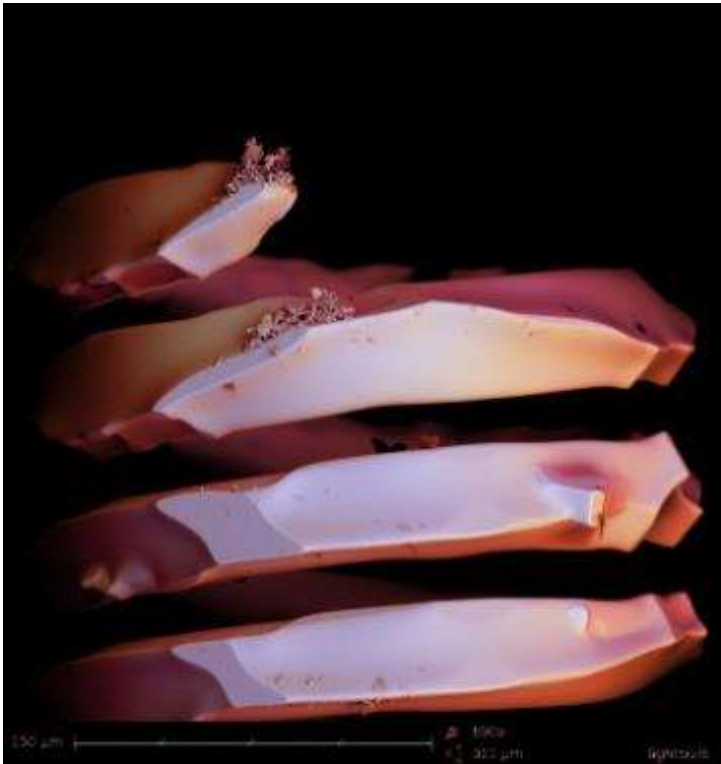
Departments using the SEM:

- Biomedical Engineering
- Chemistry

Other activities:

- Student research
- Industrial Collaborations
- Summer program for high school students

And just cool stuff that you break: Colorized SEM images of a broken light bulb filament



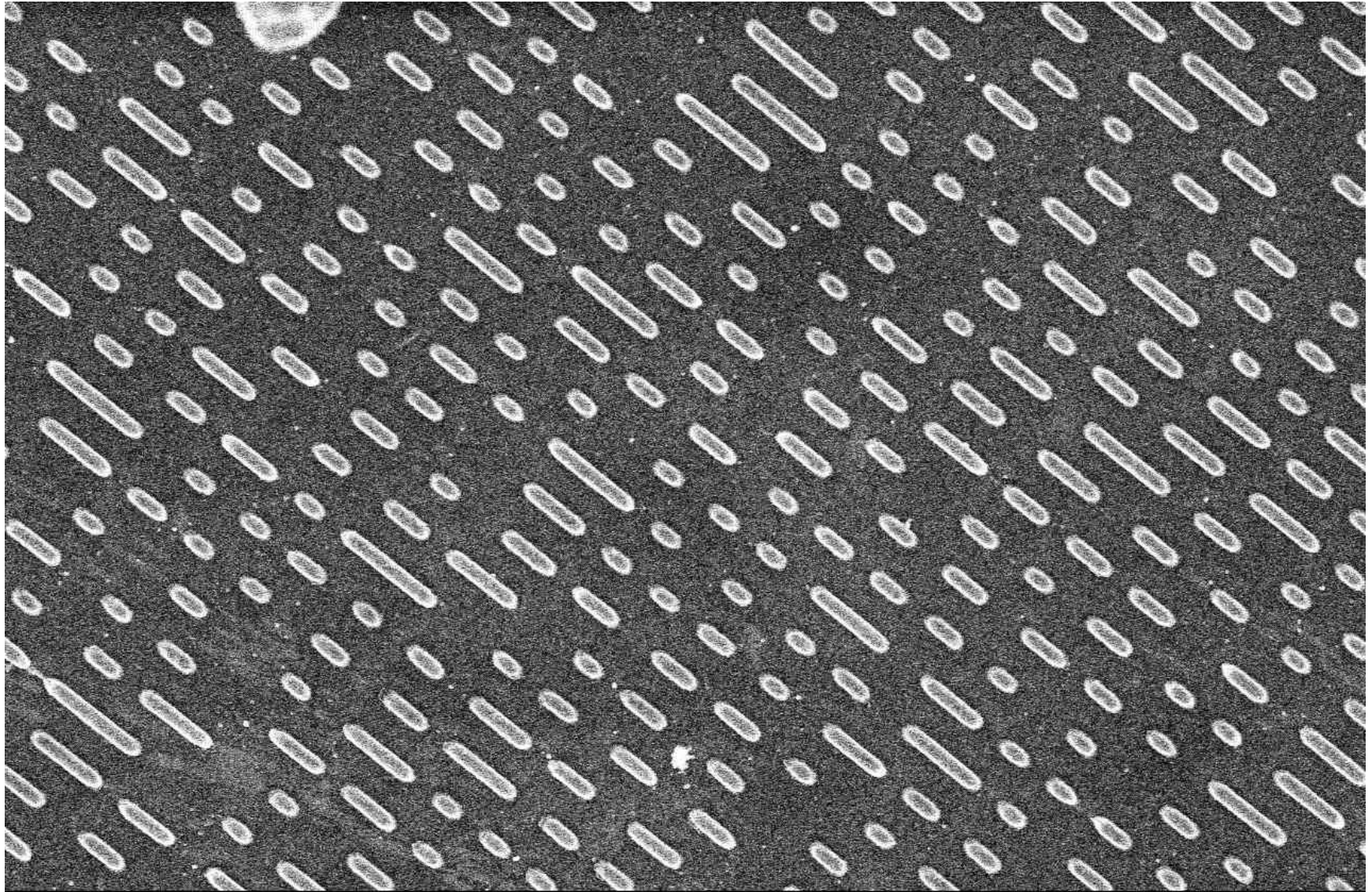


Questions?



Please type all questions or
comments into the Chat Box

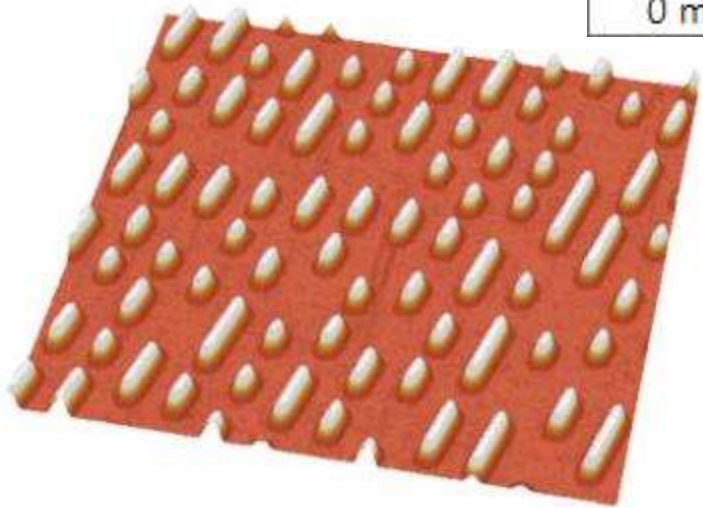
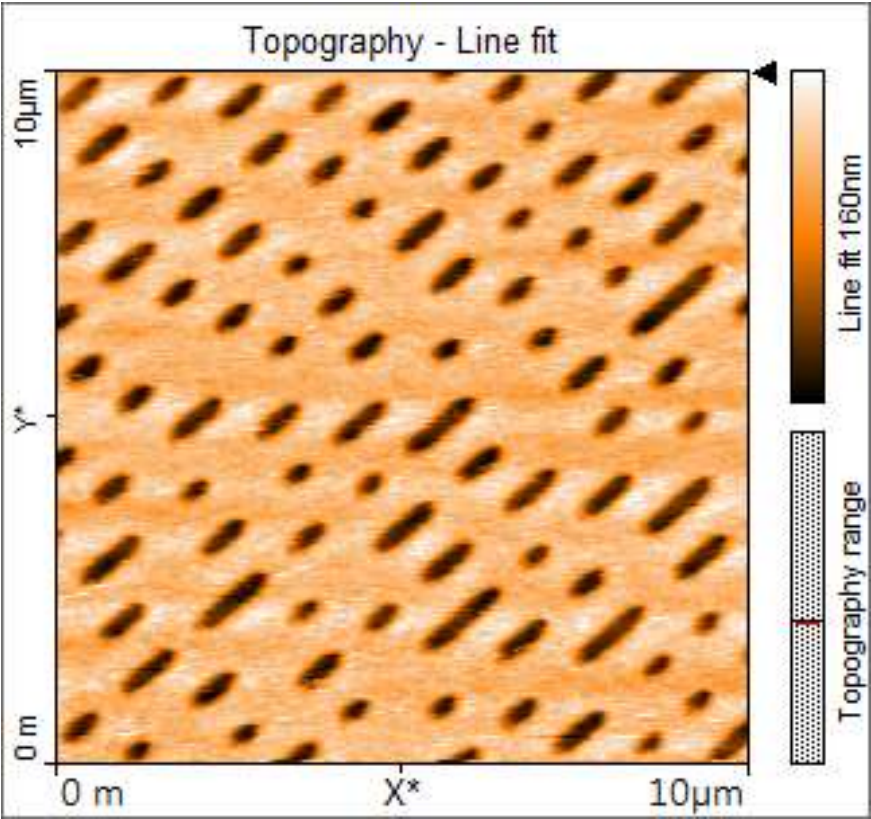
What do you think this is an SEM image of?



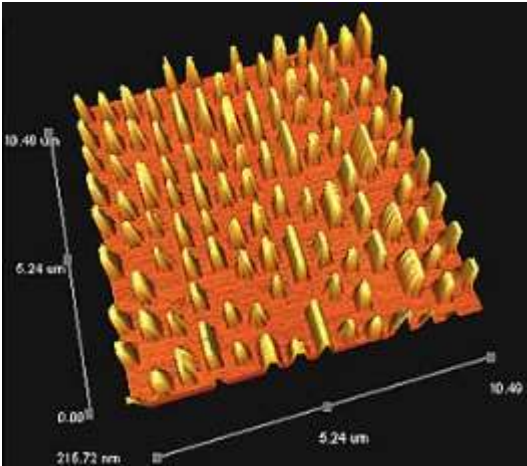
Yale 5.0kV 5.0mm x3.00k SE(M)

10.0um

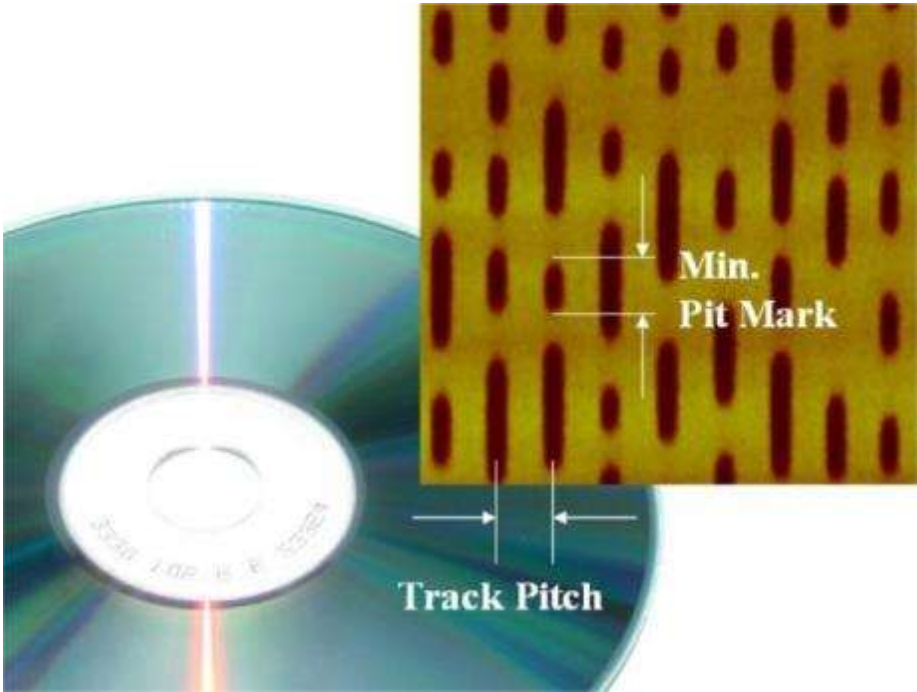
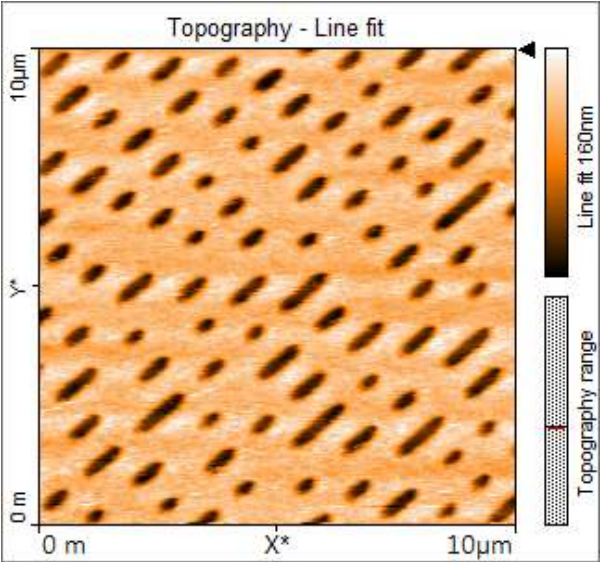
Maybe it's easier to figure out using an Atomic Force Microscope?



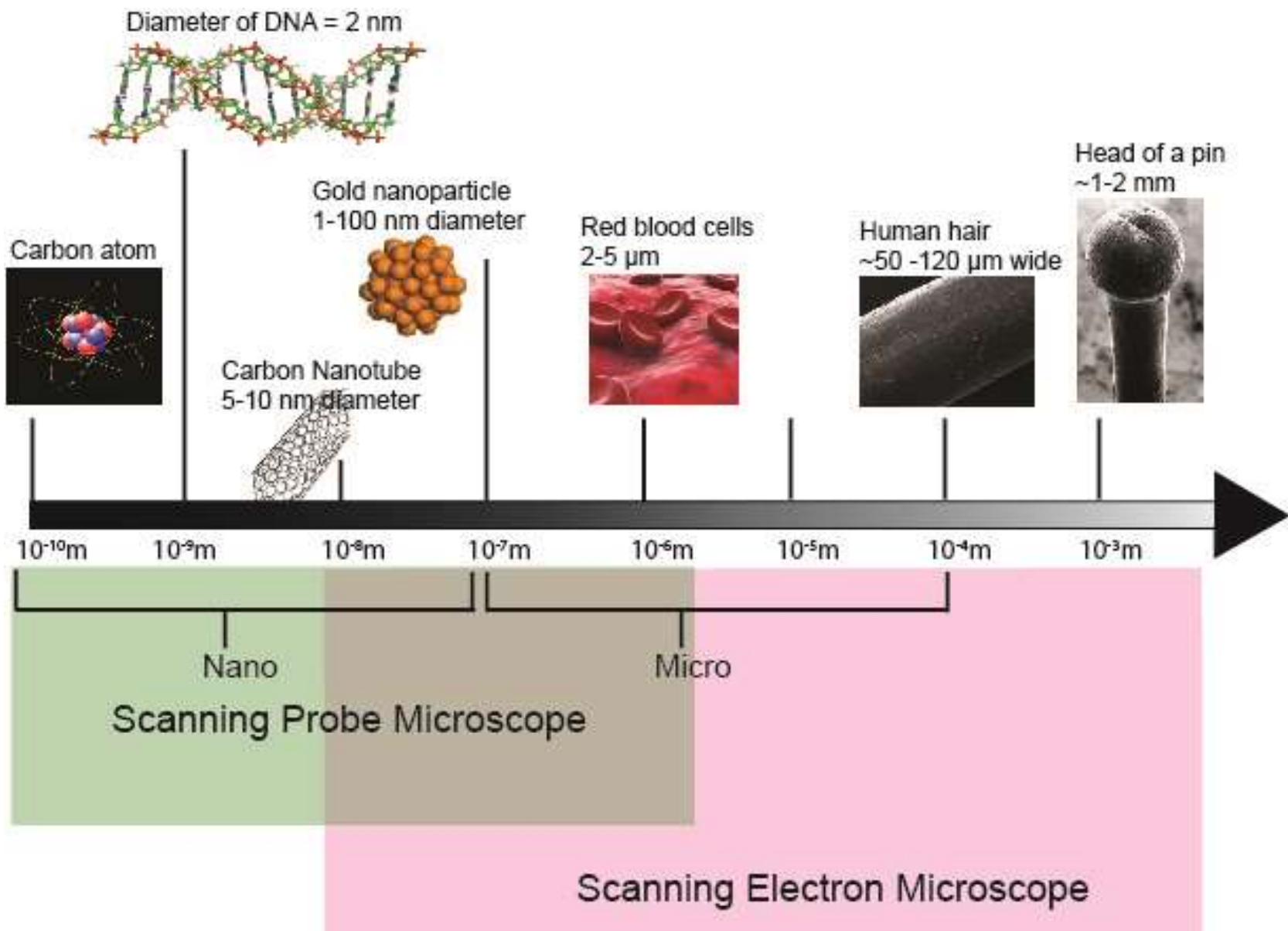
Still no idea?



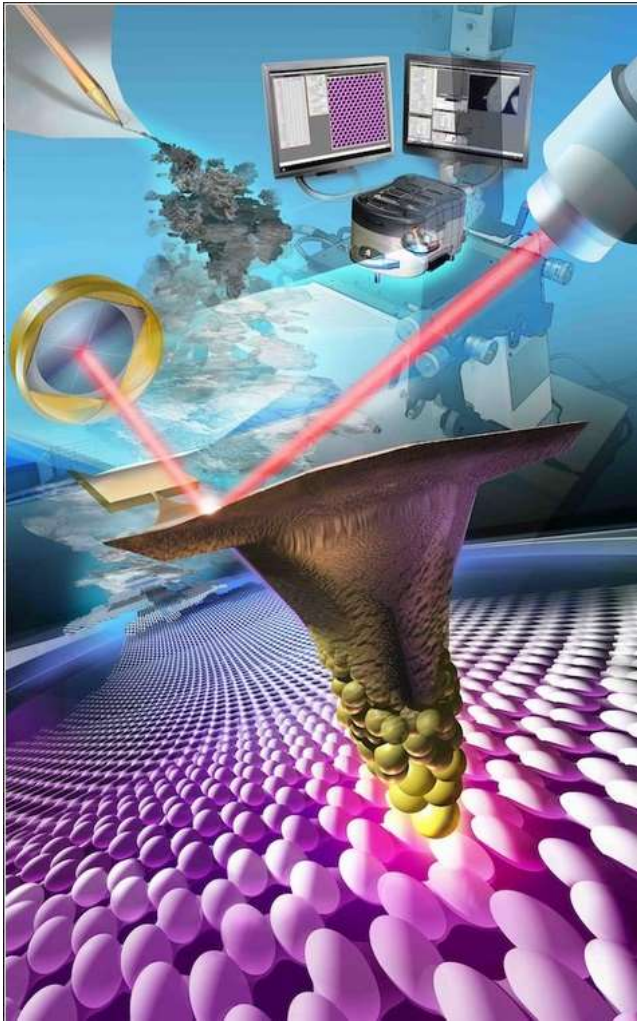
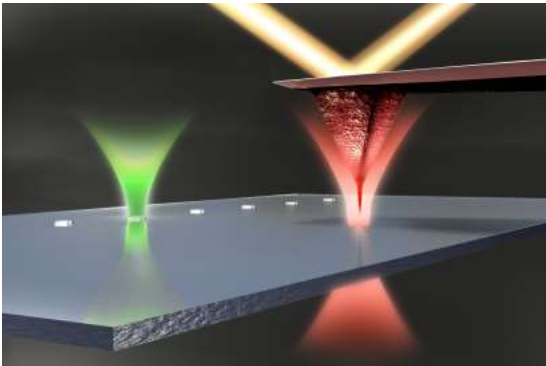
A DVD!



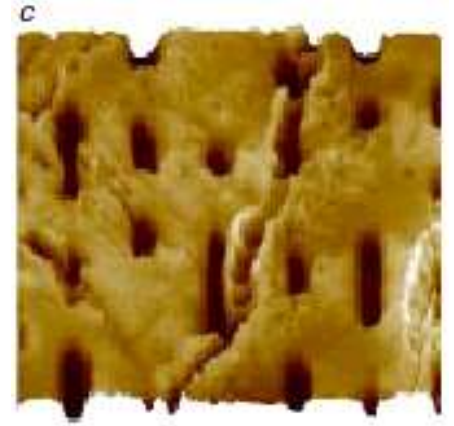
Is AFM essential to “nano”?



AFM – The Poster Child of Nano ...



Why won't my CD play after my 2-year old has slid it across the floor?



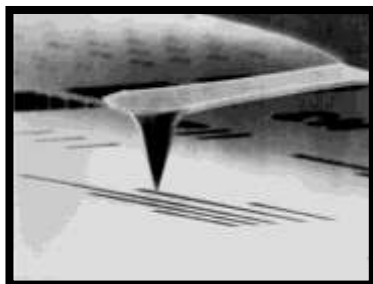
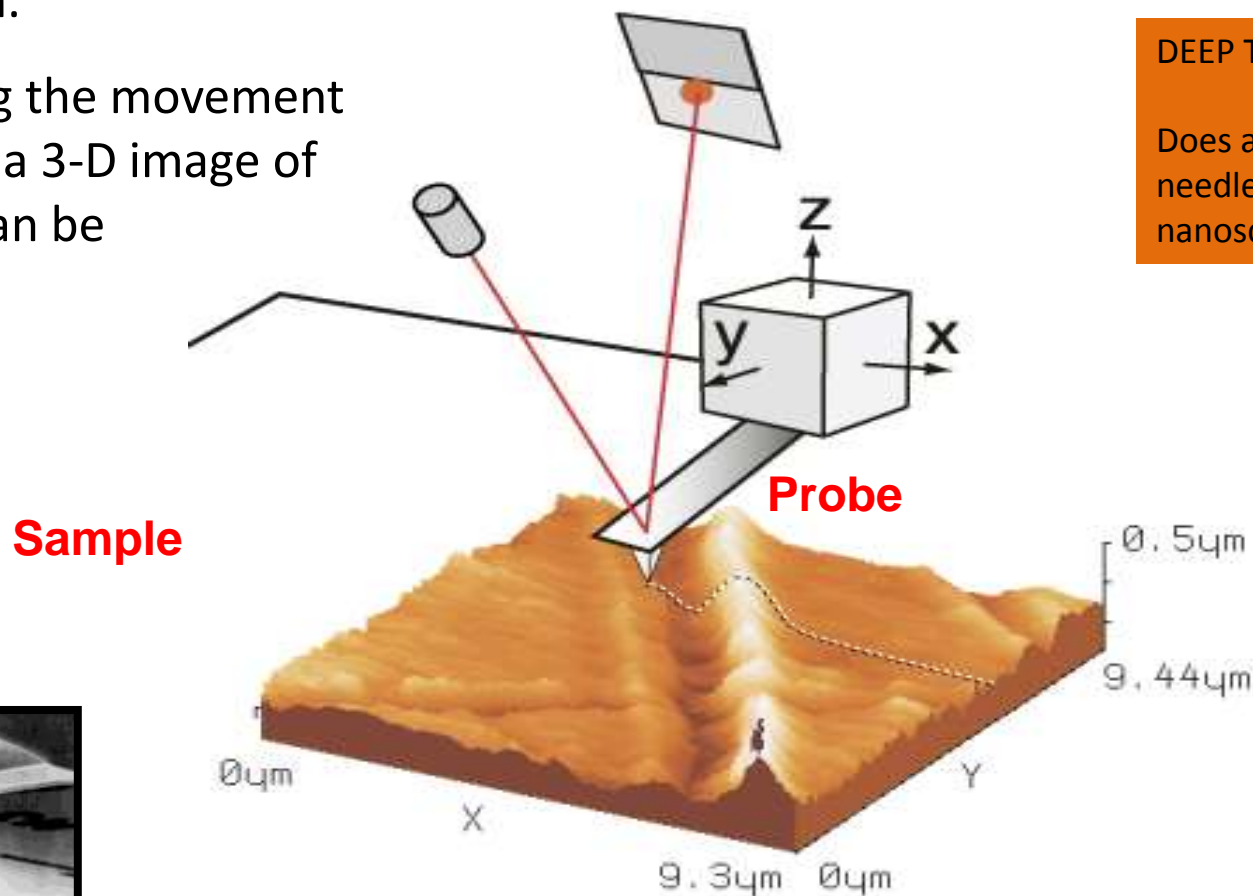
In simple terms, the atomic force microscope works by scanning a sharp probe over the surface of a sample in a raster pattern.

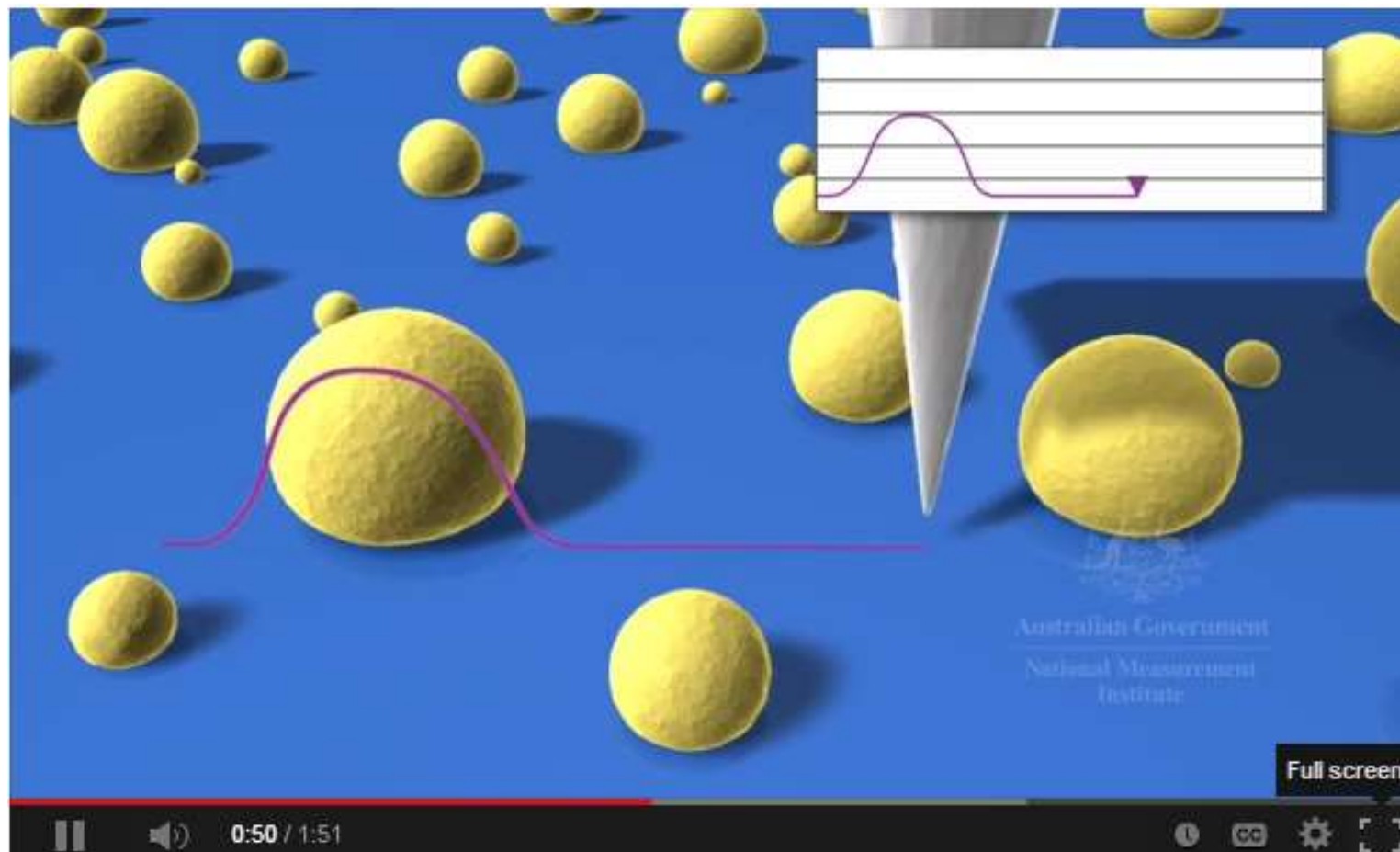
By monitoring the movement of the probe, a 3-D image of the surface can be constructed.



DEEP THOUGHT...

Does a record player
needle touch at the
nanoscale?

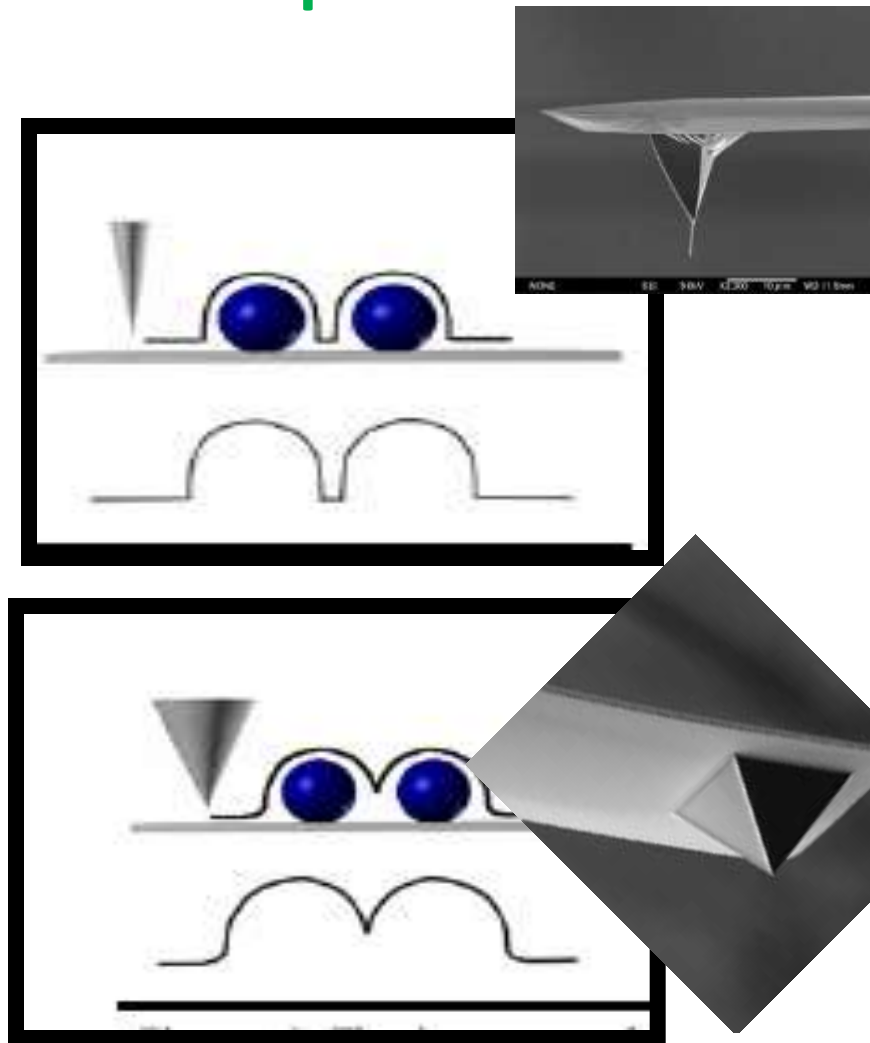




<http://www.youtube.com/watch?v=Ha53tFTsmW8>

Scanning the Sample

- Tip brought within nanometers of the sample (van der Waals)
- Radius of tip limits the accuracy of analysis/resolution
- Stiffer cantilevers protect against sample damage because they deflect less in response to a small force



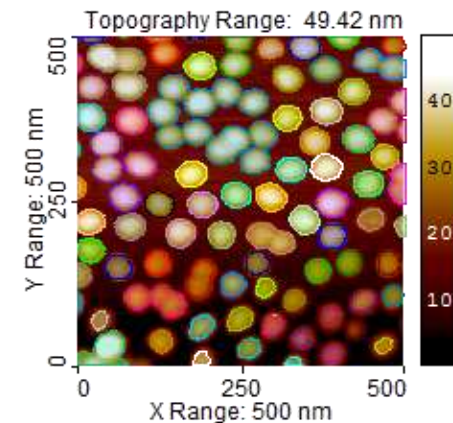
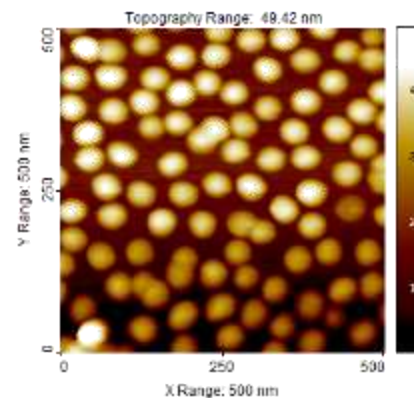
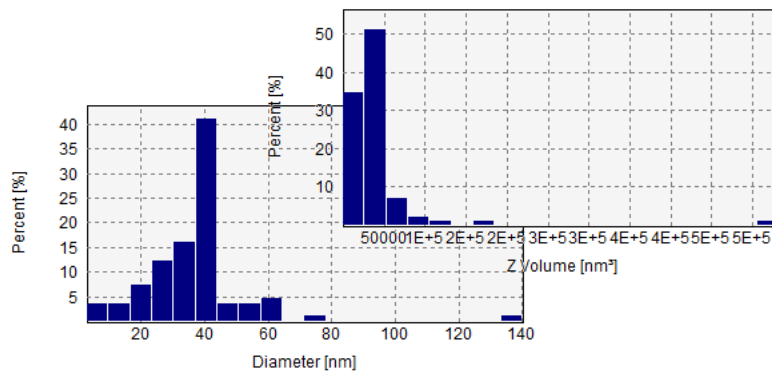
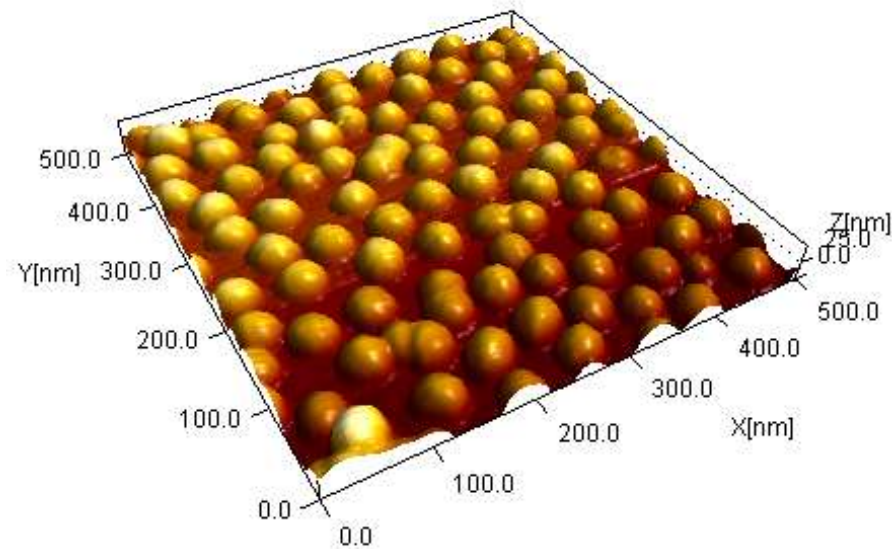
Particle Analysis

AFM can easily discern nanometer size particles/additives

Consumer Goods: Cosmetics, Hair Care, Paints/Dyes

Medical: Drug Delivery, Pill fillers, Active ingredients

Industrial: Structural additives



Nanotubes

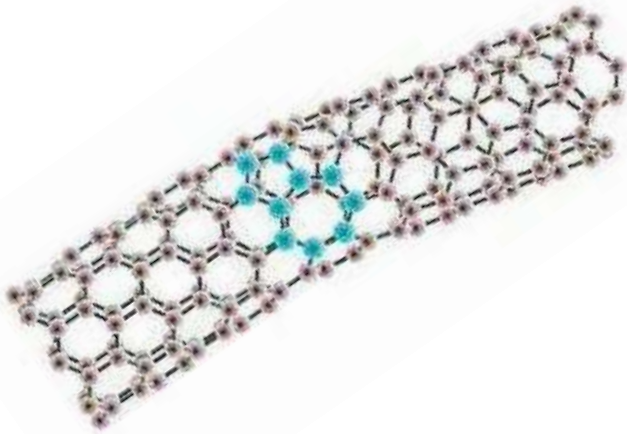
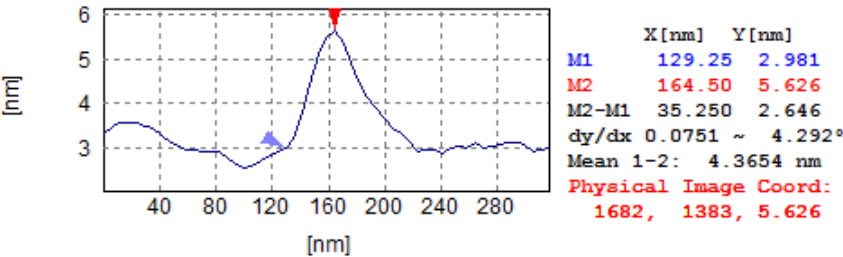
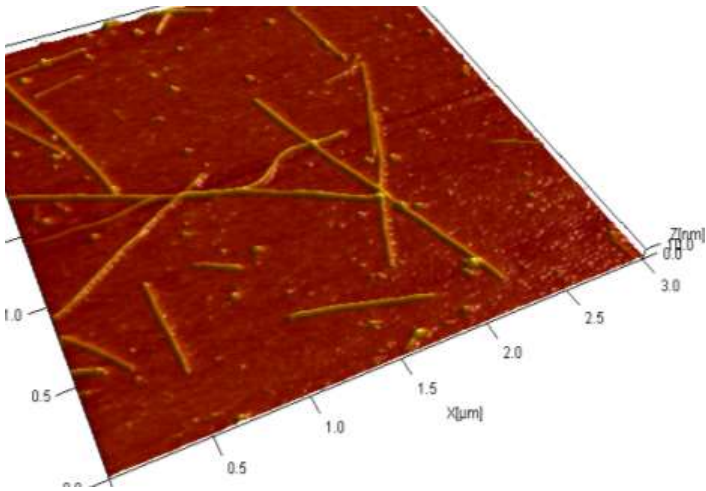
AFM is the technique of choice for characterizing carbon and other nanotubes. Length, diameter, and density can easily be determined.

Structural: Windmills, Car frames

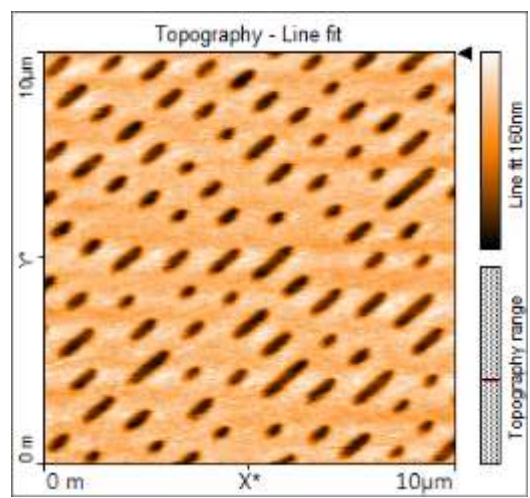
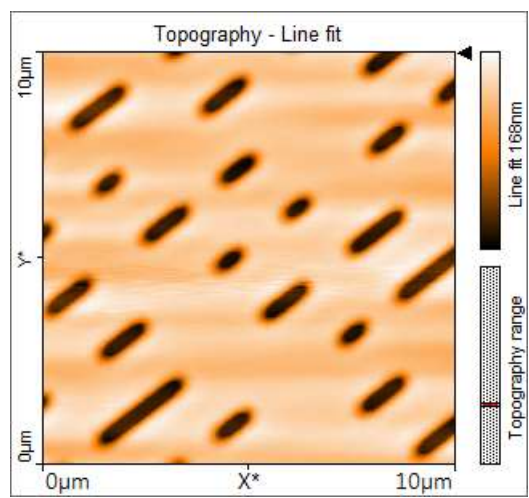
Biological: Pathogen detection, Bone scaffolding

Energy: Windmills, Solar cells

Consumer: Flexible electronics



Why are all the AFM images “orange”?



Speaking of Color...

A Matching Game...

Match the AFM
image to the Disk

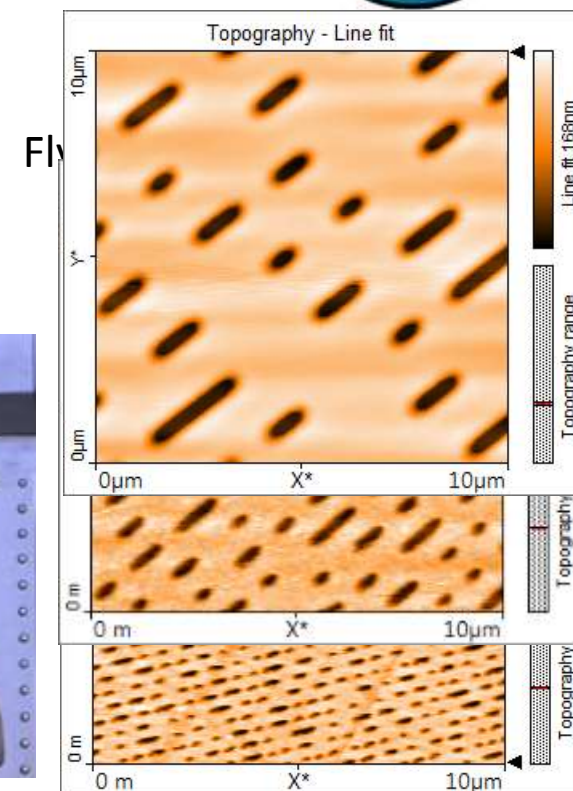


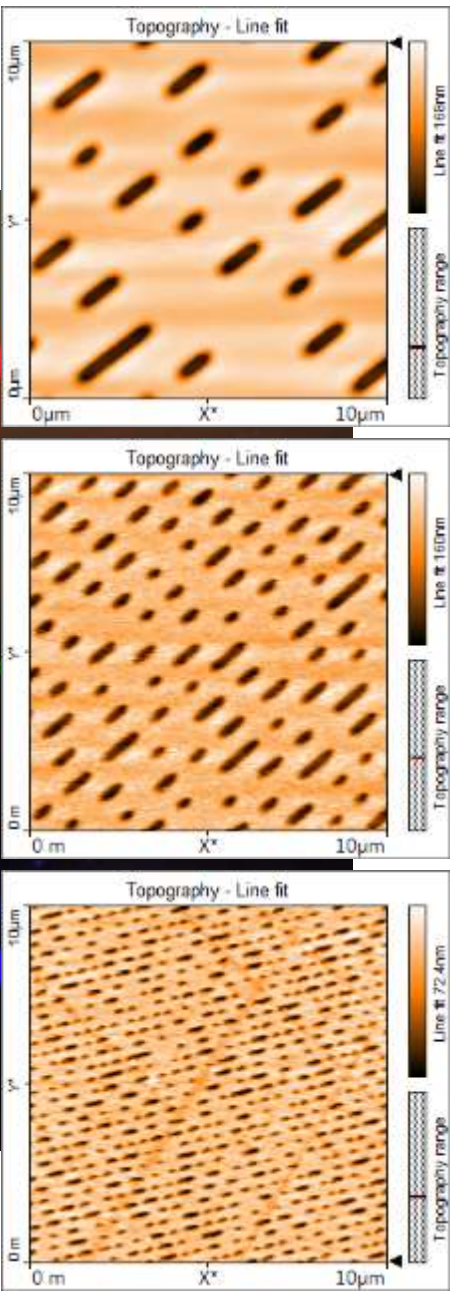
Facebook profile for Mike Davis. The profile picture shows a man in a blue shirt holding a book with a flame. The cover photo shows a periodic table of elements with the name "Mike Davis" overlaid. The profile has 161 photos, 67 mutual friends, and a bio that reads: "AFM Images I took in my basement. Updated about a month ago. 15 years ago, if you told me I would have an AFM in my basement, I would have been pissed as hell. 'Can't I leave that damn thing at the lab!'. Now I think its pretty awesome, and I would give almost anything for one of the hundreds of crappy samples I lost or threw away in grad school."

Below the bio are three AFM images, each labeled "Topography - Line fit". The first image shows a pattern of dark, elongated, parallel lines on a light orange background. The second image shows a pattern of dark, elongated, parallel lines on a light orange background. The third image shows a pattern of dark, elongated, parallel lines on a light orange background. Each image has a color scale bar on the right and a distance scale at the bottom (0 μm to 10 μm).



- ✓ CD..
- ✓ ... DVD...
- ✓ ... Blue Ray..
- ✓ A **Blue** Ray?
- ✓ Like a Ray Gun?
- ✓ Like a LASER Ray Gun?
- ✓ Like "Light
Amplification by
Stimulated Emission of
Radiation"?





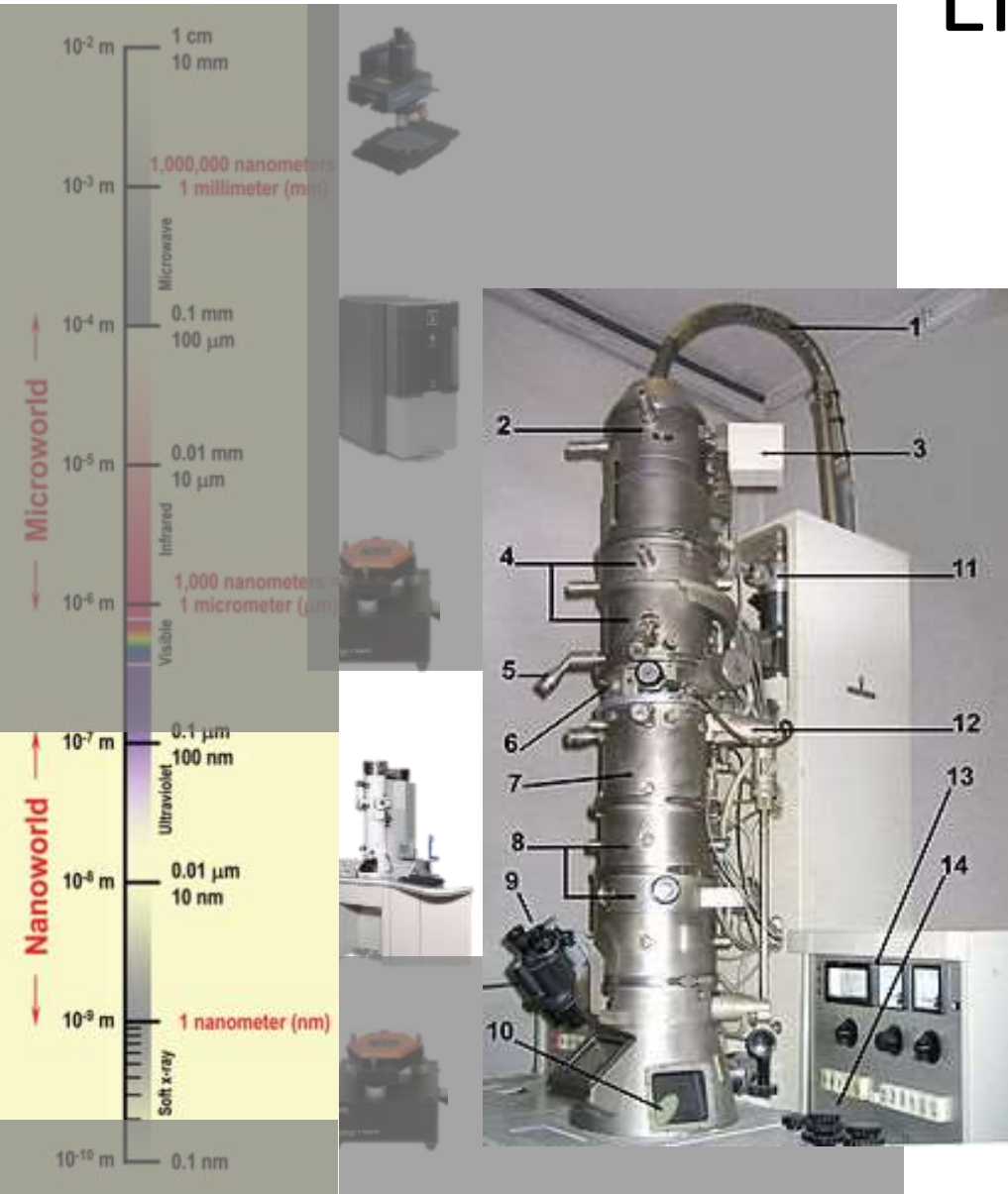
Five Microscopes

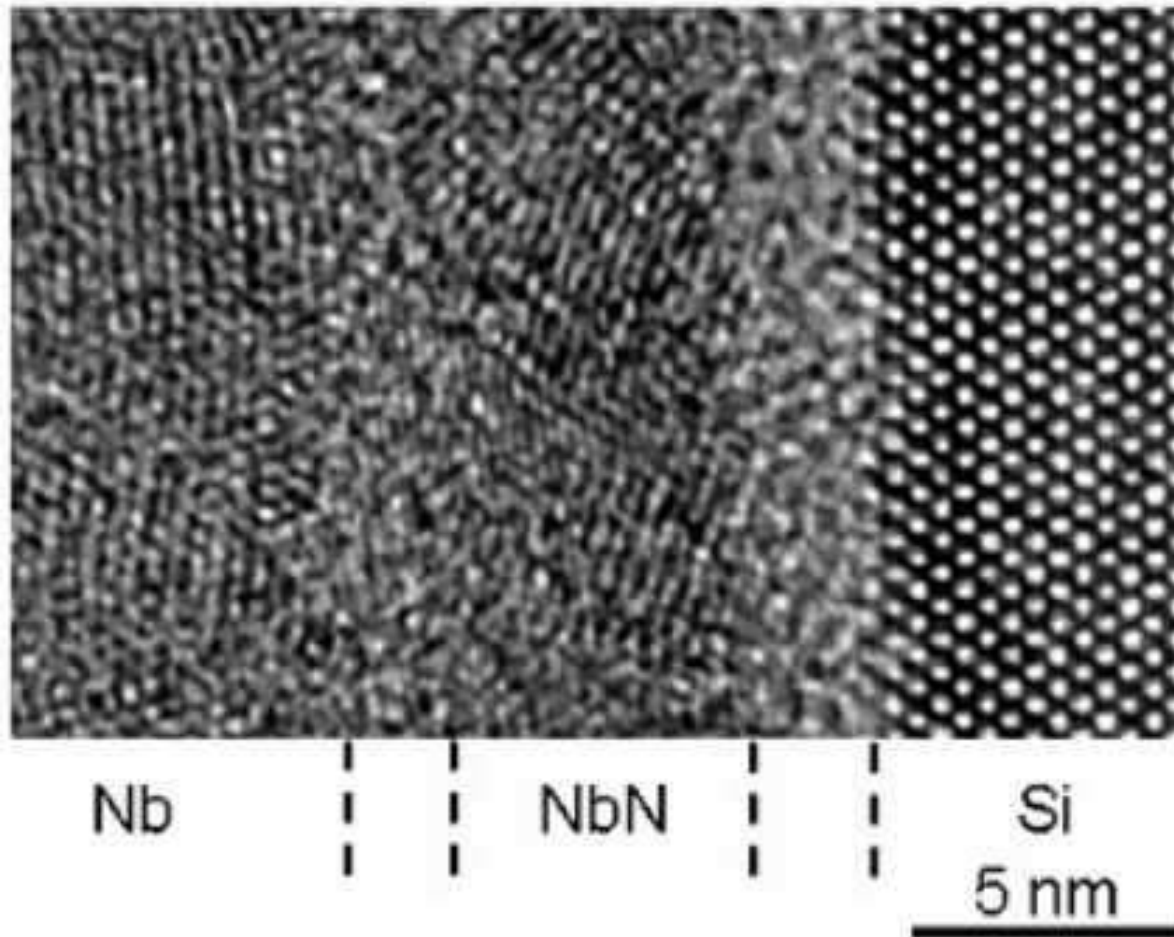
to fit the scale of things

Transmission Electron Microscope

With each instrument, I'll try to communicate:

- What it does.
- How it works, on a high level.
- Where it's used.
- What subjects can be taught with it.
- What skills your students can learn from it. (*this is subjective*)

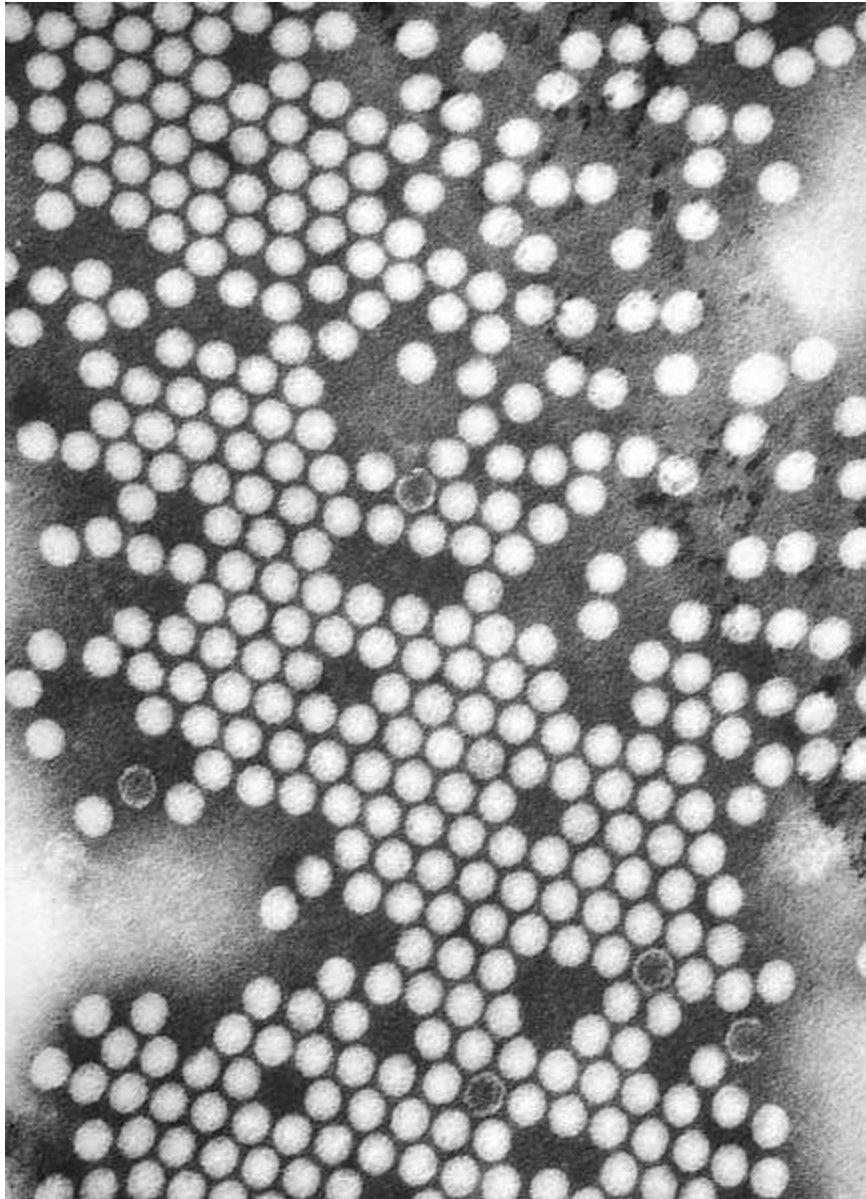




Layer structure on a silicon substrate:

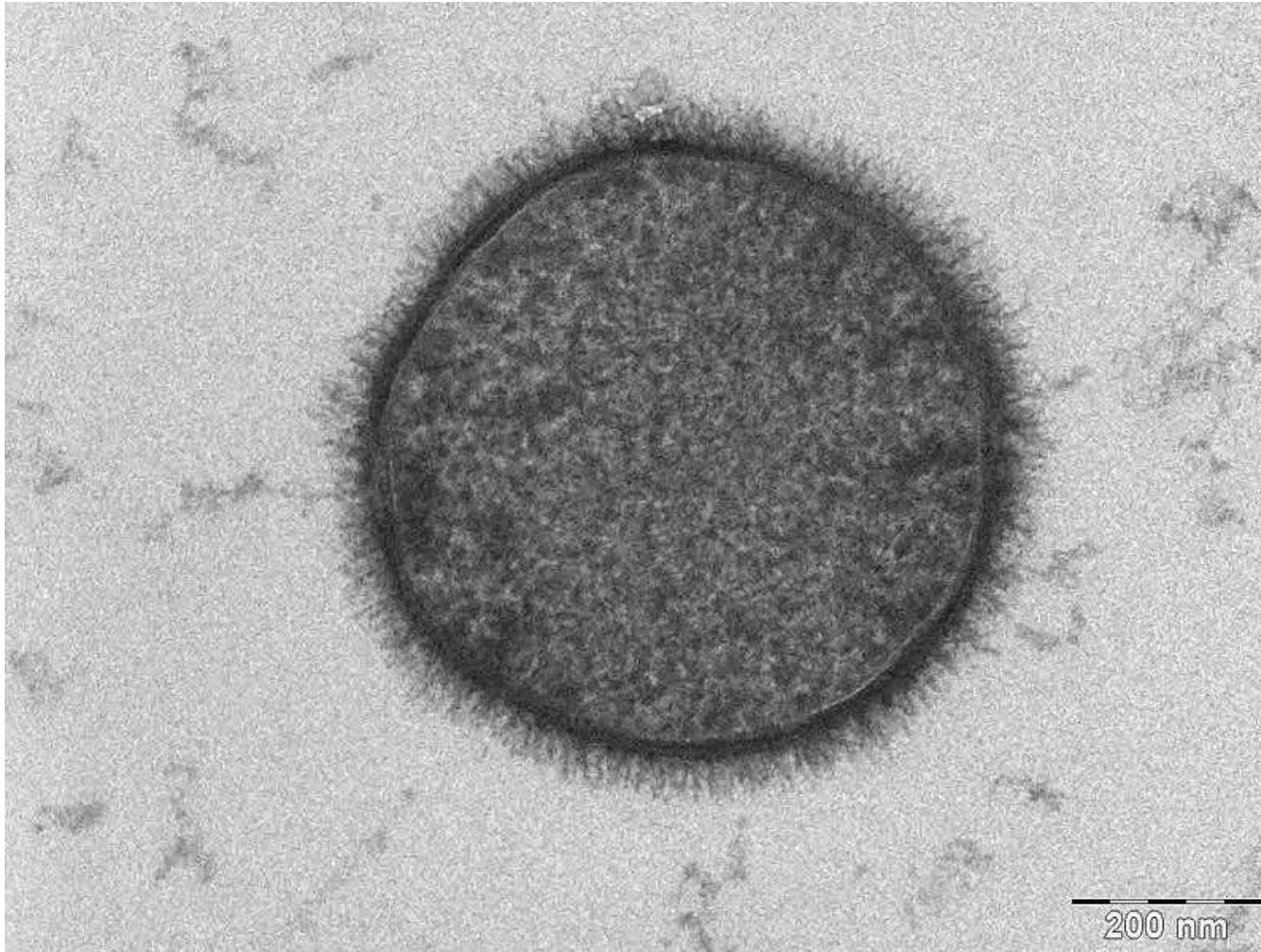
(Photo by: Siegel/Gerthsen).

http://www.kit.edu/visit/1839_156.php

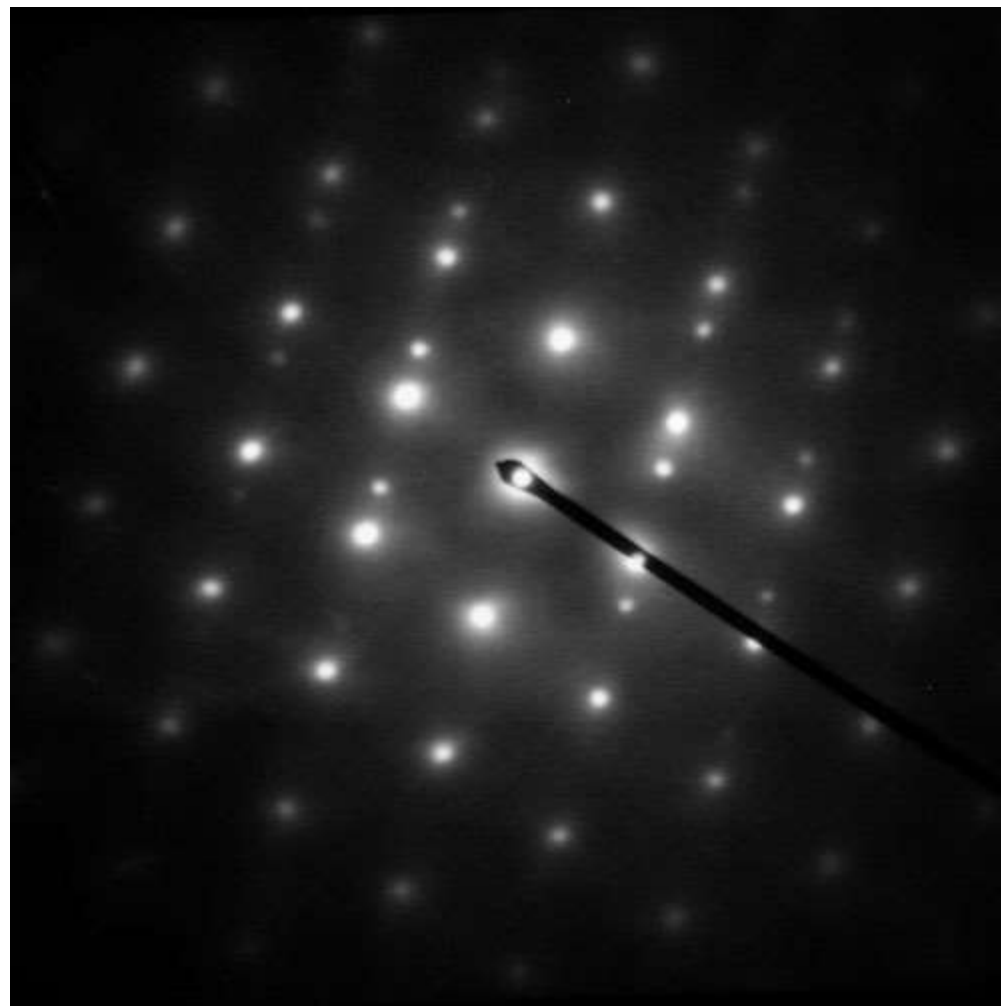


A TEM image of the [polio](#) virus.
The polio virus is 30 [nm](#) in size.

http://en.wikipedia.org/wiki/Transmission_electron_microscopy#cite_note-1



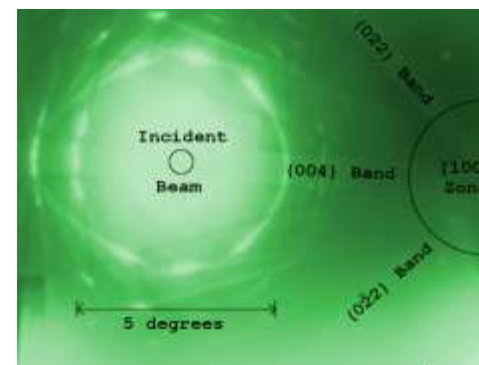
A section of a cell of *[Bacillus subtilis](#)*, taken with a Tecnai T-12 TEM. The scale bar is 200 nm.



Crystalline diffraction pattern from a twinned grain of FCC Austenitic steel

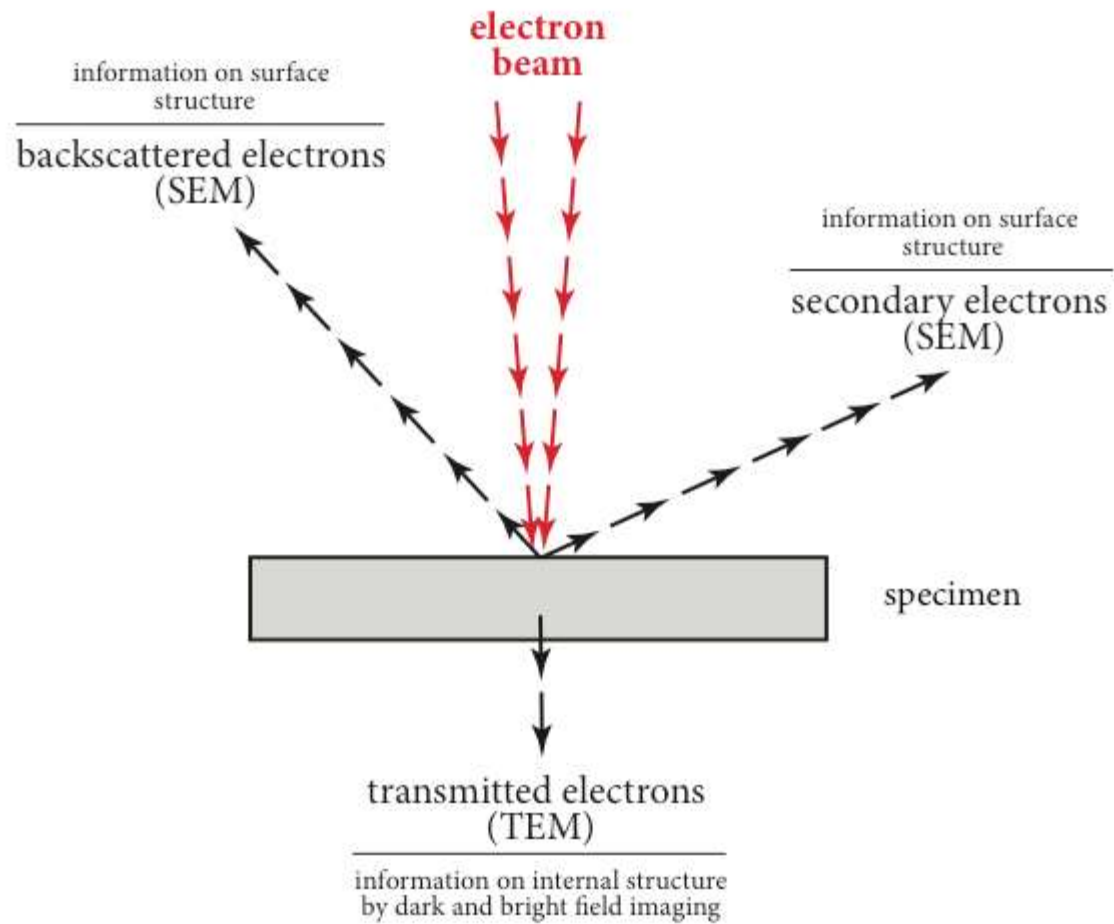


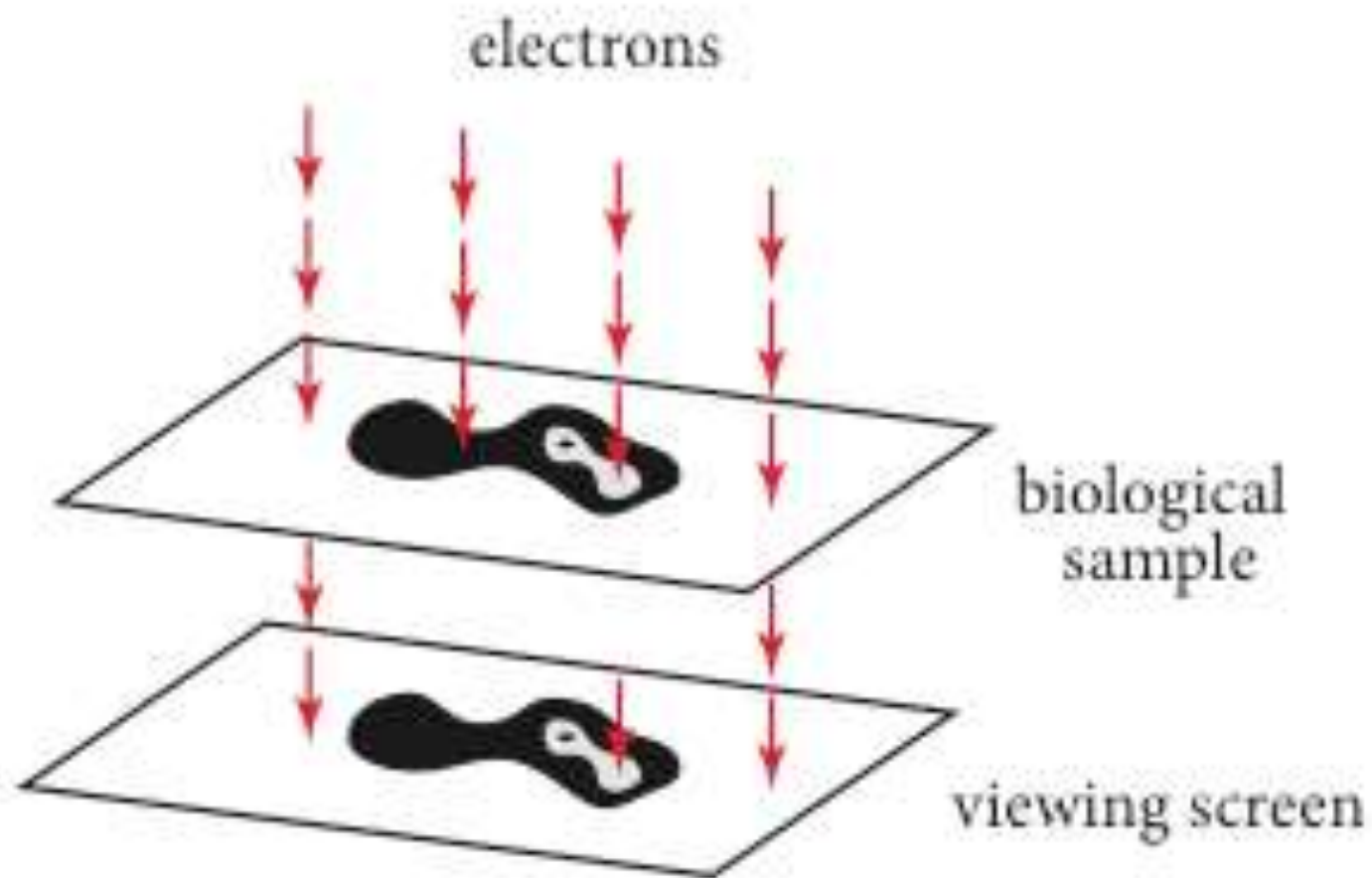
Transmission electron micrograph of [dislocations](#) in steel



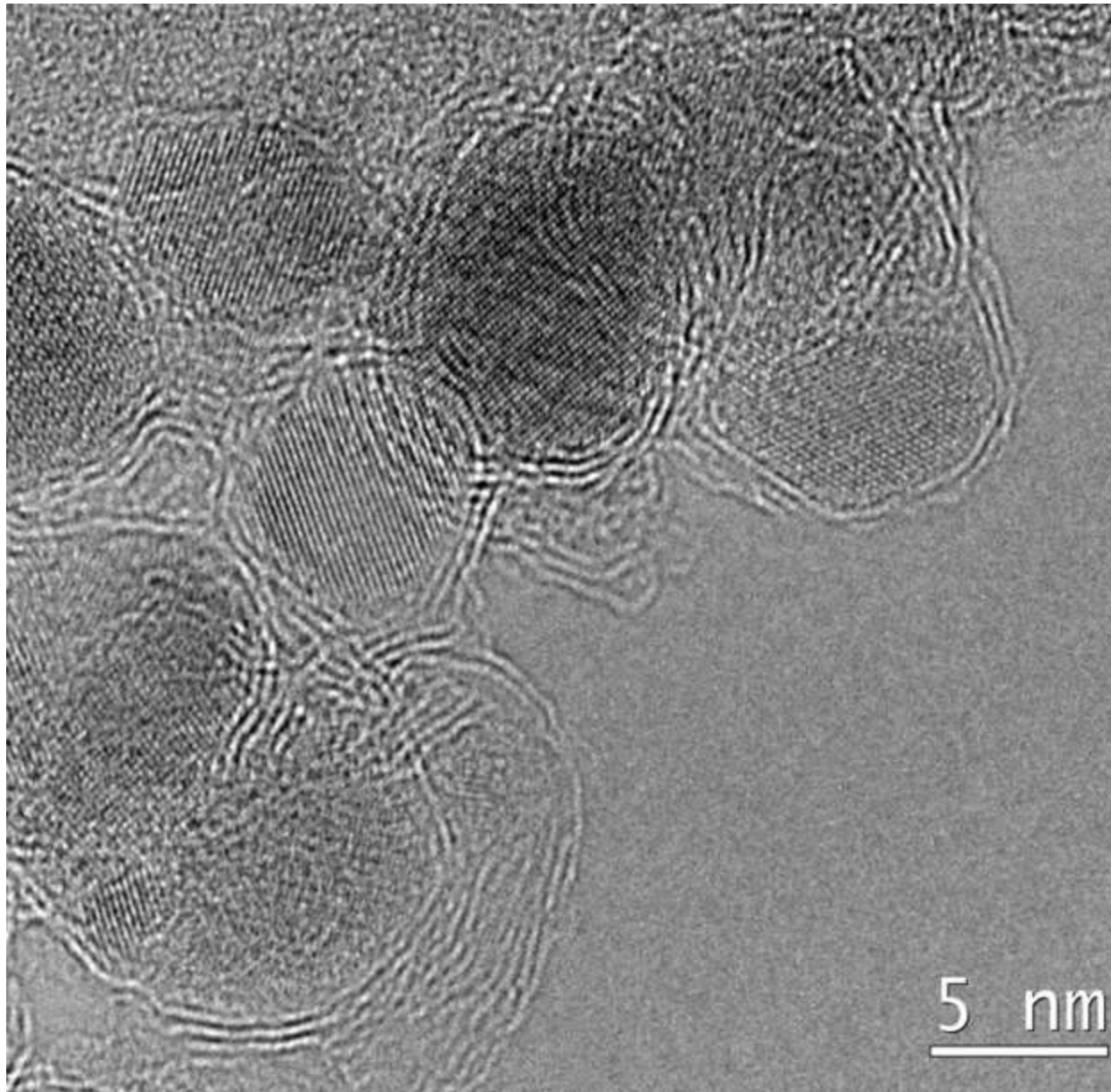
Convergent-beam Kikuchi lines from silicon, near the [100] [zone axis](#)

TEM – How does it work?





TEM

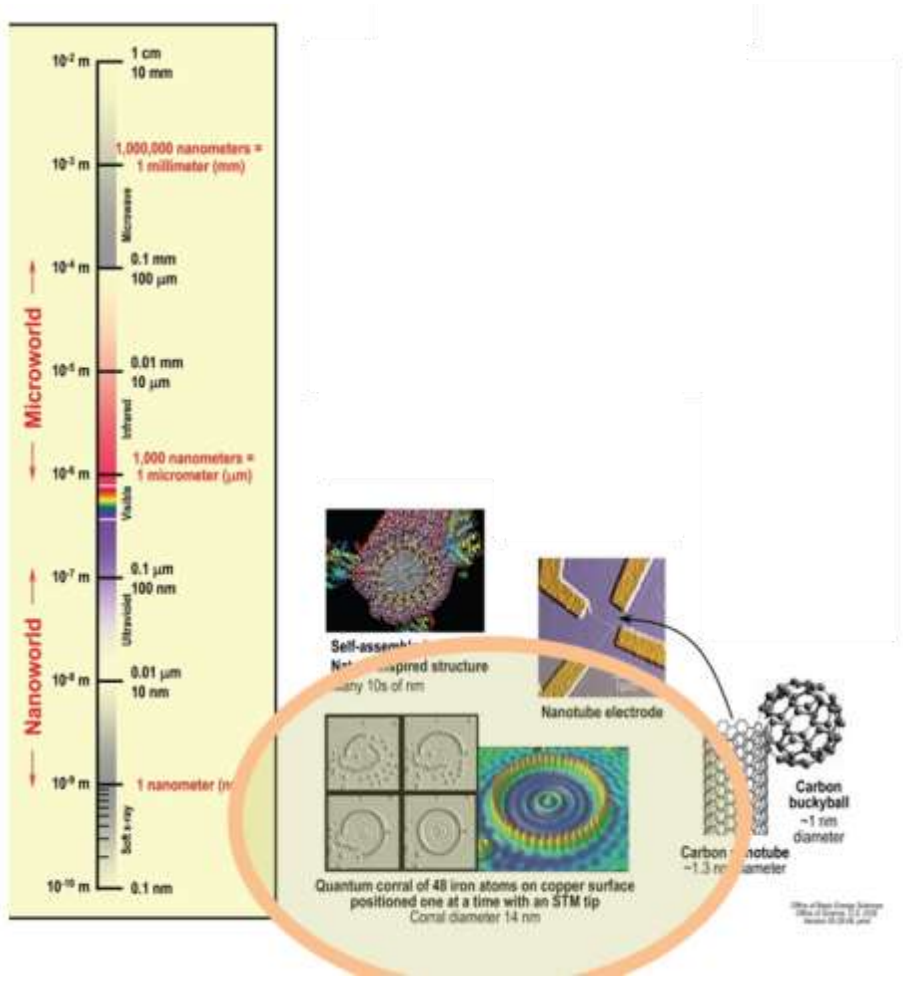
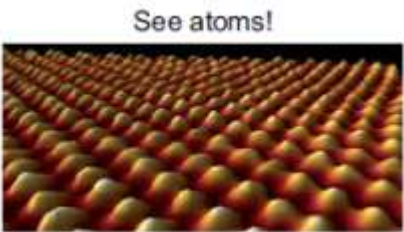


**HRTEM image of a
Fe/LiF/C anode for
lithium ion batteries**

*R. Prakash and C. Kübel et al., J. Power
Sources, 2011, 196, 5936-5944.*

SCANNING TUNNELING MICROSCOPE

- What it does:
 - Measures and creates a visual representation of very smooth, atomic level, surfaces. Image atoms.

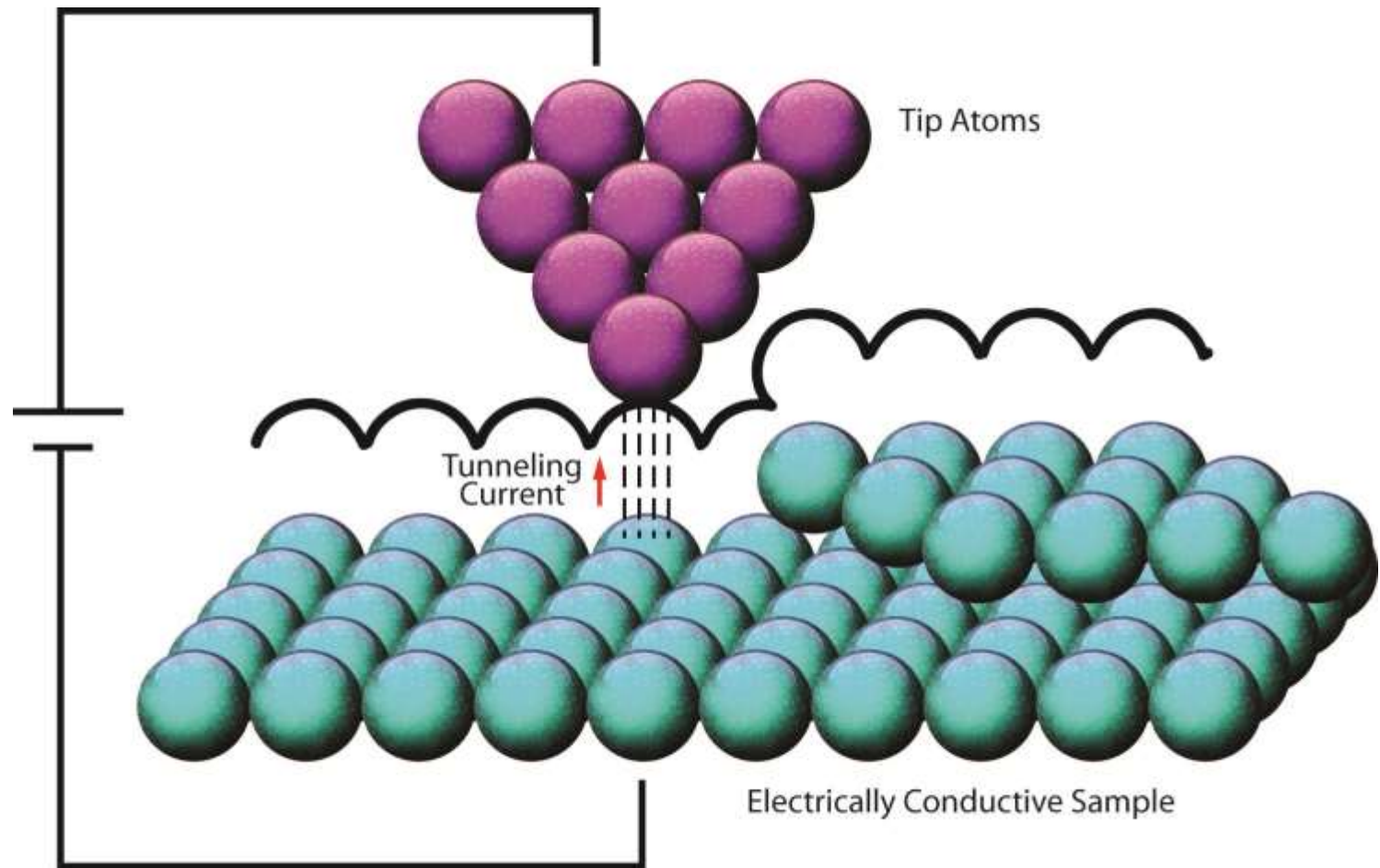


Iconic image of “Nano” from IBM in the 90’s - “Quantum Corral”

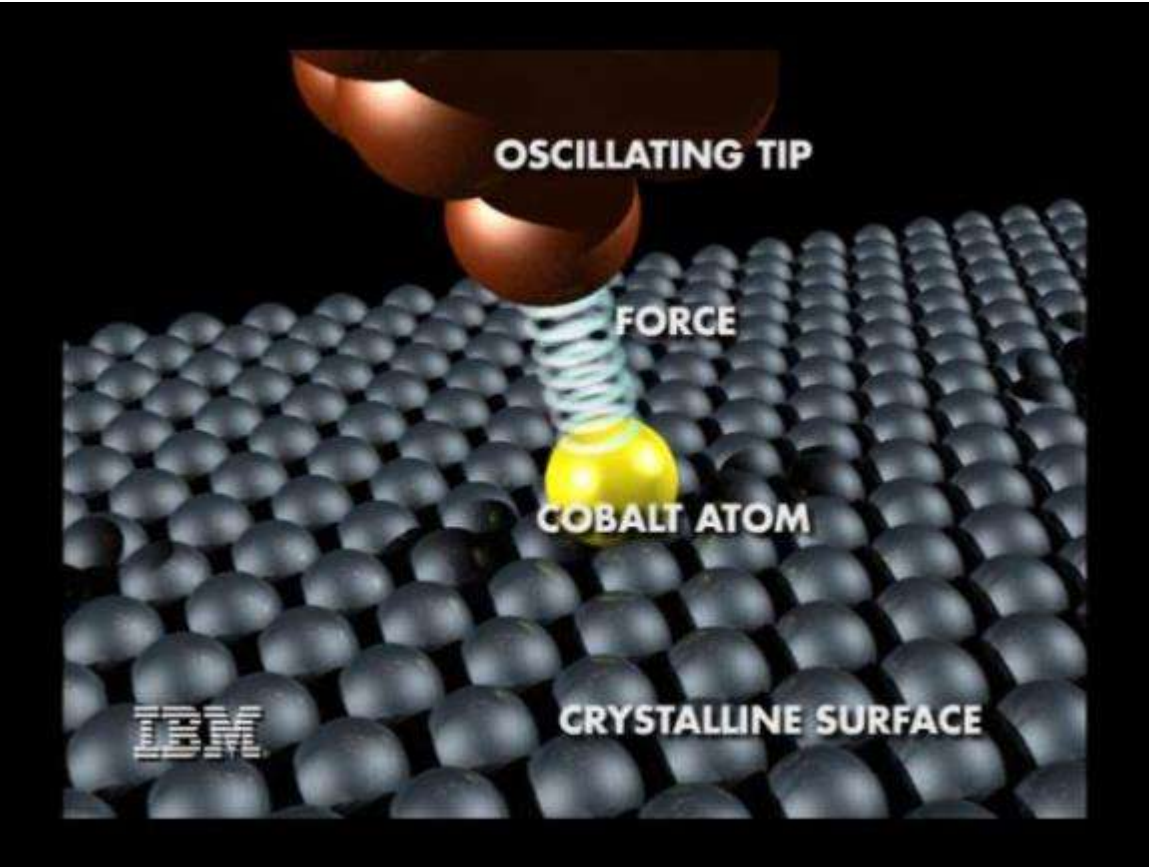
A Boy and His ATOM – World's Smallest Movie (IBM)

<http://www.youtube.com/watch?v=oSCX78-8-q0>

Quantum Tunneling



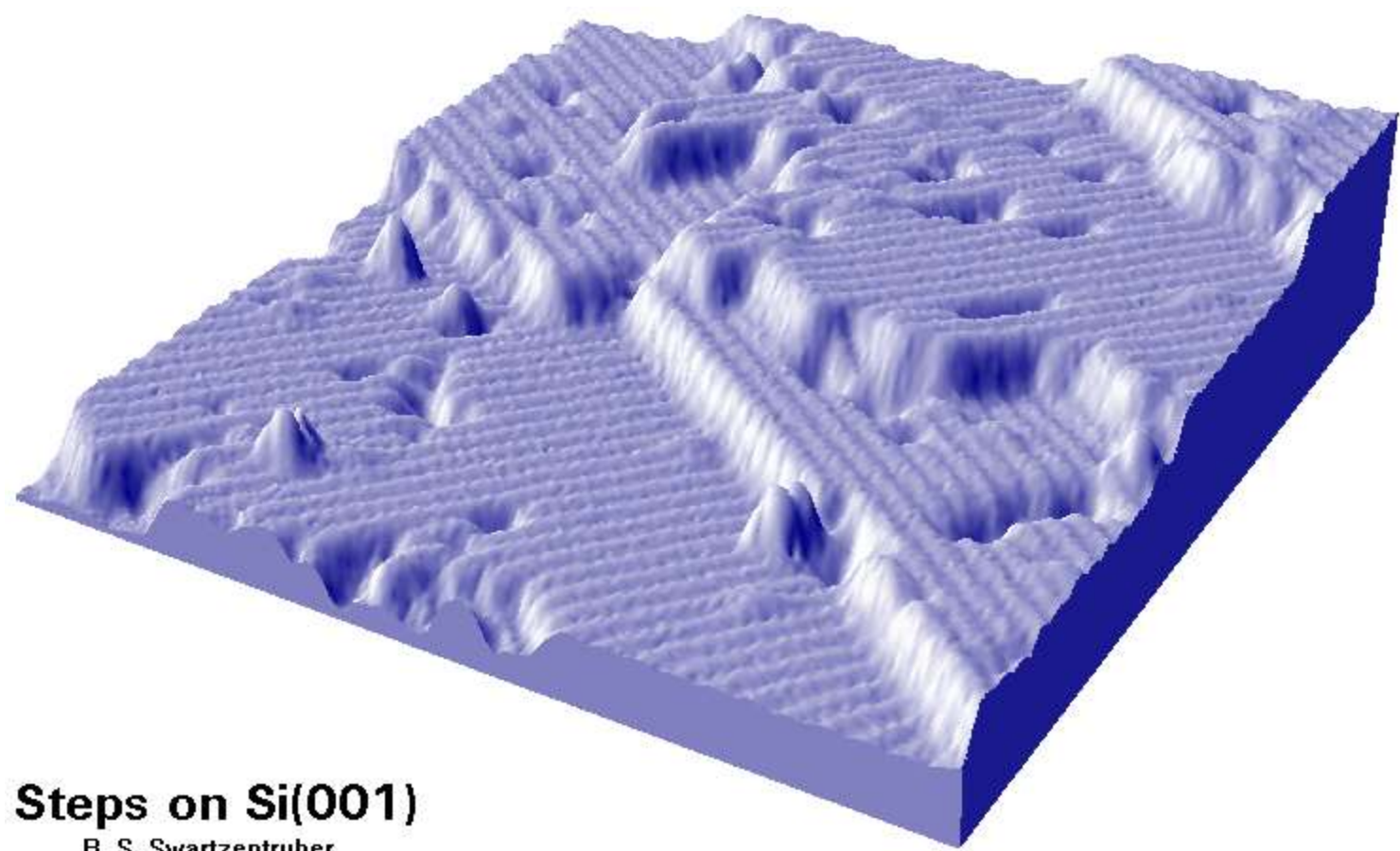
Artist's impression of the IBM microscope tip



<http://physicsworld.com/cws/article/news/2008/feb/27/feeling-the-force-on-a-single-atom>

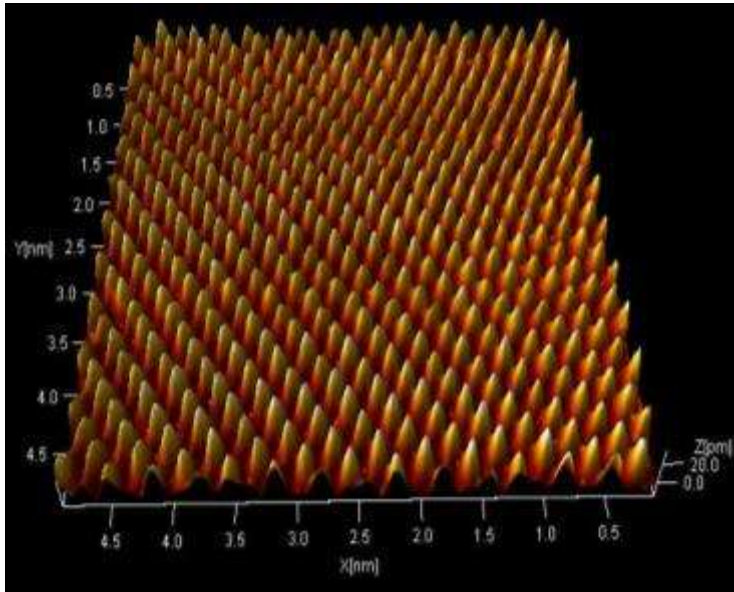
Where it's used:

- Advanced Research Labs
- *Teaching and Outreach*
- *Any other industrial uses, audience?*



Steps on Si(001)
B. S. Swartzentruber

Imaging atoms and beyond....



- What subjects can be taught with it.
 - See ATOMS!
 - Physics

- What skills your students can learn from it. (*this is subjective*)
 - *Conceptualization*
 - *Understanding data, and how it was collected*
 - *Operating delicate equipment*
 - *Not quite a resume skill yet.*

TEST... Match the image group with the Scope



3D Optical Microscope



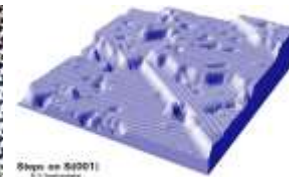
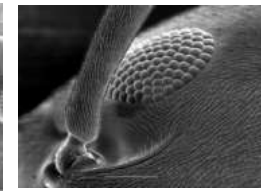
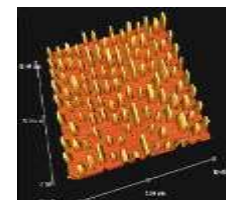
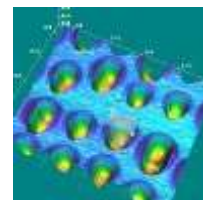
SEM



AFM



STM



Is it Practical?

Classroom Integration – Square Peg,
Round Hole?

Five Microscopes



to fit the scale of things
3D Optical
Wavelength of Light



Scanning Electron (SEM)
Wavelength of Electron



Atomic Force (AFM)
Atomic Force



Transmission Electron (TEM)
Electron interaction
through a material



Scanning Tunneling (STM)
Quantum Force





your clean room

isn't
like



isn't
like



Making microprocessors is a tricky business. The tiniest speck of dust is the equivalent to a two-ton boulder around our microscopic transistors. This is why our clean rooms are 10,000 times cleaner than a hospital operating room. It's also why our workers must wear these silly-looking outfits. Learn more at sponsorsoftomorrow.com.



Sponsors of Tomorrow.™

Practical Considerations

When considering investing in instrumentation...



- **Fast – to use – classrooms have a boxed time**
 - A 20 min “get ready” time per instrument is not realistic

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 - Pumps – basic. No dangerous chemicals. No special wet or fume hood for venting.

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- **Easy-to-use “real” scientific instrument**
 - Not a model; not ‘dumbed down’ equipment; a real instrument made intuitive; think “iPad”
 - Capable of the same type of experiments in research institutions and industry; measures in the same way



Is it Practical?
That's not the question...
Is it do-able?
Answer for yourself...



The Scale of Things – Nanometers and More

Things Natural

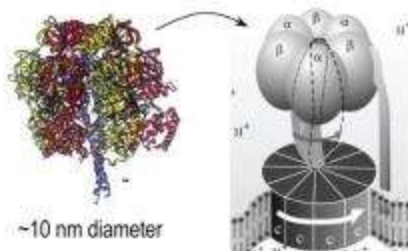


Dust mite
200 μm



Human hair
~ 60-120 μm wide

Red blood cells
(~7-8 μm)



~10 nm diameter

ATP synthase



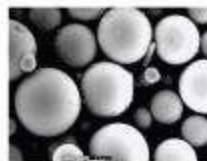
DNA
~2-1/2 nm diameter



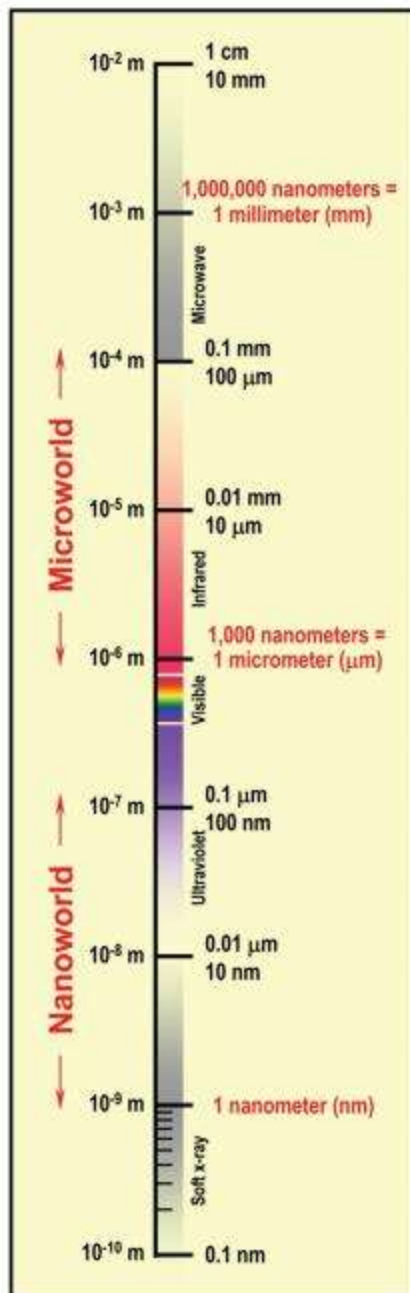
Atoms of silicon
spacing 0.078 nm



Ant
~ 5 mm



Fly ash
~ 10-20 μm



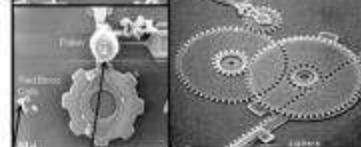
Things Manmade



Head of a pin
1-2 mm

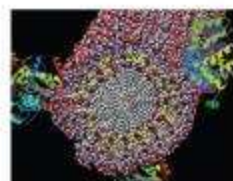


MicroElectroMechanical (MEMS) devices
10 -100 μm wide

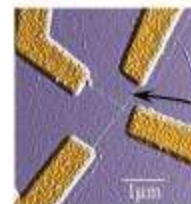


Pollen grain
Red blood cells

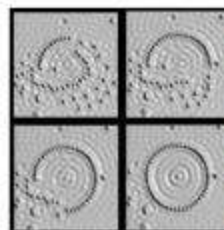
Zone plate x-ray "lens"
Outer ring spacing ~35 nm



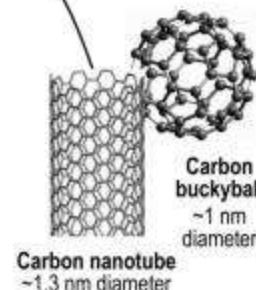
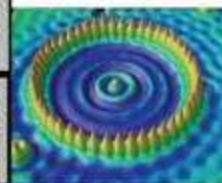
Self-assembled,
Nature-inspired structure
Many 10s of nm



Nanotube electrode



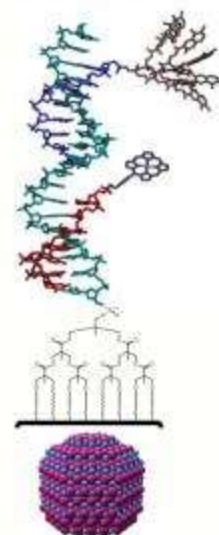
Quantum corral of 48 iron atoms on copper surface
positioned one at a time with an STM tip
Corral diameter 14 nm



Carbon nanotube
~1.3 nm diameter

Carbon buckyball
~1 nm diameter

The Challenge



Fabricate and combine nanoscale building blocks to make useful devices, e.g., a photosynthetic reaction center with integral semiconductor storage.



Questions?

Please type all questions into the Chat Box



How Can We Better Serve You?

Whether you are joining us live or watching the recorded version of this webinar, please take 1 minute to provide your feedback and suggestions.

<http://questionpro.com/t/ABkVkZQFNe>



Webinar Recordings

To access this recording, slides, and handout visit
nano4me.org/webinars.php



Certificate of Participation

If you attended the live version of this
1.5 hour webinar and would like a
certificate of participation, please email:

sbarger@engr.psu.edu



2013 Events Calendar

- October 7-10:** Course Resource Workshop II:
Workshop Patterning, Characterization, and Applications
- Nov. 1:** Nanotechnology and Manufacturing
Webinar
- Nov. 12-14:** Hands-on Introduction to Nano for Educators
Workshop

Want more events? Visit www.nano4me.org/webinars for more details about these and other upcoming workshops and webinars in 2014.



Thank You!

Thank you for attending the
NACK Network webinar

Fundamentals of Metrology and Characterization for Nanotechnology