

Introduction to Nanotechnology

Kuei-Hsien Chen: IAMS, Academia Sinica & CCMS, NTU

Ph.D. 1989 Harvard University

Hossein hosseinkhani: GSMST, NTUST

Ph.D. Kyoto University

Chunwei Chen: MSE, NTU

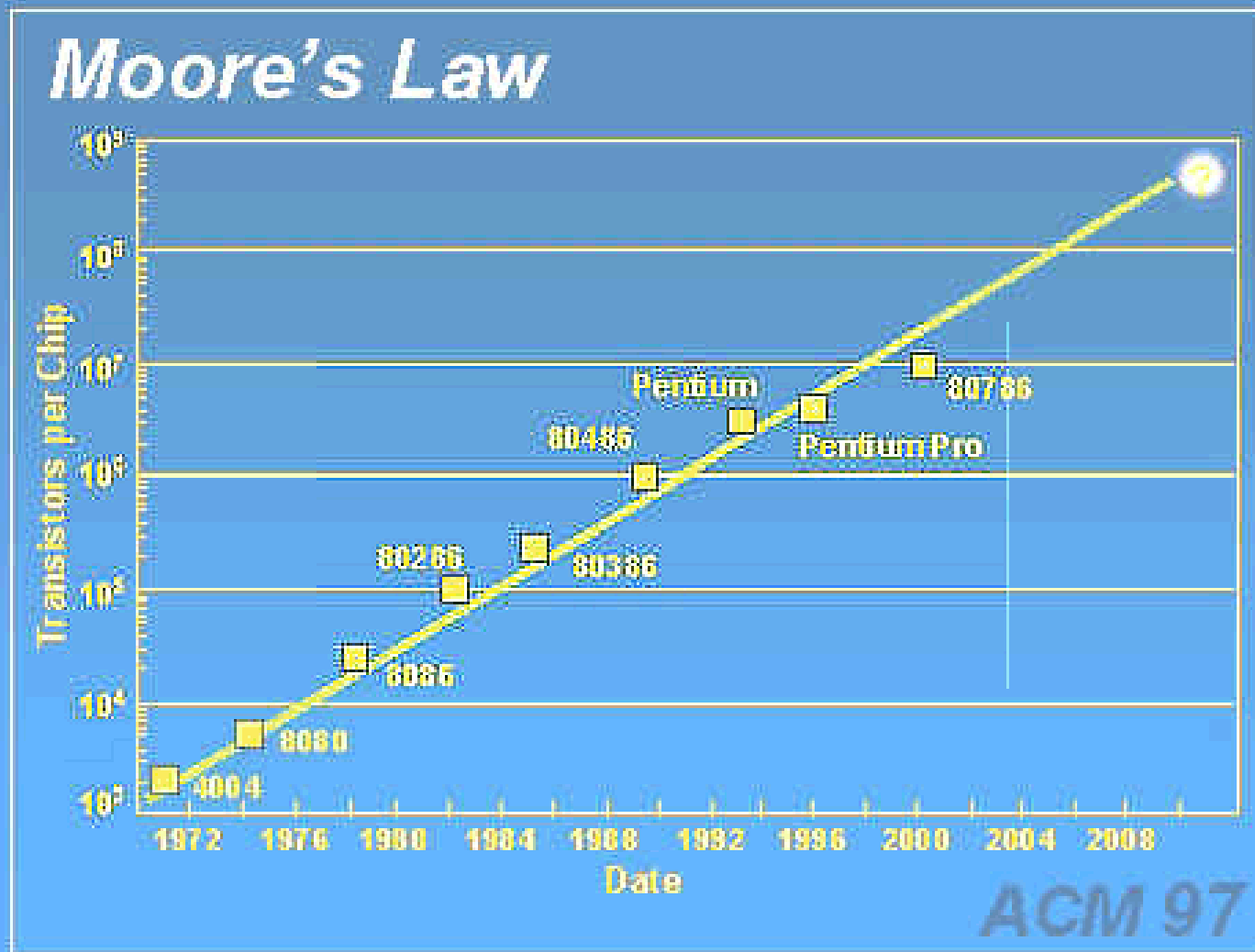
Ph.D. Cambridge University

Li-Chyong Chen: CCMS, NTU

Ph.D. 1989 Harvard University



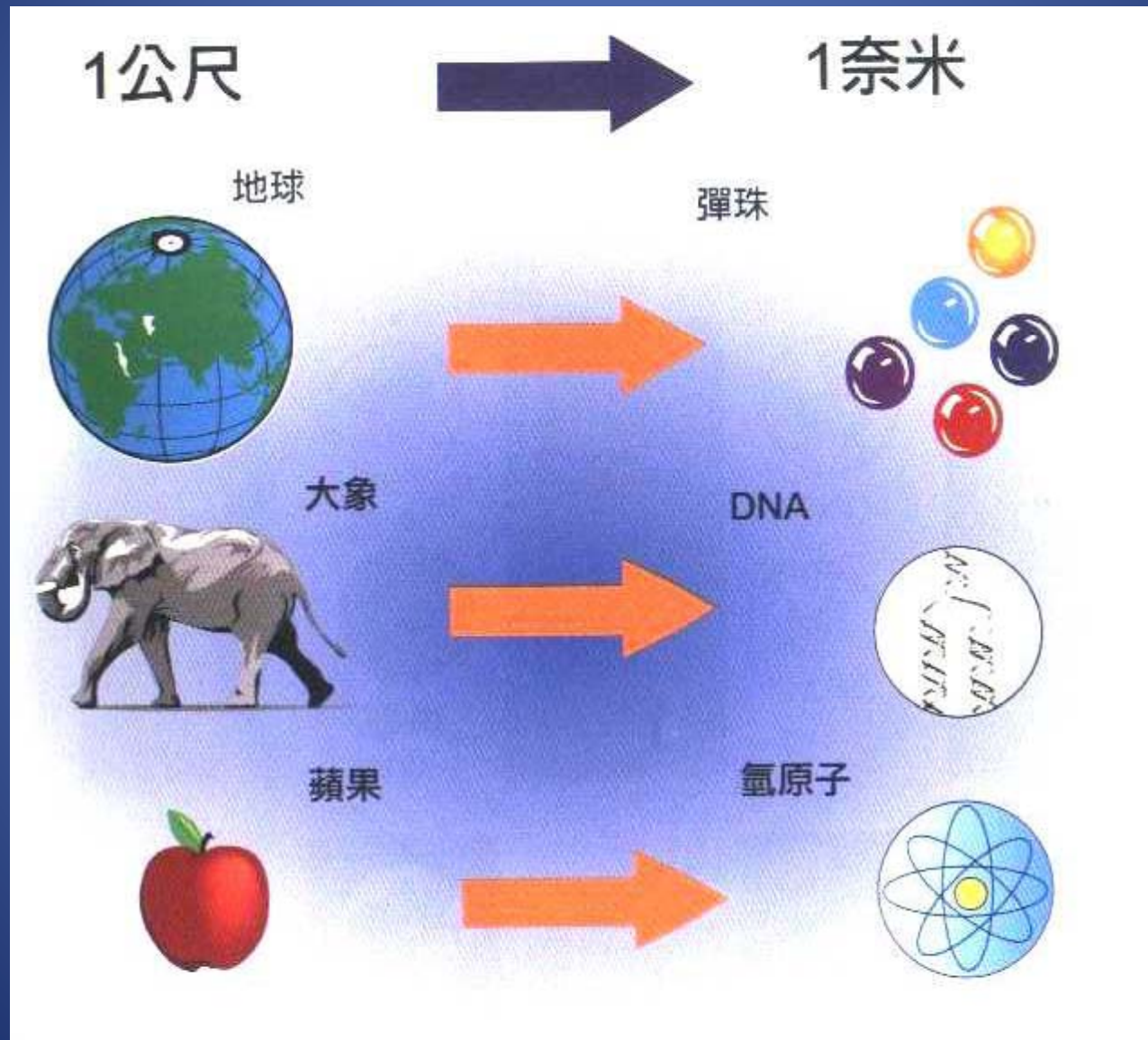
Moore's Law



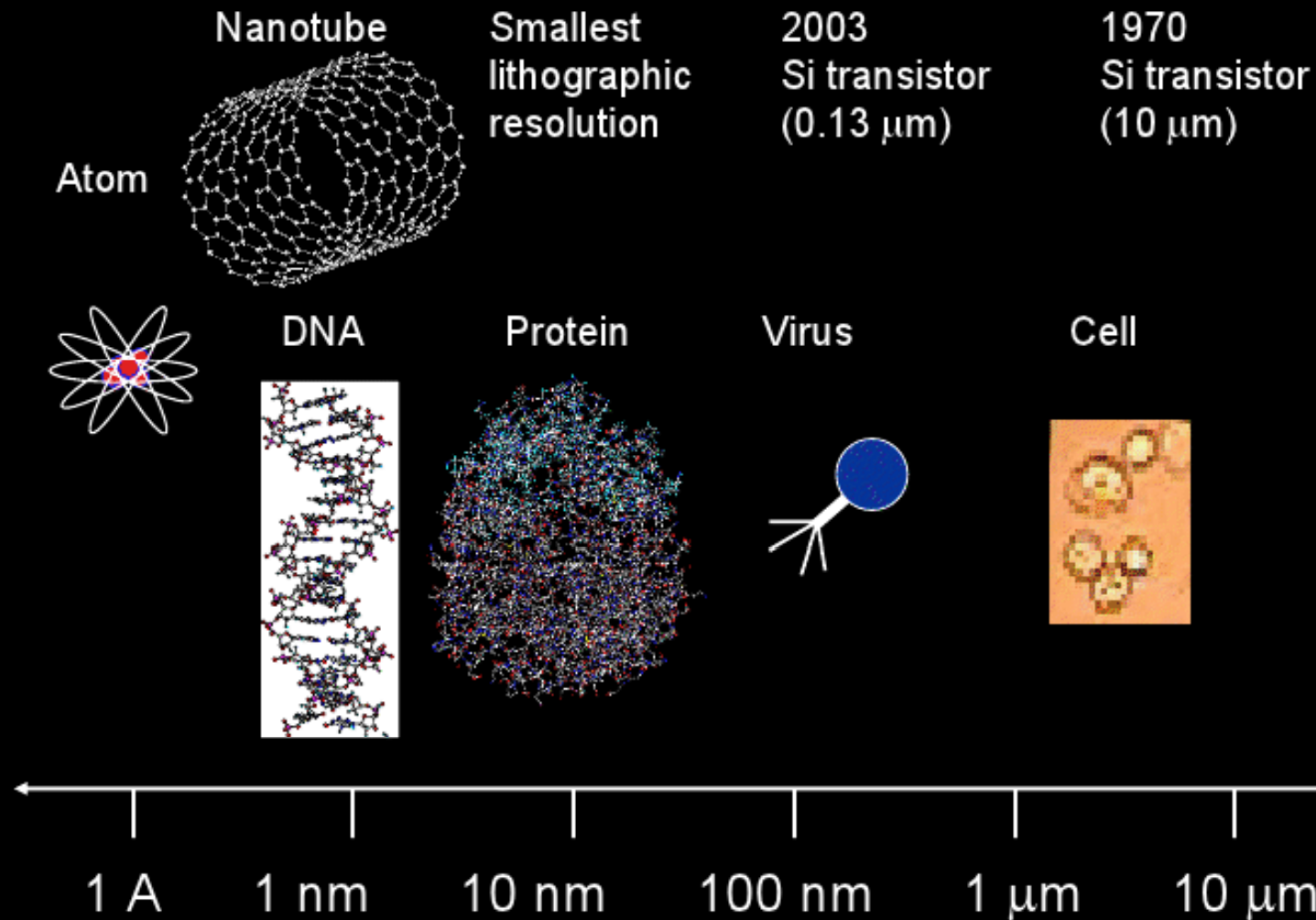
Units

- Meter (m)
- Millimeter (mm) = 10^{-3} m
- Micrometer (μm) = 10^{-6} m
- Nanometer (nm) = 10^{-9} m
- Picometer (pm) = 10^{-12} m
- Femtometer (fm) = 10^{-15} m

What is Nano?



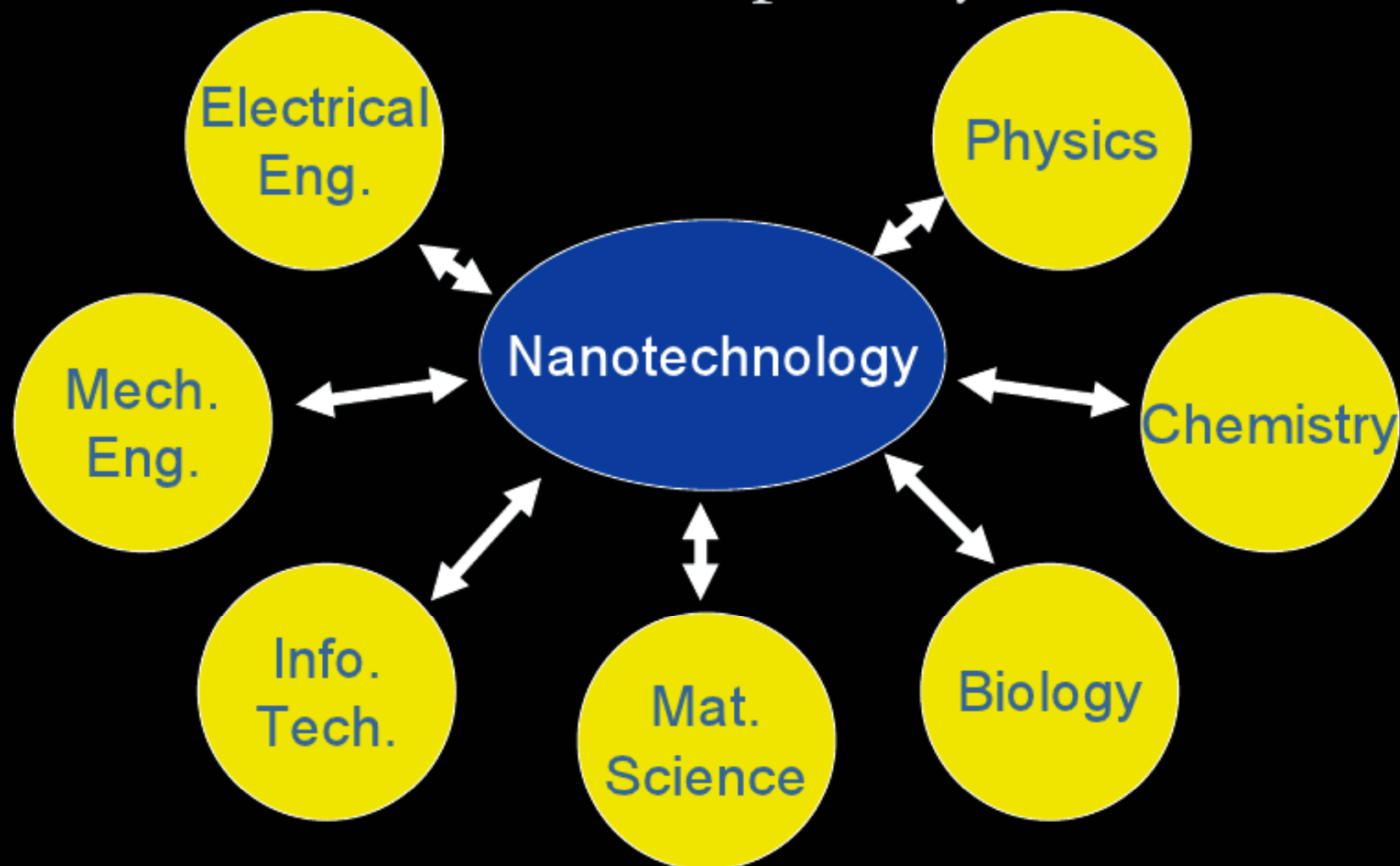
Length scales



What is nanotechnology?

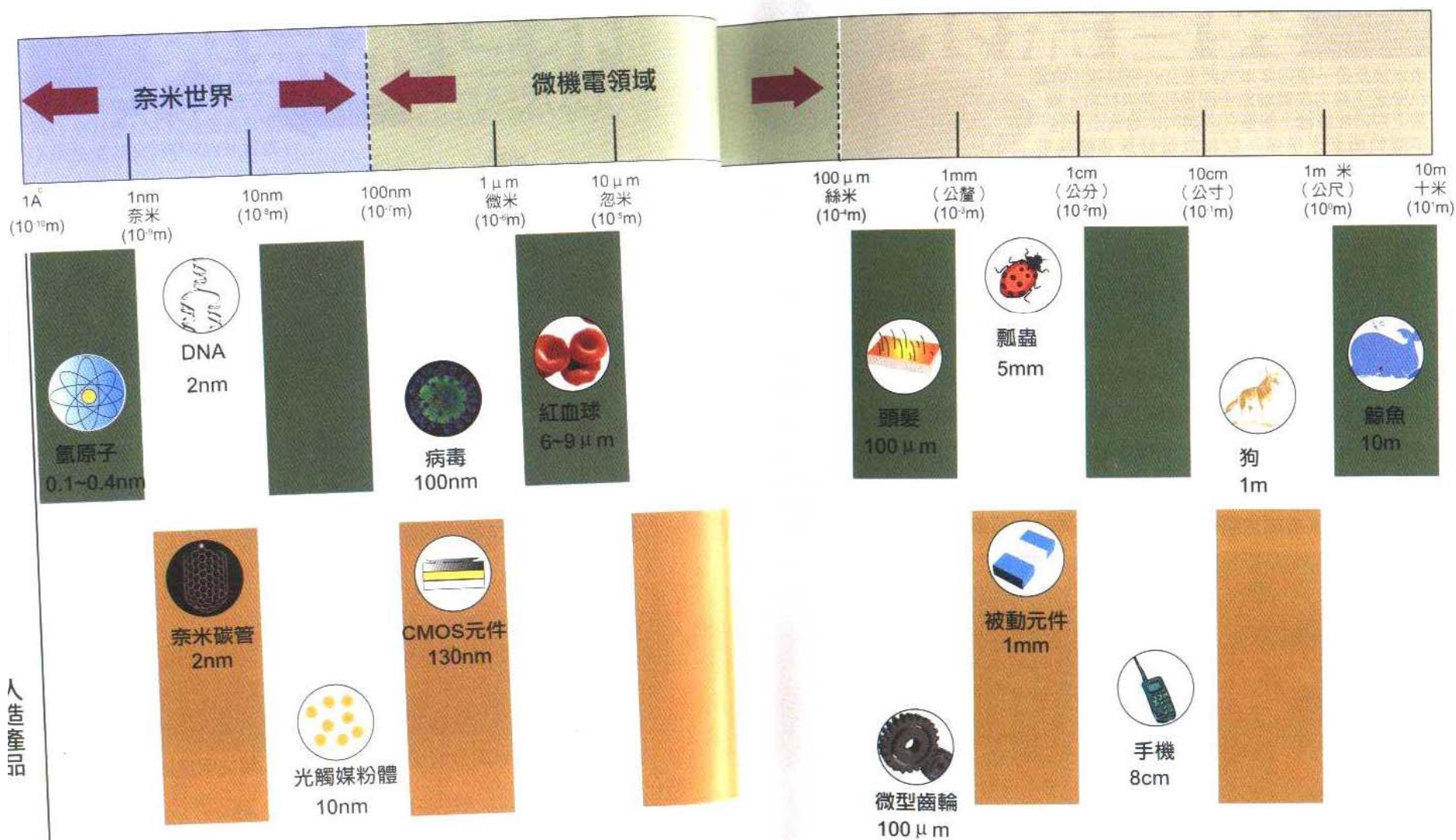
- “Top down” approach
 - Micron scale lithography
 - optical, ultra-violet
 - Focused Ion Beam
 - 10-100 nm
 - Electron-beam lithography
- “Bottom up” approach
 - Chemical self-assembly
 - Man-made synthesis (e.g. carbon nanotubes)
 - Biological synthesis (DNA, proteins)
 - Manipulation of individual atoms
 - Atomic Force Microscopy
 - Scanning Tunneling microscopy

Nanotechnology is
multidisciplinary:



奈米世界

奈米是人造科技，但自然界中其實有許多奈米物質及奈米組織，可提供我們更多創意來發展奈米技術。



A brief history of nanotechnology

- Democritus in ancient Greece: concept of atom
- Rutherford, 1900: discovery of atomic nucleus
- Feynman, 1960: speech at Caltech
- Drexler, 1986, 1992: *Engines of Creation, Nanosystems*
- Clinton, speech, Caltech, 2000
- *National Nanotechnology Initiative* since 2000

Nano-manufacturing

- Lithography can do 10 nm
- Tricks to 2 nm
- Biosystems can add 2 carbon atoms at a time
 - typical in lipid biosynthesis
 - enzymes are nano machines
- We do not know how to design enzymes, only copy them
- As such, nanotechnology does not yet exist according to Drexler's definition

Some nanotechnology uses

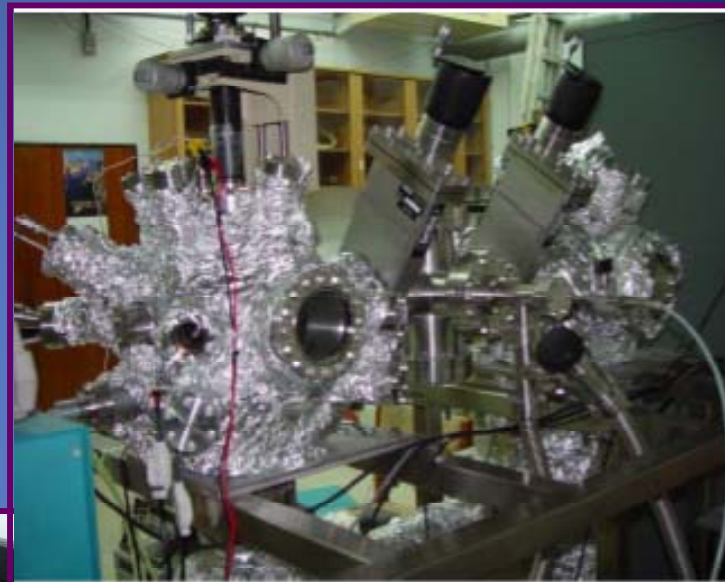
- Nanoparticles:
 - Catalysts for industrial chemical processing
- Nanocapsules
 - Possible organ specific drug delivery
- Nanomaterials
 - Improved strength and weight
 - E.g. carbon nanotube based materials could be stronger and lighter than steel
- Nanomechanical devices
 - RF signal processing
- Nanofluidic devices
 - Lab on a chip
- Nanoelectronic devices (focus of this course)
 - Computation
 - Communication
 - Nano-bio-electronic interfaces
 - Chemical and biological weapons detection
 - DNA sequencing
 - Point-of-care clinical diagnoses
 - Fundamental studies of molecular biology

Modern Alchemy (I)

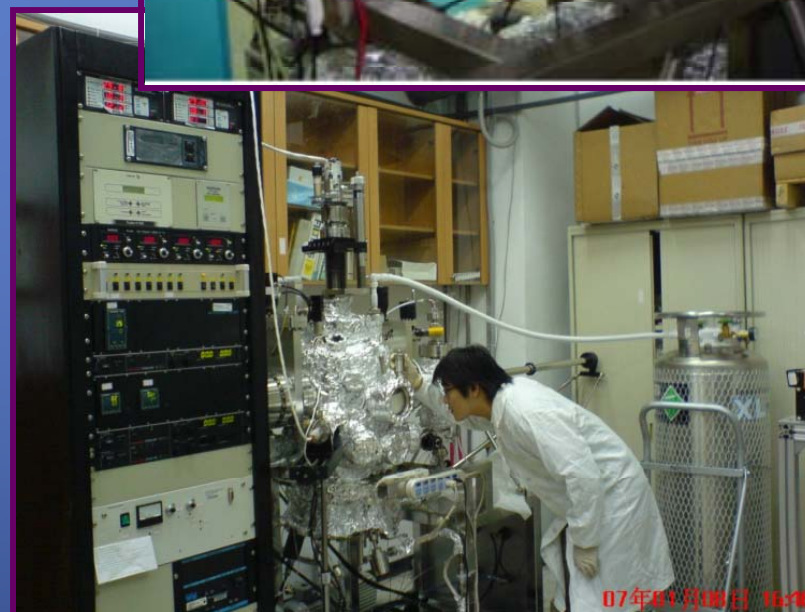
Thermal CVD



Plasma-assisted MBE



MOCVD



Core Process Techniques at CCMS-AML

CVD

- Microwave plasma
- Electron-cyclotron-resonance plasma
- Thermal- and MO-CVD
- Inductively Coupled Plasma

*Gas phase reaction, Gas-solid interaction
Formation kinetics*

PVD

- Magnetron sputtering
- Ion beam sputtering
- Atom- and Ion-beam assisted PVD
- Molecular beam epitaxy

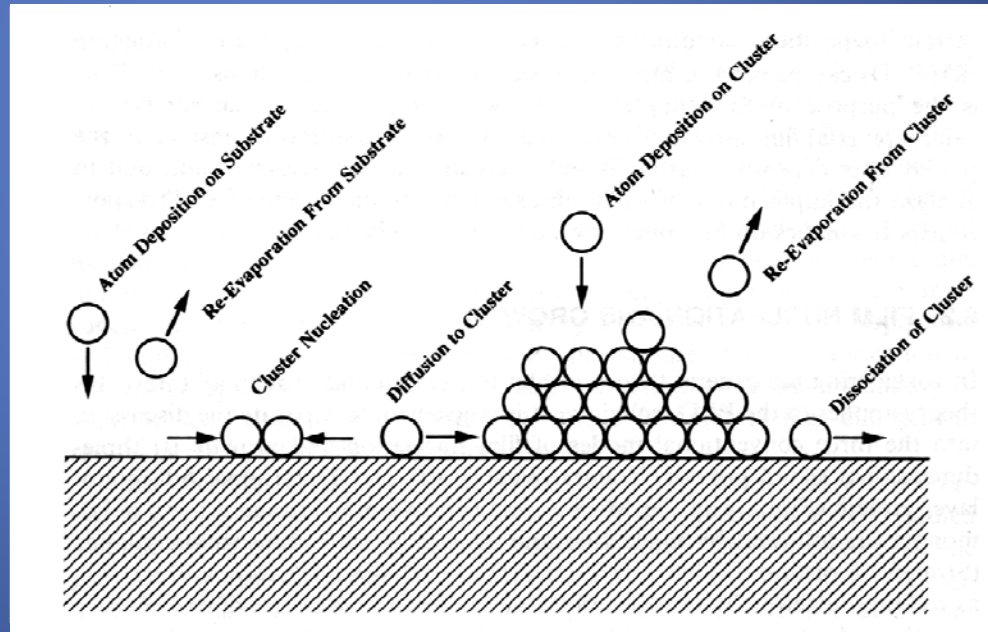
*Hydrogen vs. H-free growth environments
Film formation via physical route (varying K.E.) vs. chemical
route (reactive sputtering)*

**Highly energized vapor deposition/etching processes
under situations far away from equilibrium**

Gas Phase Syntheses

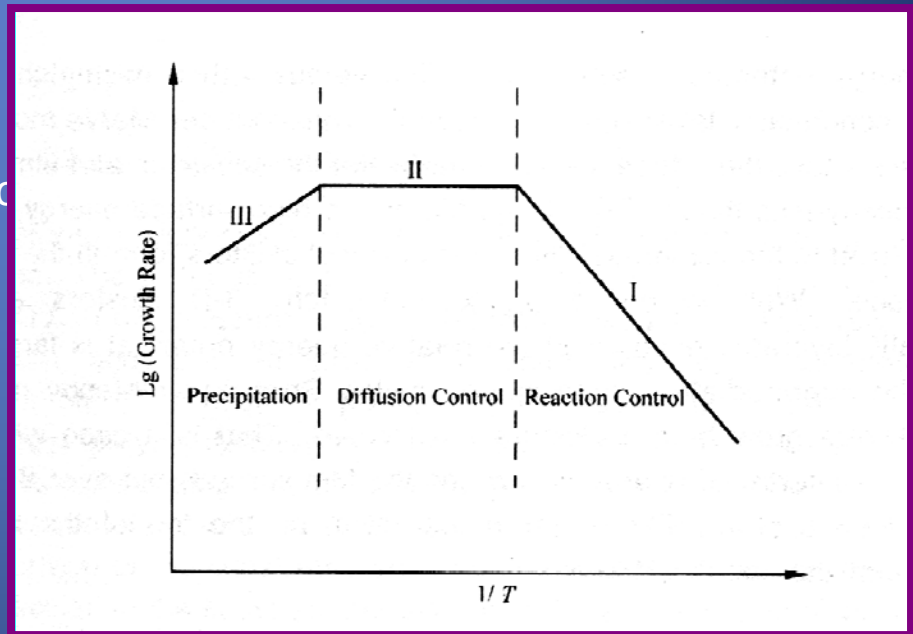
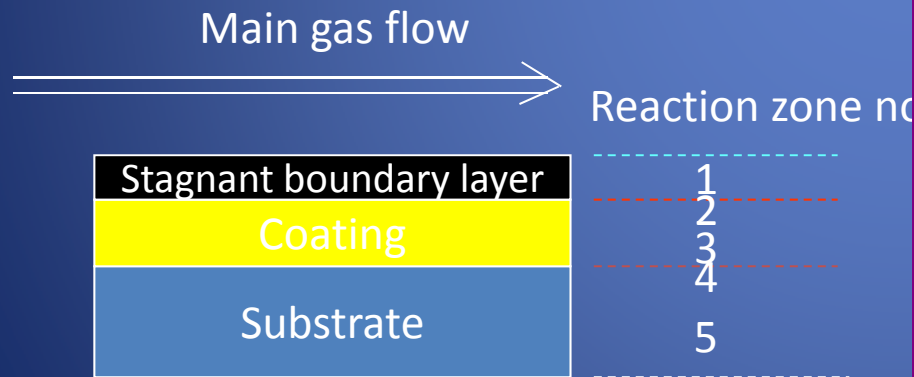
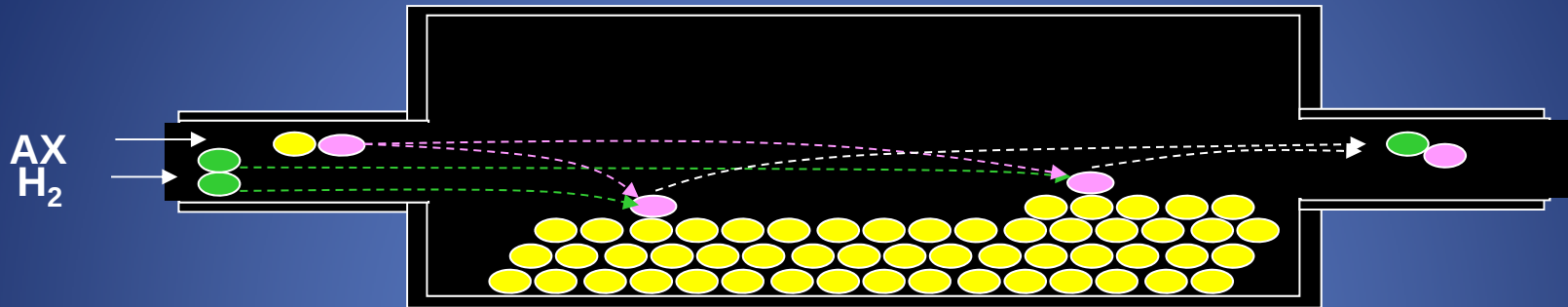
- Evaporation-Condensation (Earliest methods)
- Sputtering
- Laser Ablation
- Arc Discharge
- Aerosol Process
- Spray Pyrolysis
- Plasma Spray

atomic process in the nucleation of three-dimensional clusters of deposited film atoms on a substrate



(J. S. Horowitz and J. A. Sprague, Chap. 8, Pulsed Laser Deposition of Thin Film, Eds., D. B. Chrisey and G. K. Hubler, Wiley Interscience)

Schematic of Chemical Vapor Deposition

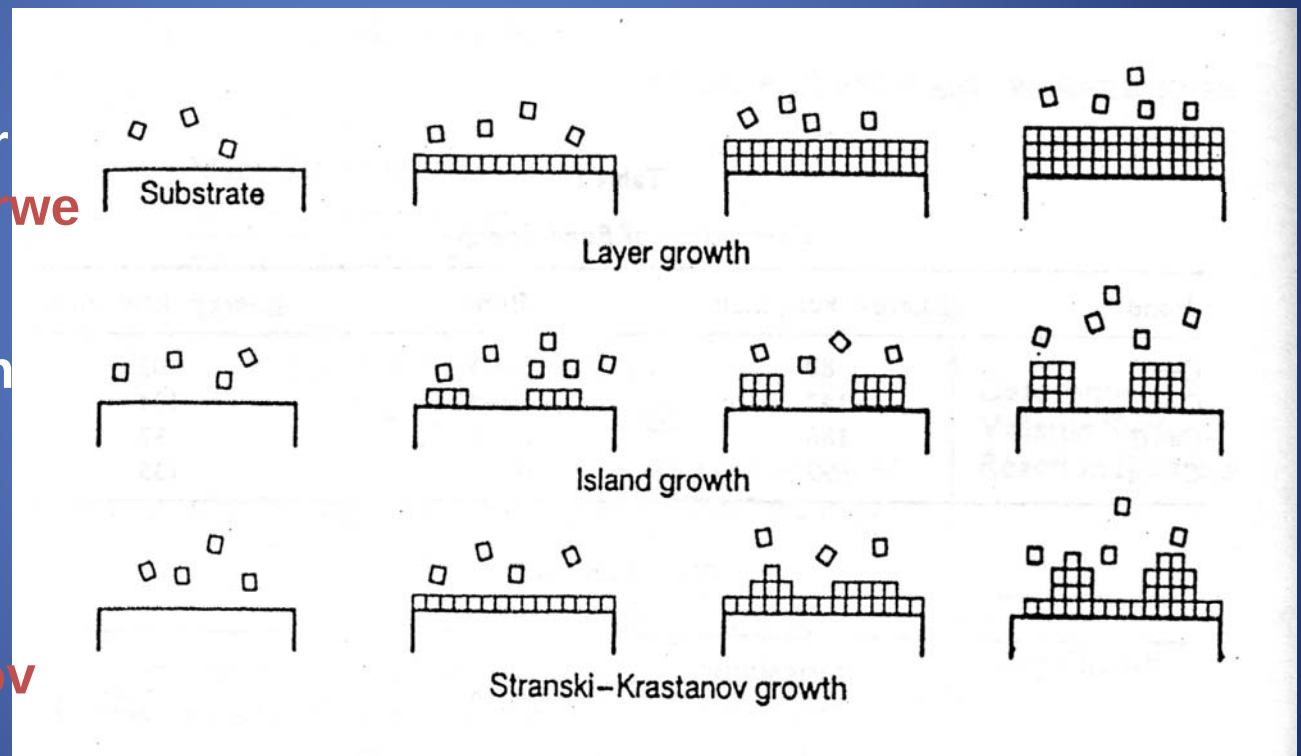


Nucleation and Growth of Films: The Three Conventional Modes

2-d full-monolayer
Frank-van der Merwe

3-d (or "0-d") island
Volmer-Weber

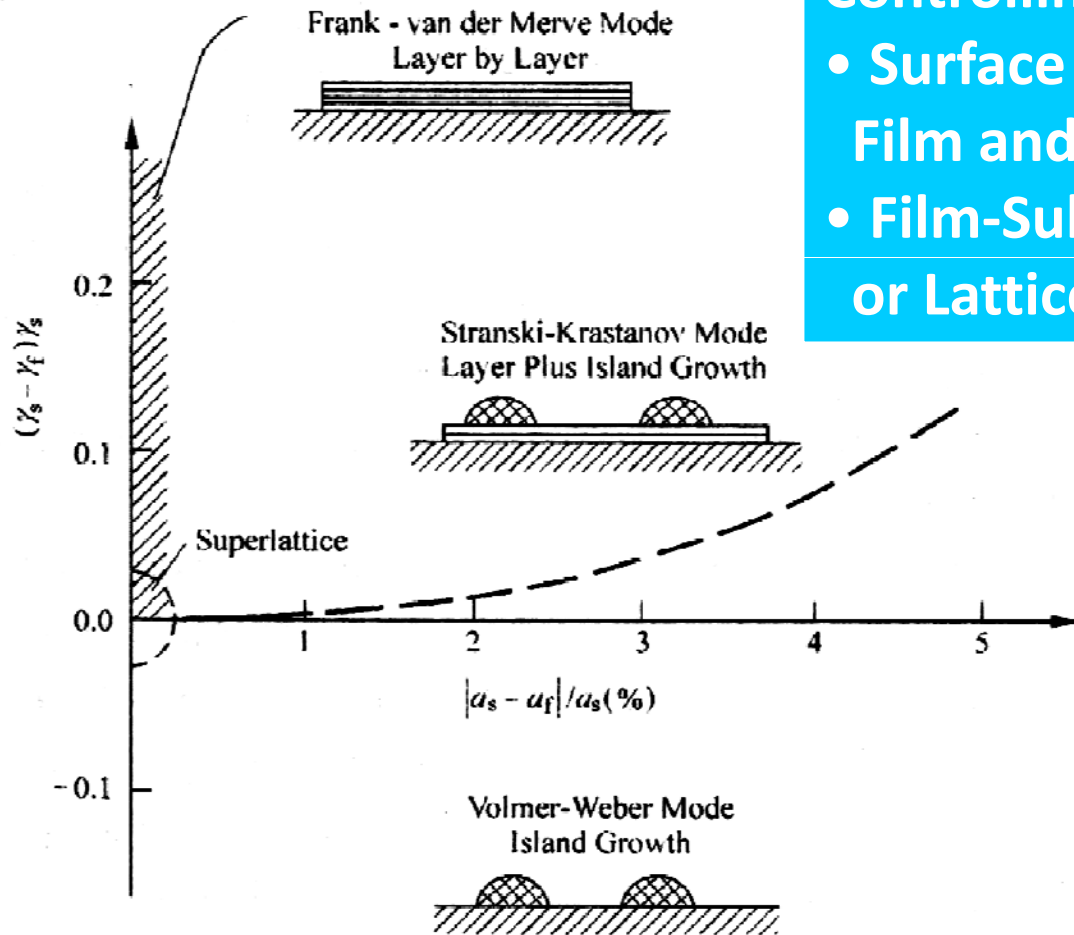
2-d and 3-d
Stranski-Krastinov



Selection of Growth Modes

Controlling Parameters:

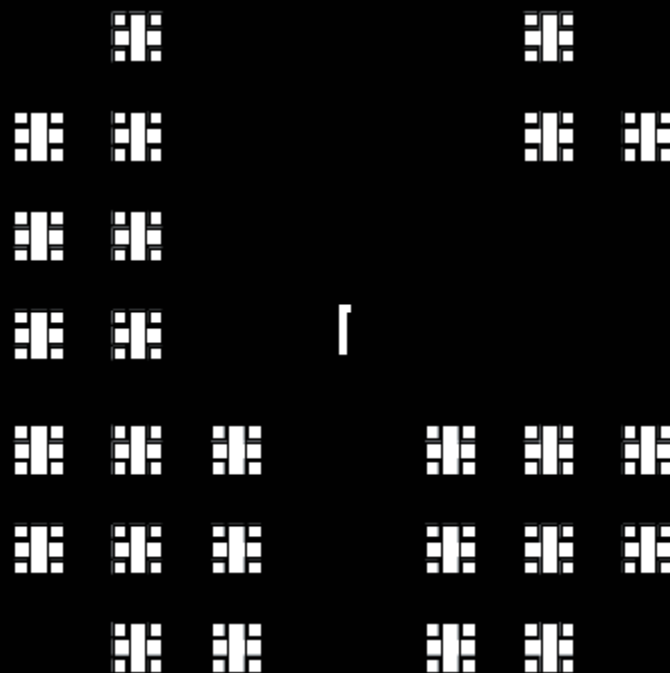
- Surface Energies of both Film and Substrate
- Film-Substrate Interface Energy or Lattice Mismatch



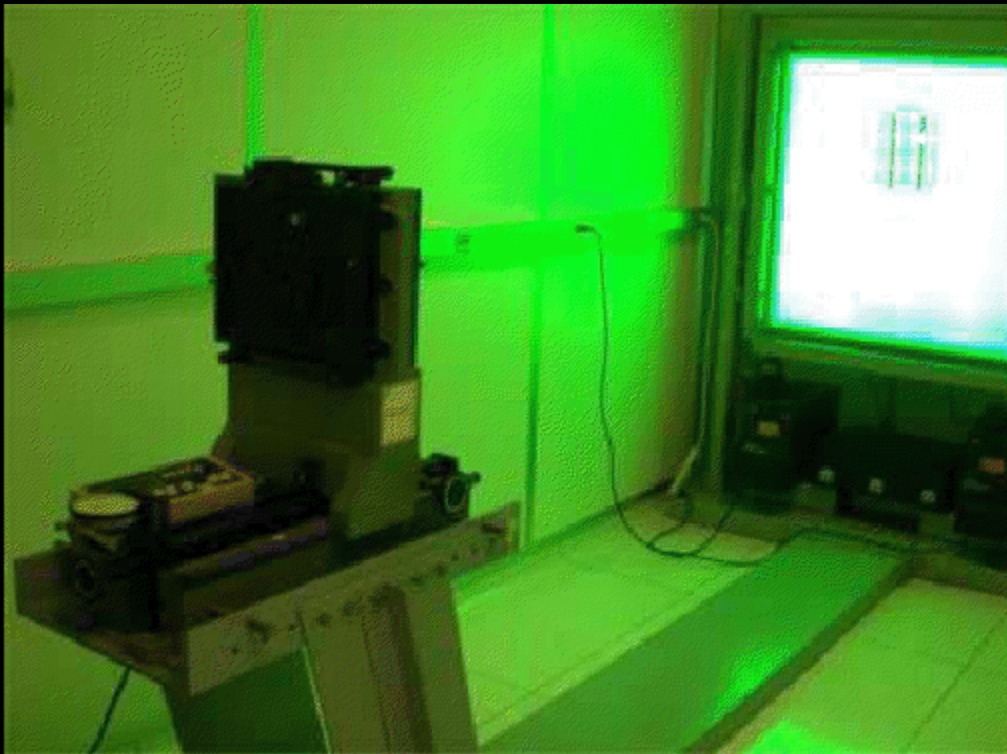
W, et al, TMS, 1986.

Photomasks

Design geometry on computer.



Mask fabrication



transparency

After Exposure
Developer
Stop bath
Fixer

Dark room (1/20 reduction)

Spin on photoresist

wafer

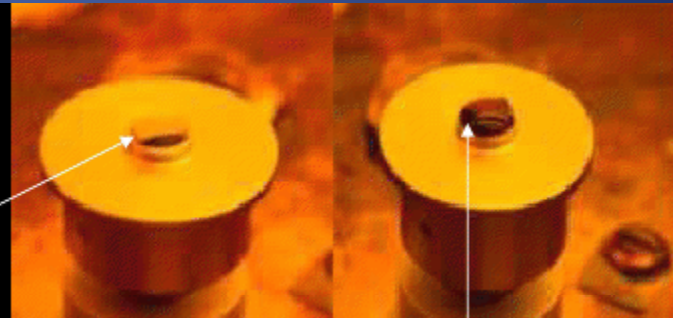


Photo resist



Photo resist spinner

Last modified 4/1/2003

EECS 217C Nanotechnology © 2003 P. Burke

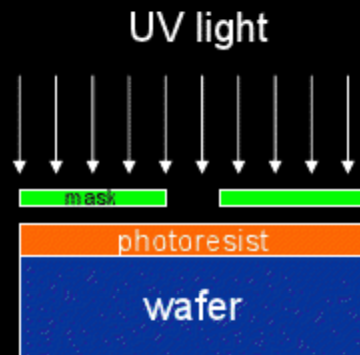
4

Soft bake



Oven for soft baking of photo resist
(at 90C for 30 min)

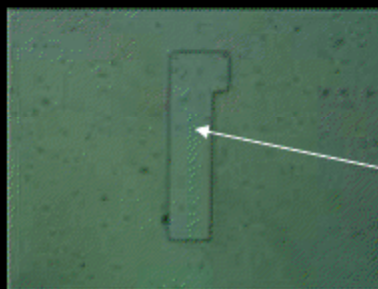
Expose to UV light



Development
For Shipley 1827
Water : MF351 = 5.5 : 1



Mask Aligner



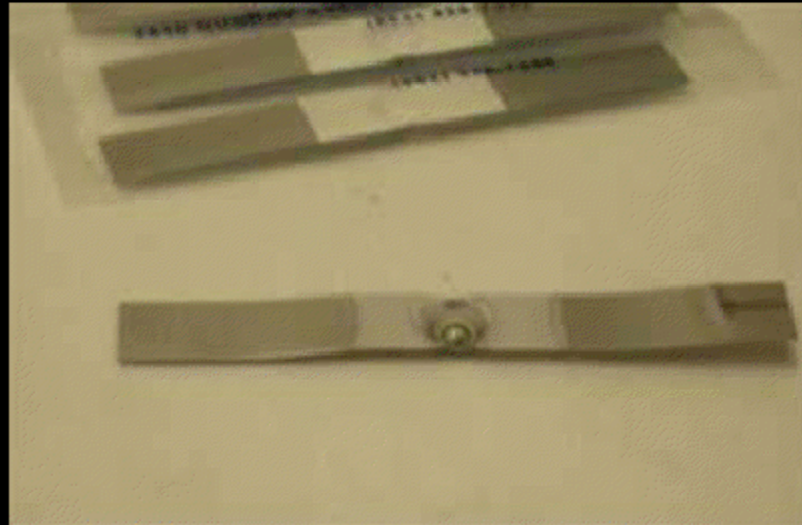
Exposed regions
dissolved in developer
leaving bare wafer

*This is the step which limits
the spatial resolution.*

Thermal evaporation



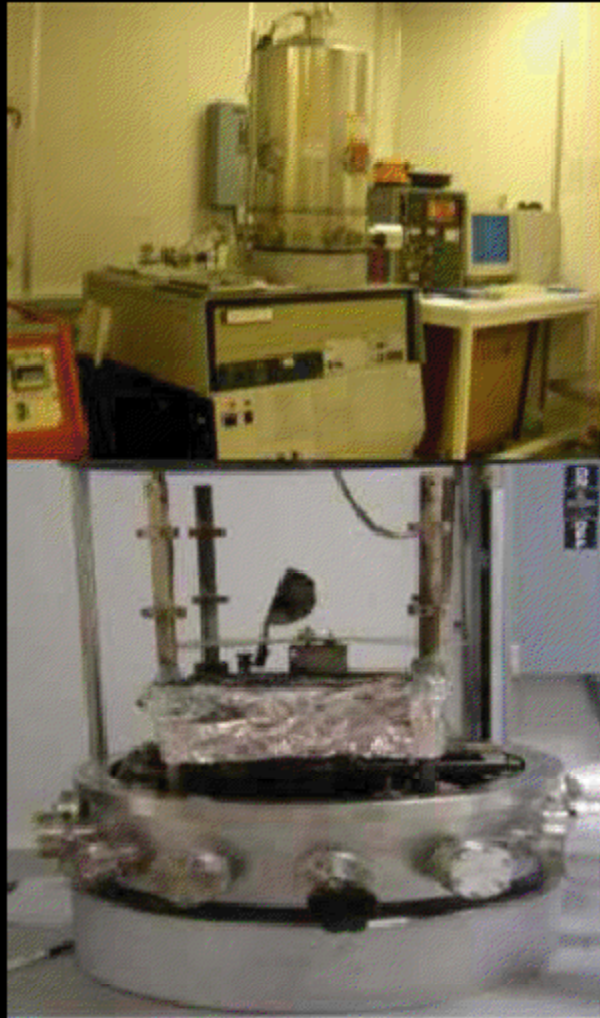
Thermo evaporator



Alumina coated W boat

Useful for e.g.
Al, Ni, Au, Cr, Ti, NiCr, Pb, Sn

E-beam evaporation

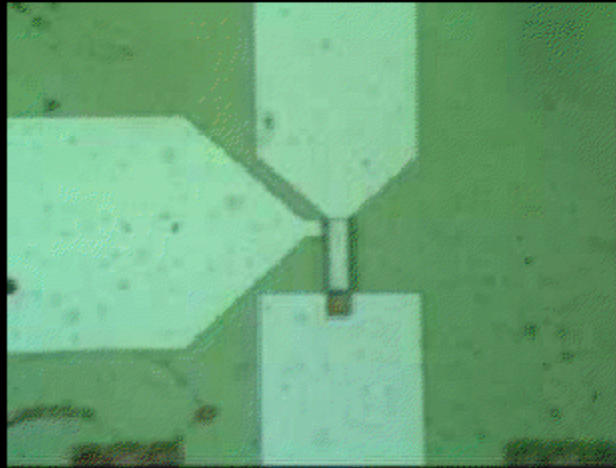


Electron beam
evaporator

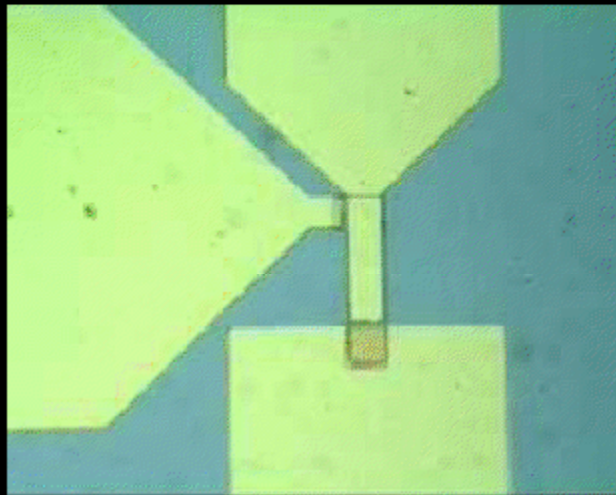
Au



Liftoff



Opening of photo resist
for Ti/Au gate



After deposition of Ti/Au,
then soaking in acetone

Resolution of optical lithography

$$R = \frac{3}{2} \sqrt{\frac{\lambda z}{2}}$$

Contact printing

z is resist thickness
(typically 0.1-1 μm)

$$R = 0.61 \frac{\lambda}{NA}$$

Projection printing

NA is numerical aperture
(typically 0.5)

Light sources

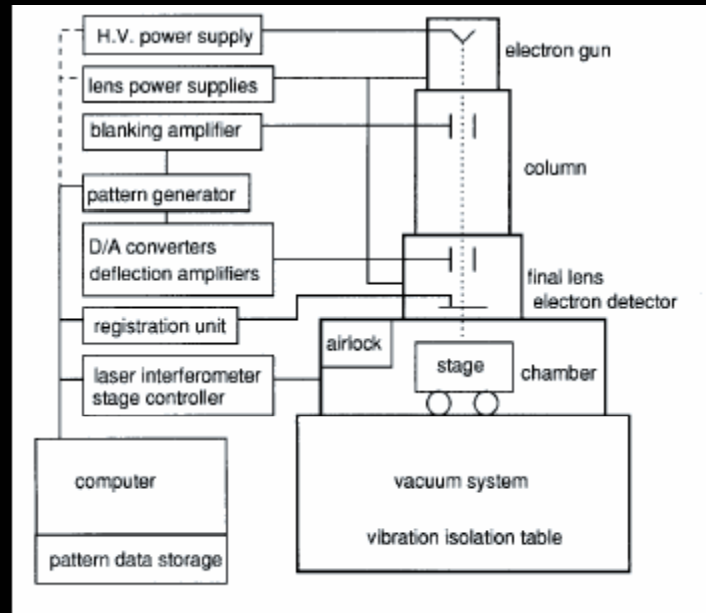
Source	λ	Resolution
• Hg lamp (g-line)	436 nm	400 nm
• Hg lamp (i-line)	365 nm	350 nm
• KrF	248 nm	150 nm
• ArF	193 nm	80 nm
• F ₂	157 nm	research

increasing cost

Extreme UV, x-ray lithography research topics.
Difficulties lie in sources, and materials for optics and masks.

Electron Beam Lithography

- Advantages
 - Resolution
 - electron wavelength small
 - beamsize 1 nm
 - resolution from scattering typically 10 nm
 - Flexibility
 - All patterns under computer control
- Disadvantages
 - Cost
 - Need high vacuum
 - Need precision electron focusing magnets
 - Throughput
 - Only one pixel exposed at a time
 - Not commercially viable except for a few applications

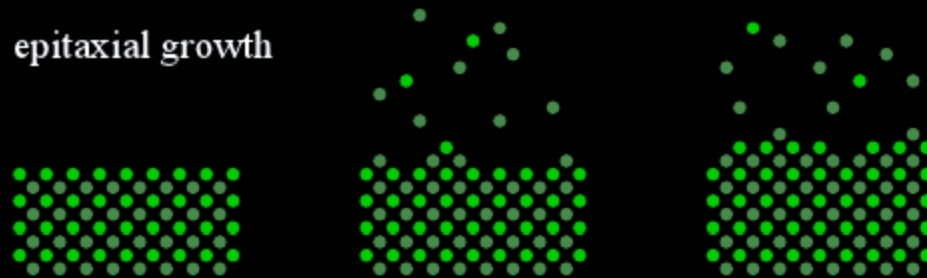


Reference: SPIE Handbook of Microlithography, Micromachining, and Microfabrication
available at <http://www.csf.cornell.edu/spebook/bc.htm>

*In spite of its disadvantages,
e-beam lithography is the main tool for nanotechnology research.*

MBE

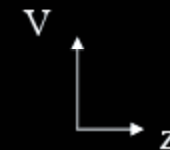
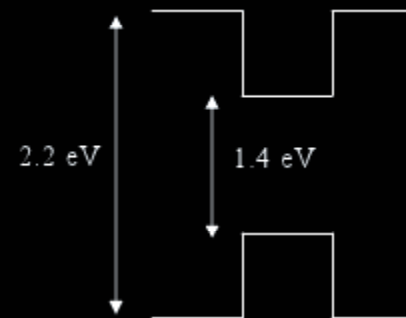
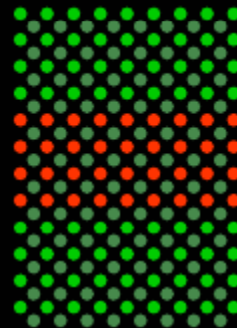
epitaxial growth



AlAs

GaAs

AlAs

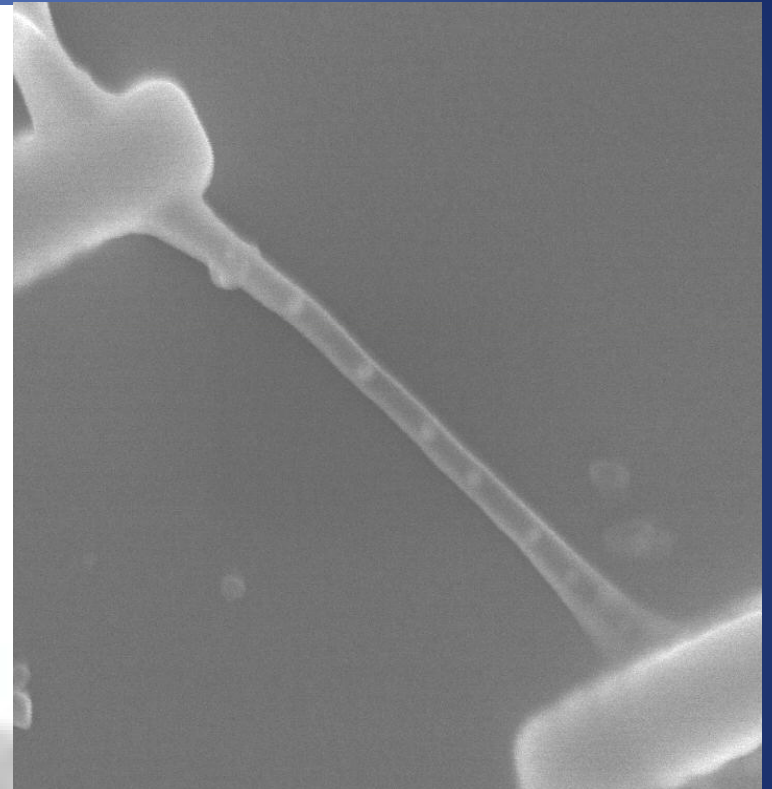


Also InP, InGaAs, InAlAs, InGaAsP ...

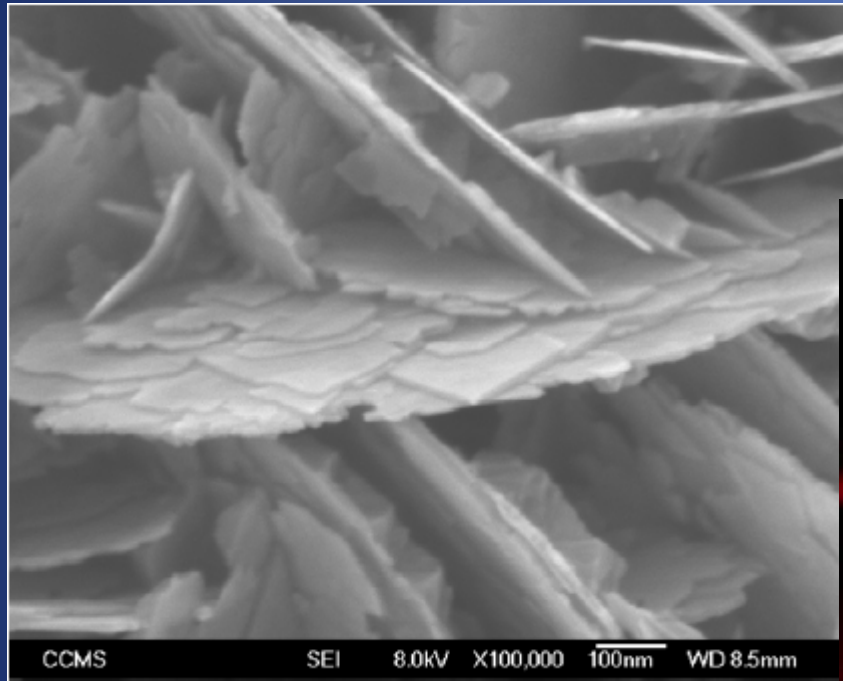
Characterization

- Optical microscopy cannot see better than wavelength of light, $\sim 1 \mu\text{m}$
- Scanning electron microscope (SEM)
- Transmission electron microscope (TEM)
- Scanning probe microscopy (SPM)
- Atomic force microscope (AFM)

SEM



SEM



First Place in Science as Art, MRS-2008



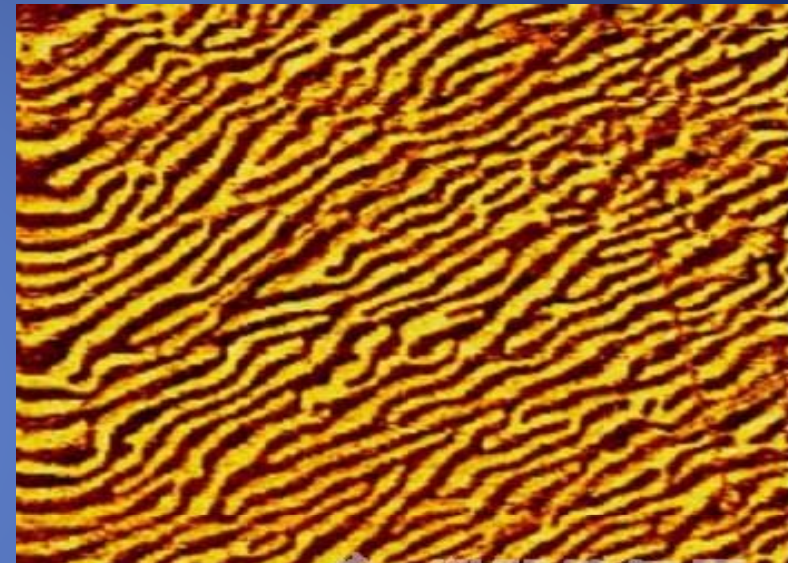
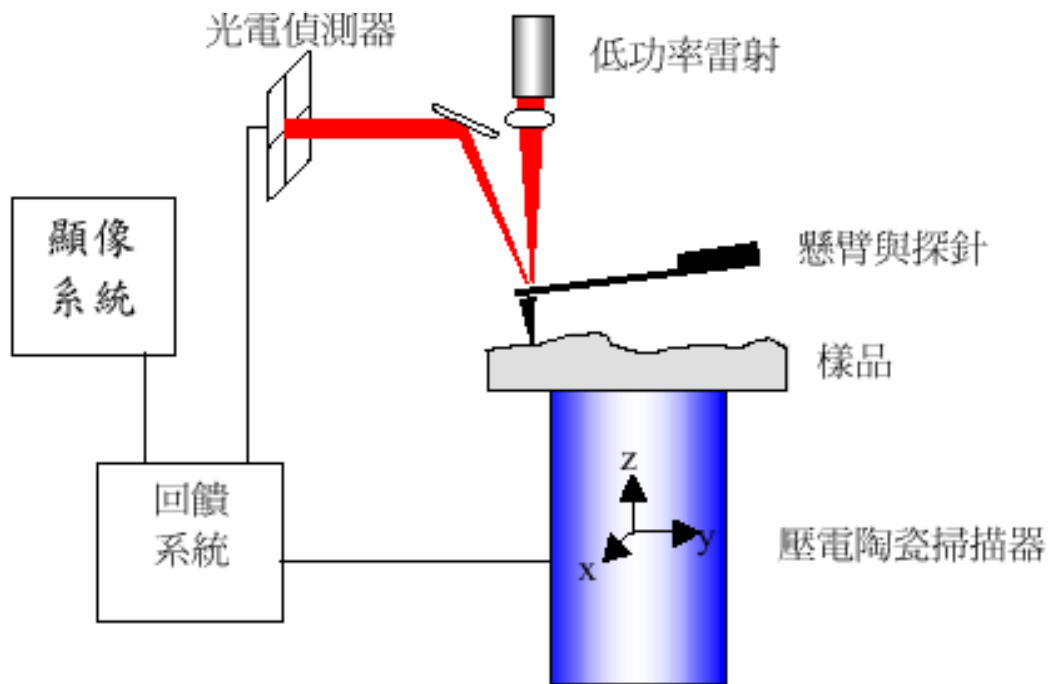
*For
Nano*

The scanning electron
image represents
wurtzite indium nitride
Rose synthesized via
epitaxy (MBE) pro
indium and a high
source, hydrazoic ac

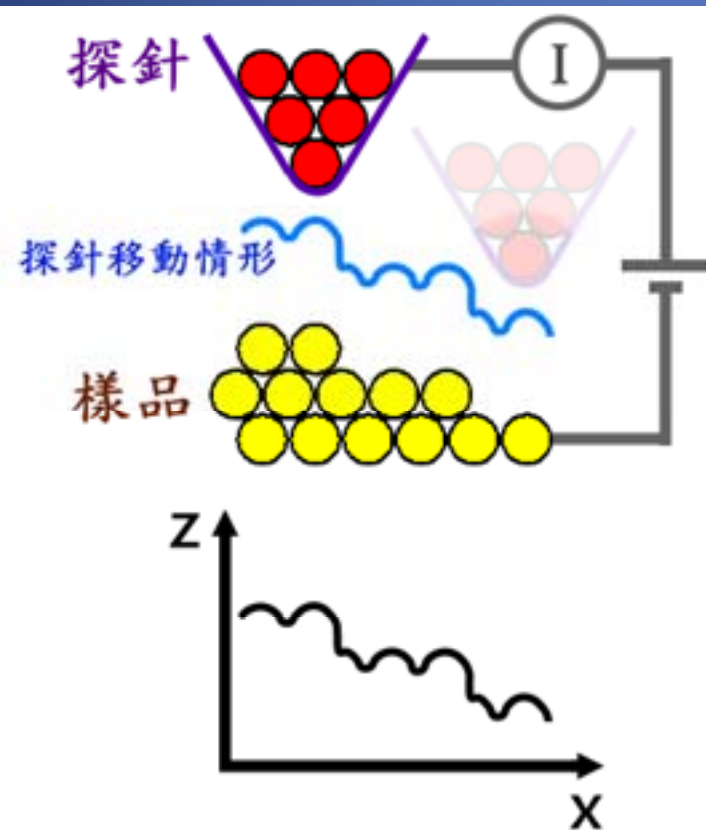
Nanotech, a cutting
reveals the essence
where tiny but exqui
the world. Among
Taiwan – an island
small on the plan
beautifully.

The work was
Advanced Materials
Dr. Li-Chyong Ch
and Dr. Kuei-Hsien
Submitter & Editor
(Department of Ma
Engineering, NTHU
Email: d937517@oz

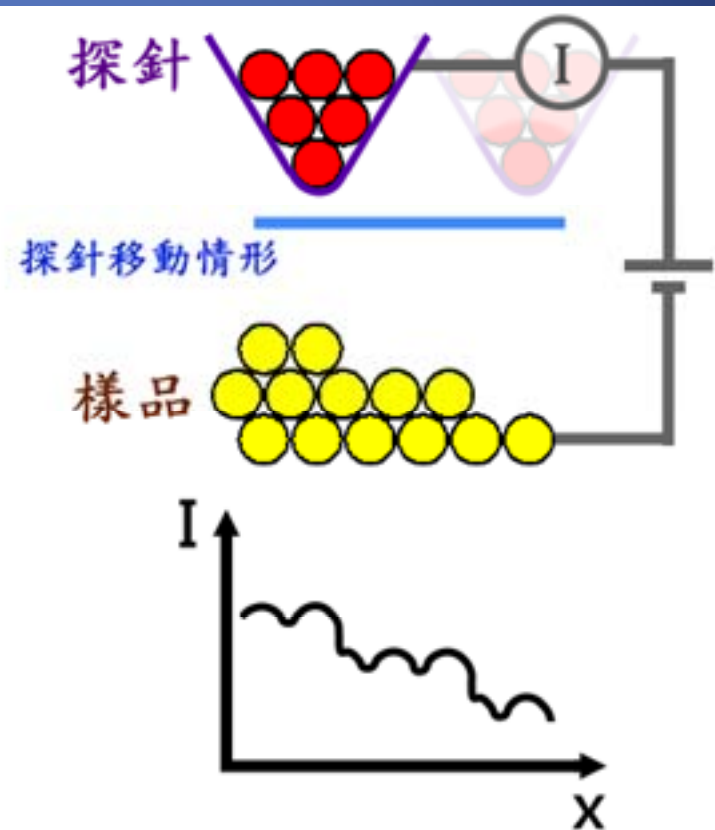
AFM



STM

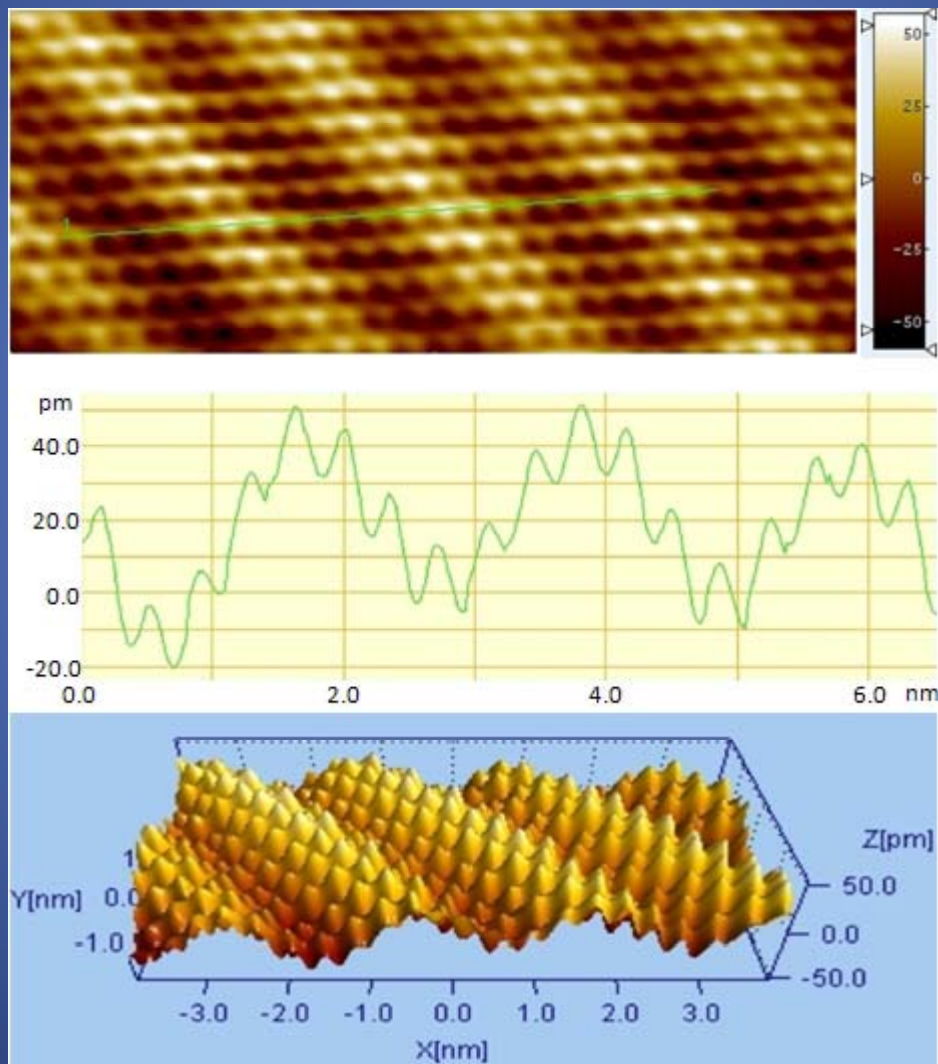


圖一、定電流模式示意圖

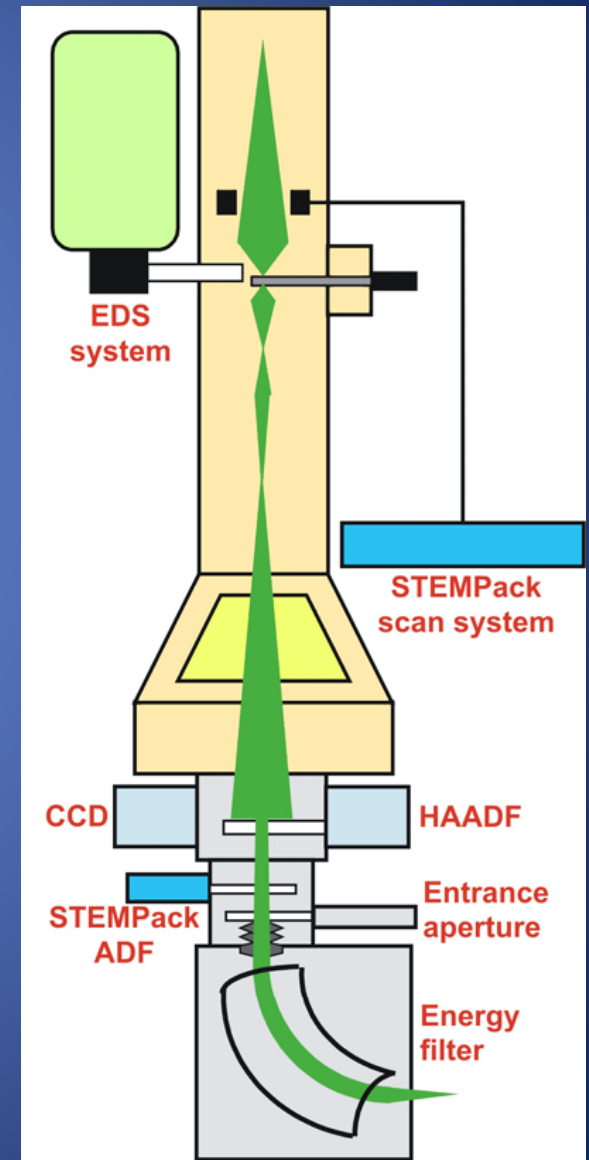


圖二、定高度模式示意圖

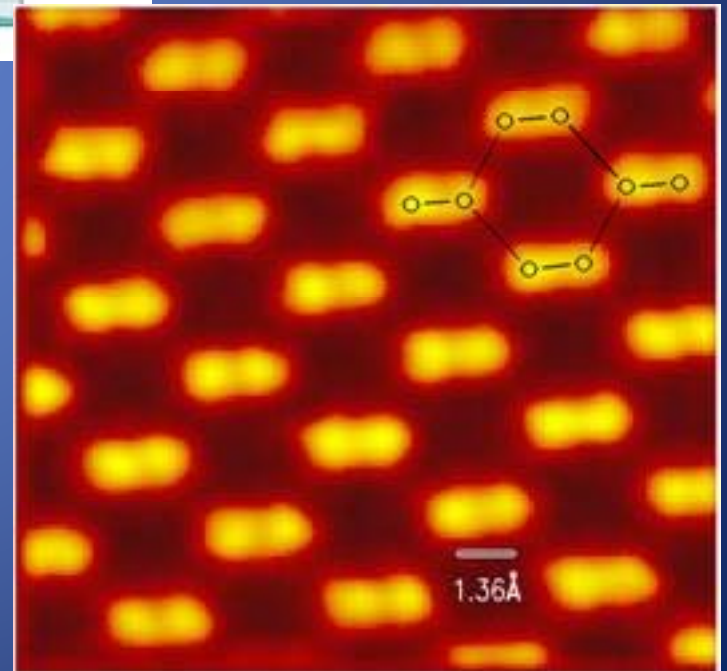
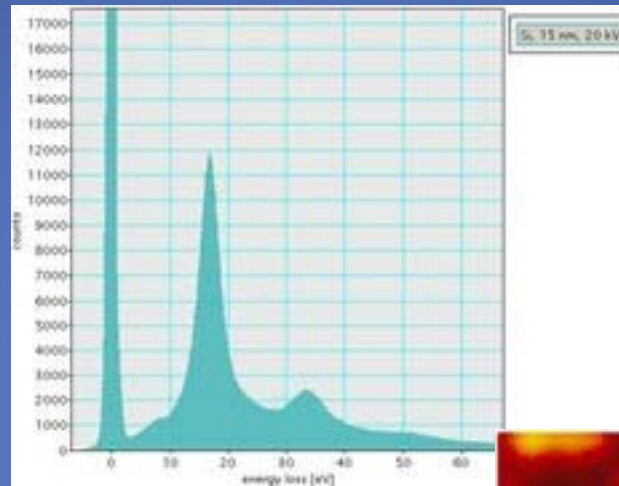
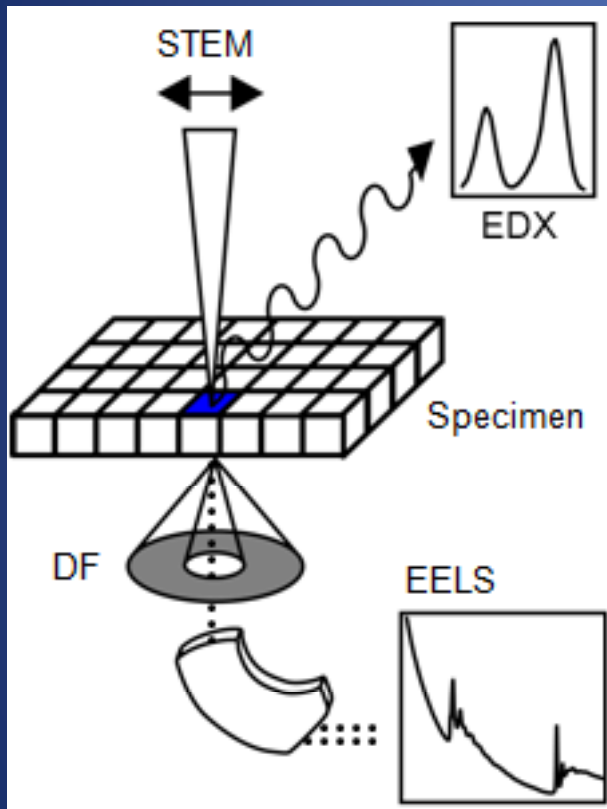
STM



TEM



TEM (EELS)

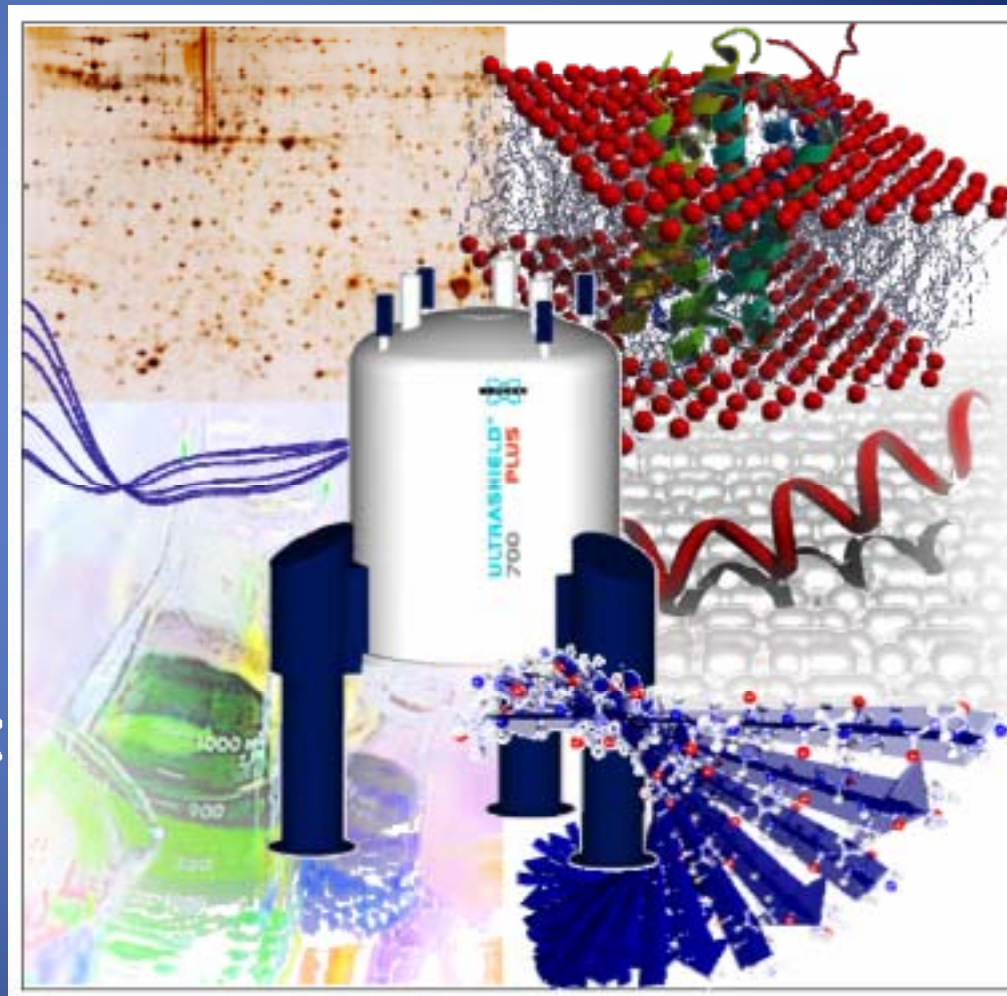
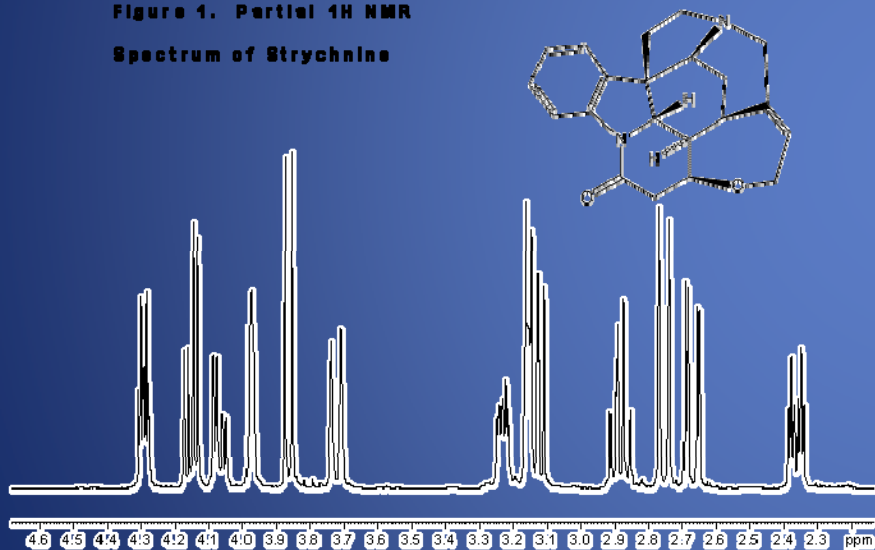


Composition Analysis

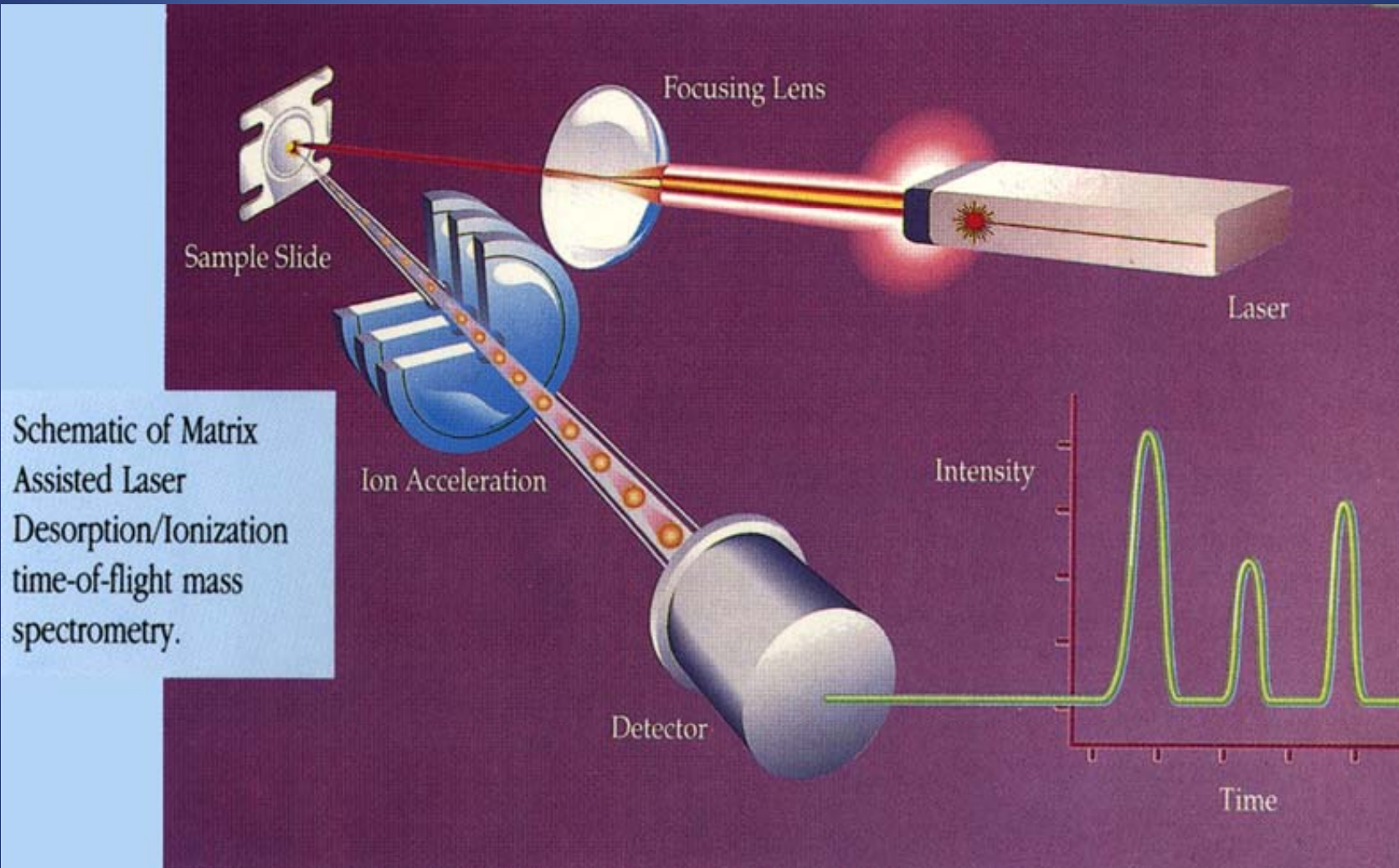
1. EL (元素分析儀)
2. EDS (X射線能量散佈分析儀)
3. AES (歐傑電子光譜)
4. NMR (核磁共振波譜分析)
5. ICP MASS (電子耦合電漿質譜)
6. MALDI (Matrix-assisted laser desorption/ionization)

NMR, MRI

Figure 1. Partial ^1H NMR
Spectrum of Strychnine



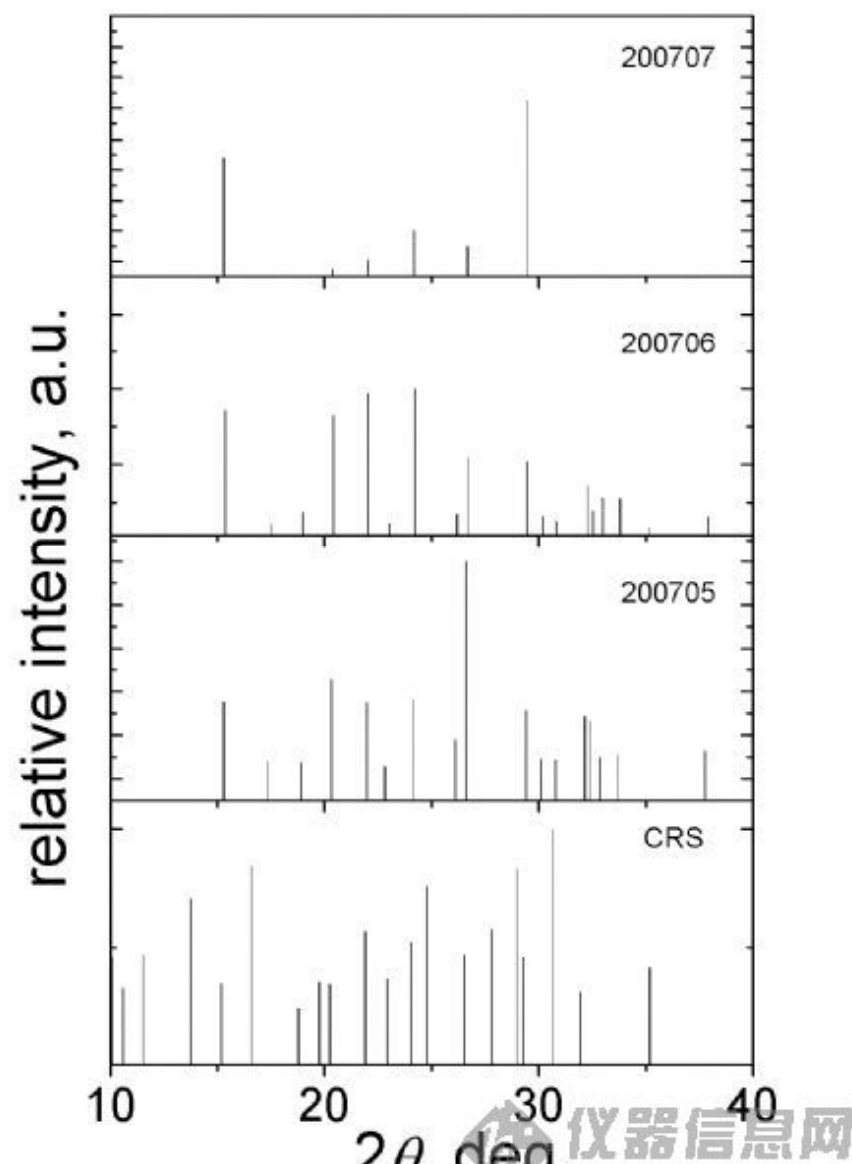
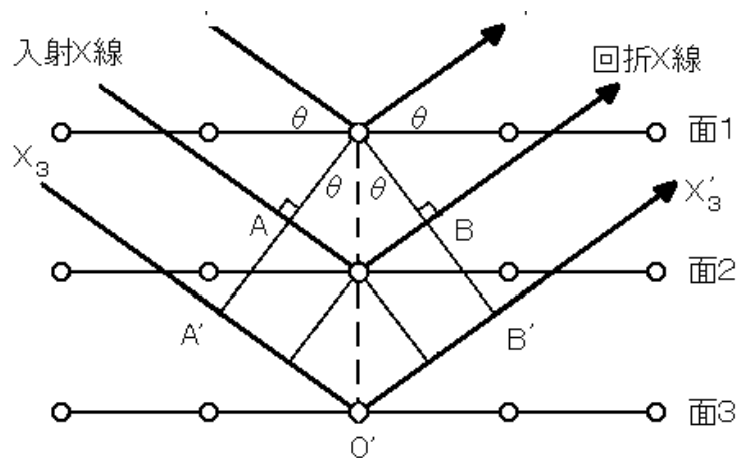
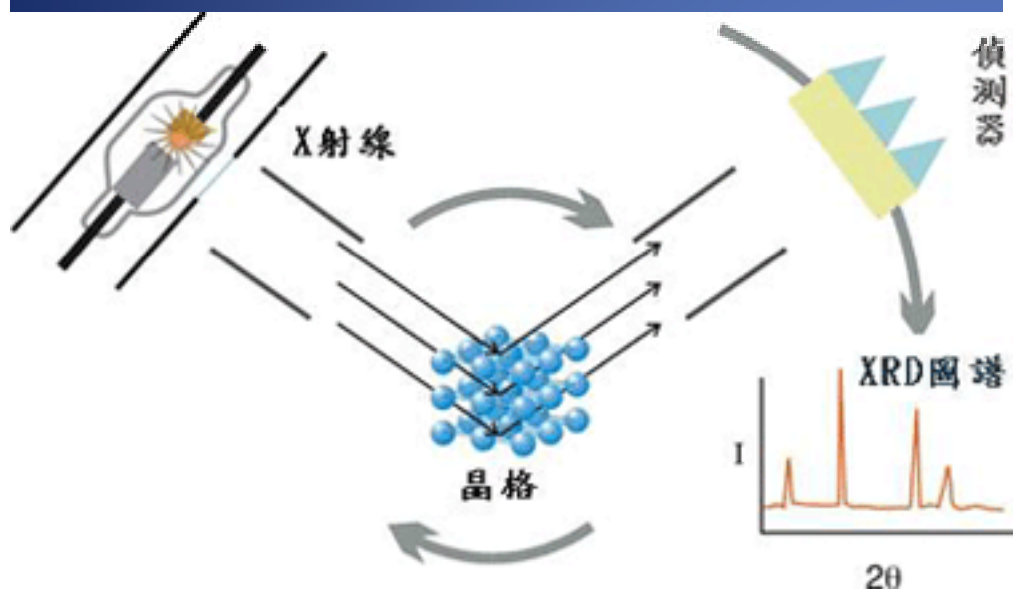
MALDI (Matrix-assisted laser desorption/ionization)



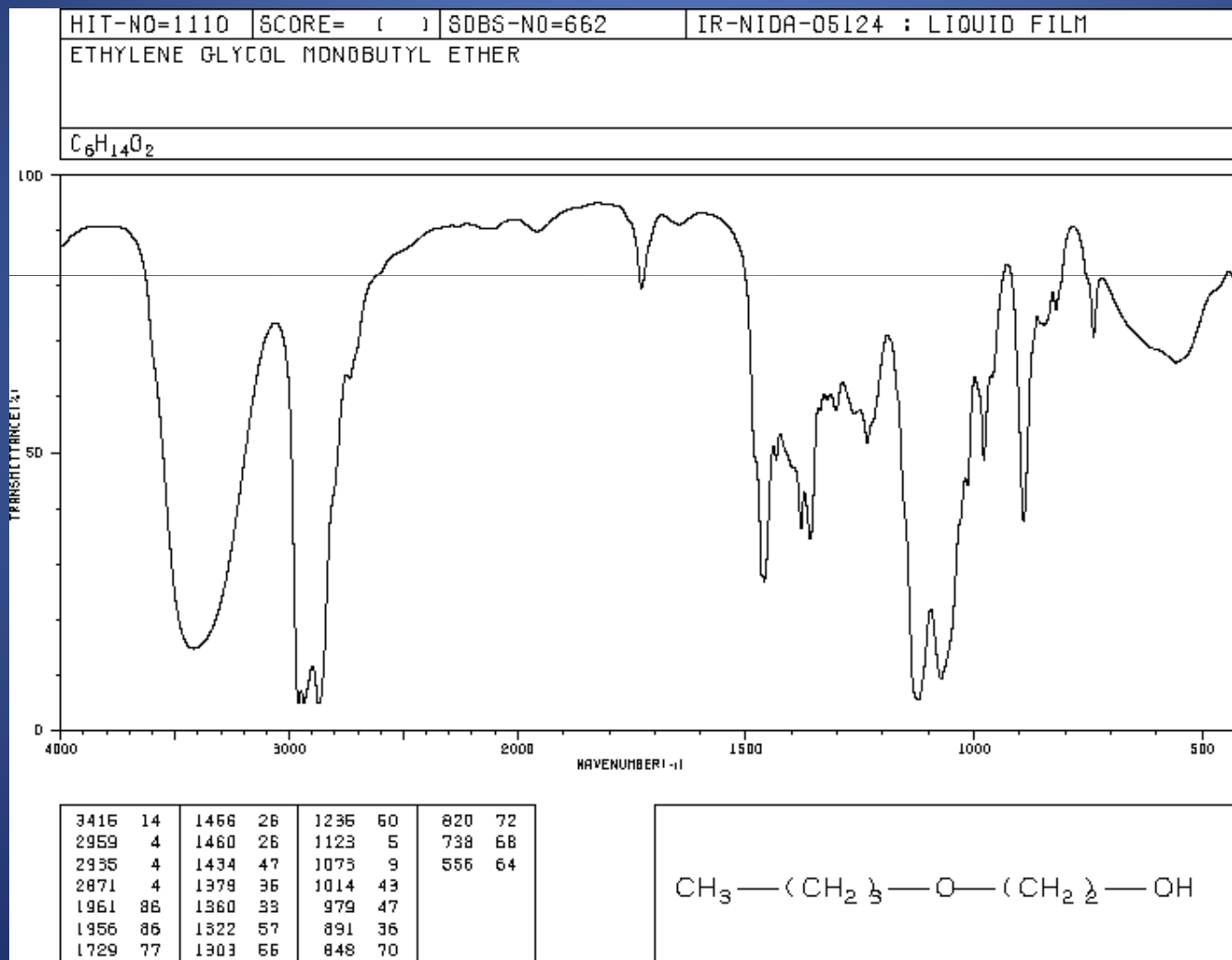
Structure Analysis

1. XRD (X光繞射)
2. TEM (穿透式電子顯微鏡)
3. FTIR (紅外光譜)
4. Raman (拉曼光譜)

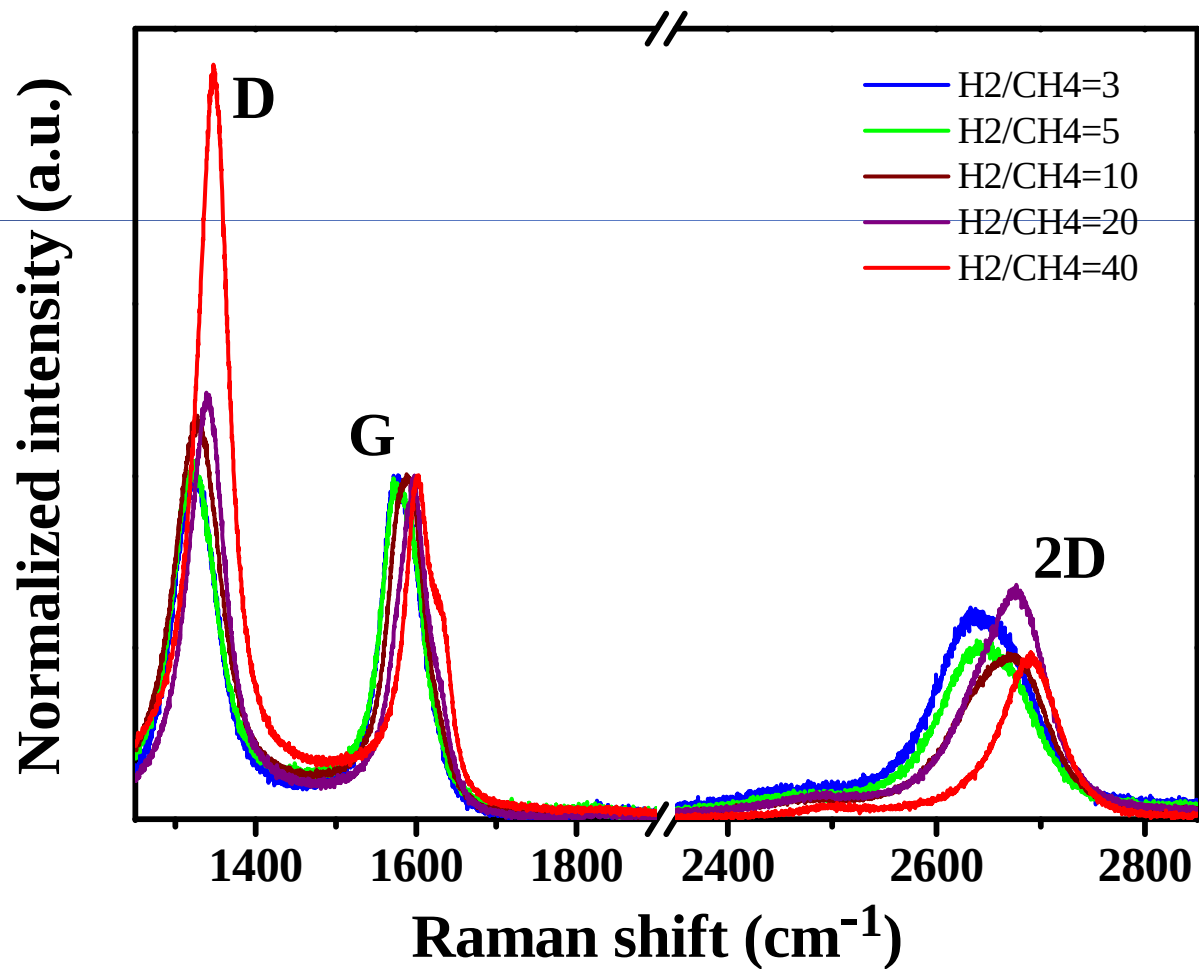
XRD (X光繞射)



FTIR (紅外光譜)(鍵結)



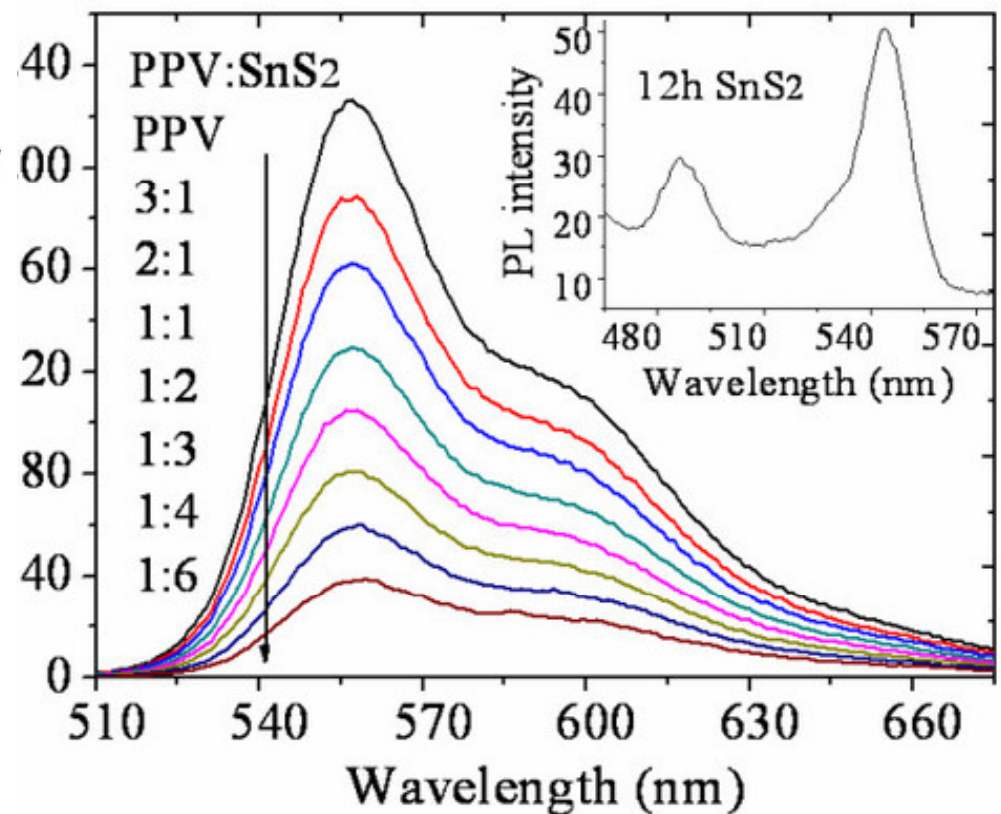
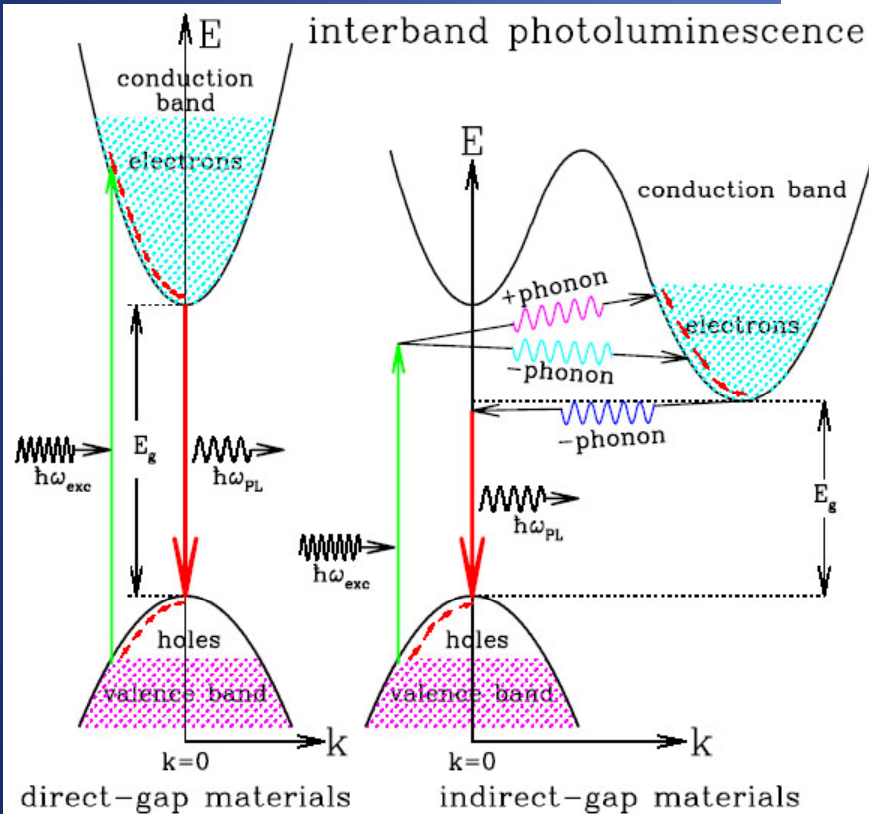
Raman (拉曼光譜)



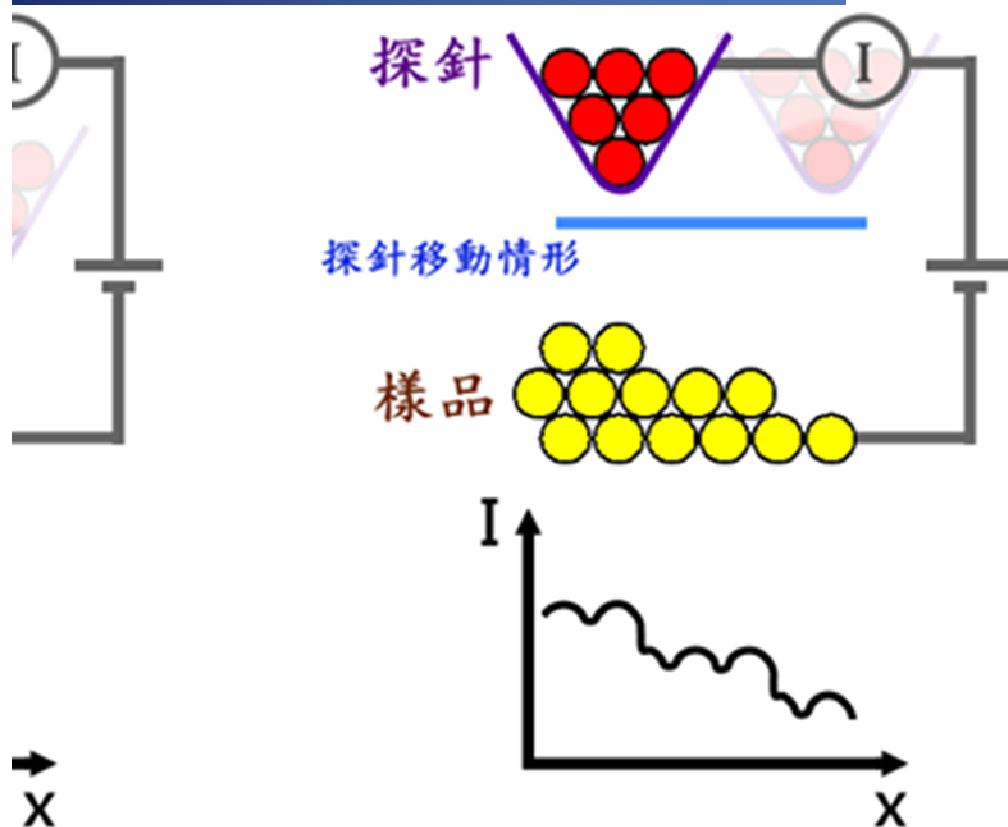
Electronic properties

1. Optical Absorption (吸收光譜)
2. Photoluminescence (螢光光譜)
3. STS (掃描穿隧顯微術)
4. XPS (X光電子光譜)
5. 同步輻射測量(SRRC)

Photoluminescence (PL & CL)

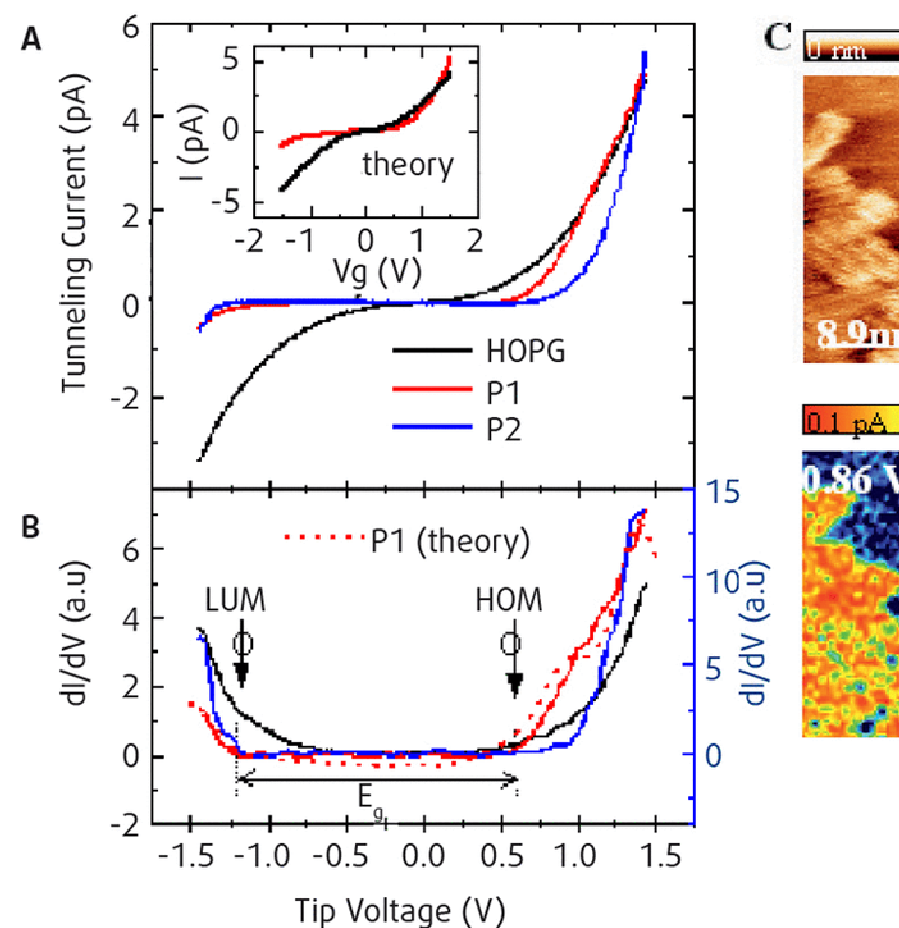


STS (掃描穿隧顯微術)

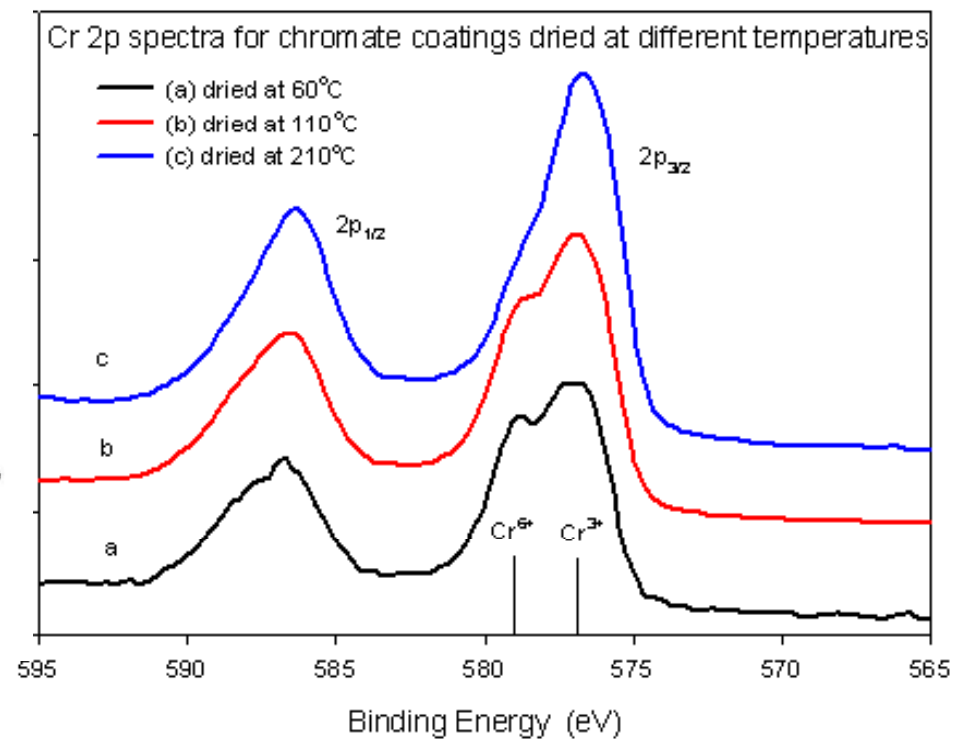
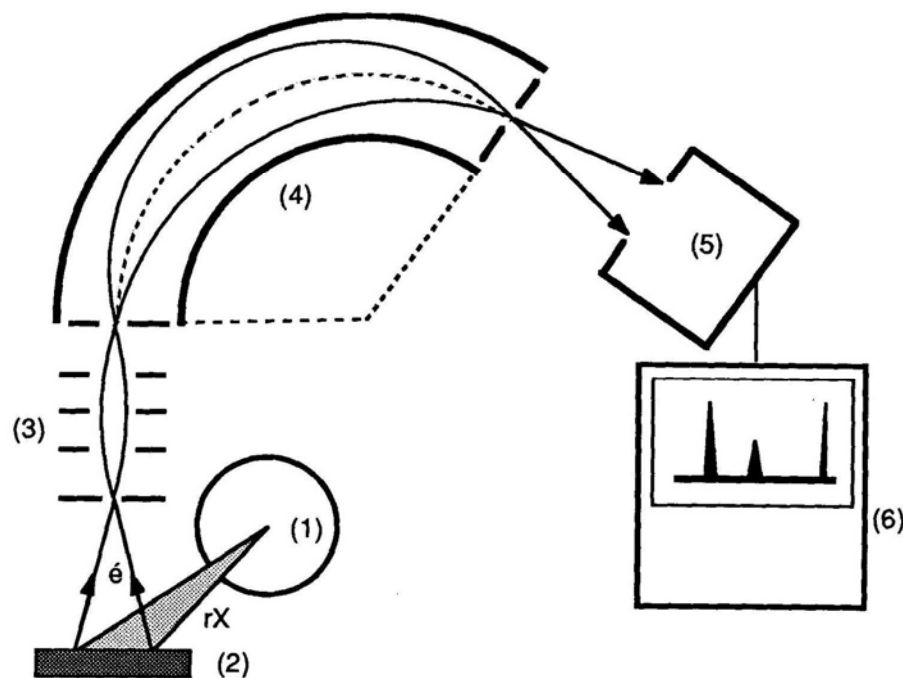


意圖

圖二、定高度模式示意圖

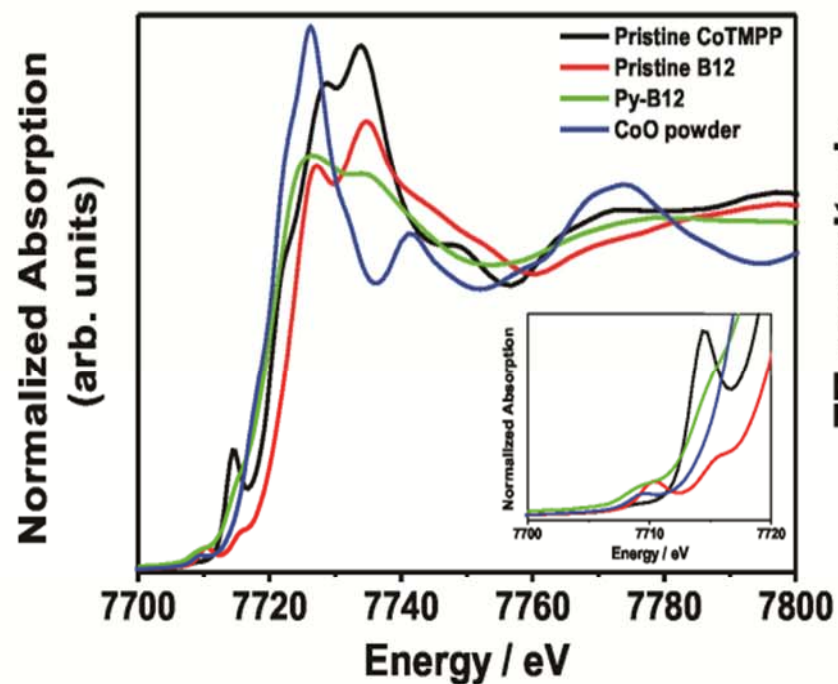


XPS (X光電子光譜)

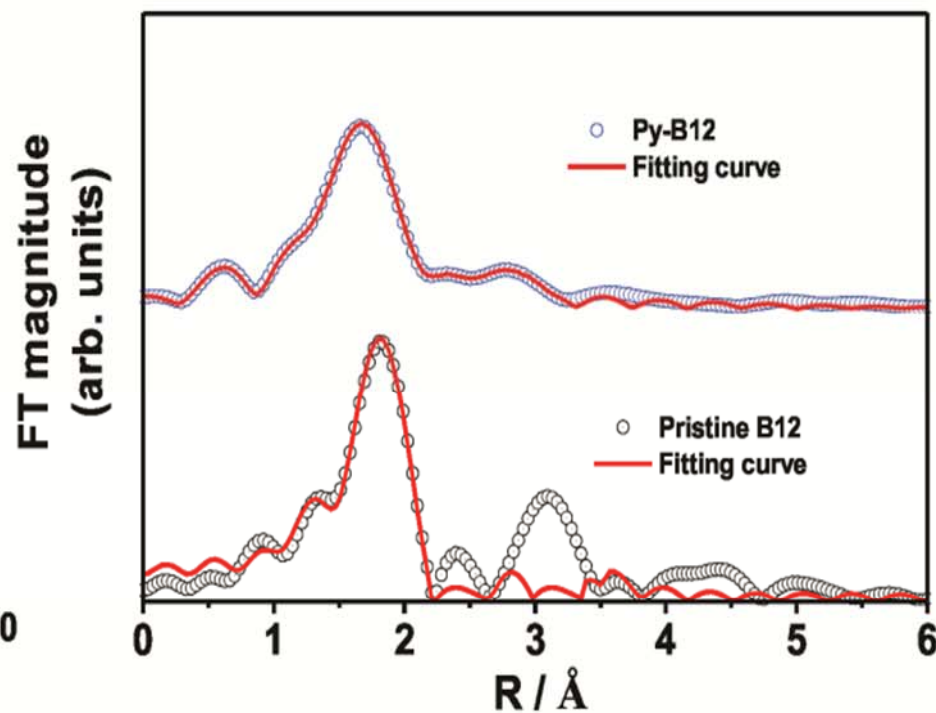


同步輻射測量(SRRC)

(a)



(b)



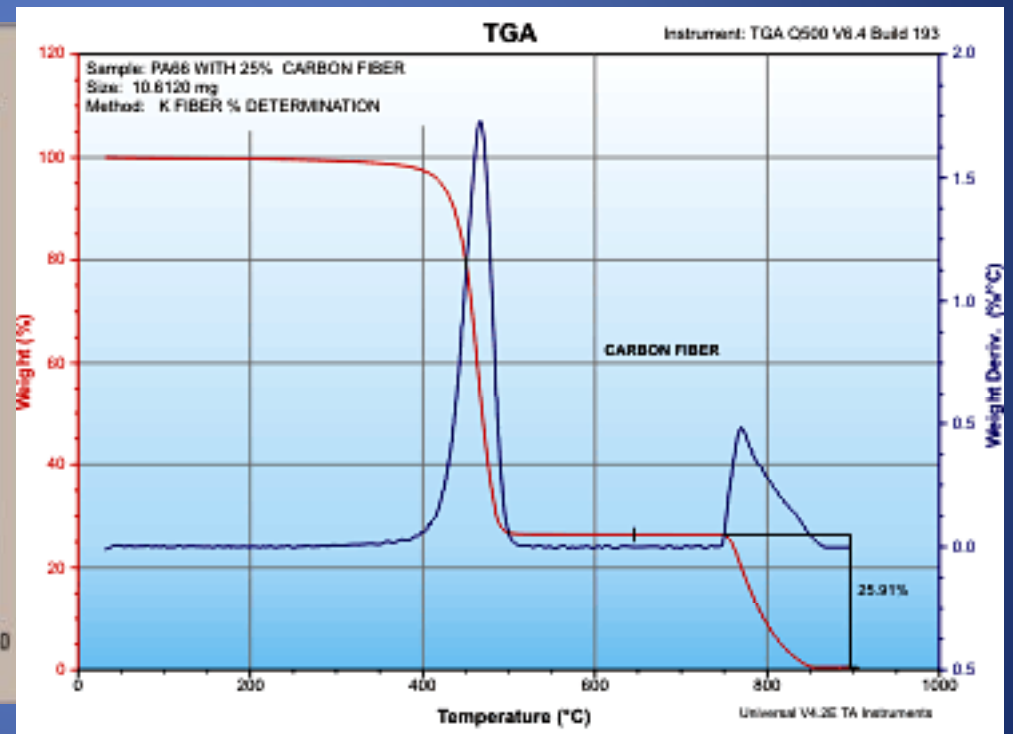
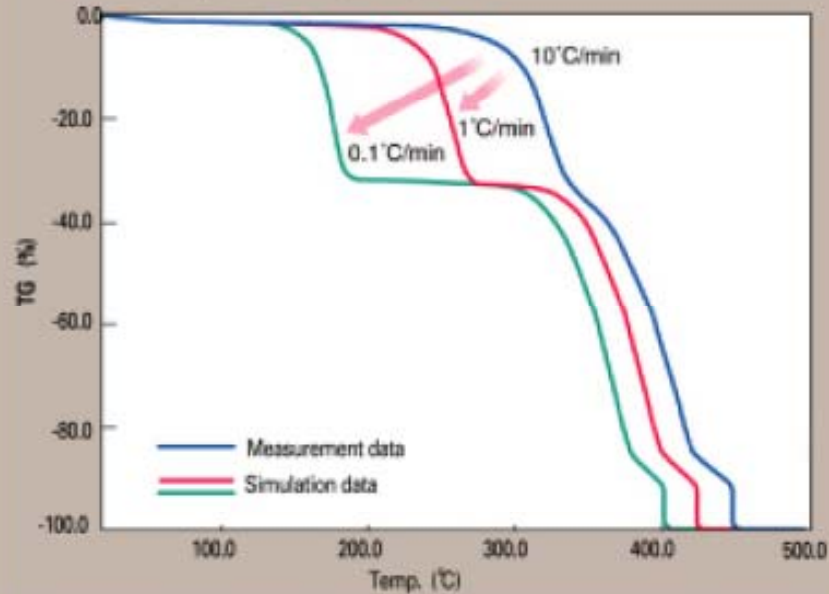
(XANES & EXAFS)

Other Thermal and Magnetic Measurements

1. 熱傳導係數測量(Thermal conductivity)
2. 熱重分析(TGA)
3. 熱分析儀 (DSC)
4. SQUID (Superconducting Quantum Interference Device)

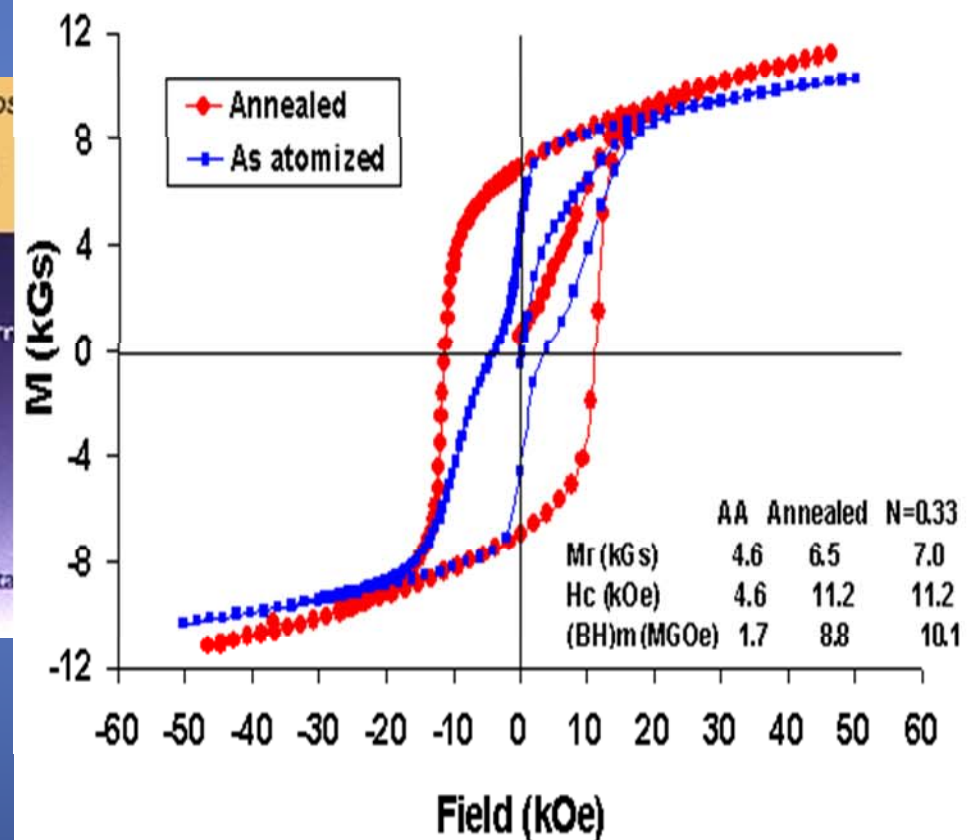
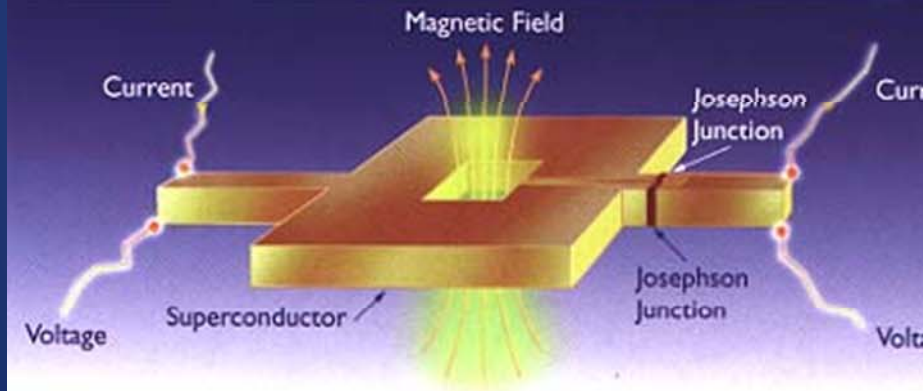
TGA & DSC

● TG Analysis and Highway TA of Fiber



SQUID (Superconducting Quantum Interference Device)

A SQUID (Superconducting QUantum Interference Device) is the most sensitive type of detector known to science. Consisting of a superconducting loop with two Josephson junctions, SQUIDs are used to measure magnetic fields.



Length scales

- Atoms
 - $\sim$ angstrom 10^{-10} m
- Light
 - wavelength $\sim \mu\text{m}$
- Electrons
 - De Broglie wavelength $= h/p$ (quantum mechanics)
 - $= \text{sqrt}(150/V)$ in angstroms (V is energy in volts)
 - $\sim 0.1\text{-}10$ nm
 - If a nanoelectronic circuit element is about the size of an electron wavelength, wave nature will be *crucial*
 - Conductance quantized at these small scales in units of e^2/h
- Mean free path (MFP)
 - 10^{-10} m in metals at room temperature
 - 10^{-4} m in ultra high quality semiconductors at low temperatures

Energies

- Electronic transition energies
 - $\sim 1\text{-}10\text{ eV}$
- Fermi energy
 - $1\text{-}10\text{ eV}$ in metals
 - $1\text{-}10\text{ meV}$ in semiconductors
- kT
 - 30 meV at room temperature





