Microscopy:
From Ants to Atoms

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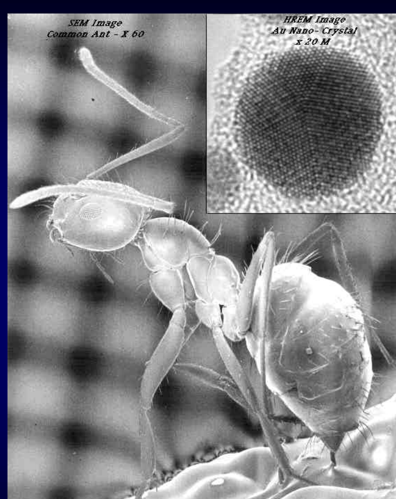
Microscopy is one of the few methodologies applied to nearly every field of science and technology in use today.

A microscope can be as simple as a hand held optical device or as complex as a multi-million dollar research tool.

Using these instruments, both scientists and students can explore the synergistic relationships of structure and properties of a wide variety materials in both the Physical and the Life Sciences.



Why Microscopy ?

- Resolution of the Human Eye ~ 0.1 mm
- Apparent resolution of the Eye for a Magnified Object is:
- $R \sim \frac{\textbf{0.1 mm}}{\textbf{Magnification}}$

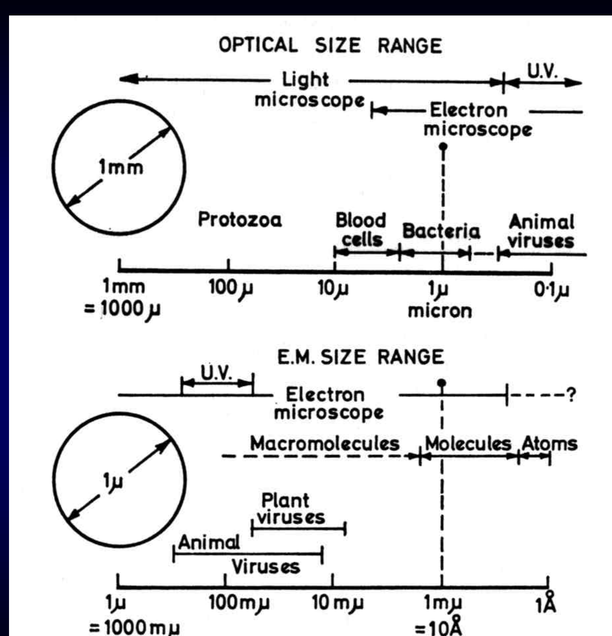
Magnification	Resolvable Distance
100	1µm - (10,000 Å)
1,000	0.1µm - (1,000 Å)
10,000	0.01µm - (100 Å)
1, 000,000	0.0001µm - (1 Å)

- What is the difference between Magnification and Resolution?

Magnification: Apparent enlargement of an object

Resolution: Capability of making distinguishable the individual parts of an objects

How Small is Small?



Basic Components of an Optical Microscope

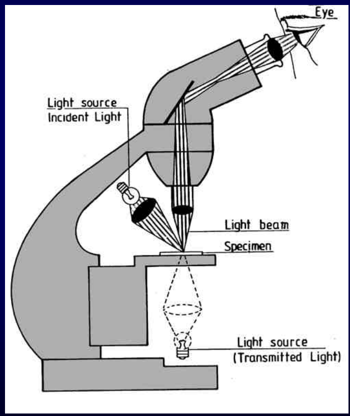
Illumination Source

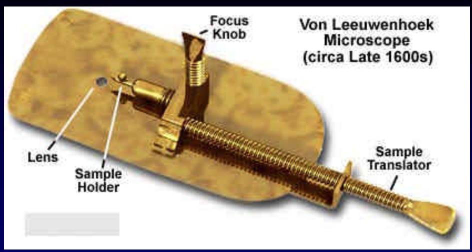
Illumination Lens

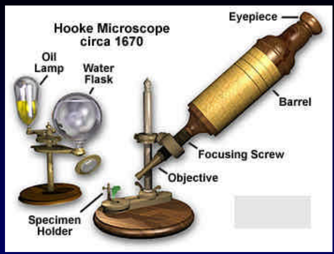
Specimen

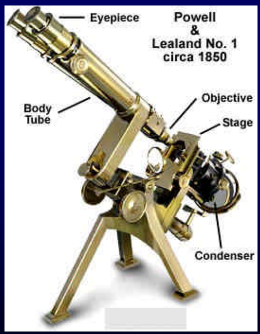
Magnifying Lens

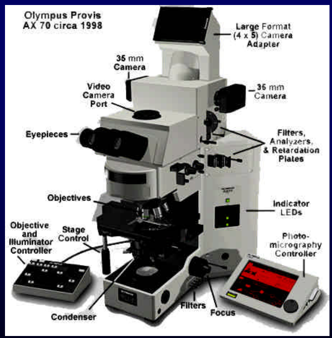
Viewer



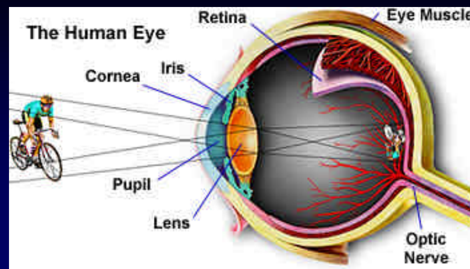


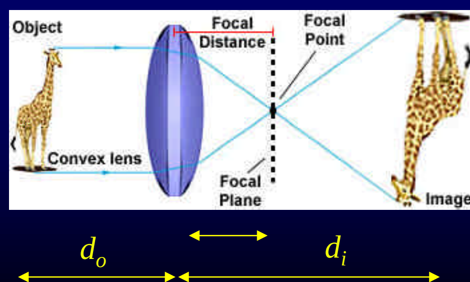






Lenses are Simple



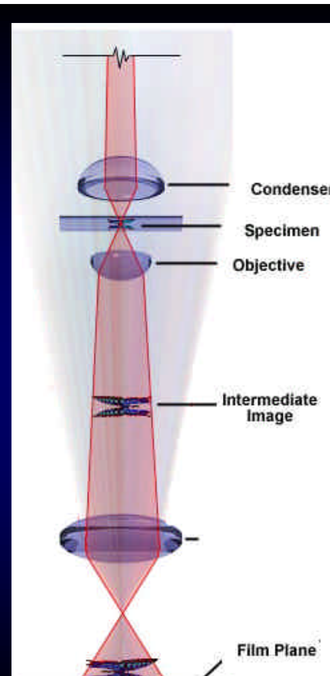


Thin Lens Formulae

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$M = -\frac{d_i}{d_o}$$

Compound Microscope



Higher Magnification is achieved by Stacking Lenses

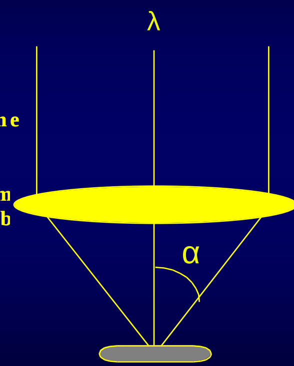
$M = M_1 * M_2 * M_3$

What are the limits of Resolution?

Abbe (Diffraction) Limit:

Defines the minimum resolvable distance between the image of two point objects using a perfect lens.

In any magnifying system a point object (i.e. zero dim cannot be imaged as a point but is imaged as a distrib intensity having a finite width.



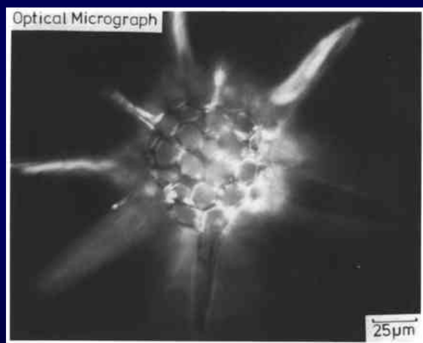
Resolution of an imaging system $= \rho = \dfrac{0.61\lambda}{\eta \sin(\alpha)}$

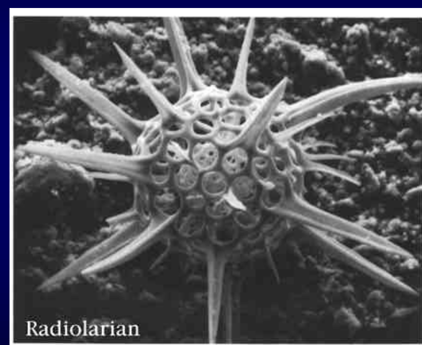
λ = wavelength of the imaging radiation
η = index of refraction of the lens
α = illumination semi-angle

Light vs Electrons

Light Microscope	Electron Microscope
λ = 0.5 μm	$\lambda \sim \sqrt{\frac{150}{V_o}}$ = 0.055 Å (@50 kV)
η = 1.5 (glass)	η = 1.0 (Vacuum)
α = 70°	α = 1°
ρ = 0.2 μm = 2000 Å	ρ = 0.00016 μm = 1.6 Å

Depth of Field





Depth of Field

The distance parallel to the optical axis of the microscope that a feature on the specimen can be displaced without loss of resolution

Optical Microscope

$$d = \frac{\lambda\sqrt{\eta^2 - (NA)^2}}{(NA)^2} + \frac{250}{M^2}$$

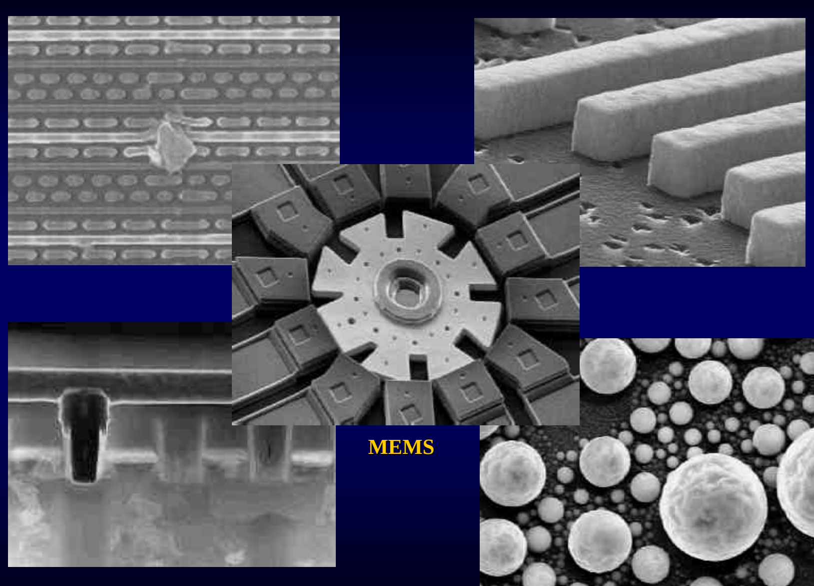
Electron Microscope

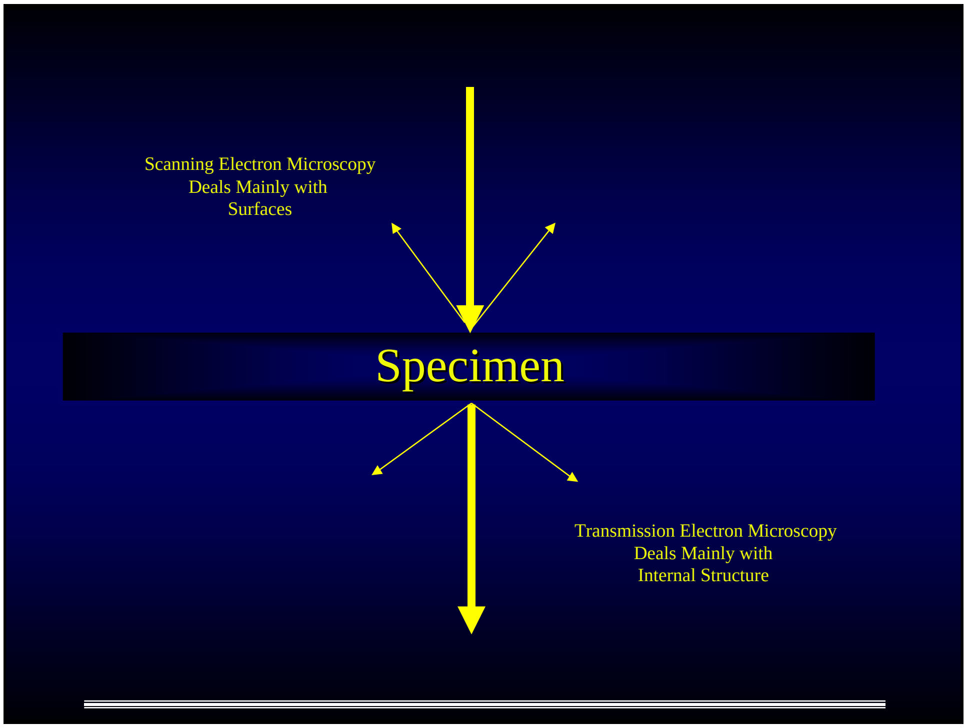
$$d = \frac{0.1\ mm}{M\,\alpha}$$

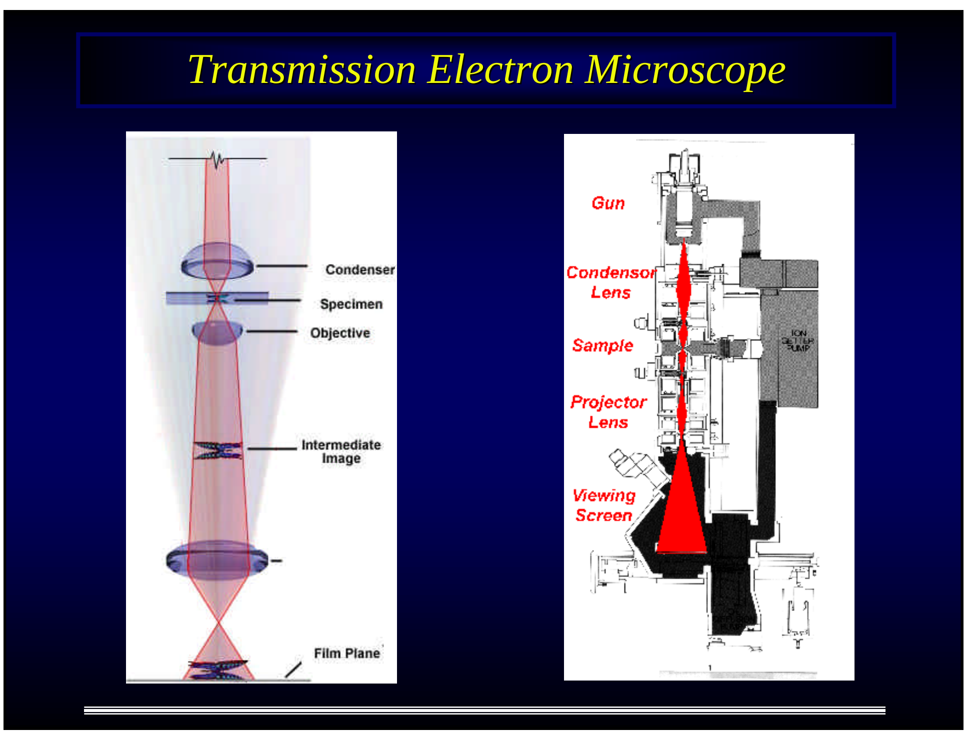
λ = wavelength
η = refractive index
α = semi angle
M = total magnification
NA= Numerical Aperture of lens

Depth of Field

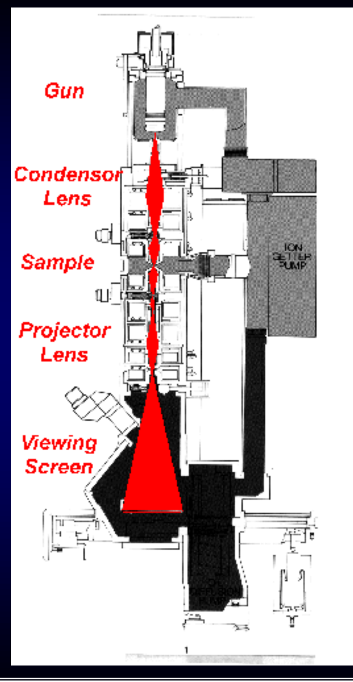
Magnification	Depth of Focus: Optical	Depth of Focus: SEM
10	60 μm	1000 μm
100	8 μm	100 μm
1,000	0.2 μm	10 μm
10,000	-	1 μm




Scanning Electron Microscopy
Deals Mainly with
Surfaces
Specimen
Transmission Electron Microscopy
Deals Mainly with
Internal Structure


Transmission Electron Microscope
Condenser
Specimen
Objective
Intermediate
Image
Film Plane
Gun
Condensor
Lens
Sample
Projector
Lens
Viewing
Screen

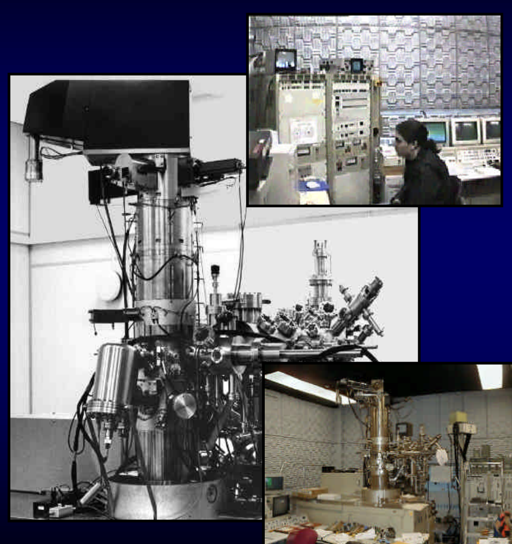
Basic Componets of an Electron Microscope



Transmission Electron Microscope

ANL - *Advanced Analytical Electron Microscope*

- ***Cold Field Emission Electron Source***
  - **Vo: 50 - 300 kV**
- ***Ultrahigh vacuum (UHV) environment***
  - **~ 1 x 10^{-11} torr - Gun, < 2 x 10^{-10} torr - Column**
  - **< 5 x 10^{-10} torr - Specimen Preparation Chamber**
- ***Electron Optics capable of :***
  - **STEM / SEM:**
  - **TEM:**
  - **CBED/SAED:**
  - **Other Modes: TSEM, TSED, RHEED**
- ***Side Entry Goniometer Stages***
  - **RT Double Tilt Beryllium:**
  - **LN2 Cooled Double Tilt Be Stage:**
  - **Single Tilt Heating Stage:**
- ***Analytical SubSystems on the E/O Column***
  - **XEDS , EELS, AES**
- ***Specimen Preparation Chamber***
  - **High Pressure/Temperature Gas Reaction Cell**
  - **Thin Film Evaporation Chamber**
  - **Mini-SIMS system - Gallium LMIS, Quad Mass Analyzer**
  - **RV LEED & Vacuum Transfer Vessel**
  - **ANL MultiPort Station for development work.**
- ***Computer Control***
- ***Special Objective Lens Port Configuration***
  - **7 Experimental Ports on Objective Lens for Analytical Equipment**
  - **3 Additional Ports for Electrical Feedthrus etc...**

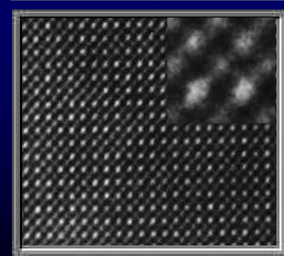


Transmission Electron Microscopy

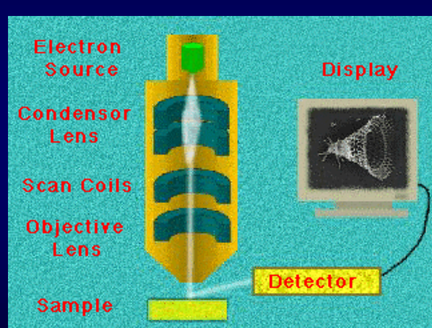
Conventional
Imaging

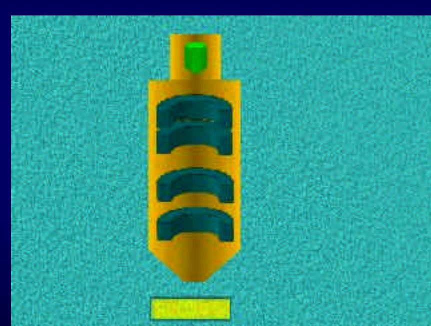
High
Resolution
Imaging

Diffraction



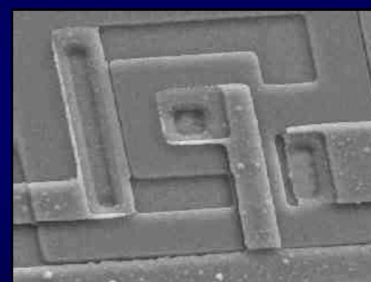
Basic Componets of a
Scanning Electron Microscope



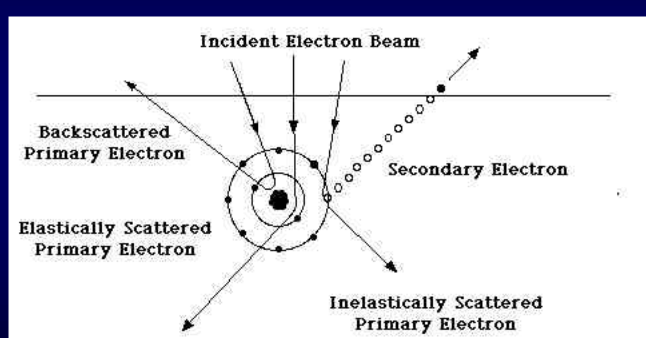


Scanning Electron Microscope

Scanning Electron Microscope



Sources of Electron Emission from the Sample

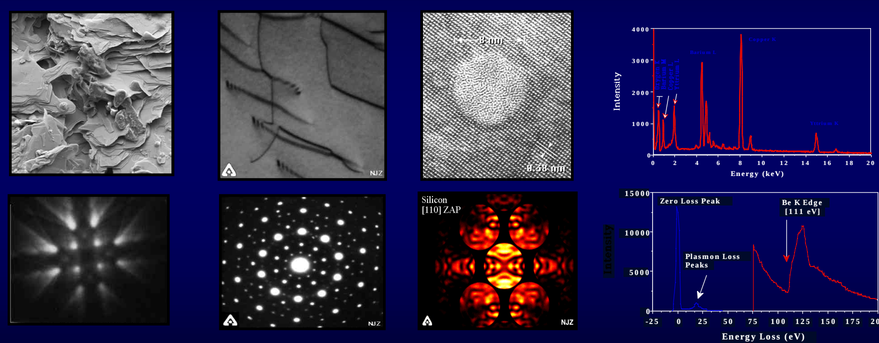


MicroCharacterization via Electron Microscopy

SEM
Scanning Electron Microscopy

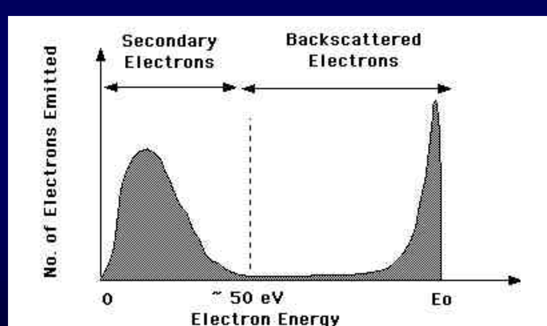
TEM - STEM - HREM
Transmission - Scanning Transmission - High Resolution Electron Microscopy

AEM
Analytical Electron Microscopy

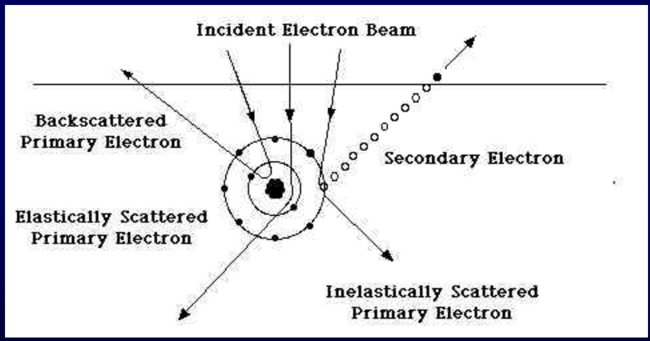


Morphology, Crystallography, Elemental , Chemical , Electronic Structure

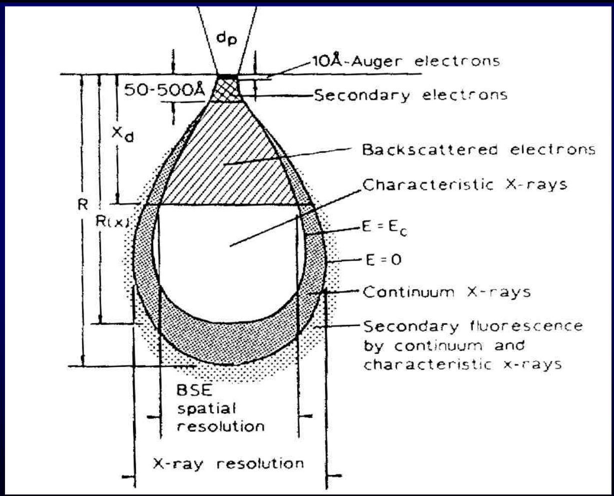
Electron Energy Distributions



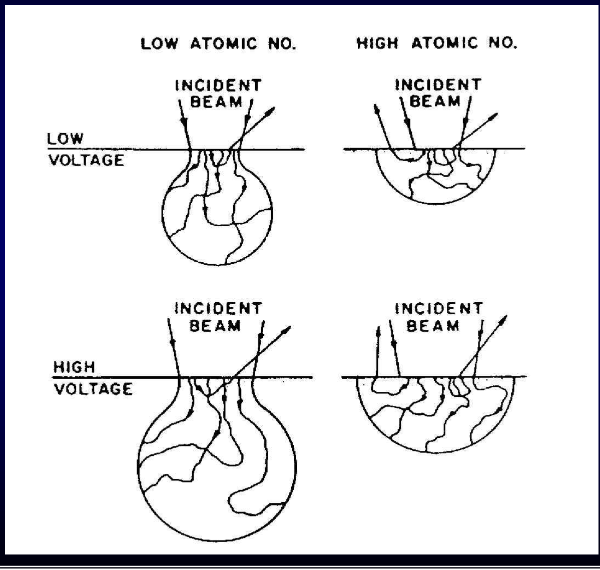
Sources of Electron Emission from the Sample



How deep does the signal come from?



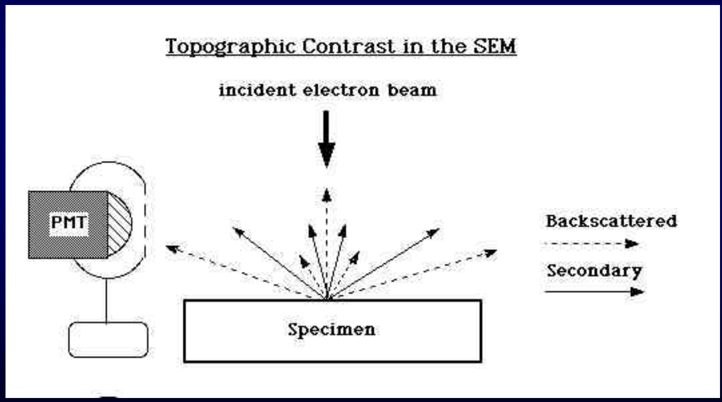
Electron - Solid Interactions Determine the "Depth" of Information

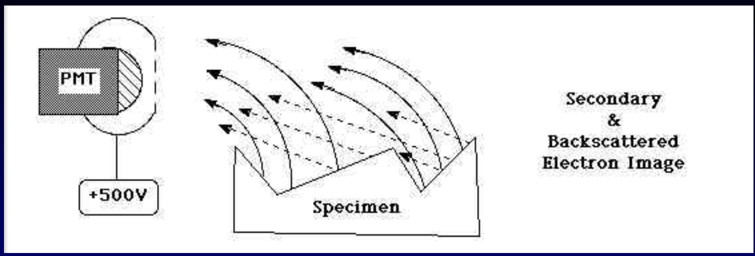


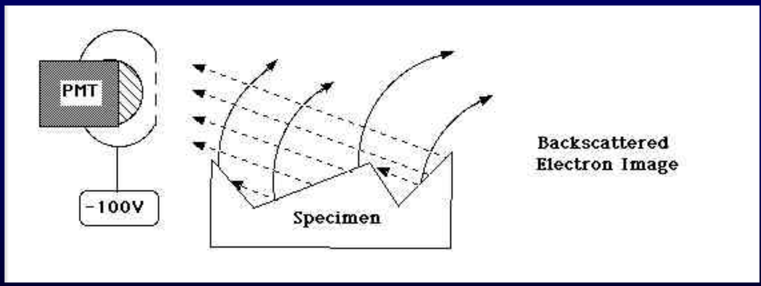
Contrast in an SEM Image

- Topographic Contrast
- Atomic Number Contrast
- Voltage Contrast
- Magnetic Contrast
- Electron Beam Induced Current
- Cathodoluminescenece
- Electron Channeling Contrast
- Electronic/Digital Signal Processing
- Characteristic X-ray Emission

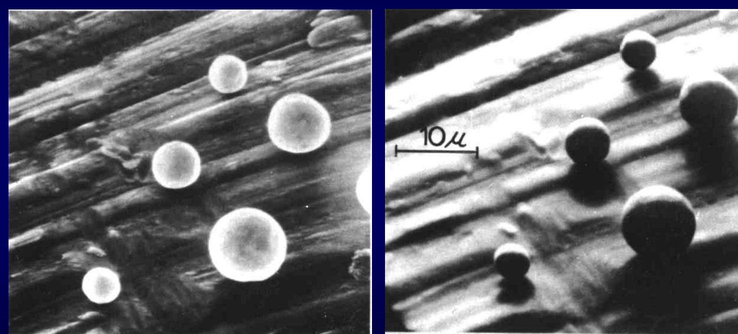
Contrast in an SEM Image

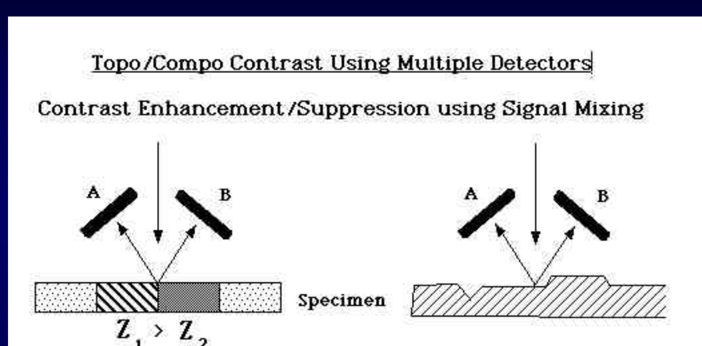


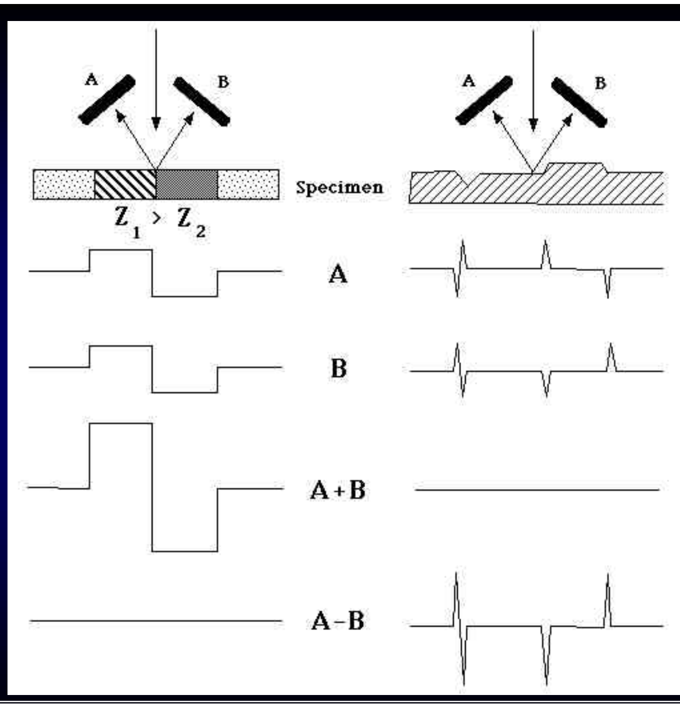




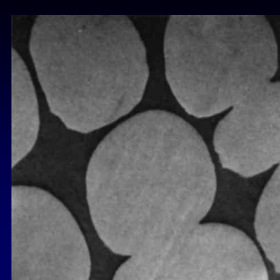
SEI vs BSI

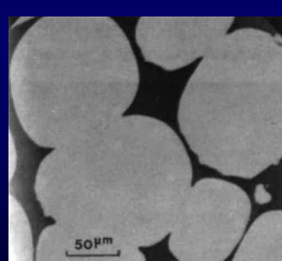

10μ

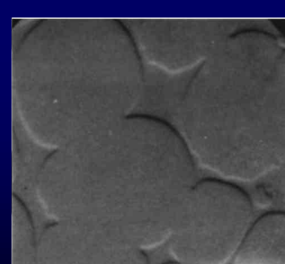

Topo/Compo Contrast Using Multiple Detectors
Contrast Enhancement/Suppression using Signal Mixing
A
B
Specimen
Z1 > Z2
A
B



Topographic
Compositonal
Contrast

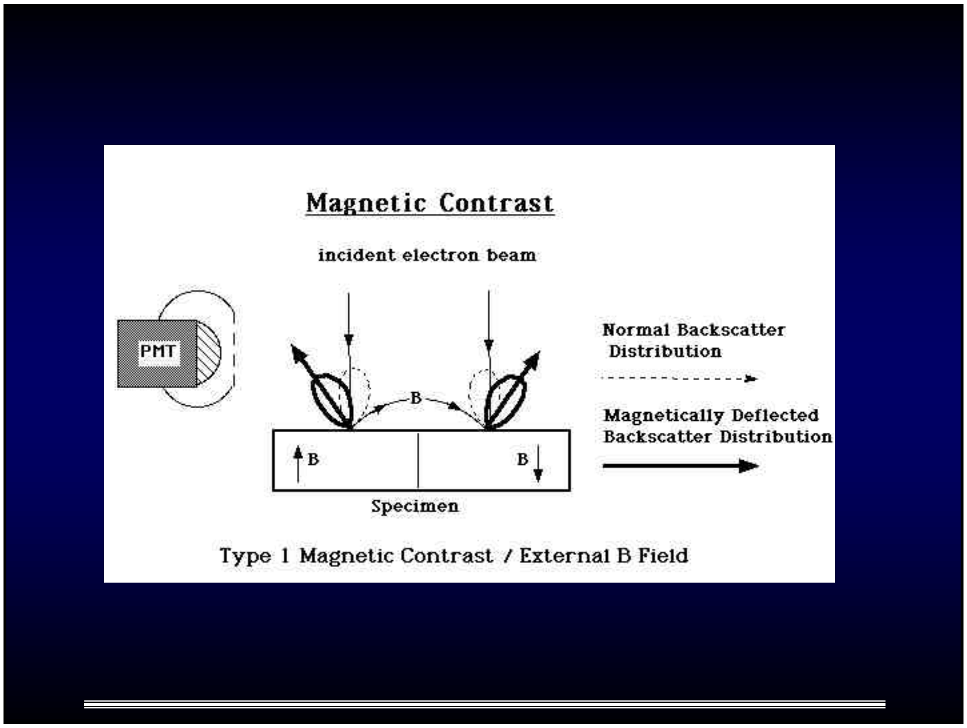


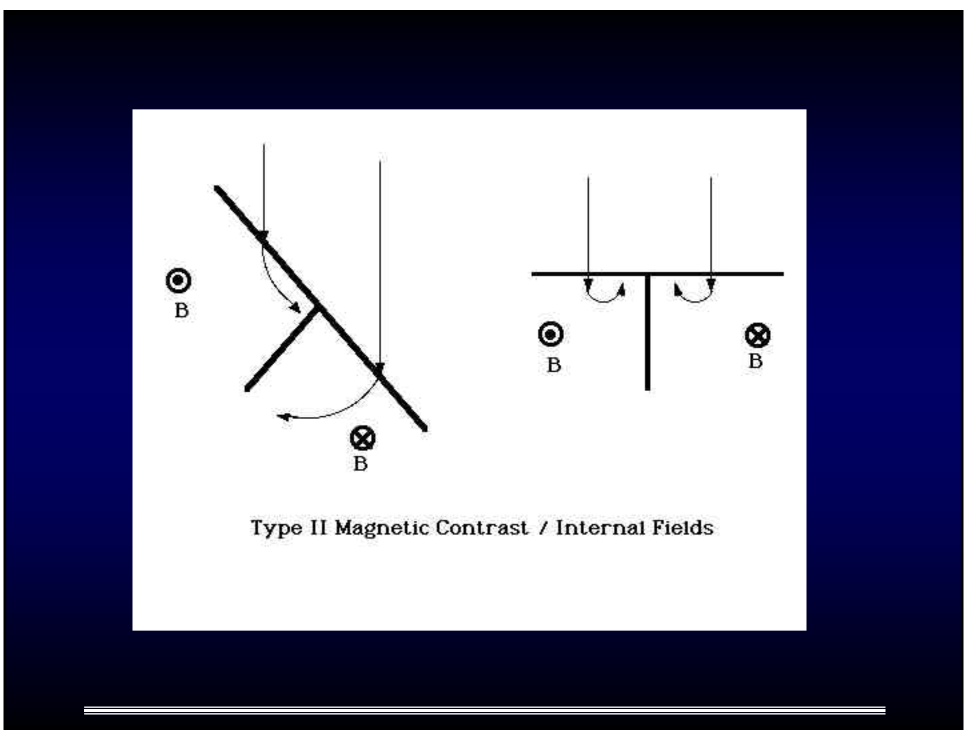




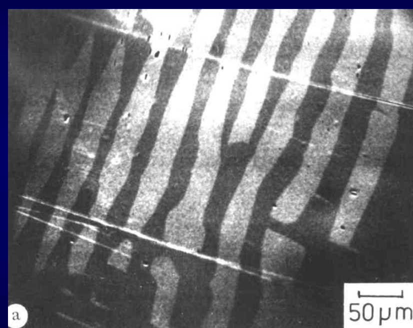
A+B

A-B

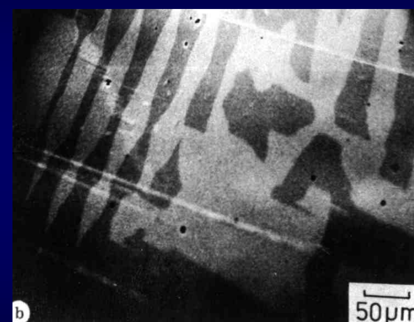

Magnetic Contrast
incident electron beam
PMT
Normal Backscatter
Distribution
Magnetically Deflected
Backscatter Distribution
B
B
B
Specimen
Type 1 Magnetic Contrast / External B Field


B
B
B
B
Type II Magnetic Contrast / Internal Fields

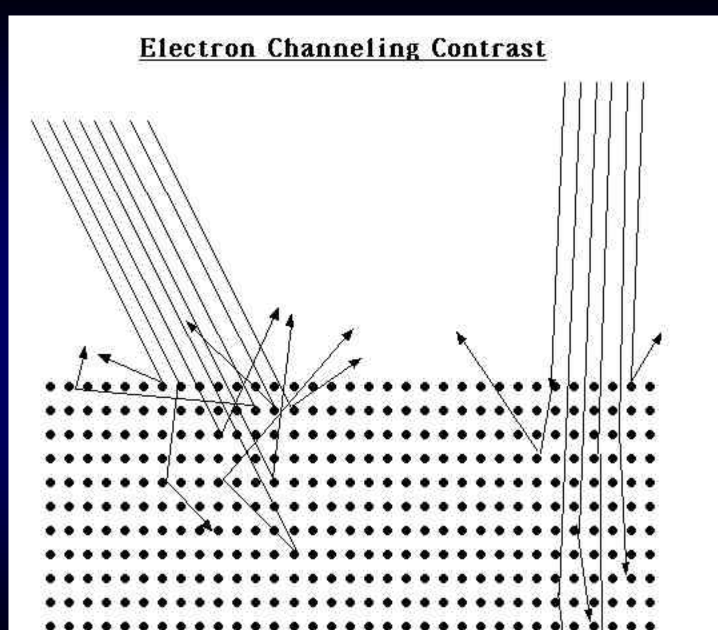
Magnetic Contrast



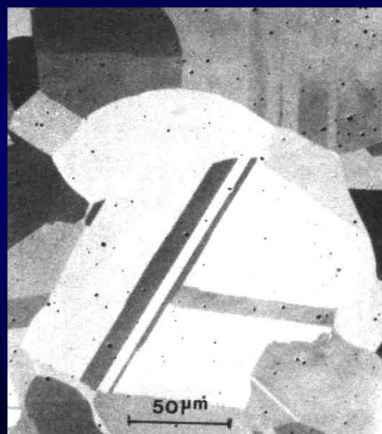
No Field

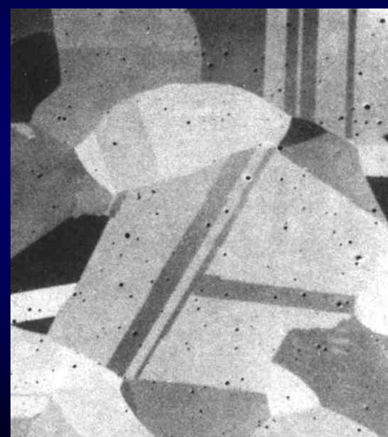


Field On

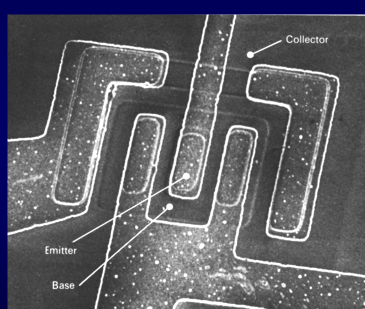


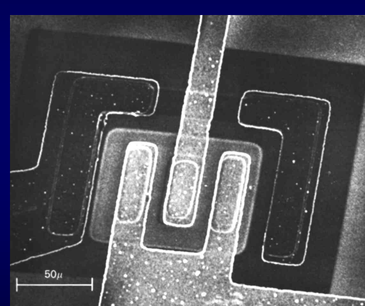
Channeling Contrast





Voltage / Current Contrast



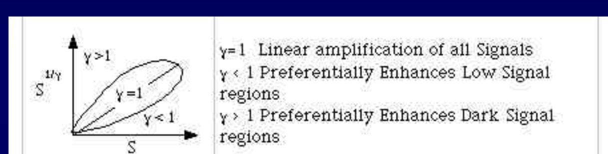


Electronic/Digital Signal Processing

This contrast methodology is independant of the actual contrast mechanism operating in the solid, however, it is sometimes critical in deremining the visibility of a signal generated by the electron-solid interaction. Today this may be done either on-line by analog processing or off-line using digital signal processing methods and dedicated image processing systems

- **Black Level Suppression**
- **Non-Linear Amplification**
- **Differentiation**
- **Signal Mixing**
- **Digital Processing**

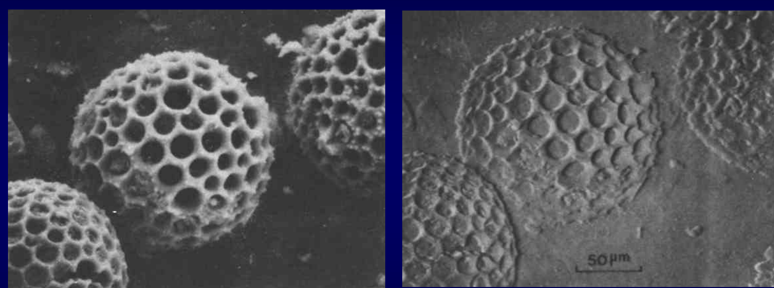
Black Level Suppression



Non-Linear Amplification

Differentiation

Digital / Electronic Processing

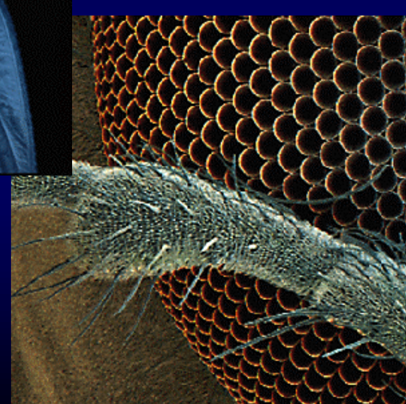


Images of the World Around Us


30 μ
MicroScape


Alien Terrain?

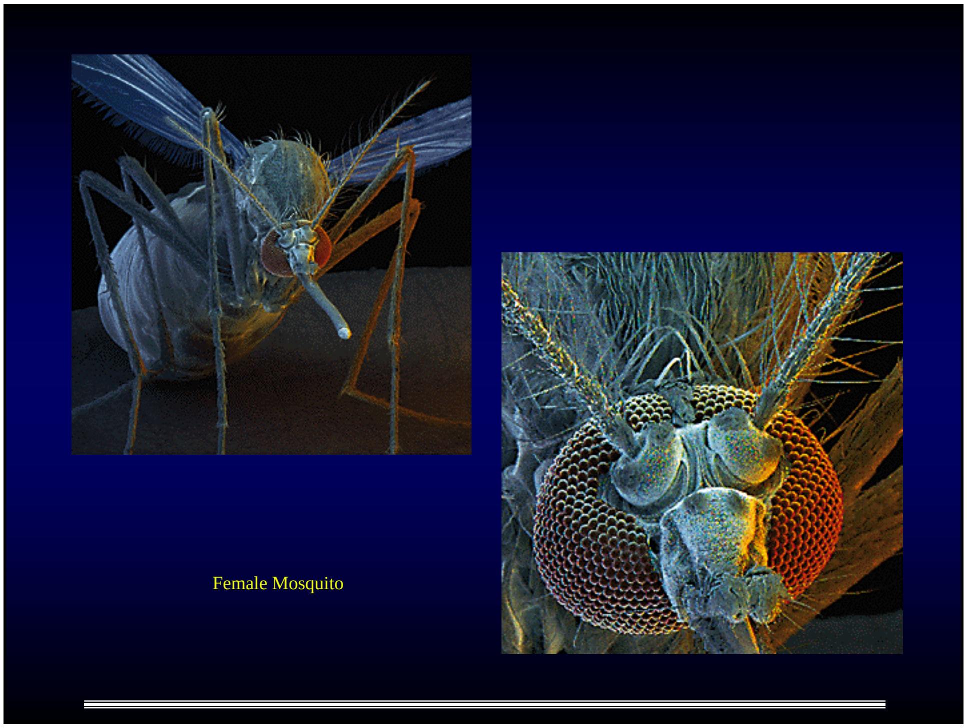
Colorized SEM Micrographs
Courtesy of David Scharf

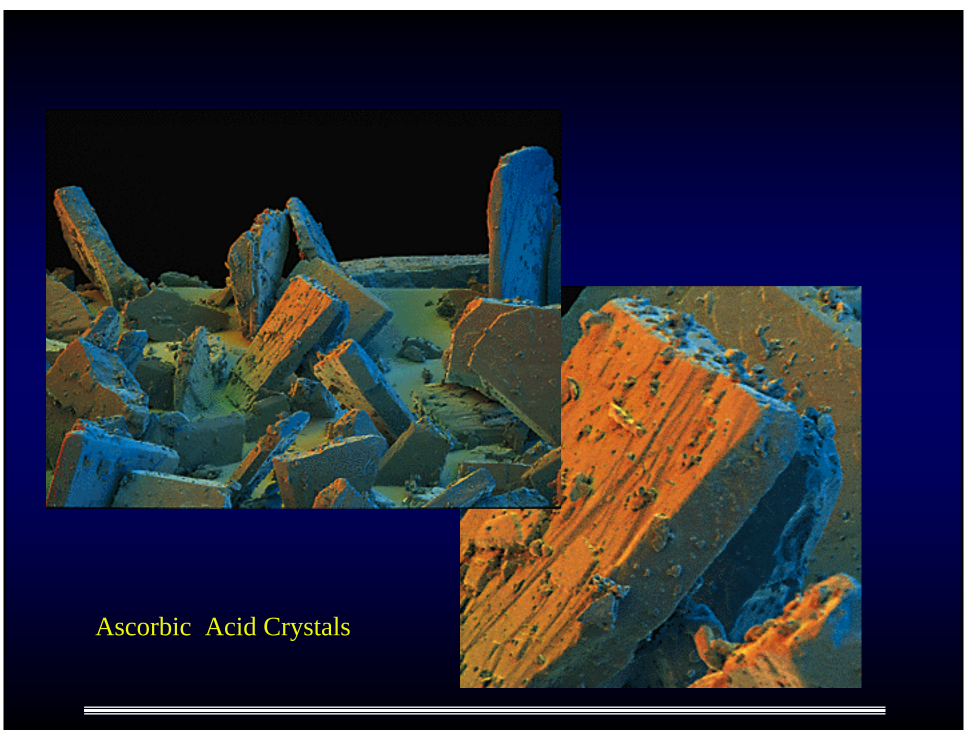


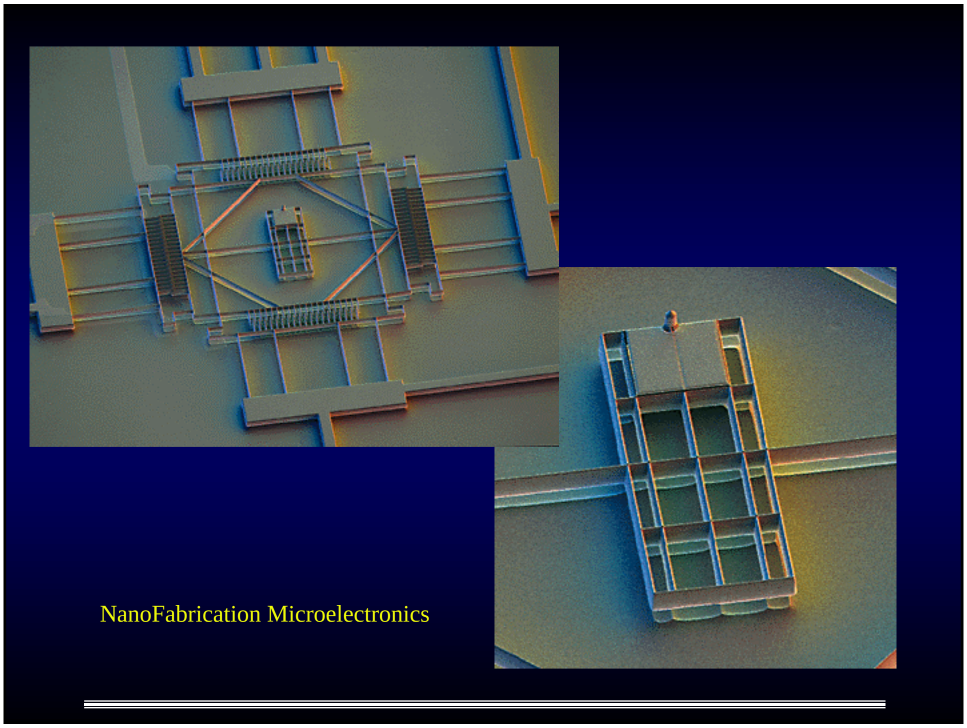
Black Fly

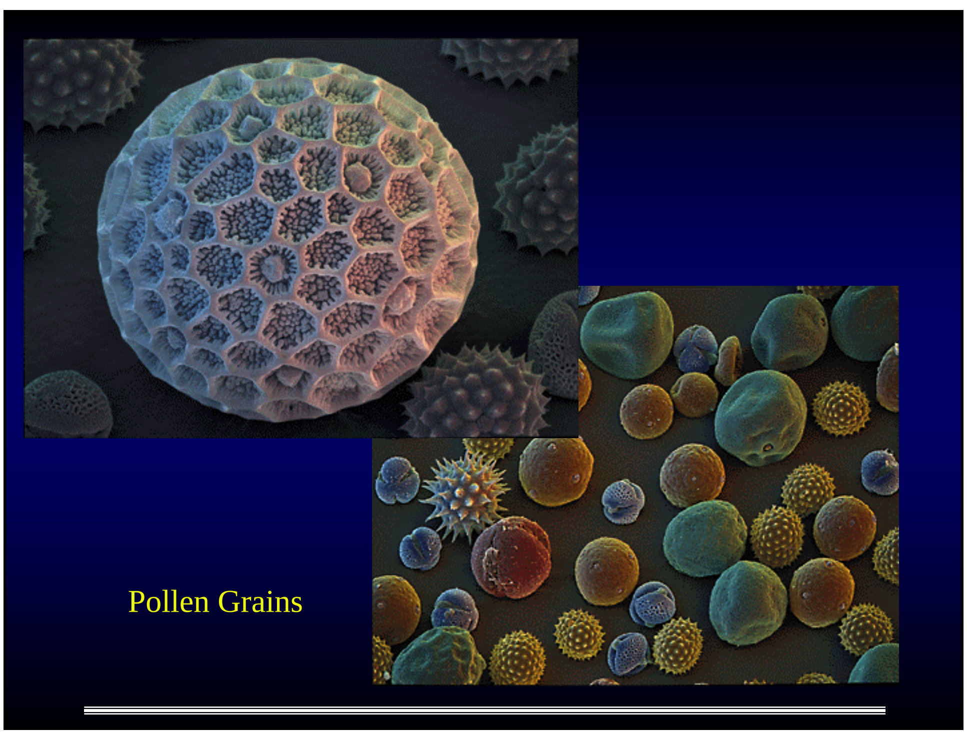

Mite Feeding on Mistococrad


Deer Tick


Female Mosquito


Ascorbic Acid Crystals


NanoFabrication Microelectronics


Pollen Grains

Microscopy Resources

http://tpm.amc.anl.gov - TelePresence Microscopy Site

http://www.amc.anl.gov - M&M WWW Site

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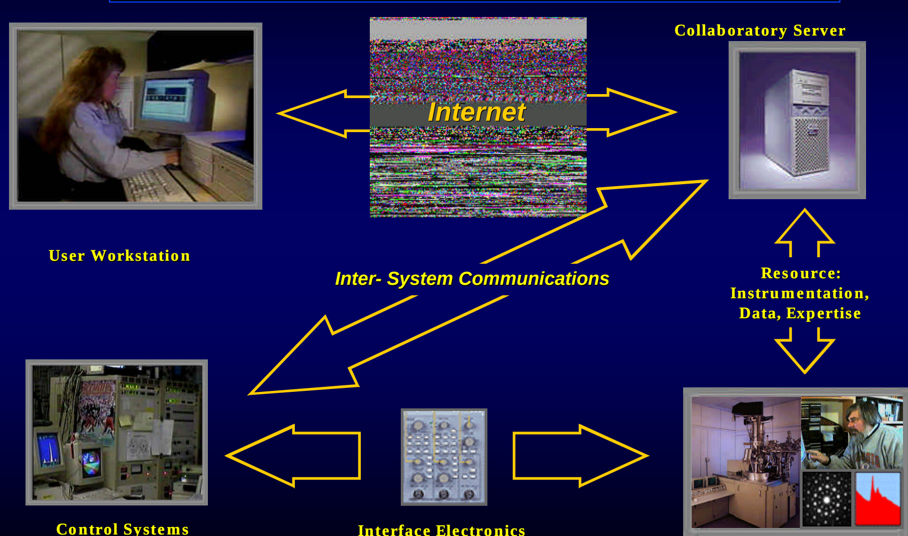
http://www.msa.microscopy.com/MicroScape/MicroScape.html

http://www.msa.microscopy.com/ProjectMicro/PMHomePage.html

http://www.msa.microscopy.com

TelePresence Microscopy Collaboratory Architecture

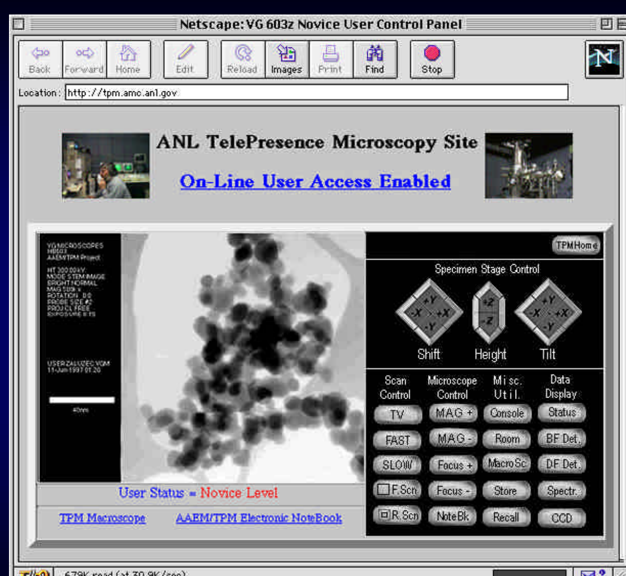


ANL - WWW TPM Server

Provides Platform Independent Access

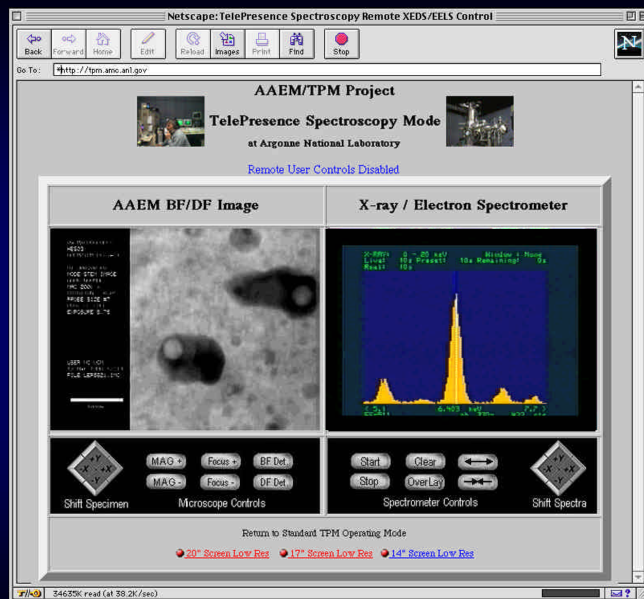
On-Line Instrument Control

Platform Independent WWW Interface



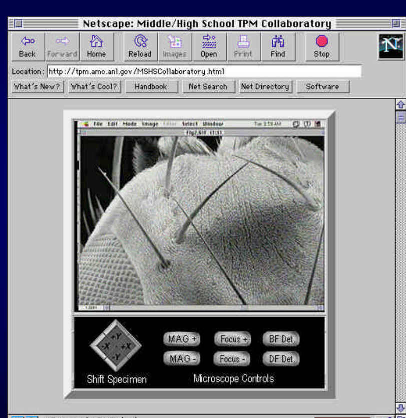
On-Line Instrument Control

Platform Independent WWW Interface



TelePresence Microscopy

Middle/High School Collaboratories



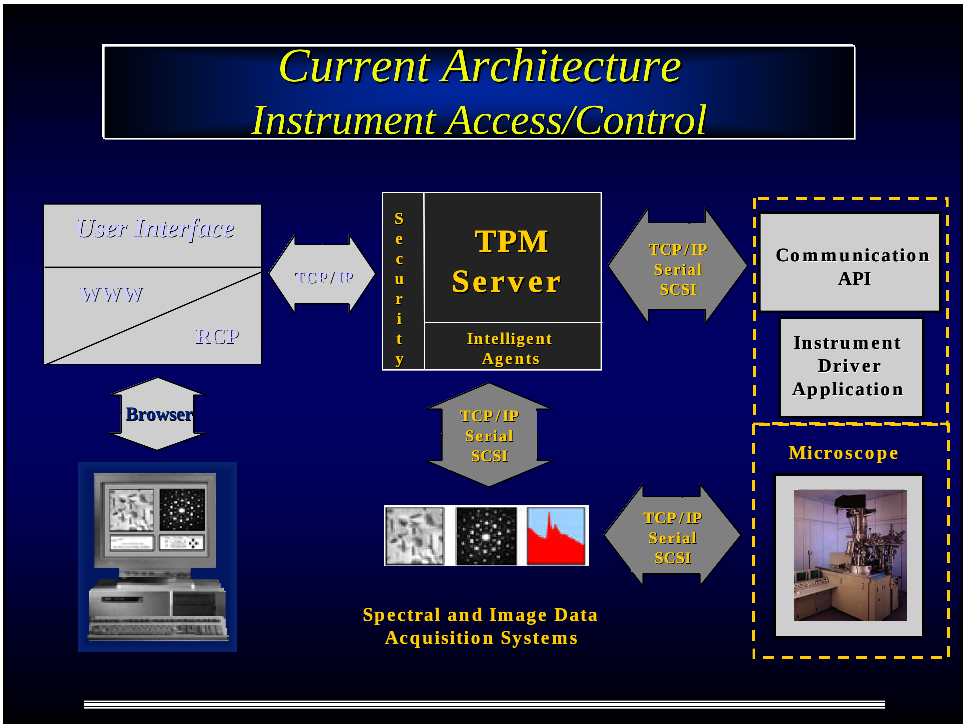
Netscape Client on Mac's & PC's in Classroom provides simple and inexpensive interface where students and remote instructors can interact with Microscopes.

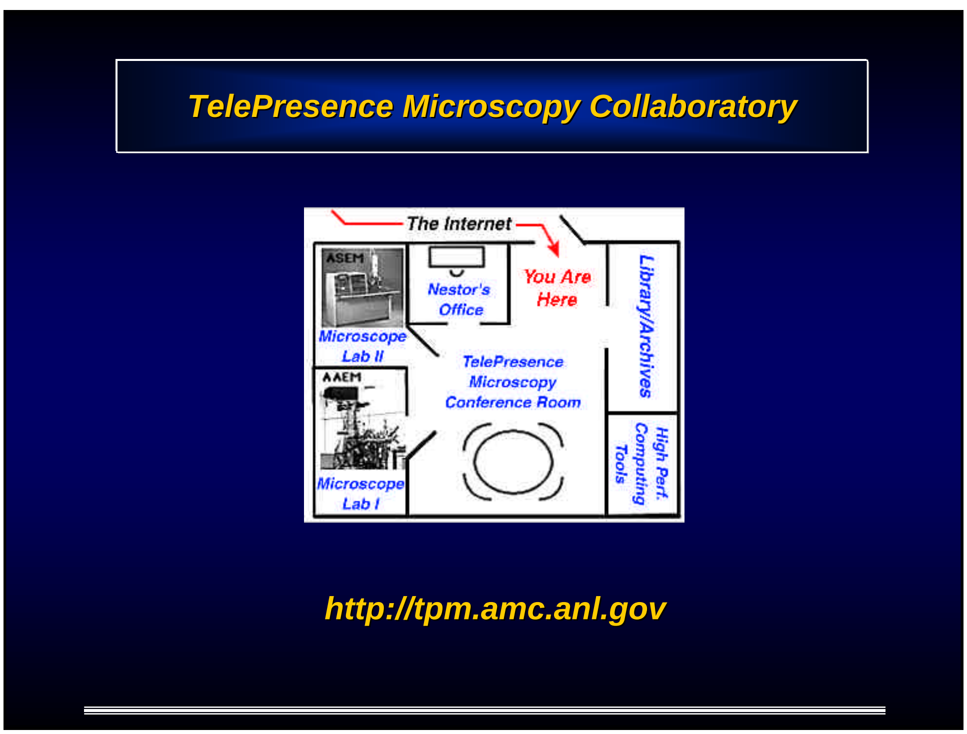
Live Video Conferencing using "CuSeeMe" provides low cost interactions between Instructor and Students

Middle/High School Collaboratories

Materials MicroCharacterization Collaboratory

http://tpm.amc.anl.gov/mmc


Current Architecture
Instrument Access/Control
User Interface
WWW
RCP
Browser
TCP/IP
Security
TPM Server
Intelligent Agents
TCP/IP Serial SCSI
Communication API
Instrument Driver Application
TCP/IP Serial SCSI
TCP/IP Serial SCSI
Microscope
Spectral and Image Data Acquisition Systems

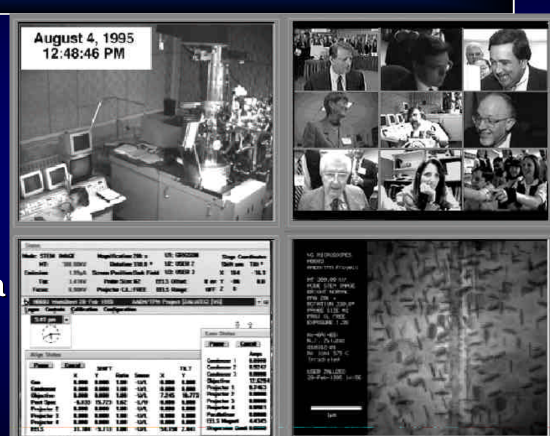

TelePresence Microscopy Collaboratory
The Internet
ASEM
Nestor's Office
You Are Here
Library/Archives
Microscope Lab II
AAEM
TelePresence Microscopy Conference Room
High Perf. Computing Tools
Microscope Lab I
http://tpm.amc.anl.gov

Network Based Video Conferencing is Possible, but Immature

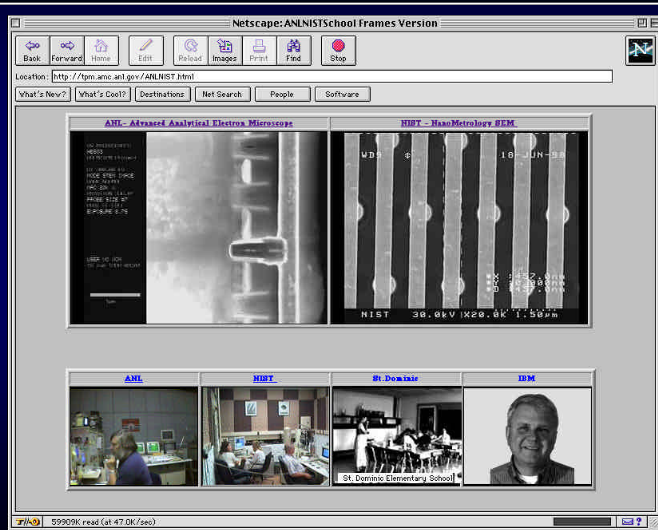
TelePresence Microscopy

Provides Access to:

- **Instrument Room**
- **Instrument Status**
- **Experimental Data**
- **On-Line Control**
- **Video Conferencing**
- **Electronic**

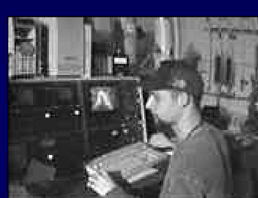


Middle/High School Collaboratories

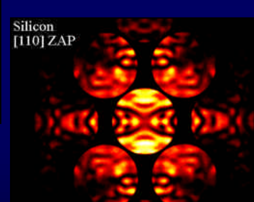


TelePresence Collaboration

Key to All Scientific Experiments is the Interaction of Investigators with:



Instrumentation



Data

Collaboration