Welcome to the

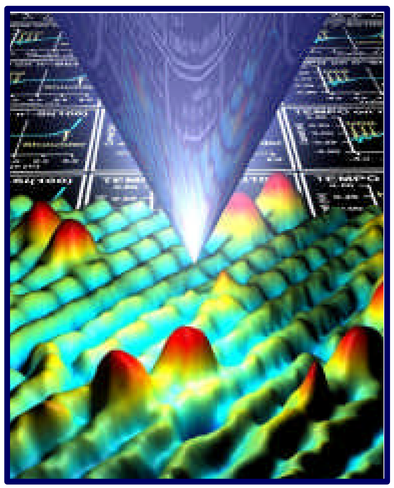
NCLT

Monthly Seminar

http://www.nclt.us

January 18 2005

Introduction to Nanometer Scale Science and Technology



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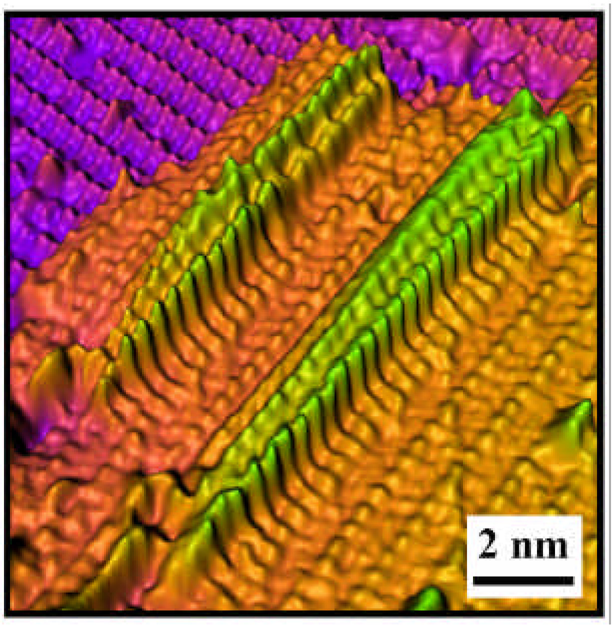
Outline



- History/motivation
- What is a nanometer?
- Controlling matter at the nanoscale
- Size-dependent properties
- Applications
- Educational issues

"640K ought to be enough for anybody"
- Bill Gates, 1981

There's Plenty of Room at the Bottom:

An Invitation to Enter a New Field of Physics

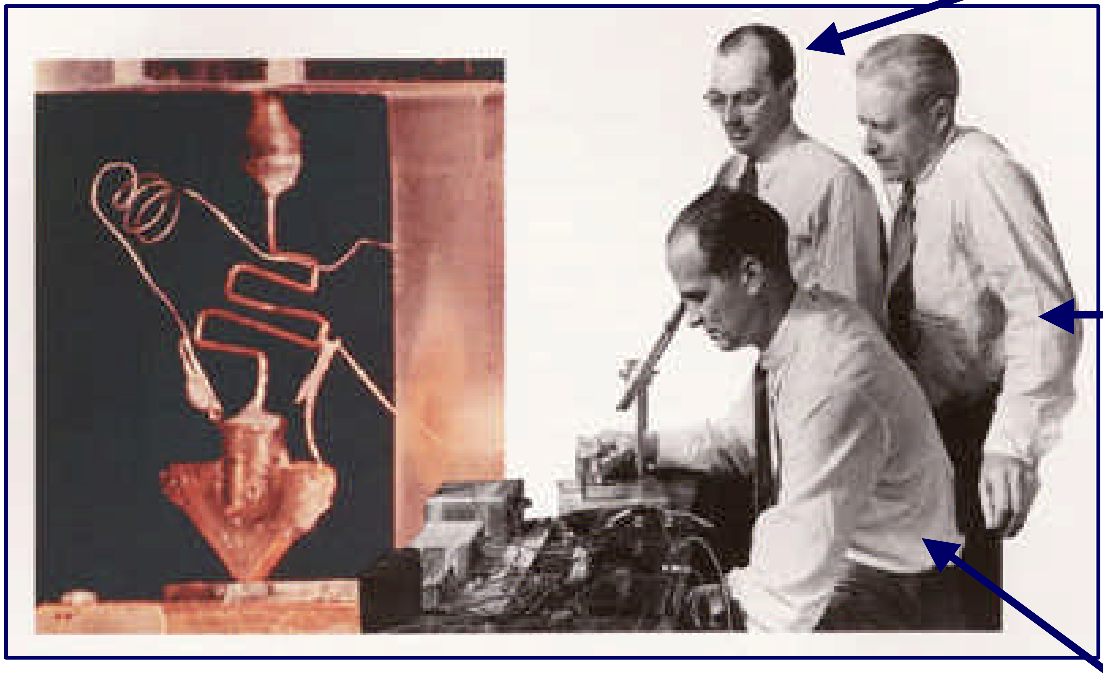
Richard Feynman
Cal Tech, 1959

"People tell me about miniaturization, and how far it has progressed today. They tell me about electric motors that are the size of the nail on your small finger. And there is a device on the market, they tell me, by which you can write the Lord's Prayer on the head of a pin. But that's nothing; that's the most primitive, halting step in the direction I intend to discuss. It is a staggeringly small world that is below. In the year 2000, when they look back at this age, they will wonder why it was not until the year 1960 that anybody began seriously to move in this direction. *Why cannot we write the entire 24 volumes of the Encyclopedia Brittanica on the head of a pin?"*

This goal requires patterning at the 10 nanometer scale.

Invention of the Transistor

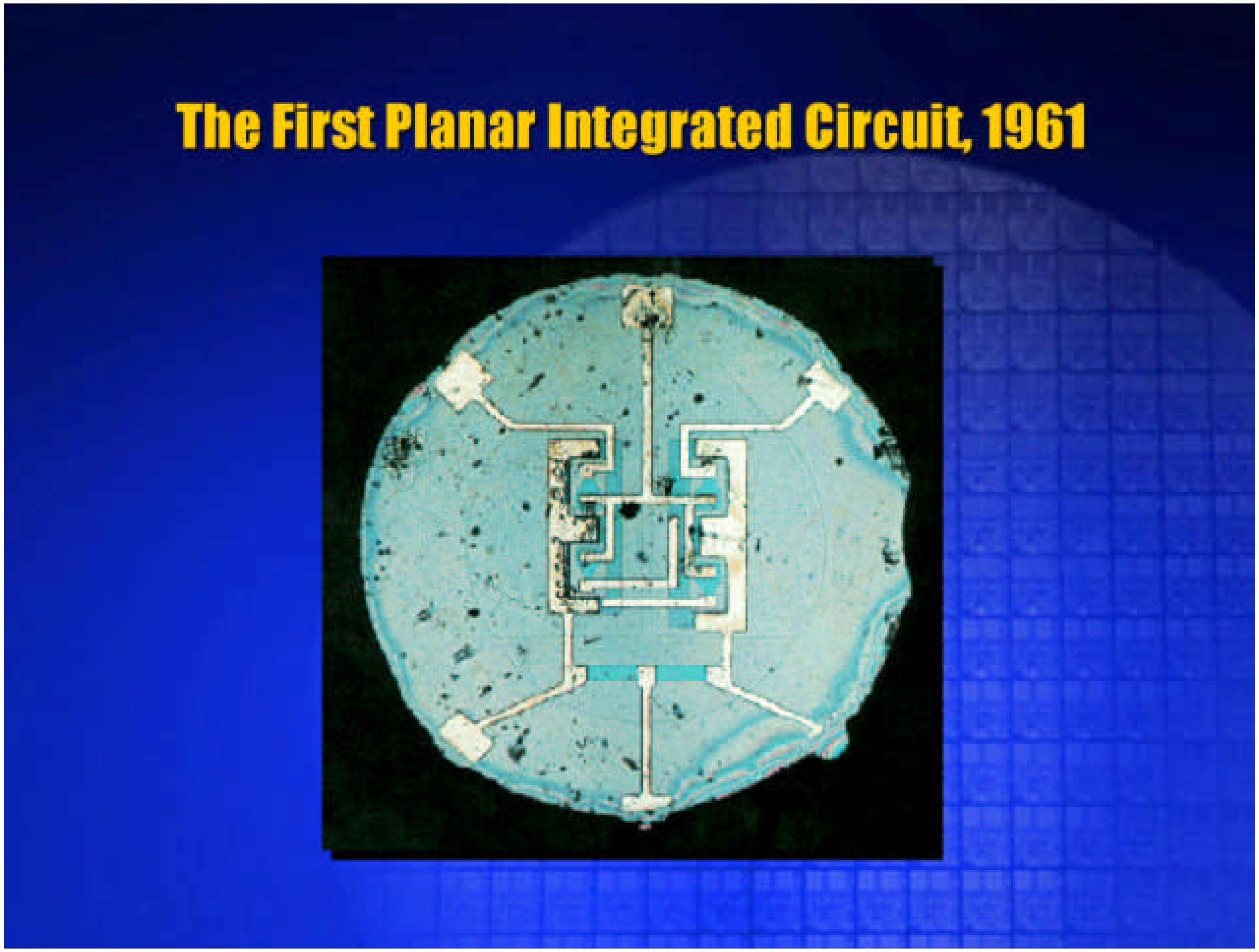
John Bardeen



Walter Brattain

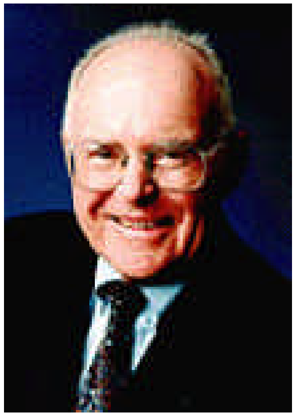
William Shockley

Bell Laboratories, 1947

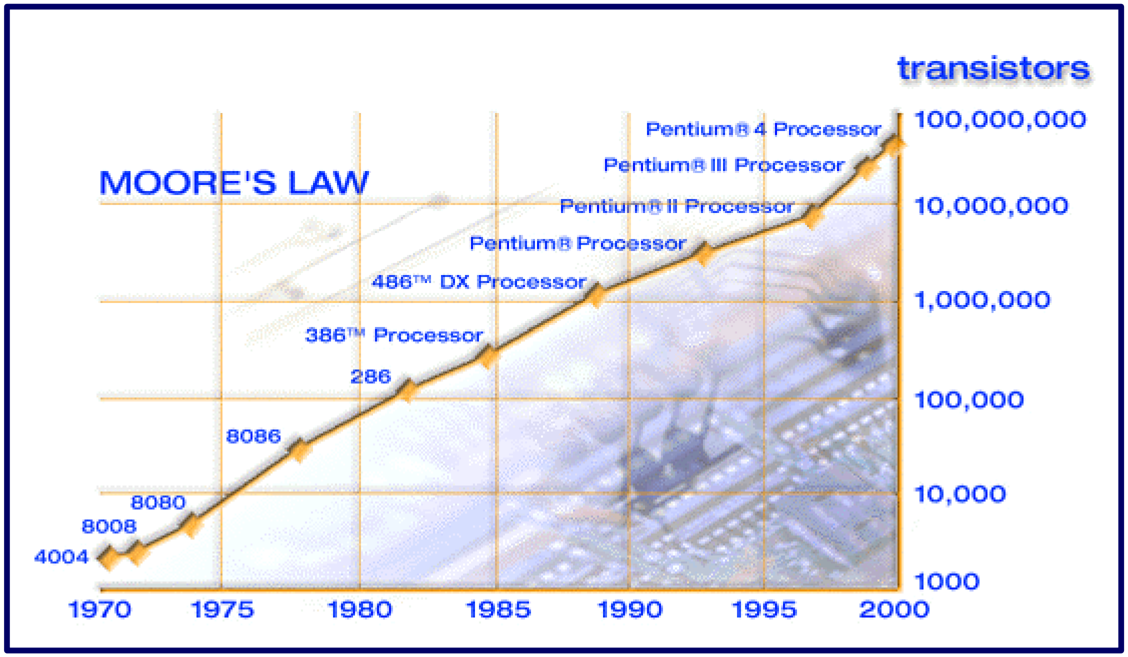


"No Exponential is Forever … but We Can Delay 'Forever',"
Gordon E. Moore, International Solid State Circuits Conference, Feb. 10, 2003.

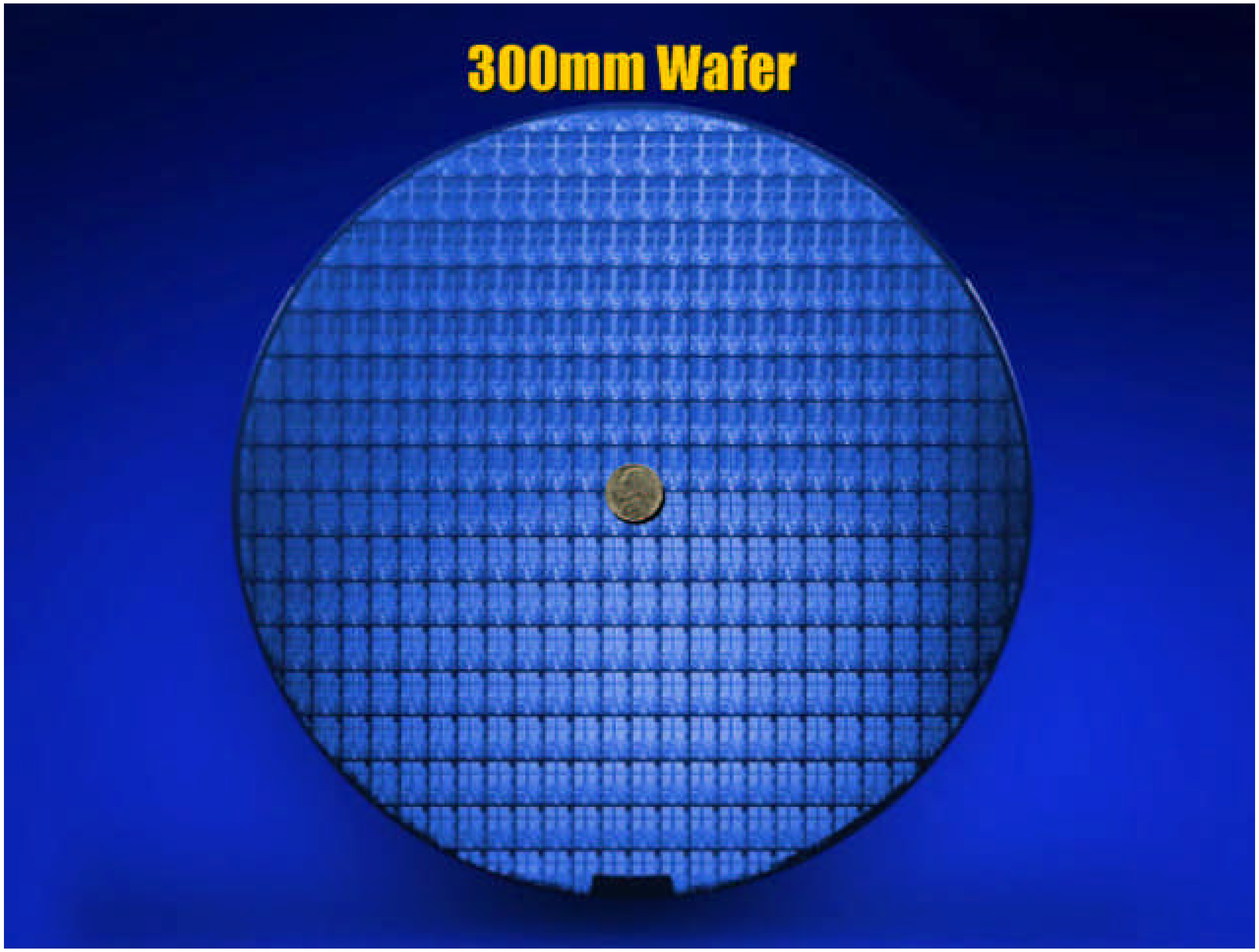
Moore’s Law



Intel Co-Founder
Gordon E. Moore



“Cramming More Components Onto Integrated Circuits”
Author: Gordon E. Moore
Publication: Electronics, April 19, 1965



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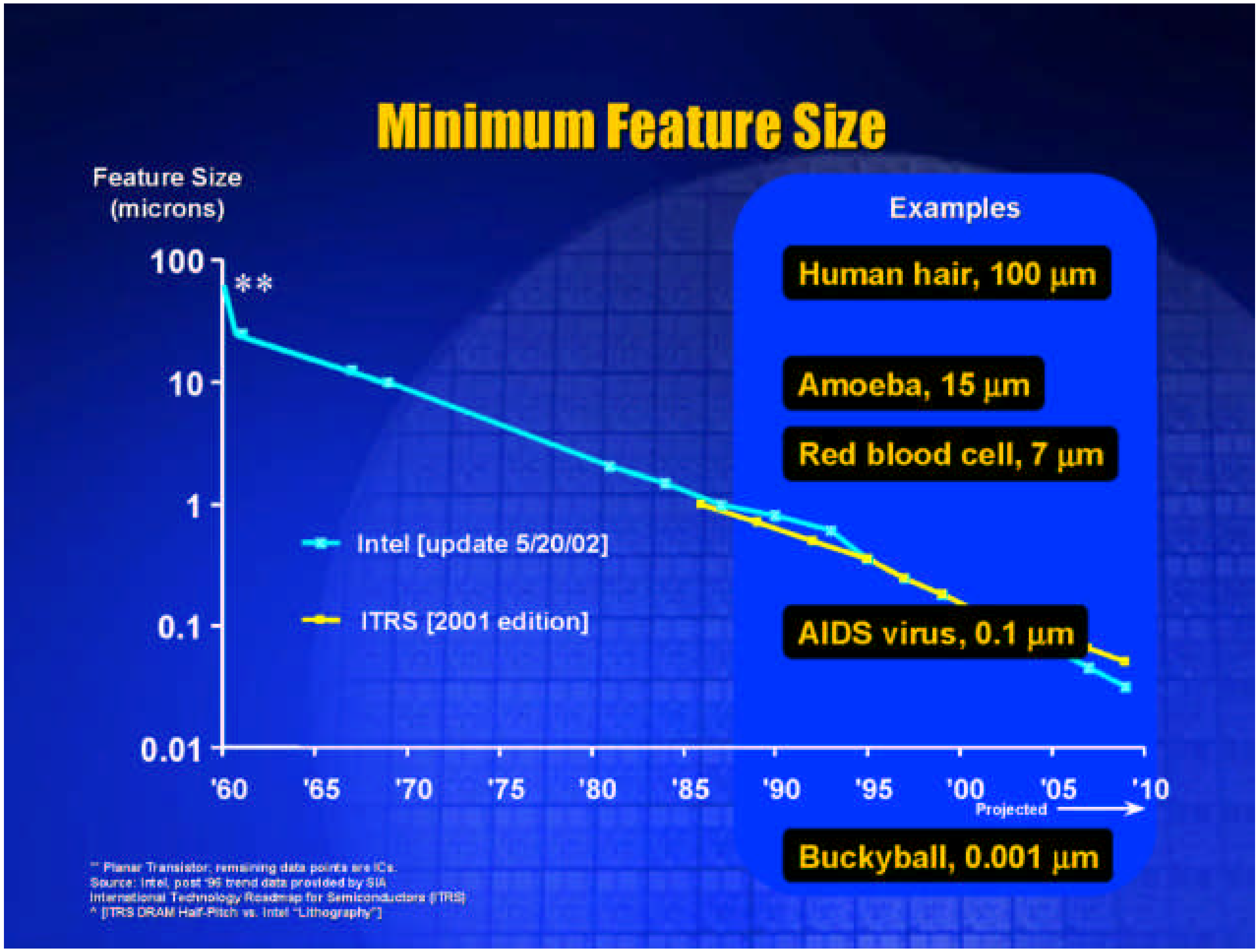

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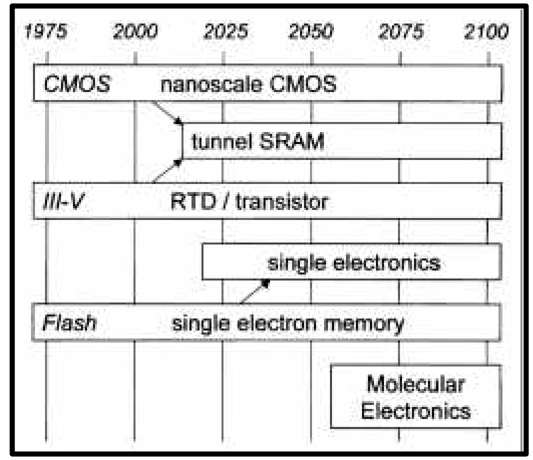
Molecular Nanoelectronics?



Projected timeline for the electronics industry:

A. C. Seabaugh, P. Mazumder,
***Proceedings of the IEEE*, 87, 535 (1999).**

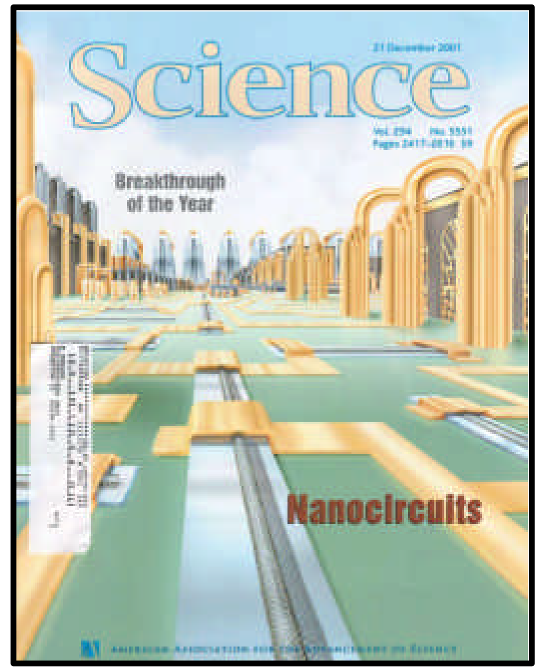
President William J. Clinton
State of the Union Address
January 27, 2000

"Soon researchers will bring us devices that can translate foreign languages as fast as you can talk; materials 10 times stronger than steel at a fraction of the weight; ***and -- this is unbelievable to me -- molecular computers the size of a tear drop with the power of today's fastest supercomputers.***"

2001: A Nanotechnology Odyssey

July 23, 2001

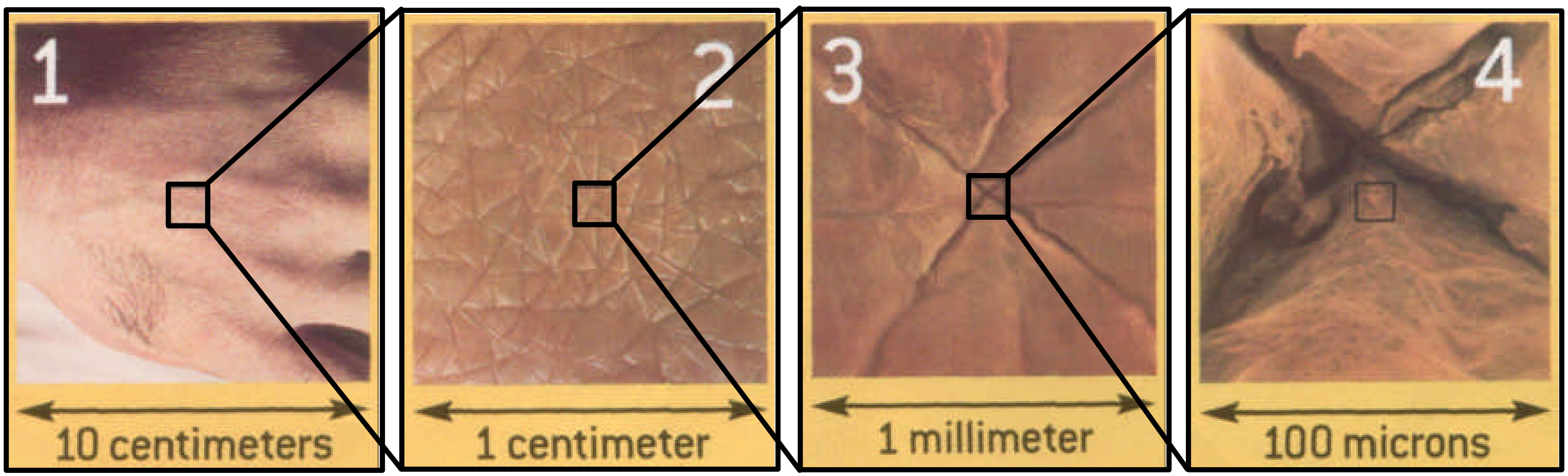
September, 2001



December 21, 2001

What is a Nanometer?

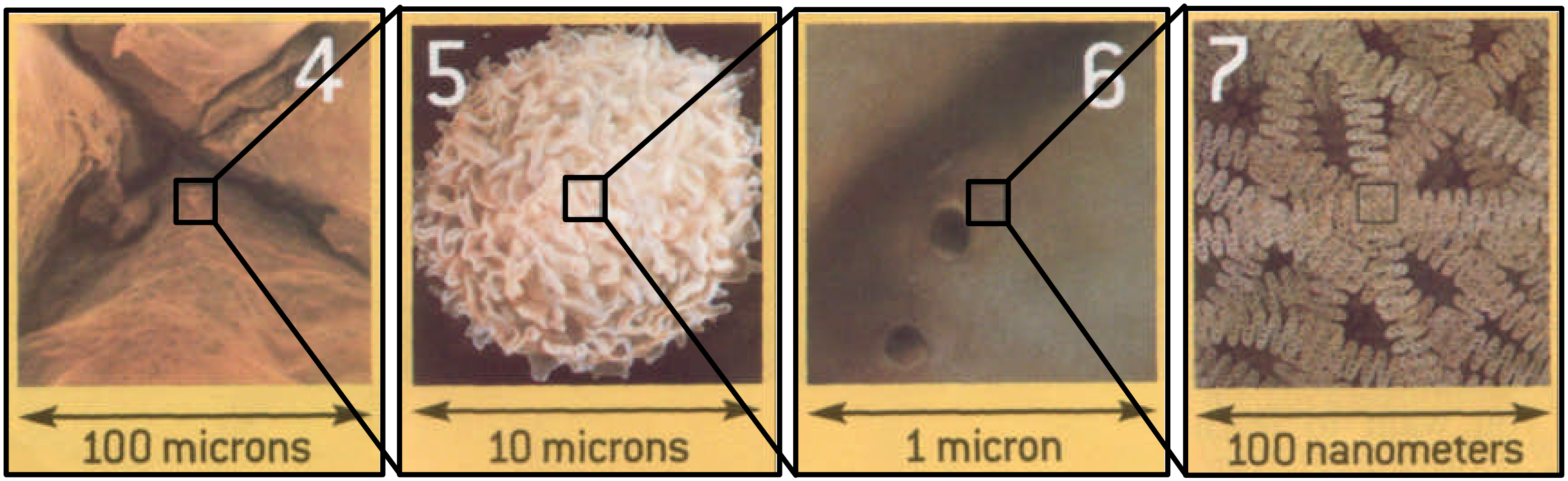
Consider a human hand:



Skin

What is a Nanometer?

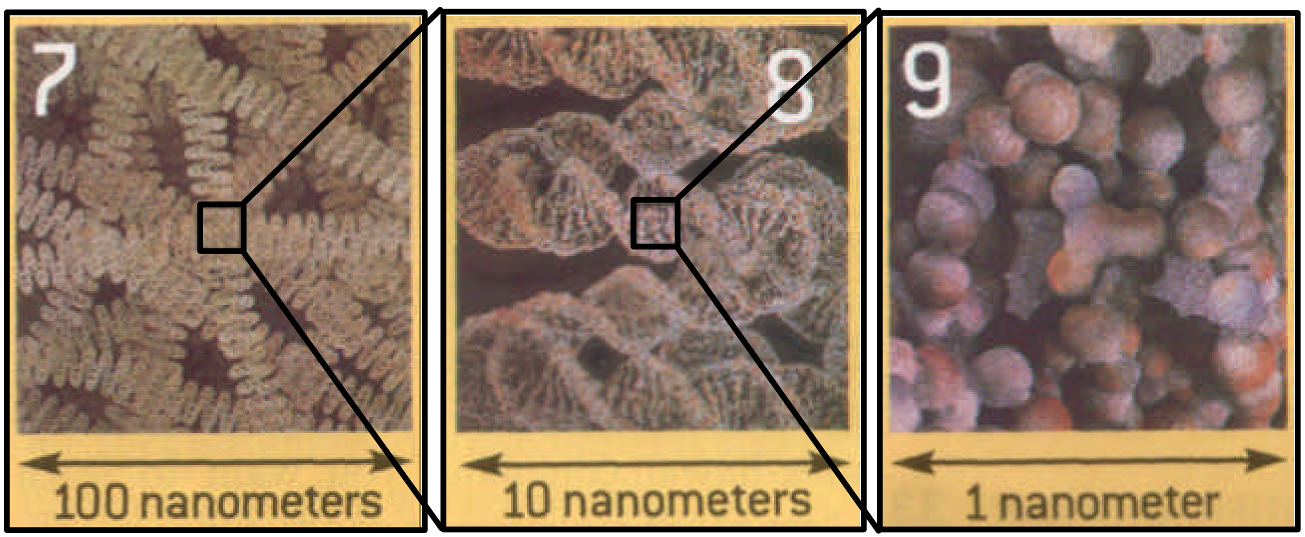
Consider a human hand:



Skin **White blood cell** **DNA**

What is a Nanometer?

Consider a human hand:



DNA

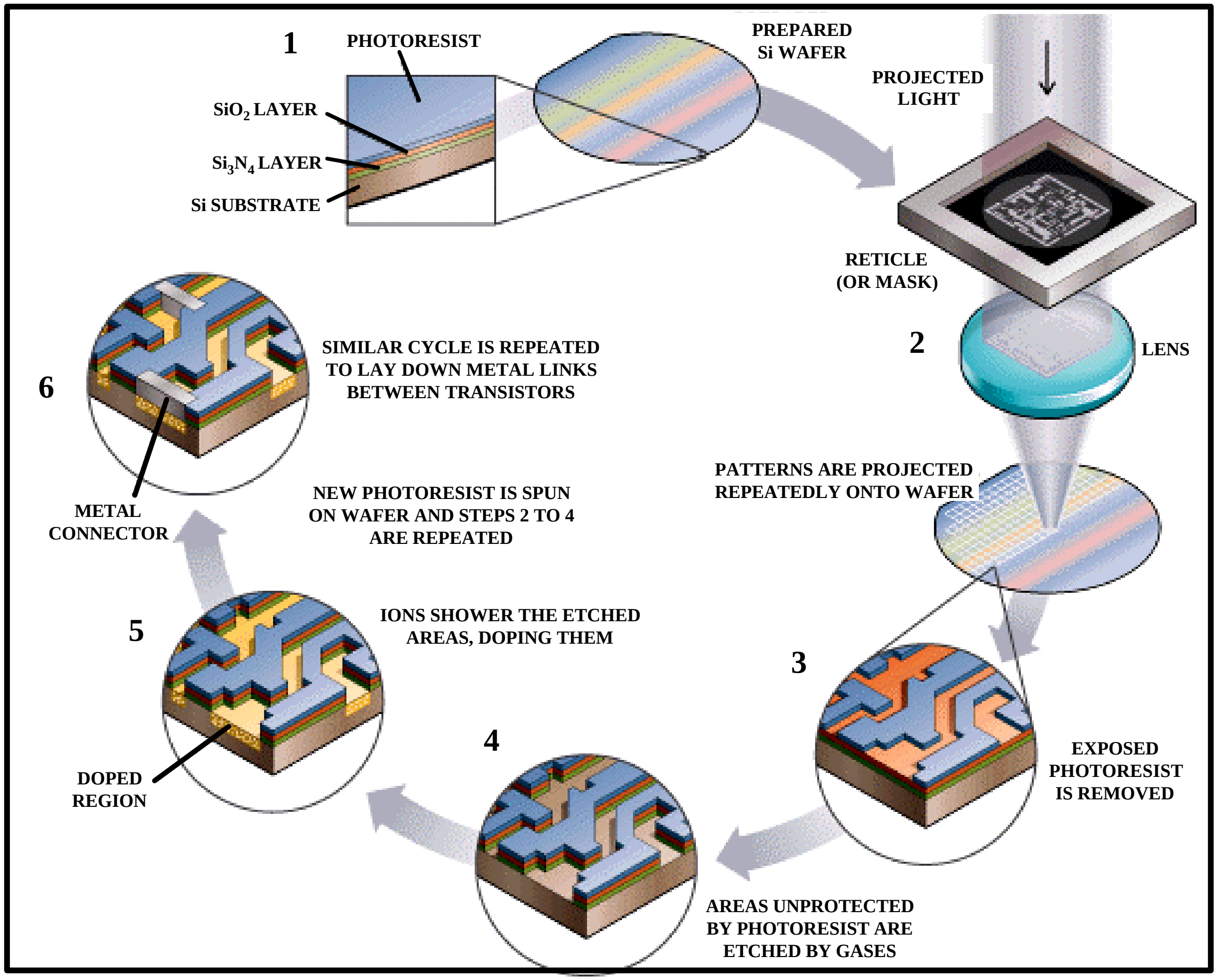
Nanofabrication

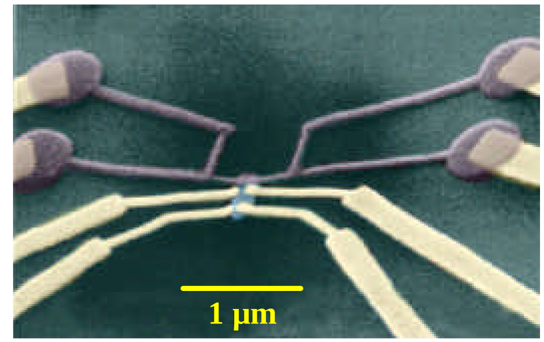
Top-down: Chisel away material to make nanoscale objects

Bottom-up: Assemble nanoscale objects out of even smaller units (e.g., atoms and molecules)

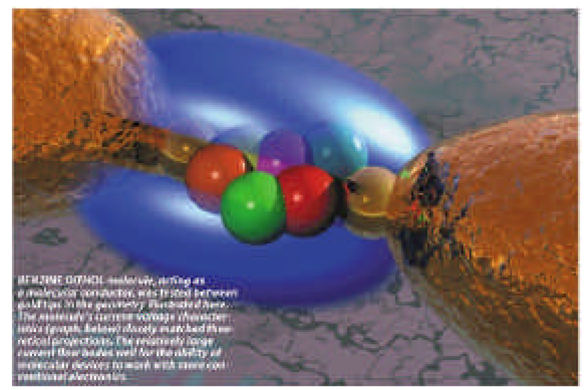
Ultimate Goal: Dial in the properties that you want by designing and building at the scale of nature (i.e., the nanoscale)

Top-Down: Photolithography



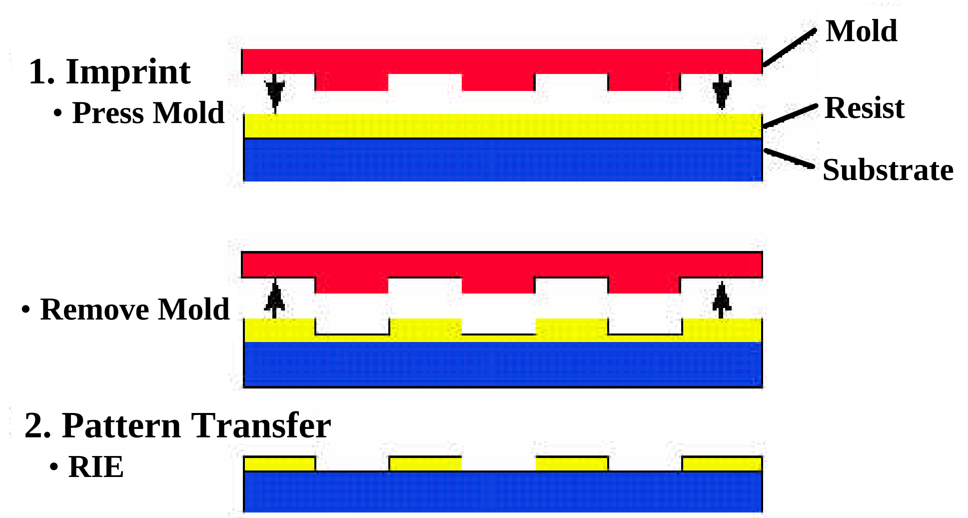


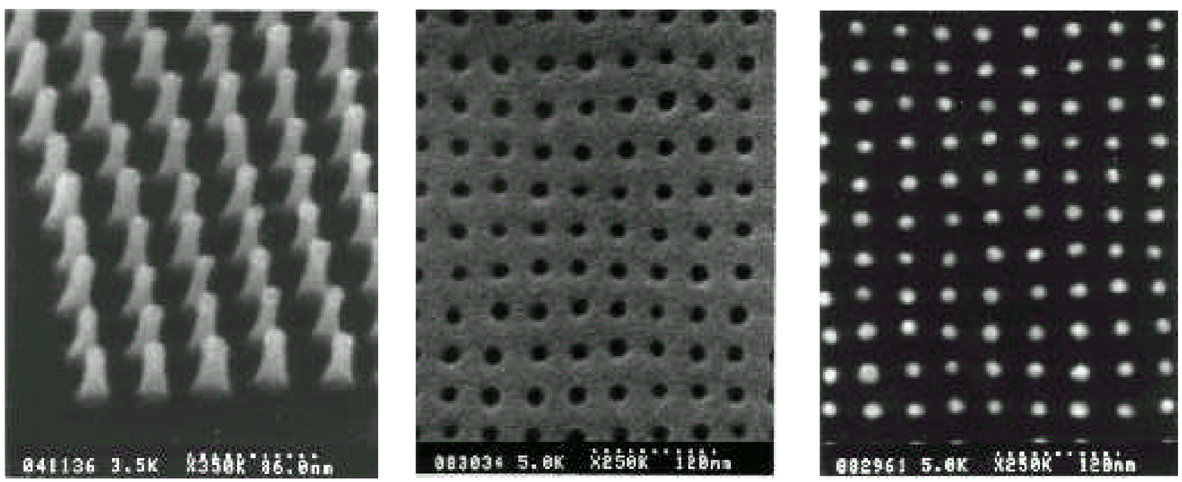
Ferromagnetic/superconducting devices (e-beam lithography)



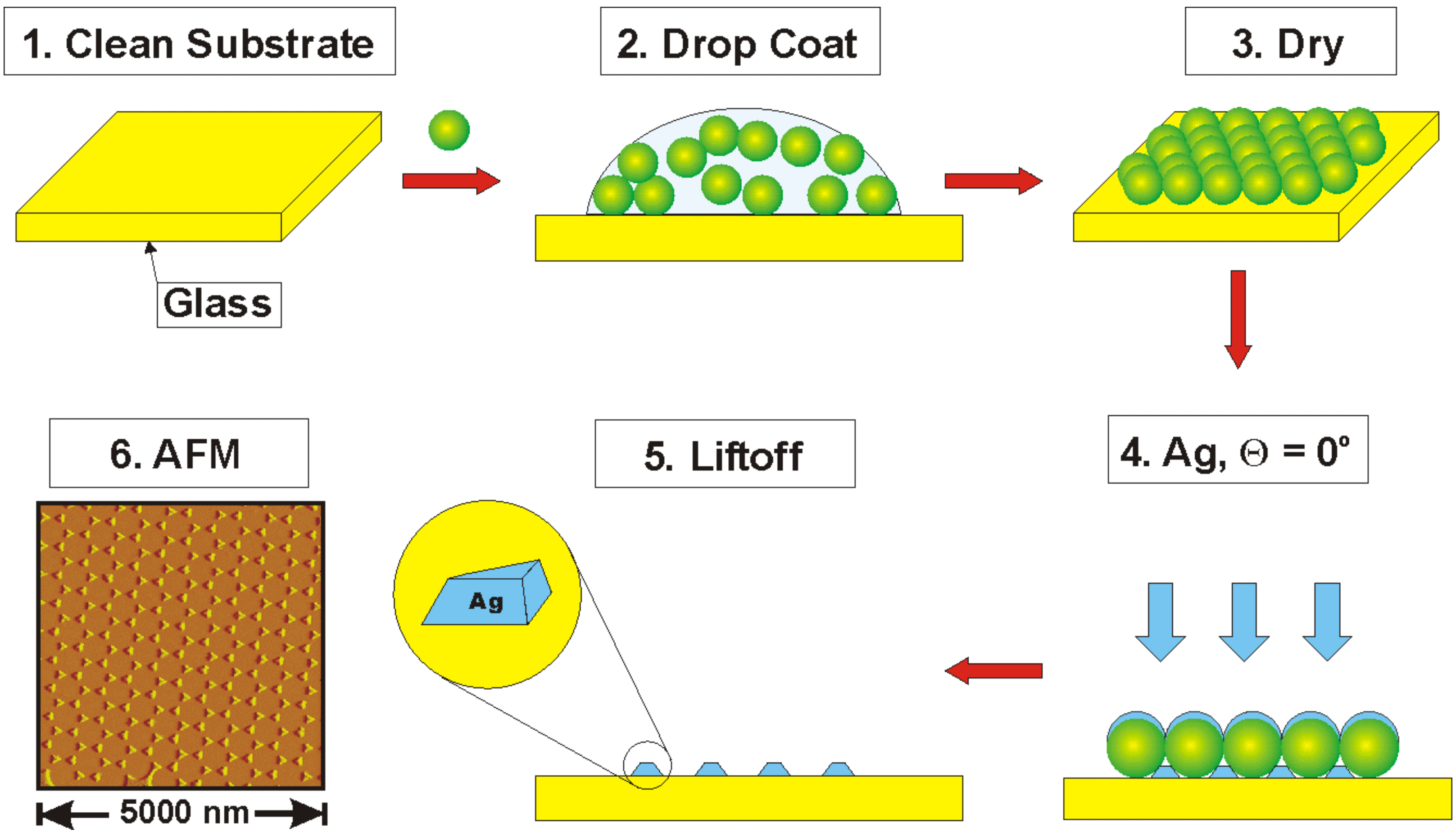
Molecular electronics (e-beam lithography)

Top-Down: Nanoimprint Lithography

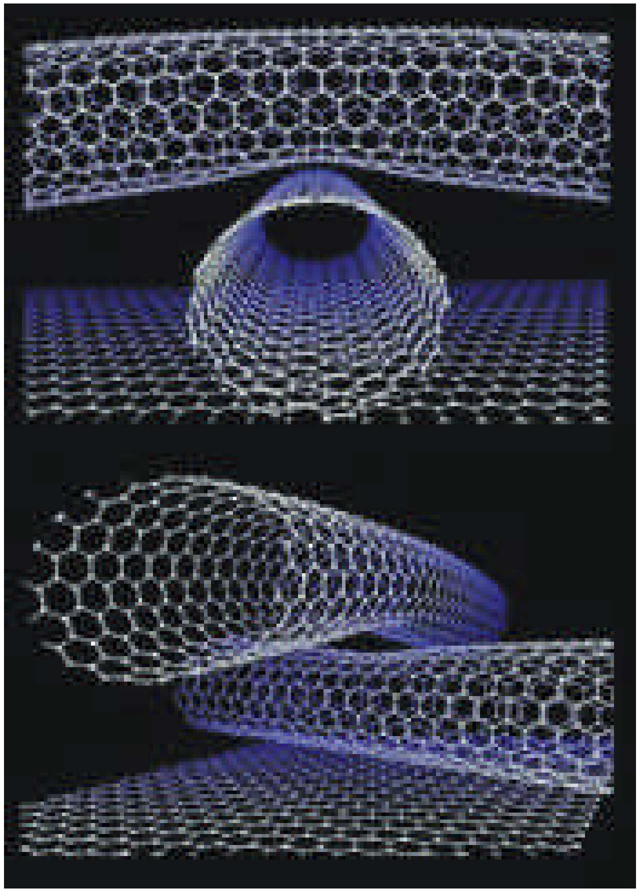


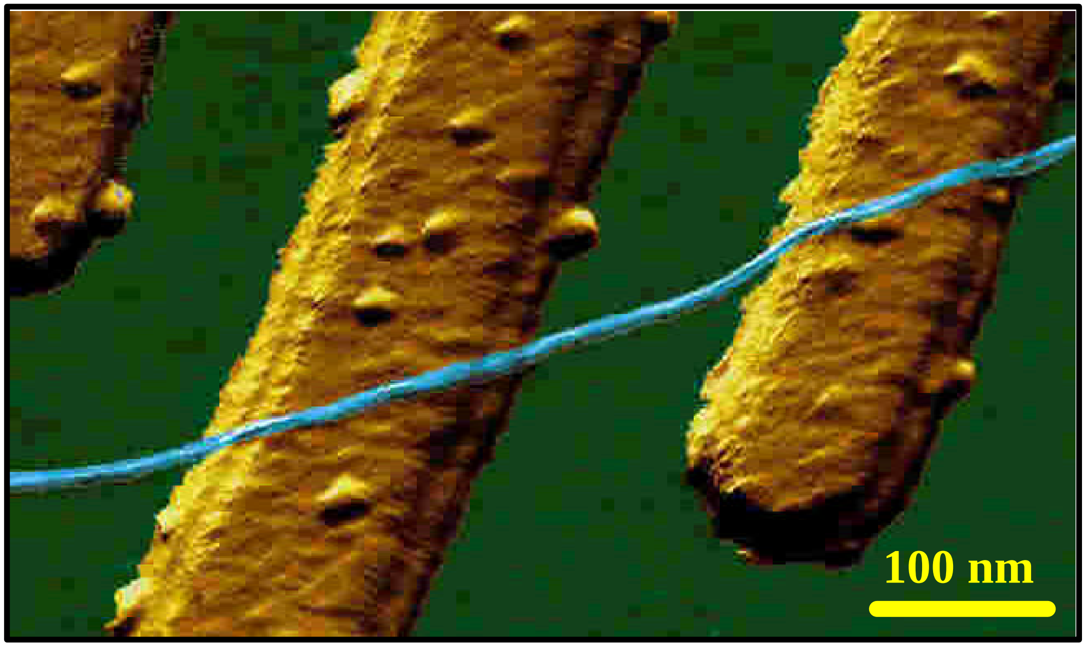


Top-Down: Nanosphere Lithography



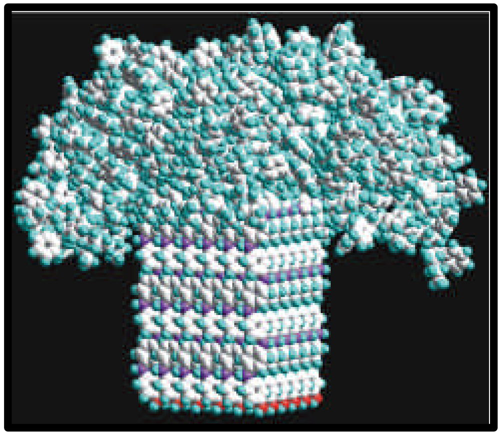
Bottom-Up: Carbon Nanotube Synthesis



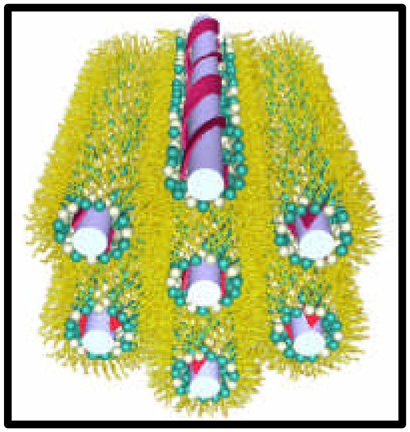


Bottom-Up: Molecular Self-Assembly

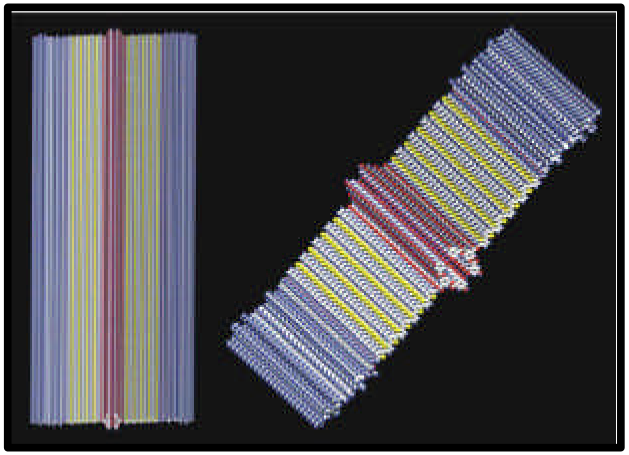
- Spontaneous organization of molecules into stable, structurally well-defined aggregates (nanometer length scale).
- Molecules can be transported to surfaces through liquids to form self-assembled monolayers (SAMs).



Supramolecular rodcoil "mushrooms"

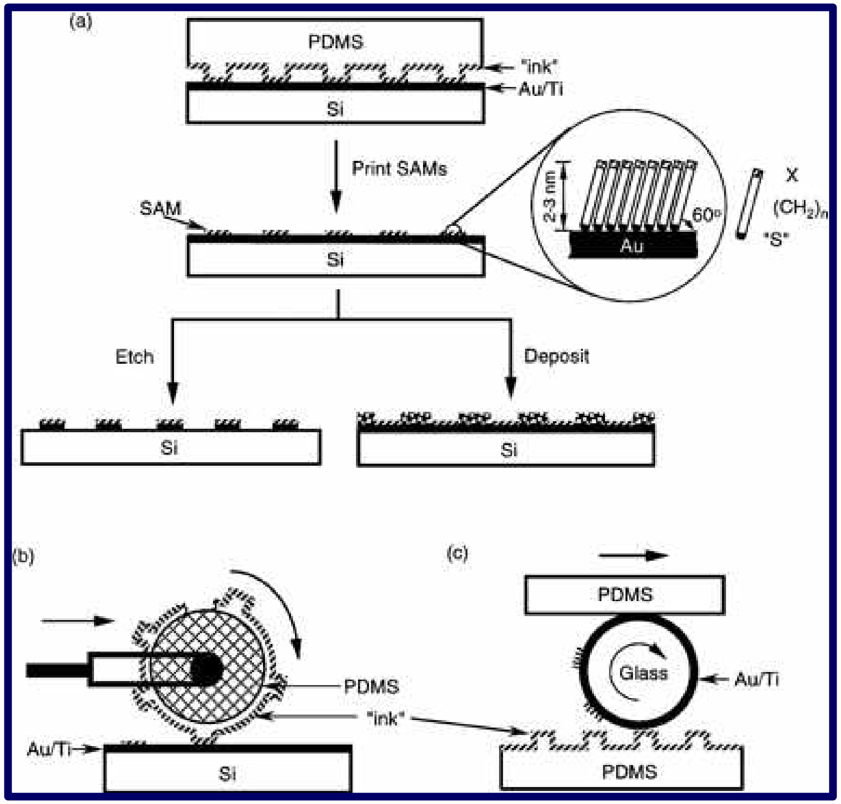


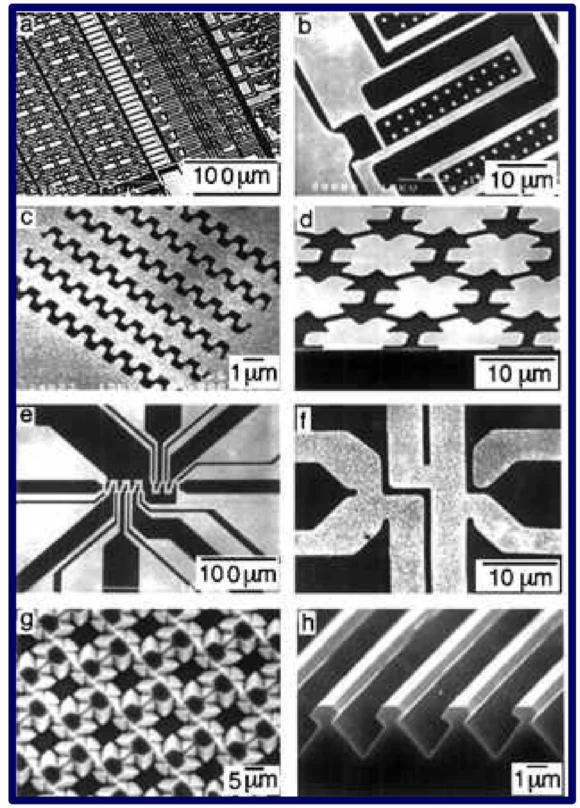
Polythiophene wires



Supramolecular rodcoil nanoribbons

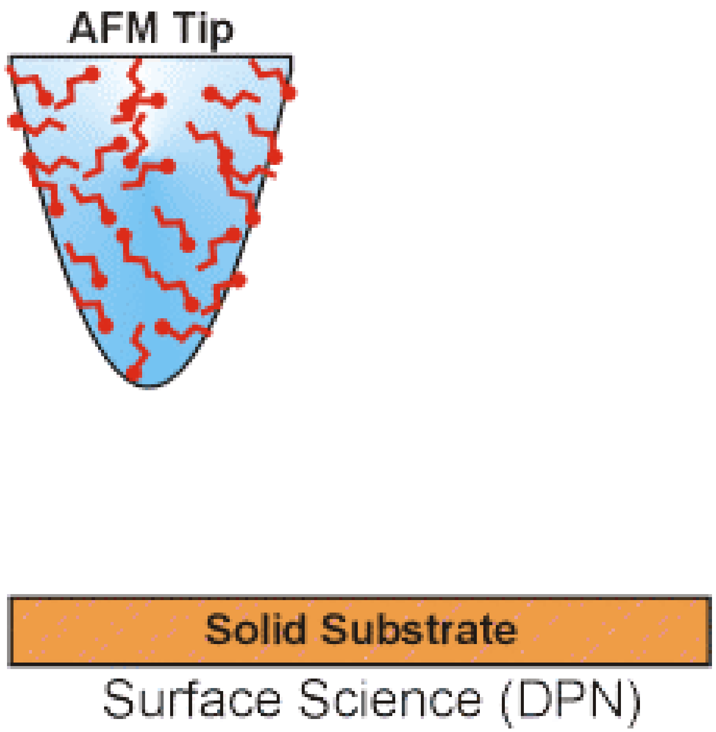
Microcontact Printing



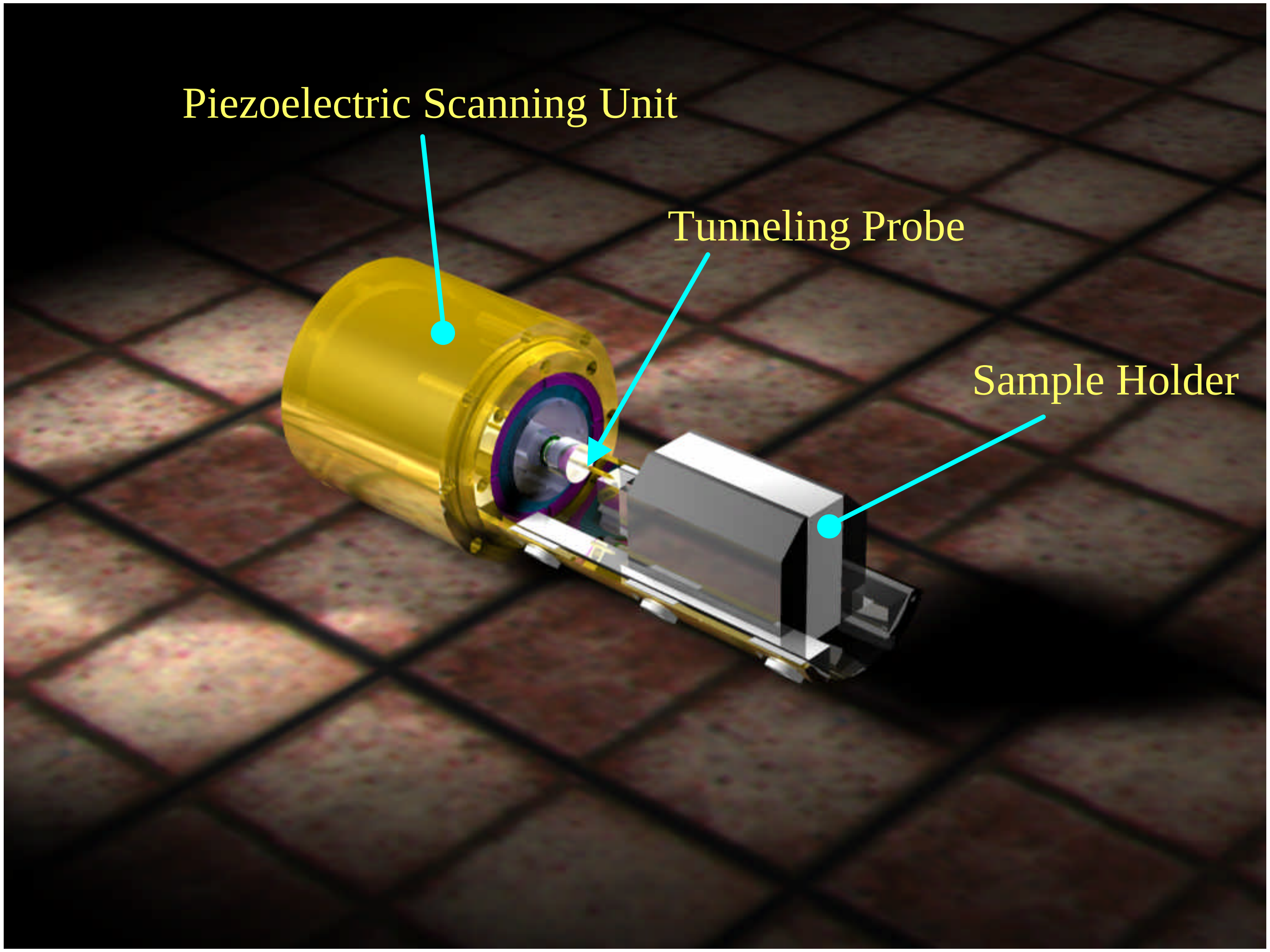


- Use a stamp to transfer “ink” to surface.
- Can be rolled onto curved surfaces.

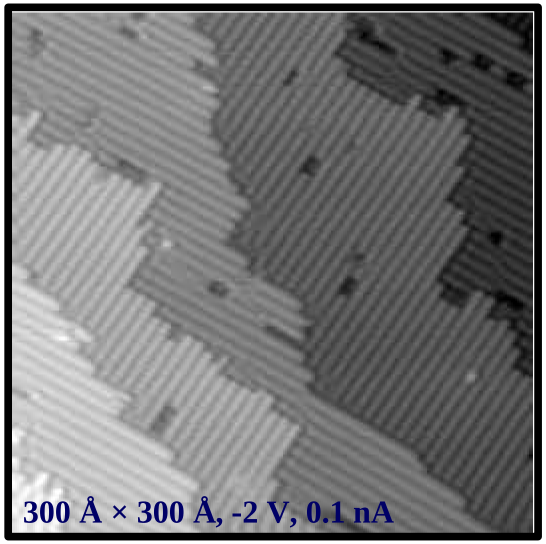
Dip Pen Nanolithography



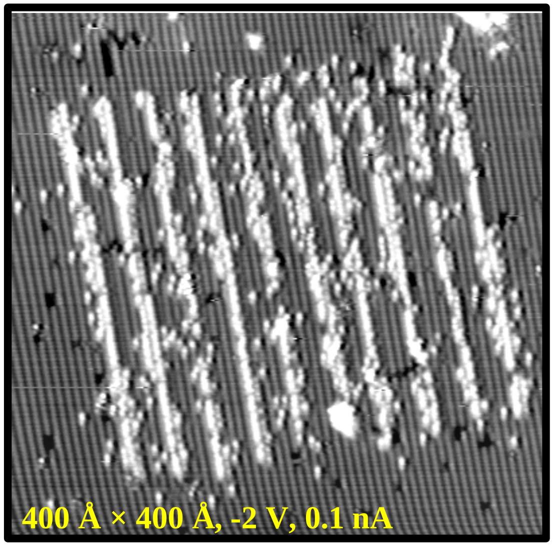
Scanning Tunneling Microscopy



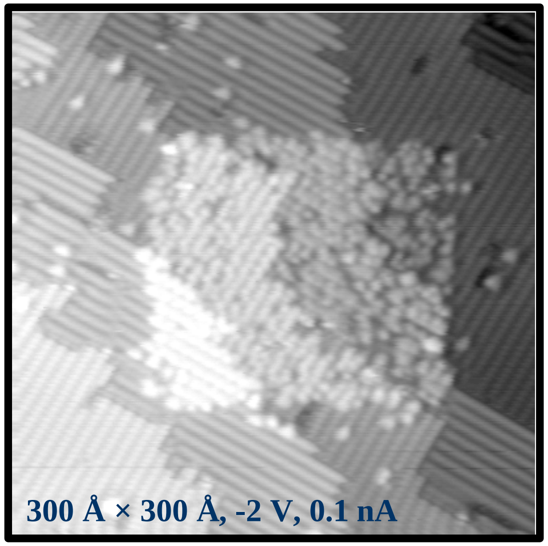
Nanolithography with Ultra-high Vacuum Scanning Tunneling Microscopy



A relatively stable and unreactive surface is produced by hydrogen passivating the Si(100)-2×1 surface in ultra-high vacuum (UHV).



Highly reactive "dangling bonds" are created by using the STM as a highly localized electron beam.

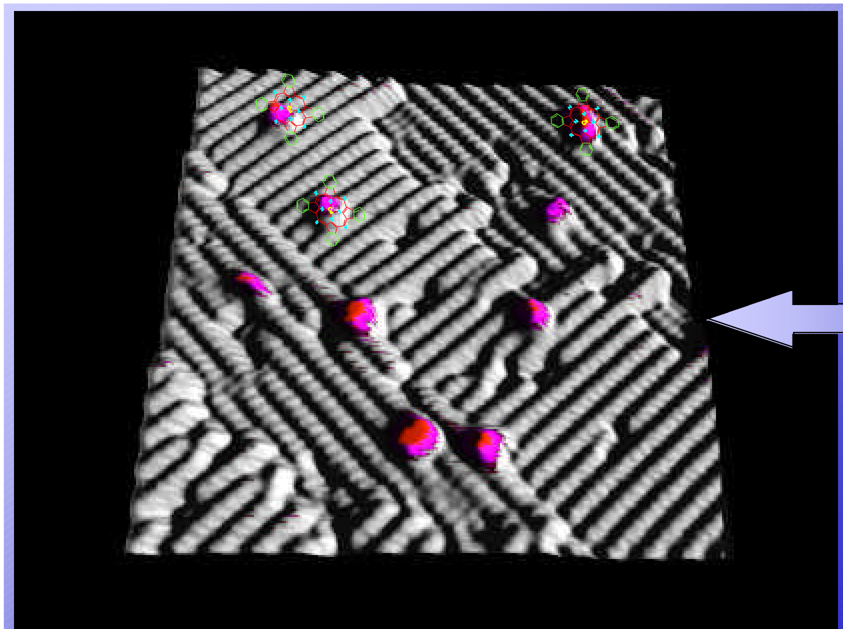


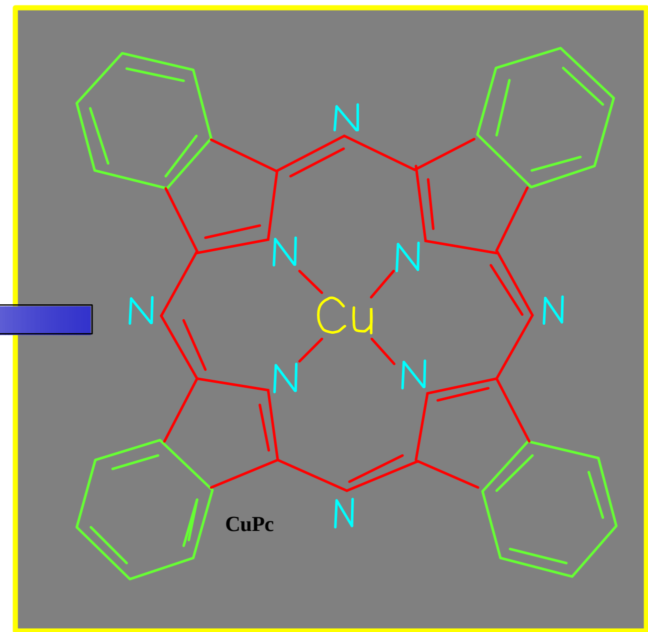
The linewidth and desorption yield are a function of the incident electron energy, the current density, and the total electron dose.

Selective chemistry can be accomplished on patterned areas.

Feedback Controlled Lithography

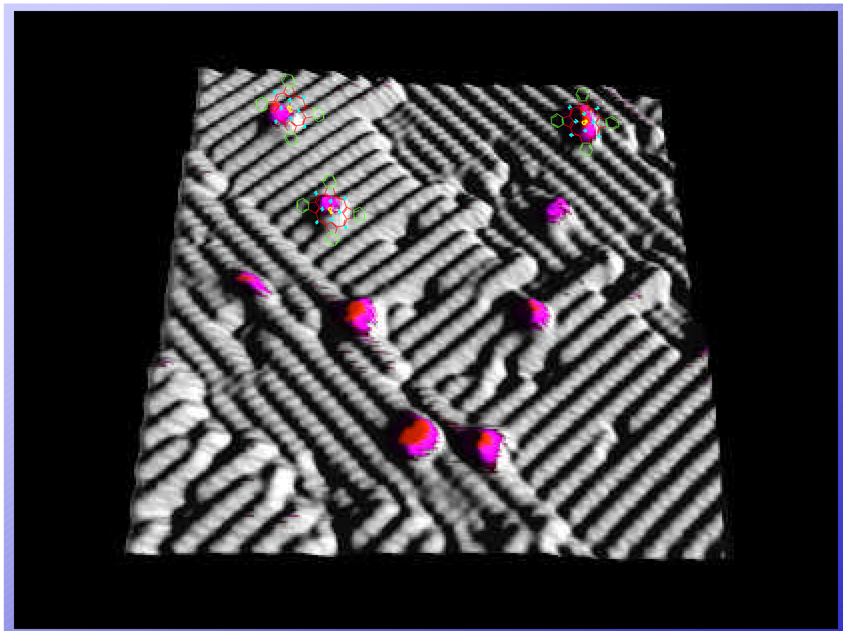
Dose Surface with Molecules like Copper Phthalocyanine

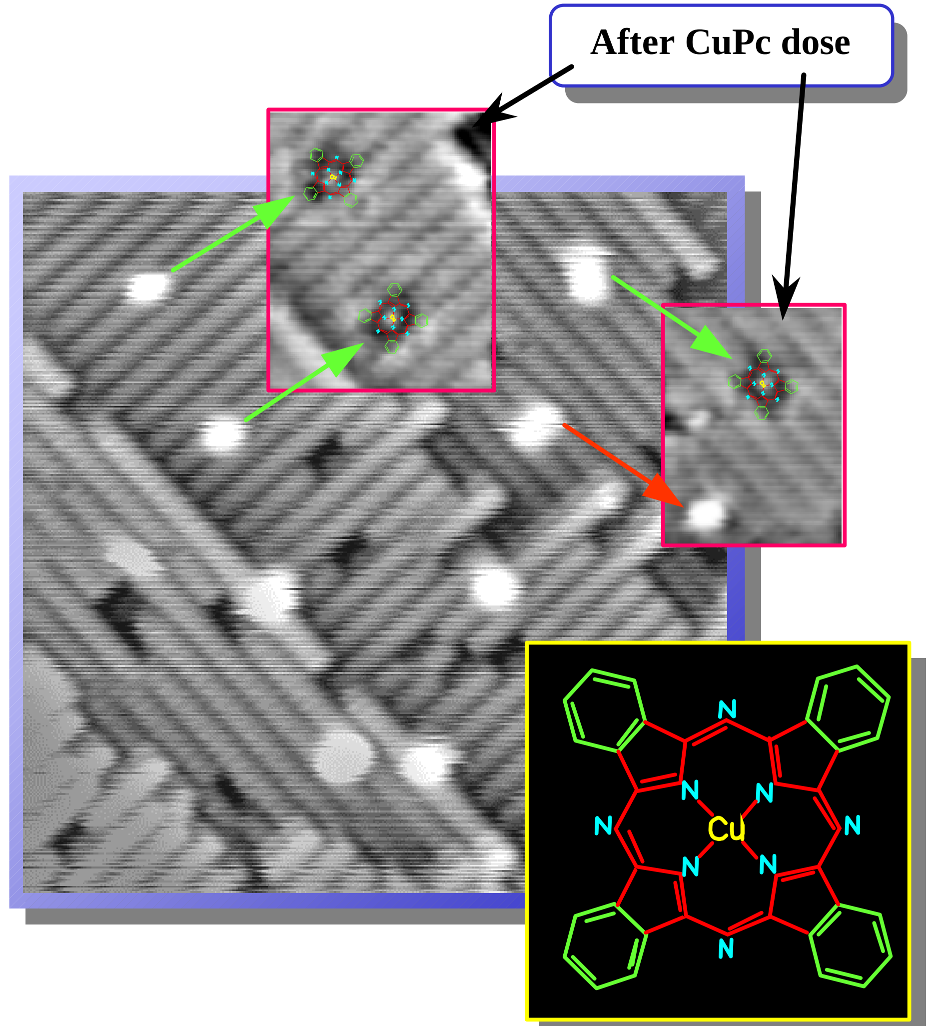




Feedback Controlled Lithography

Dose Surface with Molecules like Copper Phthalocyanine





Size-Dependent Properties

At the nanometer scale, properties become size-dependent.

For example,

(1) Thermal properties – melting temperature
(2) Mechanical properties – adhesion, capillary forces
(3) Optical properties – absorption and scattering of light
(4) Electrical properties – tunneling current
(5) Magnetic properties – superparamagnetic effect

→ New properties enable new applications

Melting Temperature

Nanocrystal size decreases

↓

surface energy increases

↓

melting point decreases

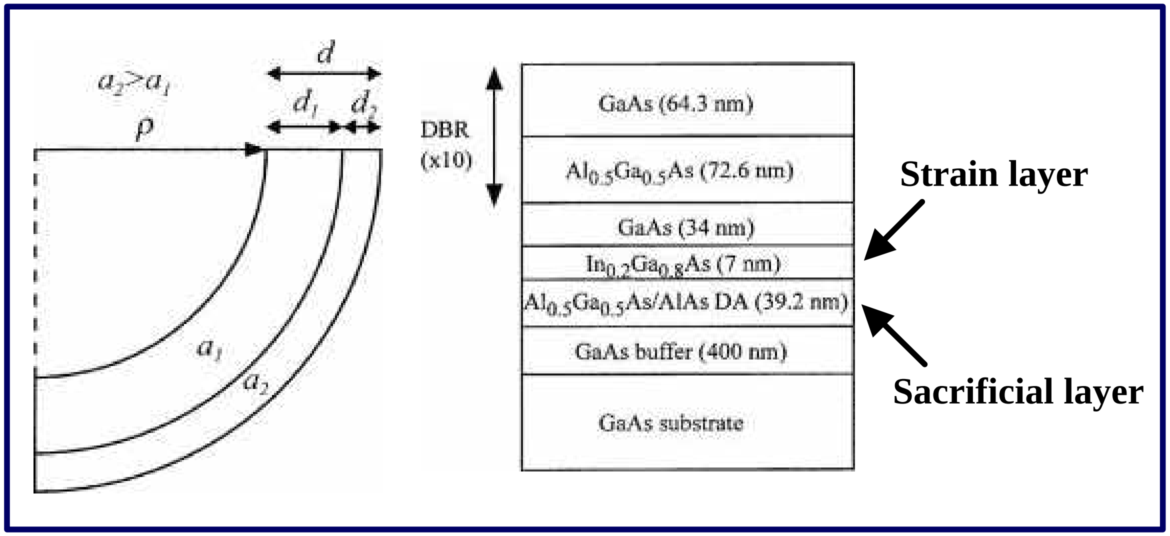
e.g., 3 nm CdSe nanocrystal melts at 700 K compared to bulk CdSe at 1678 K

Mechanical Properties

• At the nanoscale, surface and interface forces become dominant.

For example,

(1) Adhesion forces
(2) Capillary forces
(3) Strain forces



• Surface coatings are extremely important to prevent sticking in nanoscale electro-mechanical systems (NEMS)

Optical Absorption

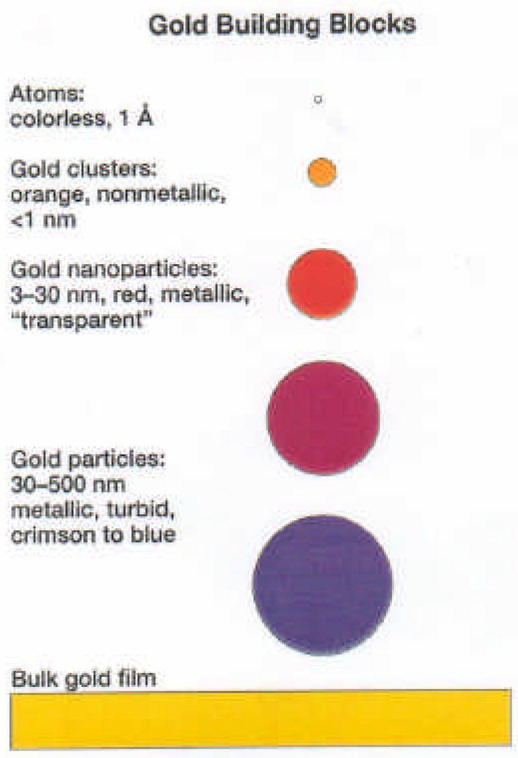


Figure 1. Gold building blocks, from the atomic to the mesoscopic, and their changing colors.

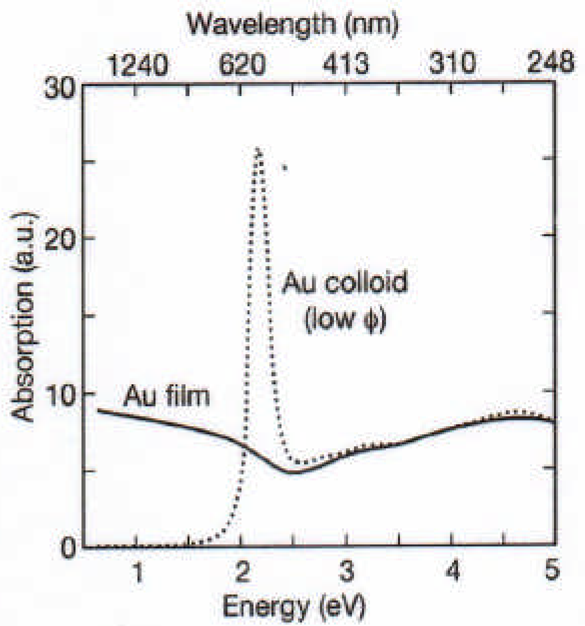


Figure 3. Absorption spectra of a gold nanocrystal film and a thin, bulk gold metal film of equivalent thickness. ϕ is the volume fraction of gold in the sample.

Historical Use of Nanoparticles: Stained Glass

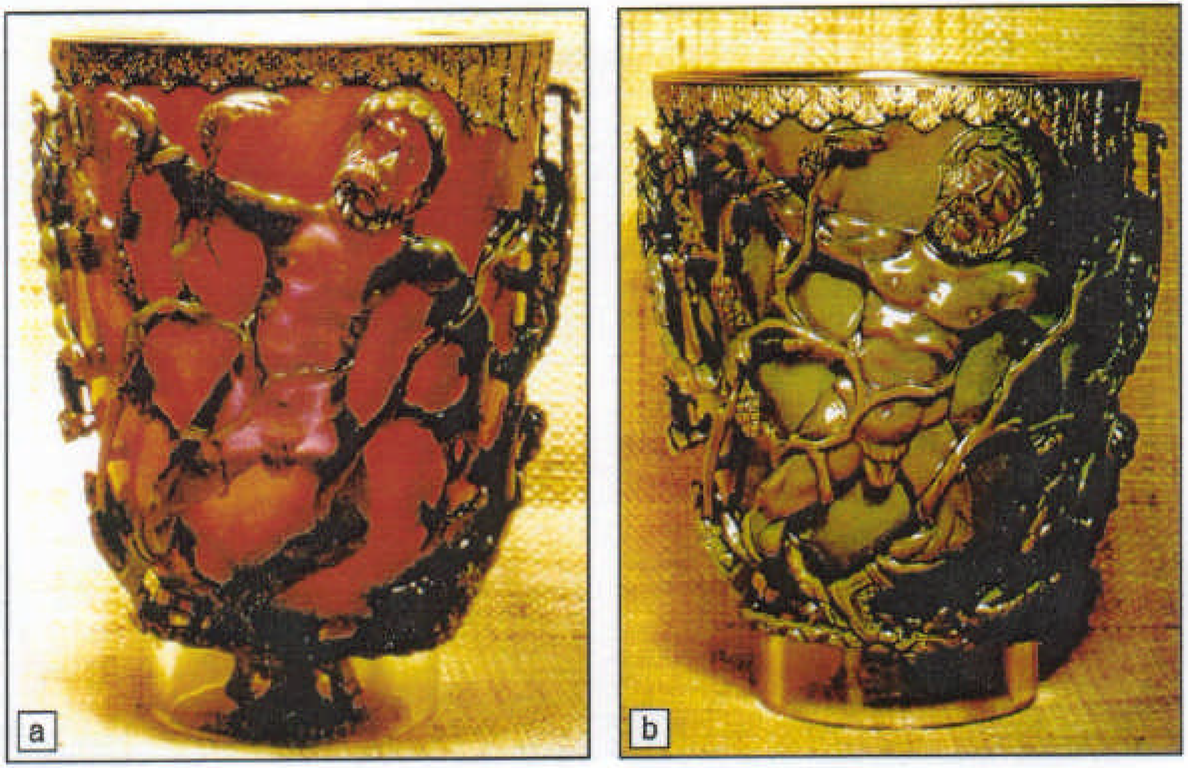
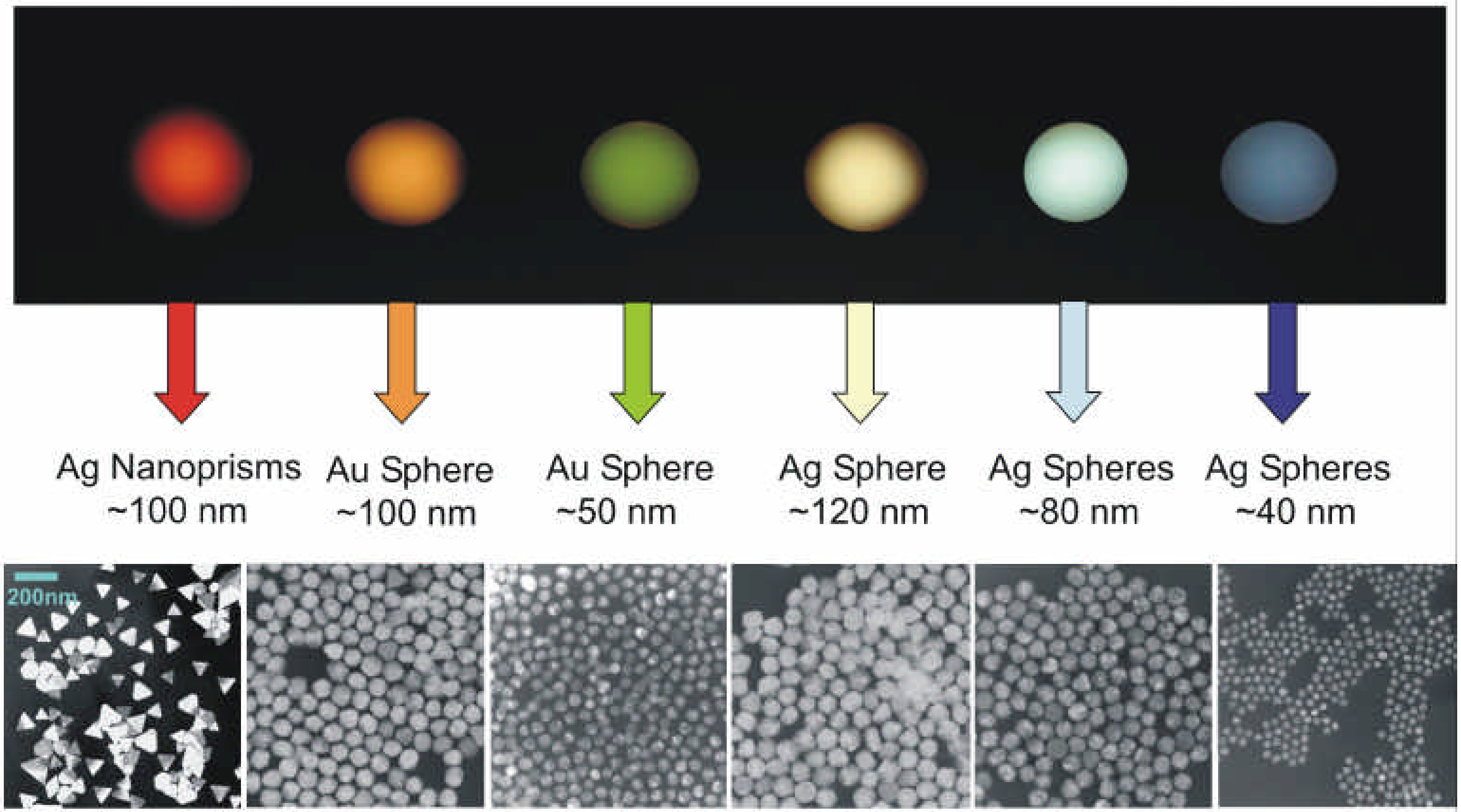


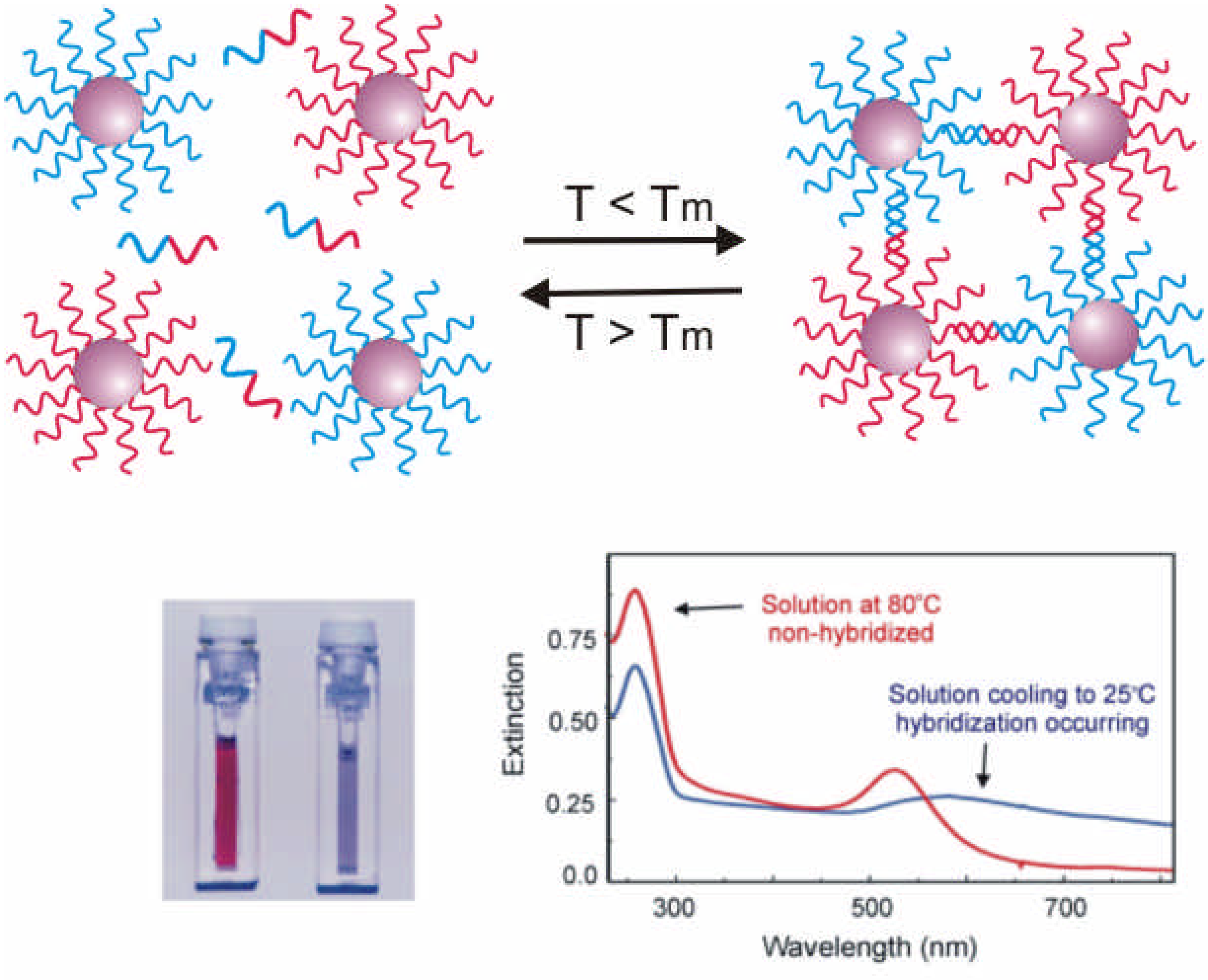
Figure 2. The Lycurgus Cup, dating from the 4th century A.D., is made from glass impregnated with gold nanoparticles; seen in (a) transmitted light and (b) reflected light.

Rayleigh Light-Scattering of Nanocrystals: Shape, Size, and Composition Matter



* The scale bar is the same for all the images.

Modern Use of Nanoparticles: Biosensors



Electrical Properties: Tunneling Current

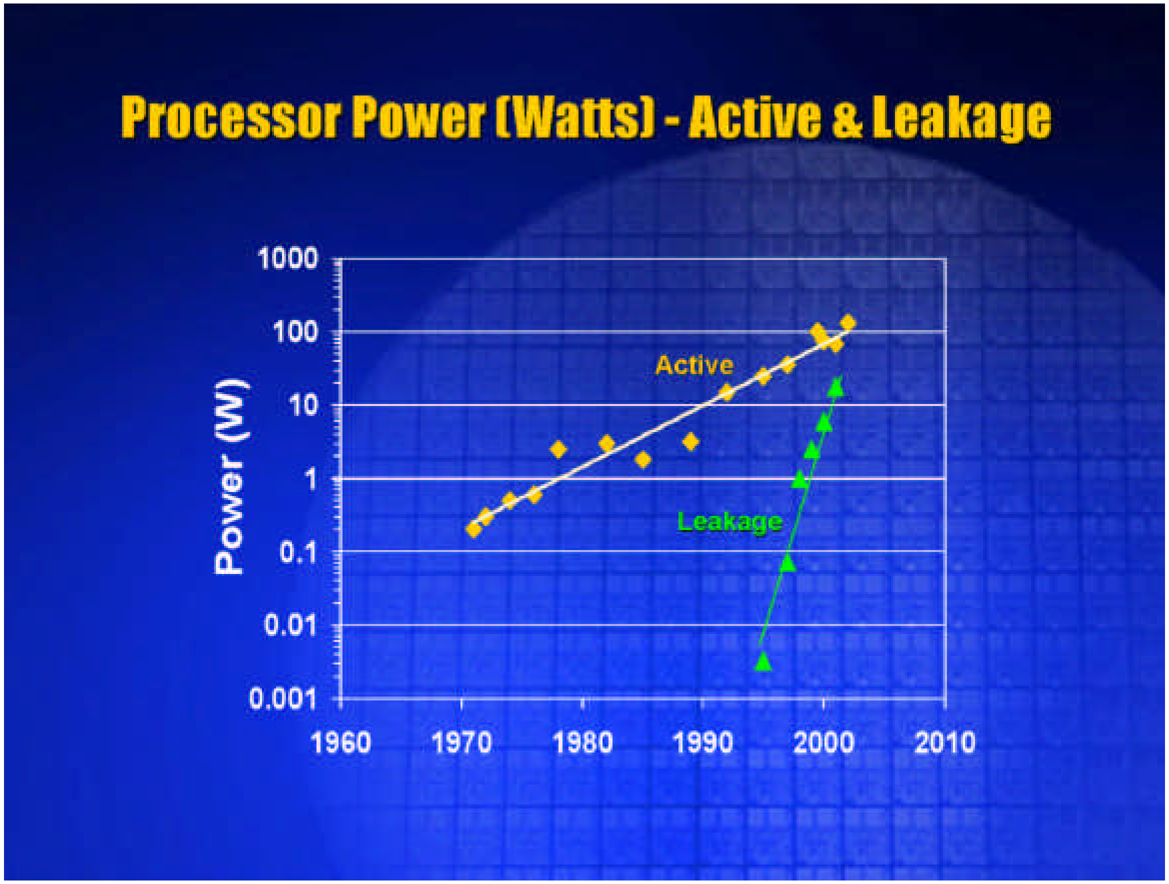
• At the nanometer scale, electrical insulators begin to fail to block current flow.

• Quantum mechanical effect known as tunneling.

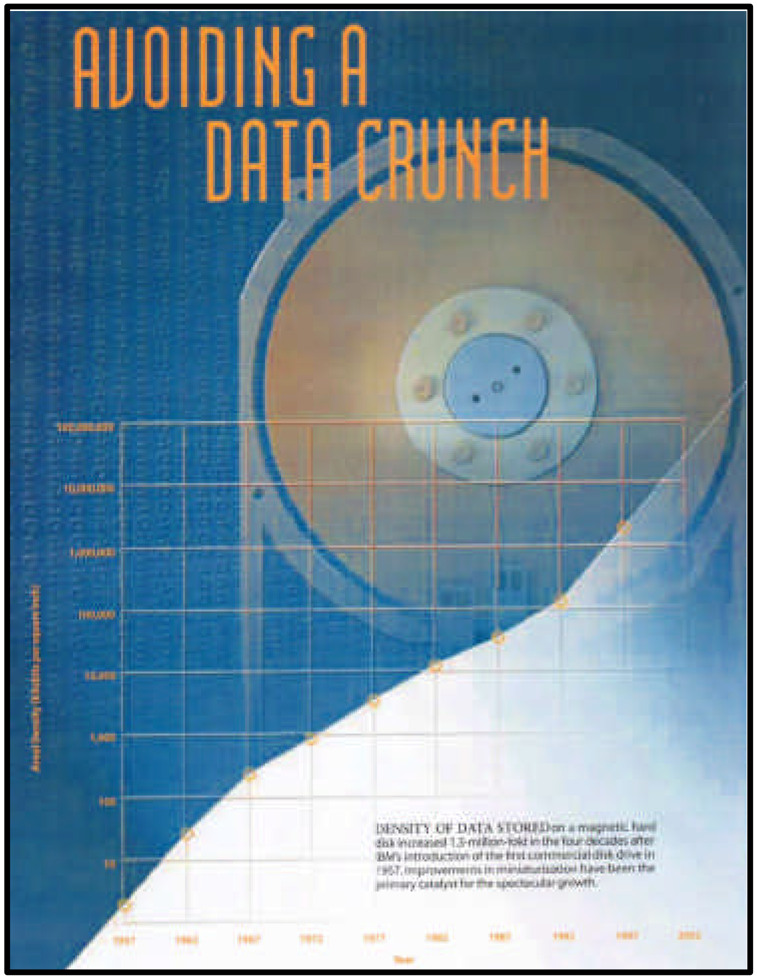
• Tunneling current increases exponentially as the thickness of the insulator is decreased.

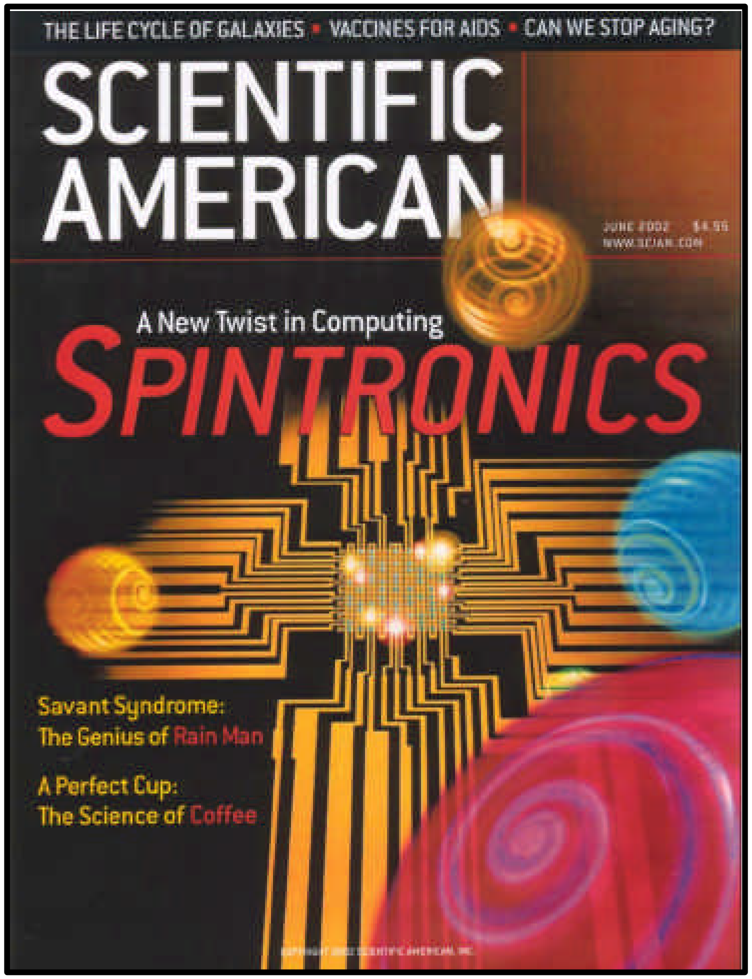
• Tunneling is the basis of the scanning tunneling microscope and covalent chemical bonding.

Practical Implications of Tunneling: Leakage Current in Microprocessors

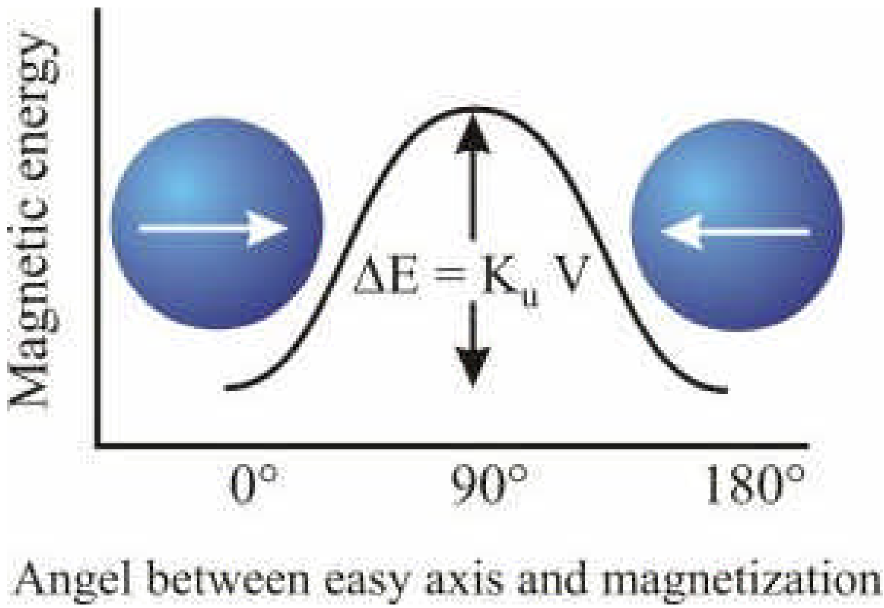


Nanomagnetism





Superparamagnetic Effect

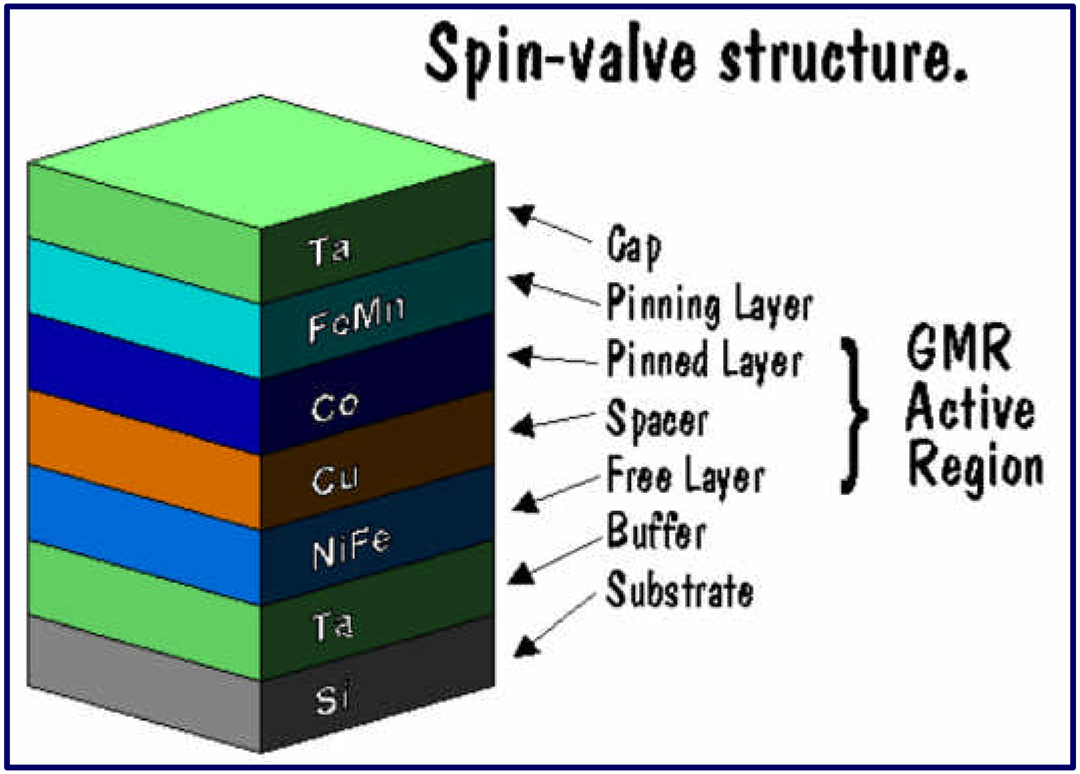


K_u is the magnetic anisotropy

V is the bit volume

As the volume of a magnetic bit is decreased, its stability decreases.

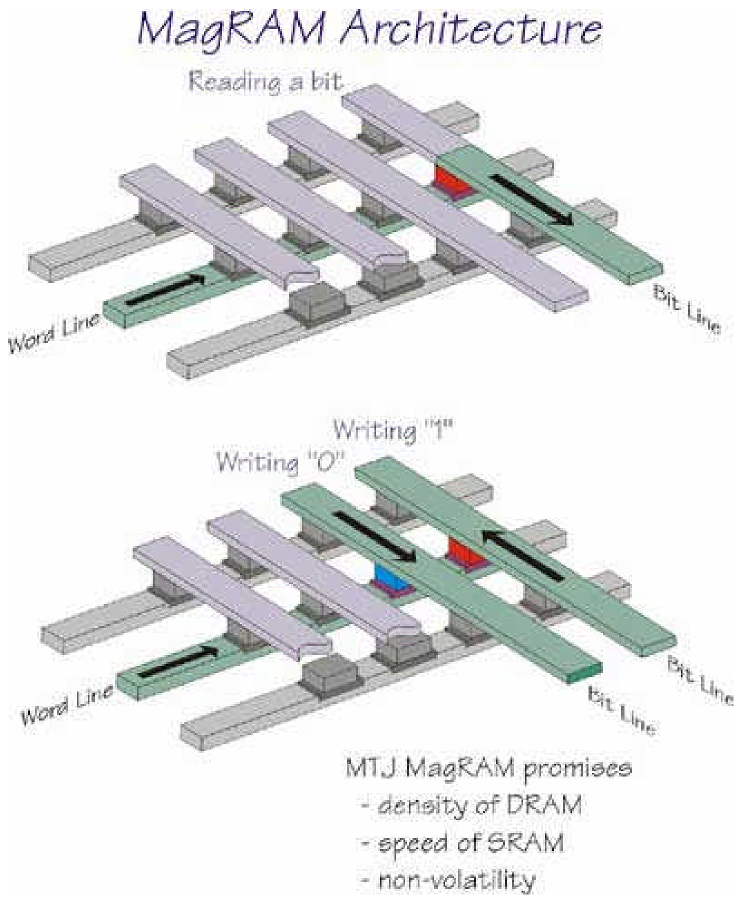
Giant Magnetoresistance



Nanometer thick films of magnetic and electrically conductive materials experience large variations in electrical resistance in the presence of a magnetic field.

This phenomenon is used to read bits in hard disks.

Spintronics



Magnetic Random Access Memory

Use the angular momentum (spin) of the electron in addition to its charge for information storage.

High speed, high density, and non-volatile.

Summary

- Nanotechnology is inherently an interdisciplinary field that encompasses physics, chemistry, biology, and engineering.

- Recent years (and months) have seen significant scientific and technological advances in nanotechnology.

- The federal government and industry are investing heavily in nanotechnology research and development.

- Many future developments and technologies have been promised – are they realizable?

MSE 376: Nanomaterials

- Developed by Hersam in Spring, 2001

- Has been taught by Hersam in 2001, 2002, 2003, 2004

- Senior undergraduate / junior graduate level course

- Attracts students from many departments:
  - Materials Science and Engineering
  - Electrical and Computer Engineering
  - Chemical Engineering
  - Mechanical Engineering
  - Chemistry

MSE 376 Course Objectives

Throughout this course, students will:

(1) Study how the structure of materials can be controlled down to the nanometer scale through various processing methods.

(2) Study structure-property relationships at the nanoscale.

(3) Study applications involving nanostructured materials.

(4) Develop effective interdisciplinary communication skills.

(5) Critically evaluate topics in the emerging field of nanomaterials (i.e., distinguish progress from hype).

MSE 376 Pedagogical Practices

Promote critical thinking and interdisciplinary communication through:

- Collaborative group problem solving and analysis
- Group presentations and writing assignments
- Peer assessment

Details can be found in the following reference:

M. C. Hersam, M. Luna, and G. Light, "Implementation of Interdisciplinary Group Learning and Peer Assessment in a Nanotechnology Engineering Course," *Journal of Engineering Education*, Vol. 93, pp. 49-57 (2004).

- NCLT will allow for further development of this course.