

# **Nanoscience and Nanotechnology: An Introduction**

**Junior Research Seminar  
Spring 2004**

**30 March 2004**

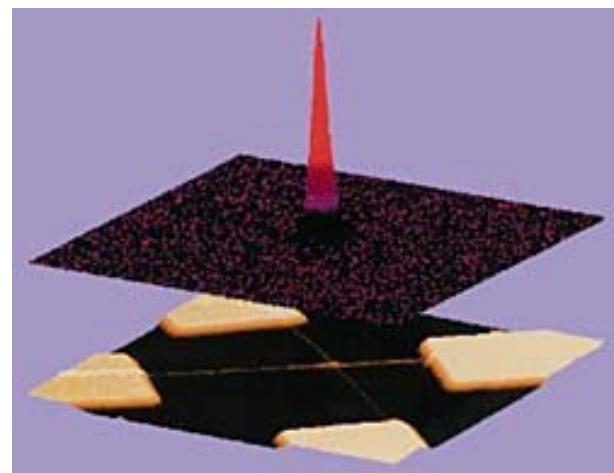
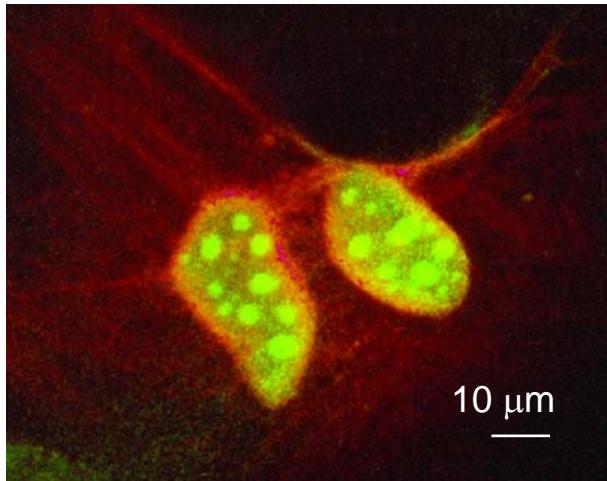


# Why *Nano* Rather than Something Else?

- **A popular, understandable (but largely incorrect?) vision**
  - Drexler, Merkle, Joy, Golden, ...: little submarines; the “replicator”
  - The spice of apocalypse: “grey goo”
- **Legitimate scientific opportunity**
- **An inseparable mélange of accomplishment and hyperbole**
- **Unified support from the physical (and biological) sciences**
  - A common “story” for the physical sciences; strong advocates across competing disciplines
- **High potential for technological relevance**
  - Information; military/national security; biomedicine
- **A “New, new thing”: venture capital**



# What is *Nano* (i.e. less than 100 nm)?



- Small aggregates/Single atoms
- Quantum phenomena (1-30 nm)
- New materials
  - Ultrahigh surface area
  - Low defects
  - New properties
  - Hierarchical structures: bottom-up and top-down
- Biological/cellular “machinery”
  - ATPase, chloroplast, ribosome...
  - Sensors smaller than a cell
- Large numbers of components
  - High-density technologies (e.g., memory)
  - Complex systems

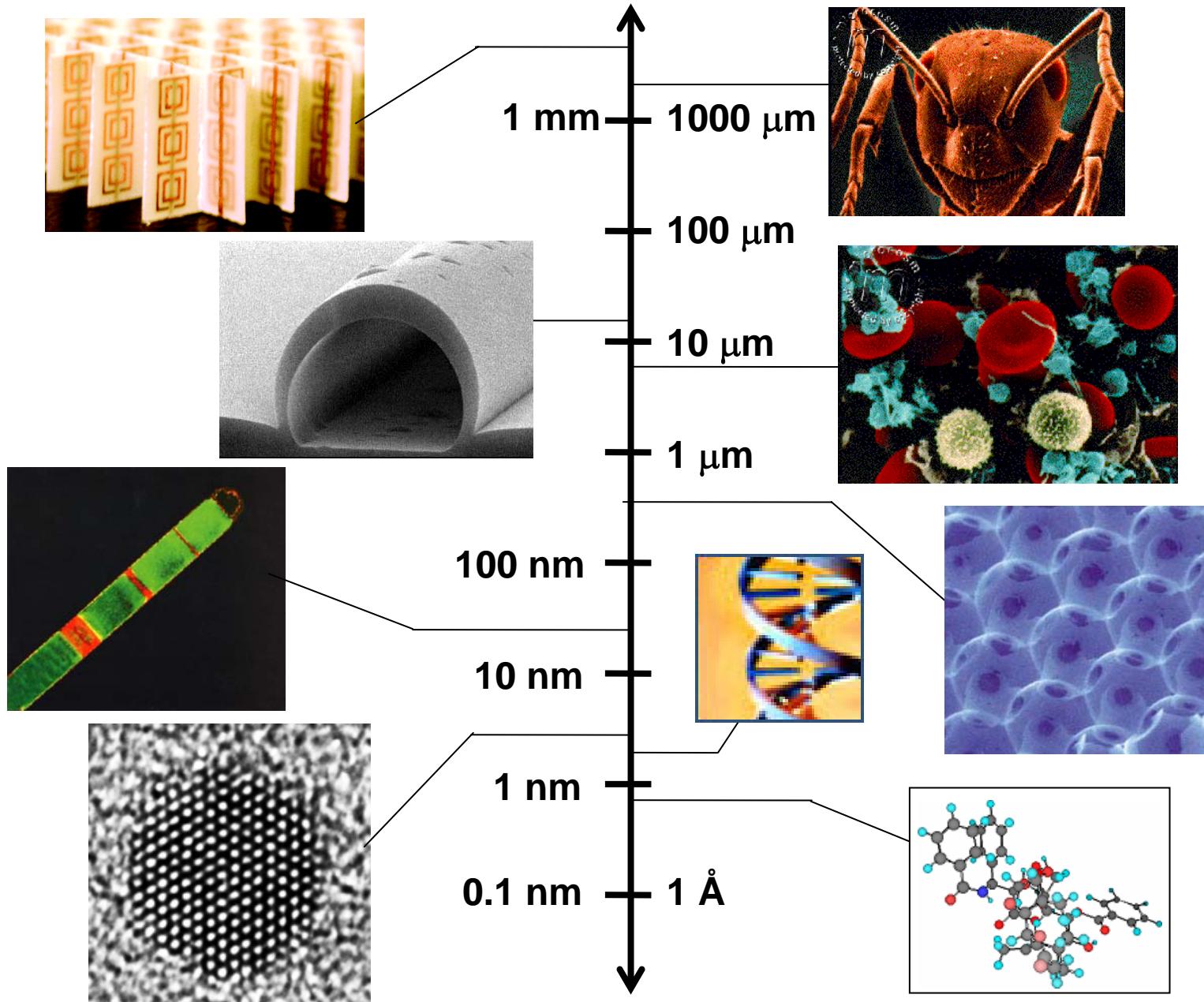
# What is Nanotechnology?

Basic research on man-made structures that:

- Have at least one dimension of less than 100 nanometers;
- Are designed through a process that exhibits fundamental control over the physical and chemical attributes of the structures; and
- Can be combined to form larger structures.

\* This definition is attributed to Mihail Roco, senior advisor to the National Nanotechnology Initiative.





# ***Nanoscience and Nanotechnology***

**Science**

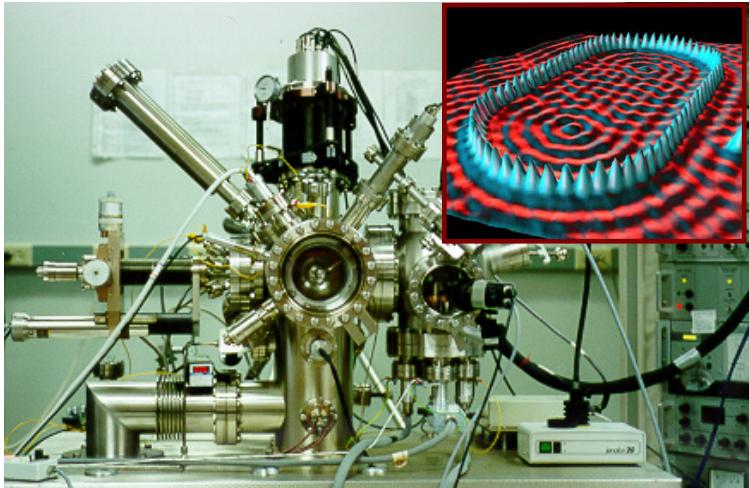
Technology

Patterning

Societal implications



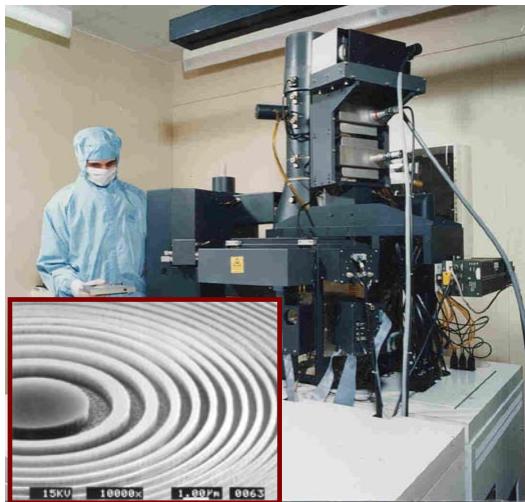
# Science: New Tools



Eigler et al., IBM Research

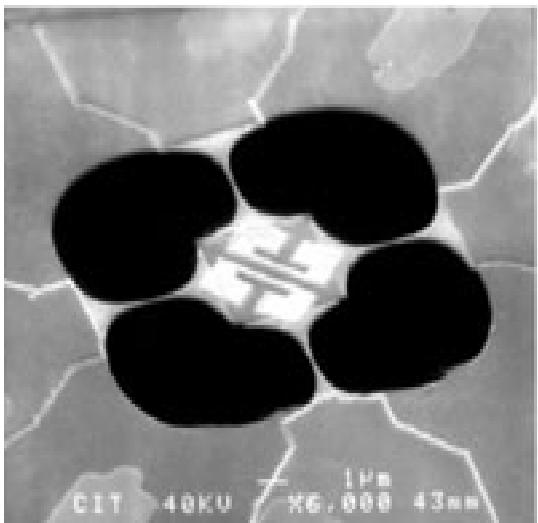


S. Block, Stanford



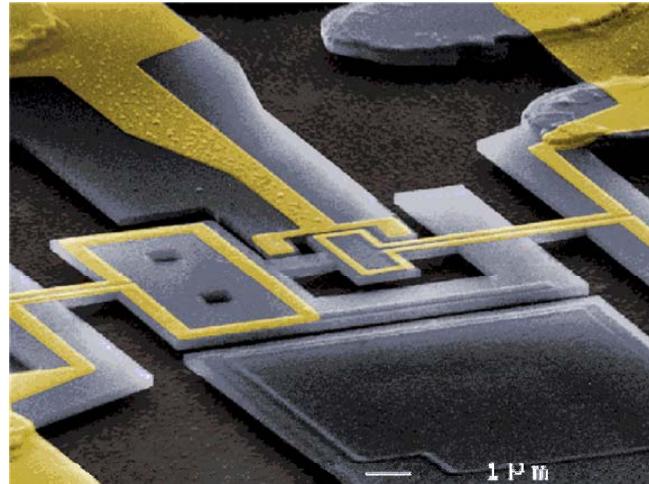
# Science: New Physics

Single phonon counting

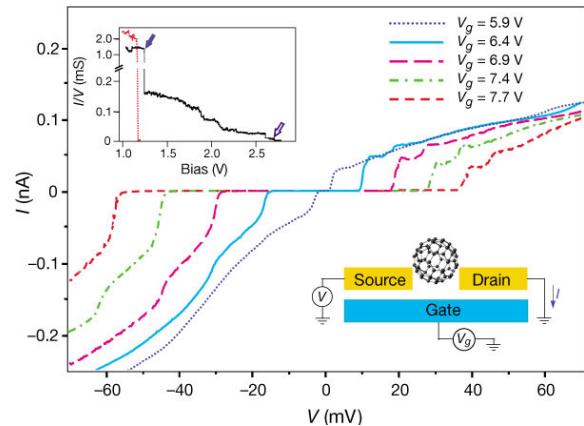


M. Roukes (Cal Tech)  
*Nature* 404, 974 (2000)

Single electron detection through mechanical motion



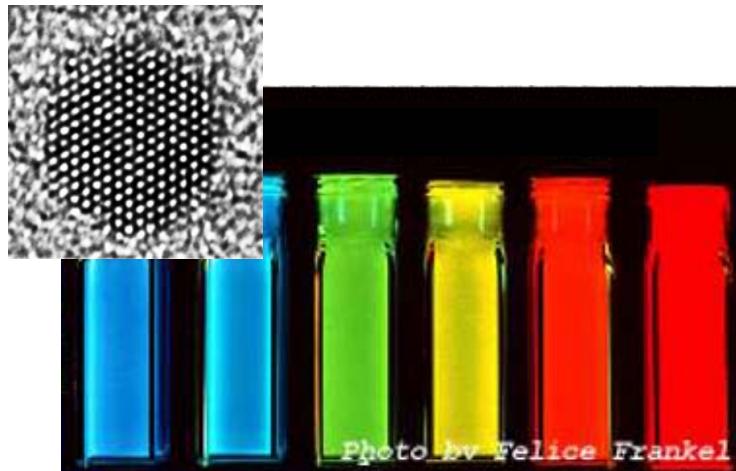
M. Roukes, Cal Tech



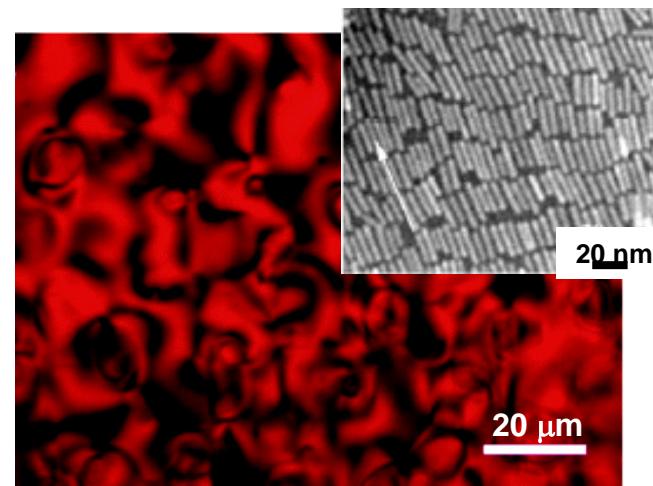
H. Park, P. Alivisatos, P. McEuen, U.C. Berkeley



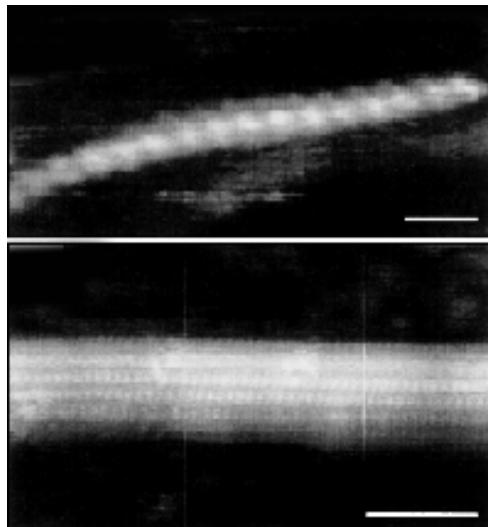
# Science: New Chemistry



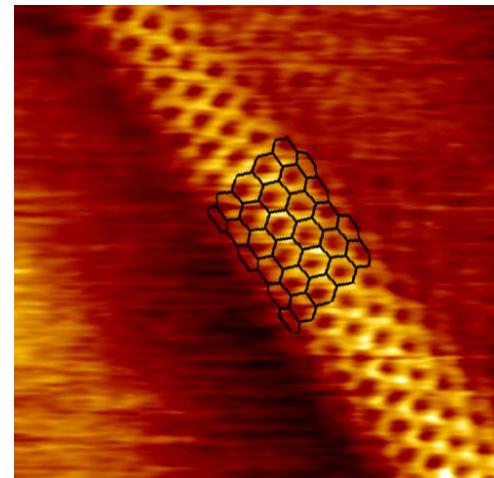
M.G. Bawendi (MIT)



A.P. Alivisatos (U.C. Berkeley)



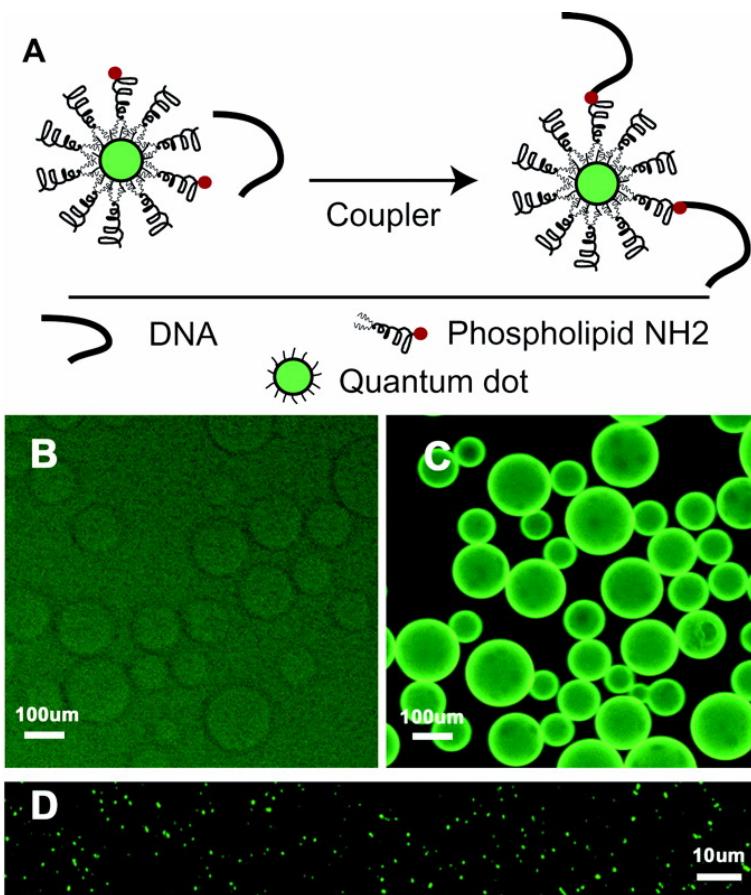
C.M. Lieber, *Phys. Rev. Lett.* 83, 5334 (1999)



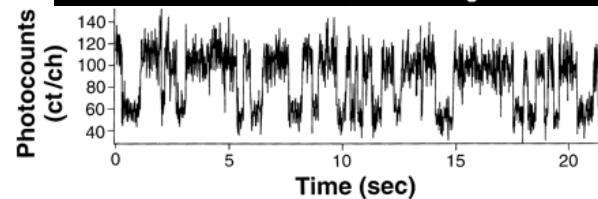
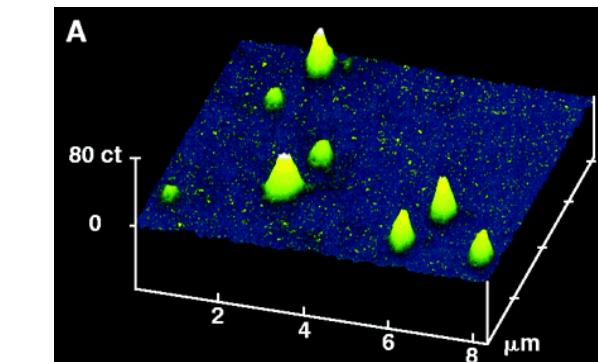
C.M. Lieber (Harvard), *Nature* 391, 62 (1998)



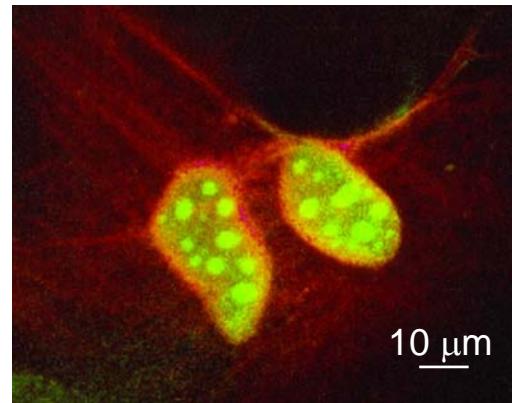
# Science: New Biology



A. Libchaber (NEC) *Science* 298, 1759 (2002)



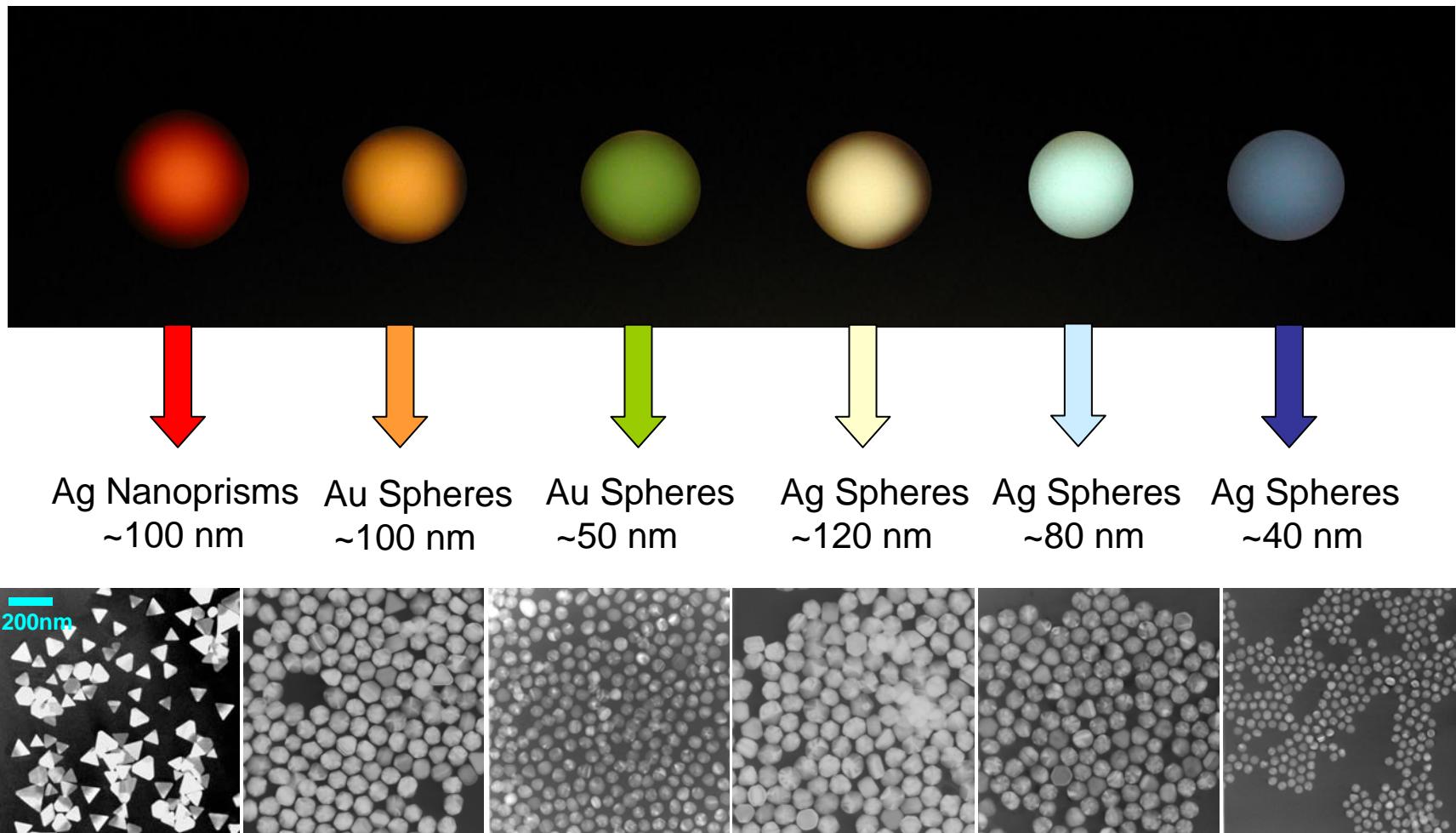
X.S. Xie (Harvard), *Science* 282, 1877 (1998)



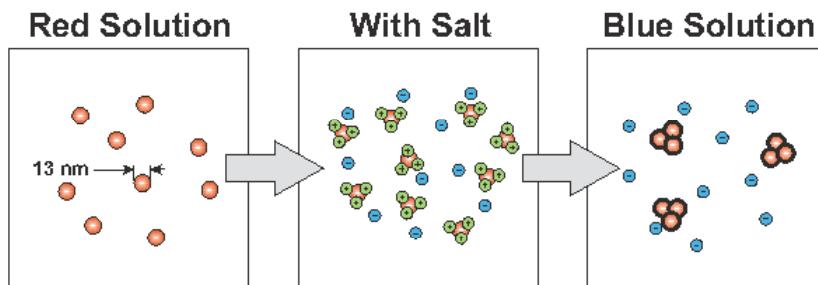
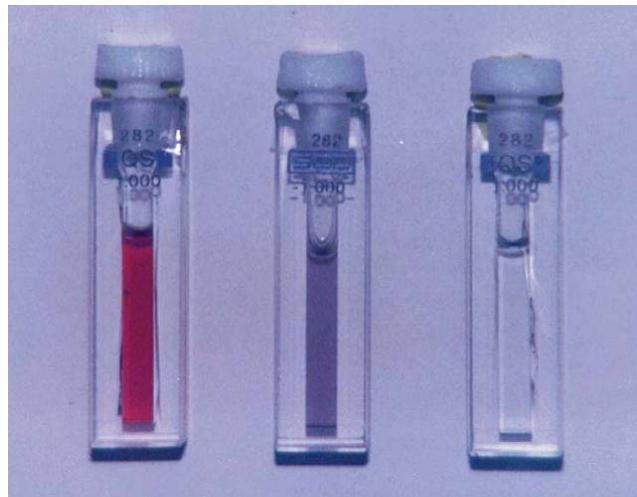
A.P. Alivisatos (U.C. Berkeley), *Science* 281, 2013 (1998)



# Size-Dependent Properties



# Bench-top Nanoscale Experiments: *Nanocrystal Synthesis*



# ***Nanoscience and Nanotechnology***

Science

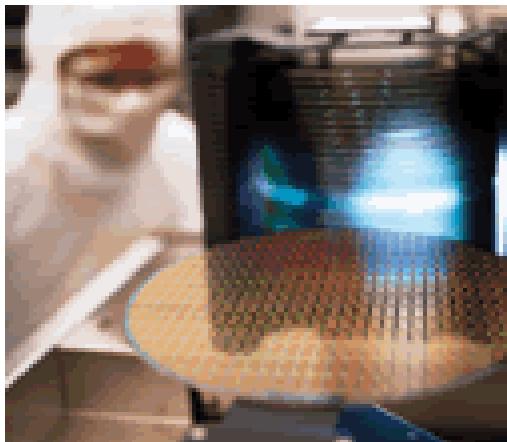
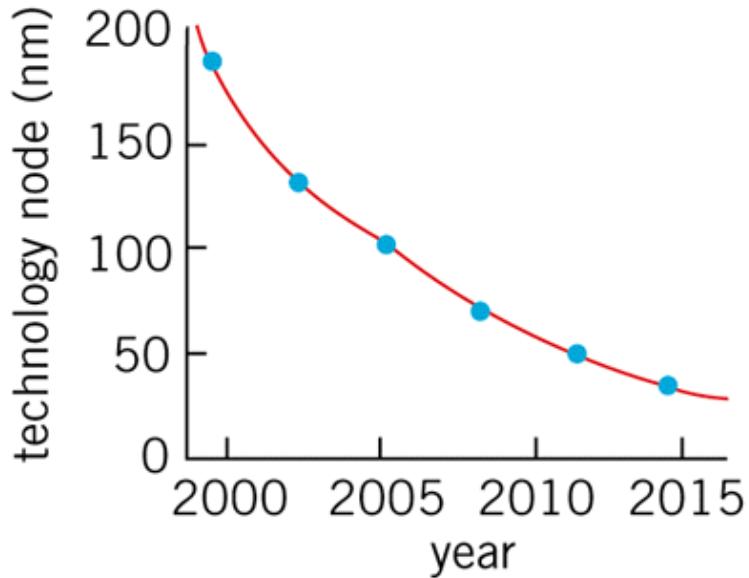
Technology

Patterning

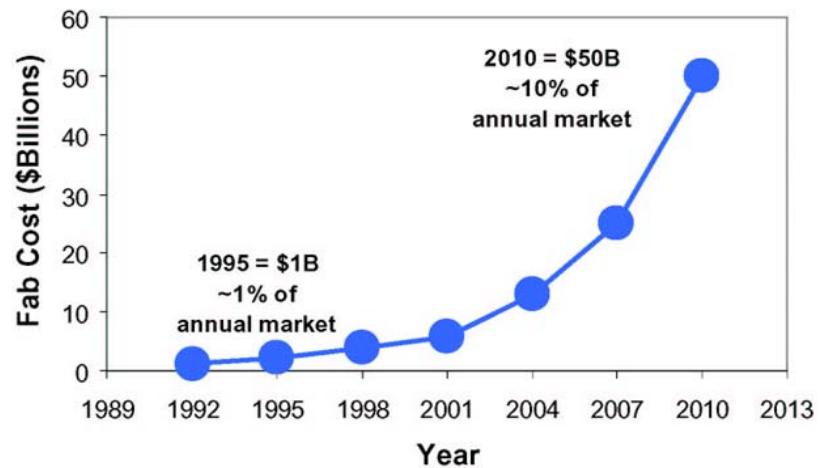
Societal implications



# Revolution or Evolution?



Cost of New Fab



# **Evolution and/or Revolution in Information Systems?**

## ***Evolution***

- Ultradense memory
- Faster microprocessors
- Customized/specialized microprocessors
- Portable systems
- Medium performance/  
Low Cost Systems
  - Organic compounds as conductors and semiconductors

## ***Revolution***

- True Nano ICs (<10 nm); single molecule electronics
- Cellular automata
- Quantum computing
- Self-assembling /3D / Biomimetic systems
- Bio-hybrids

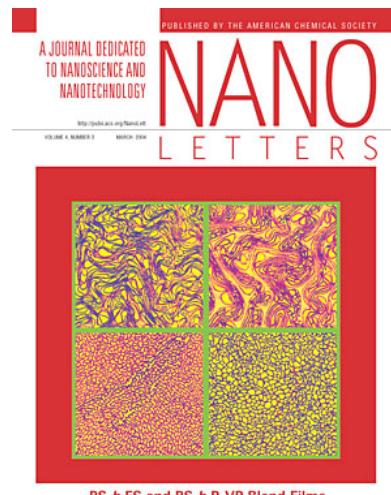


# Revolutions in Technology

- ***Microelectronics and Information Technology***
  - *Silicon, the transistor, photolithography, the integrated circuit, displays, microprocessors and memory, software, the laser, optical fiber, the world-wide web*
- ***Biotechnology***
  - *DNA, sex, the double helix, restriction endonucleases, cloning, expression vectors, protein engineering, polymerase chain reaction, the cell cycle, oncogenes, apoptosis, genetically engineered foods*
- ***Nanotechnology***
  - Scanning probe microscopy, carbon nanotubes, nanowires, top-down nanofabrication, colloidal chemistry, structural biology
  - ?? Nano-IC, bio/IT interface, “applied quantum strangeness”/ quantum computation, self-assembly, molecular electronics, mechanical genomic surgery, sophisticated biomimicry, synthetic complexity ??



# Nanotechnology in the News



# Nanotechnology Start-up Companies



Converting the Promises of Nanotechnology into Reality



*Leading-Edge Developer of Nanoclay Technologies for Plastics*



# **Other Targets of Nanotechnology**

- Advanced Materials
- Five minute health swab tests
- Interactive glucose sensing
- Human repair
- Genomic Medicine
- Optical Computers
- Self-monitoring food packaging
- Fully target drug delivery
- Heatless lights (LEDs)
- Efficient solar radiation capture



# Nanotechnology Today

- **\$22 billion industry**
- **Heterogeneous catalysts**
  - Zeolite MCM-41 for higher octane gasoline
  - Cracking hydrocarbons
  - 40% of gas produced this way
- **Wilson Tennis Balls**
- **Oil of Olay and L’Oreal**
- **NanoPants (Nano-Care Khakis)**



Eddie Bauer



# Worldwide Government Spending on Nanotechnology Today

FY 2003

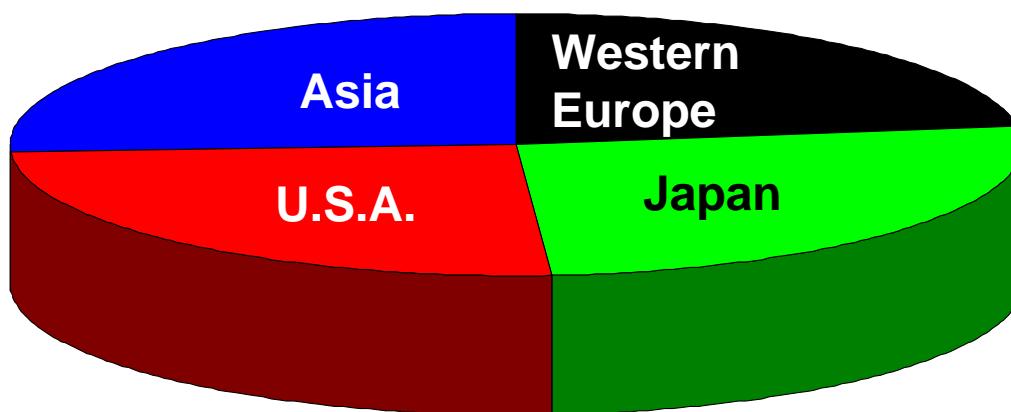
Western Europe: \$699 M

Japan: \$810 M

U.S.A.: \$774 M

Asia: \$800 M

Total Worldwide: \$3.083 B



Source: NSF  
[www.nanotechfoundation.org](http://www.nanotechfoundation.org)



# US Government Outlook: 10-15 years

- **Need 1-2 million workers**
- **\$1 Trillion industry**
  - New materials (\$340 Billion)
  - Electronics (\$300 Billion)
  - Pharmaceuticals (\$180 Billion)
  - Transportation (\$70 Billion)



NANOMEDICINE ROADMAP INITIATIVE  
Project Launch Meeting  
NIH, Masur Auditorium, Building 10, Bethesda, MD USA  
Tuesday, May 4, 2004



# ***Nanoscience and Nanotechnology***

Science

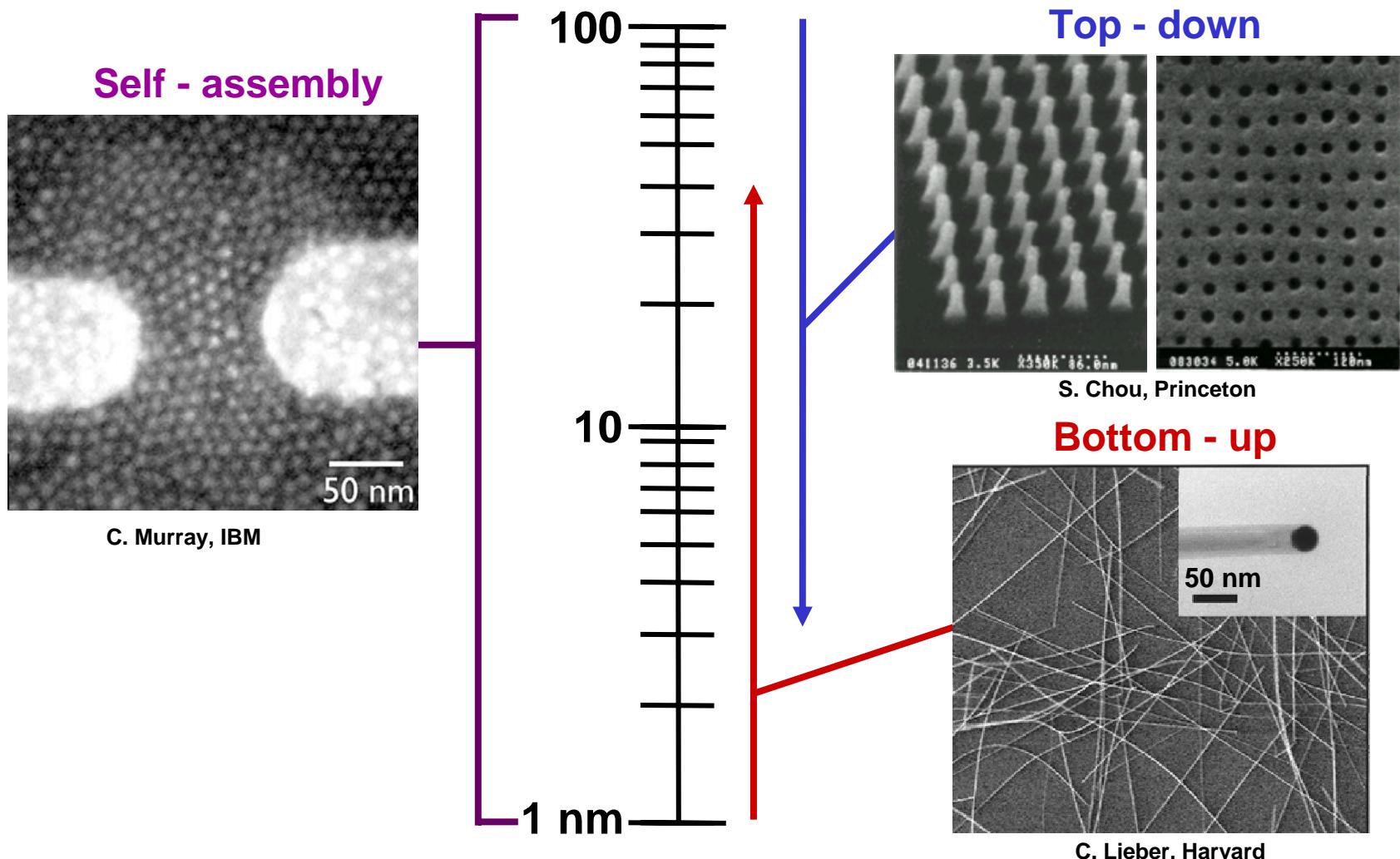
Technology

**Patterning**

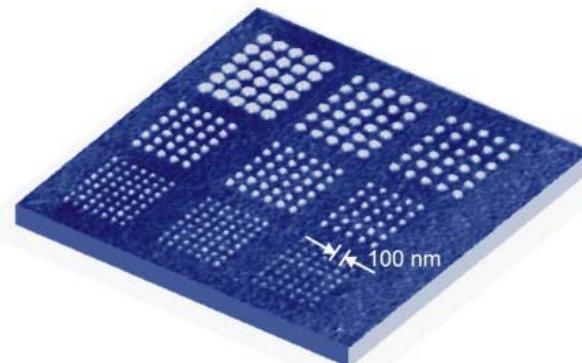
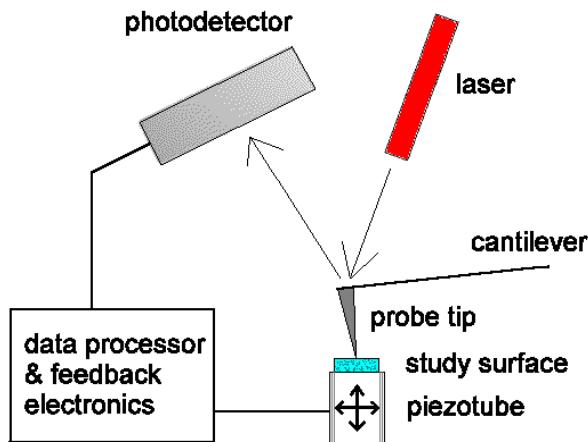
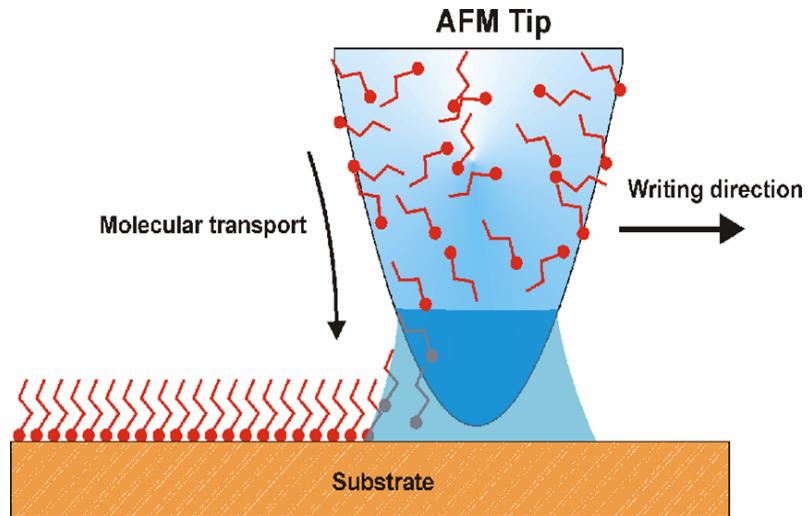
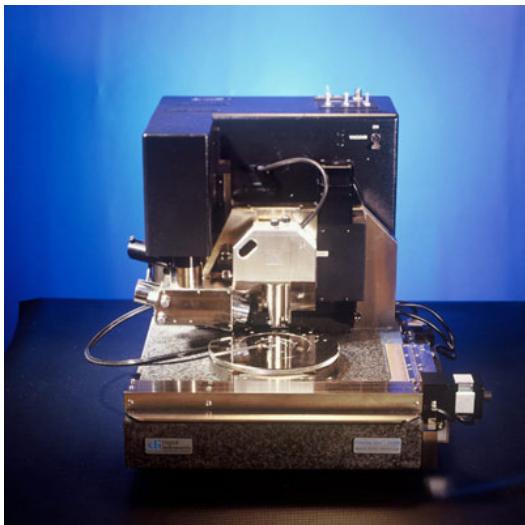
Societal implications



# Nanoscale Patterning

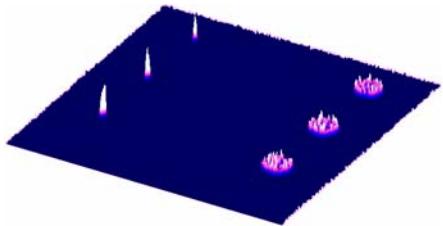


# Scanning Probe Lithography



Chad Mirkin, Northwestern

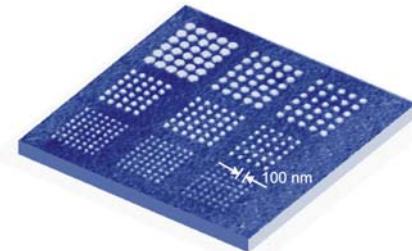




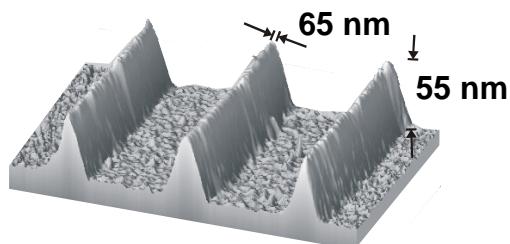
**Orthogonal Assembly of Nanoparticles**

As soon as I mention this, 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 2060, 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.

Richard P. Feynman, 1960



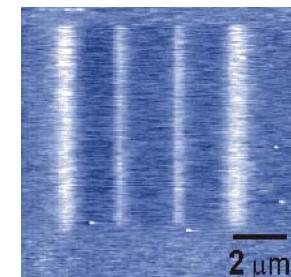
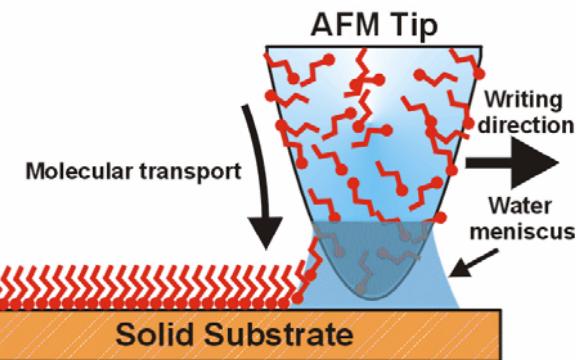
**Combinatorial DPN Templates**



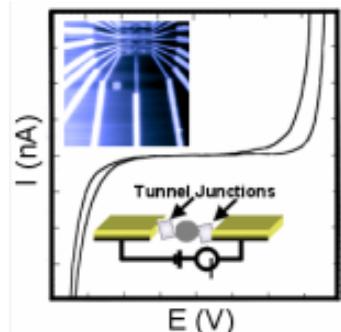
**Silicon Nanostructures**

### Flexible Nanolithographic Capability

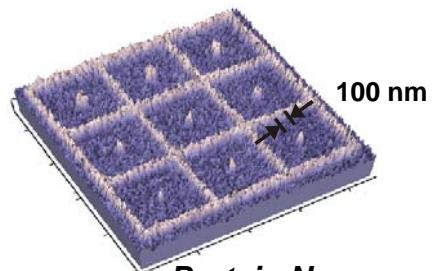
## Dip-Pen Nanolithography



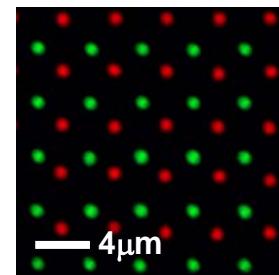
**Polymer precursors**



**Bio-nanoelectrics**



**Protein Nanoarrays**

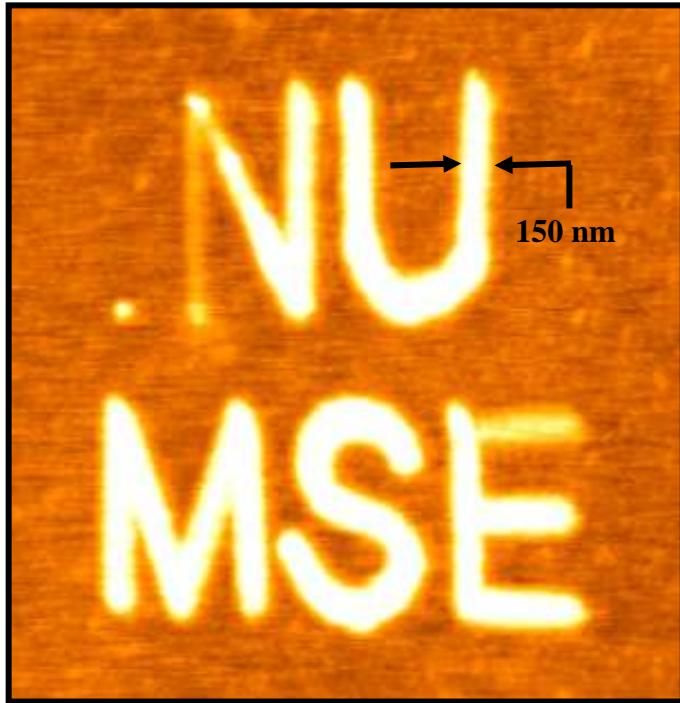


**Ultrahigh Density DNA Arrays**

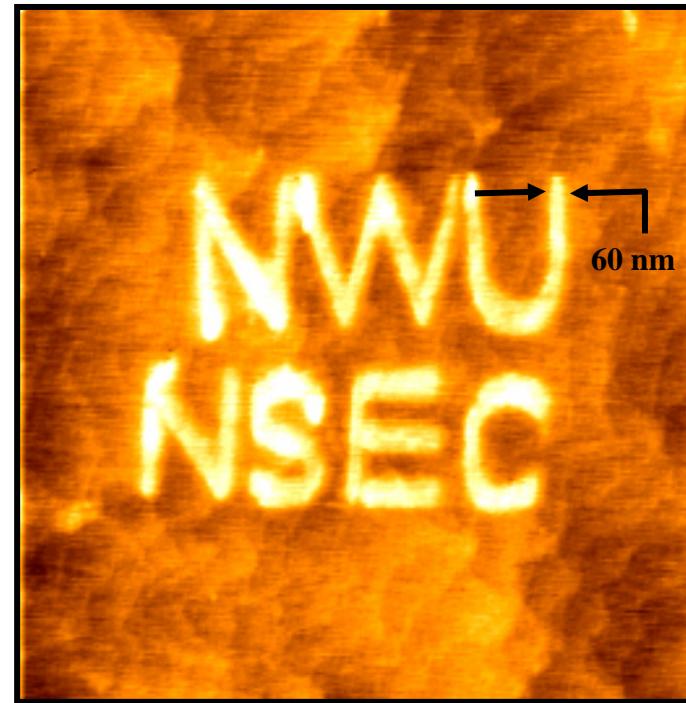
Chad Mirkin, Northwestern



# AFM Field-Induced Oxidation



- Lines written on  $\text{SiO}_x$
- Variability in line width
- No chemical contrast

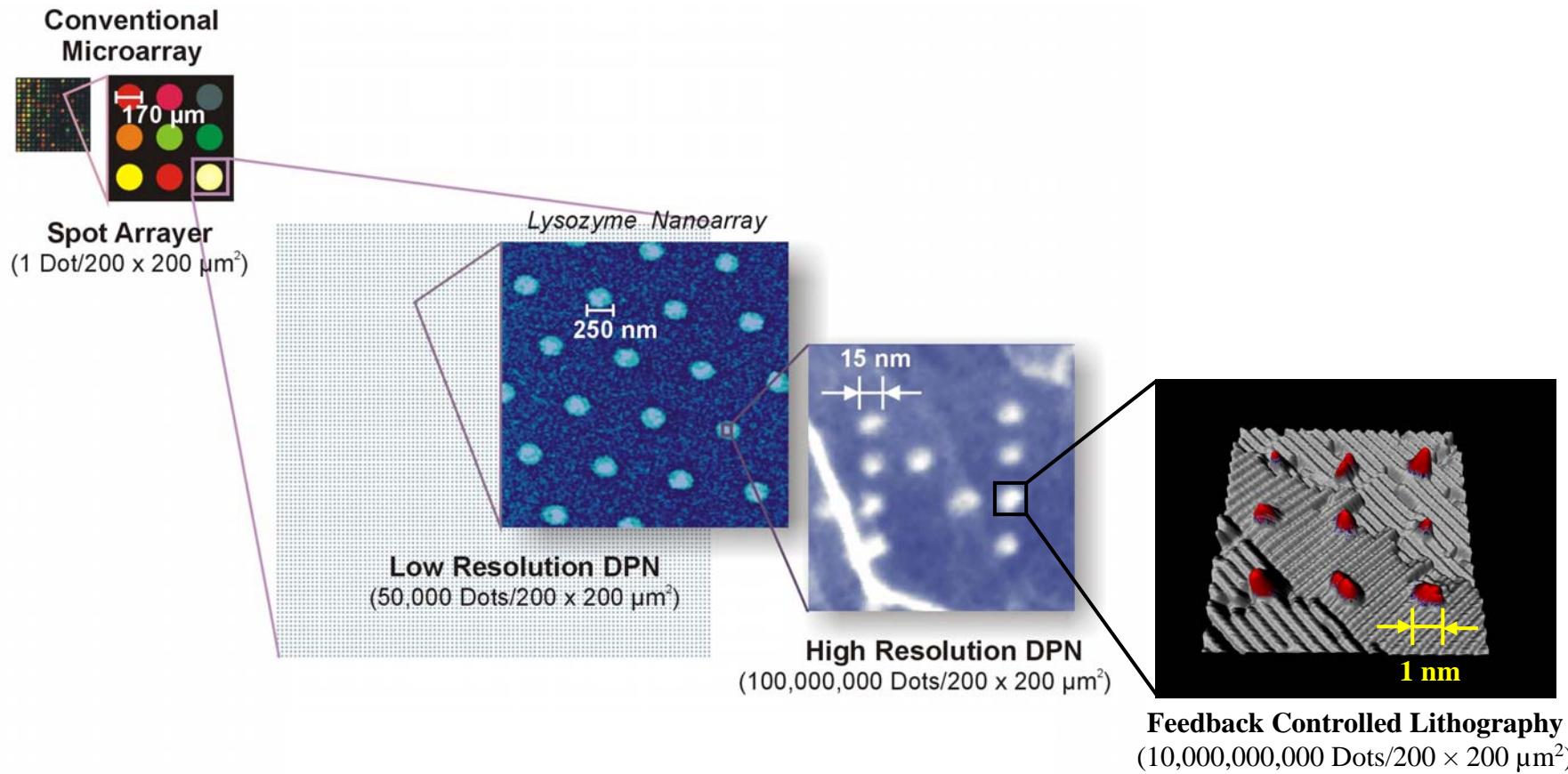


- Lines written at on  $\text{Si}(111):\text{H}$
- Reproducibly narrow line width
- Hydrophilic/hydrophobic contrast

Mark Hersam, Northwestern



# The Ultimate in High Density Arrays

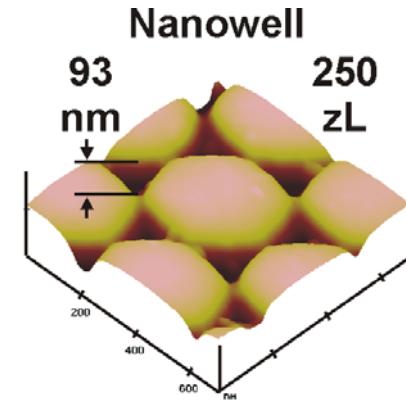
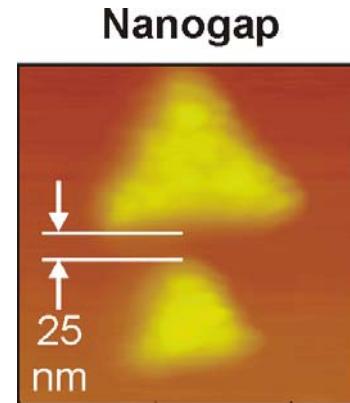
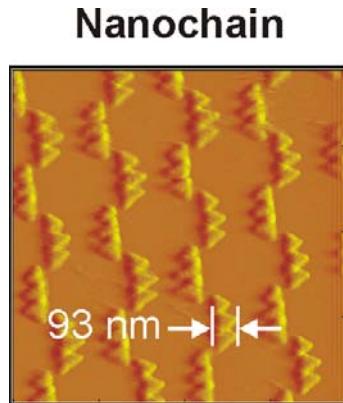


## Biological Nanoarrays:

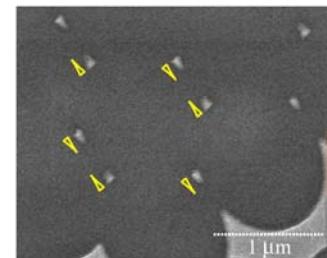
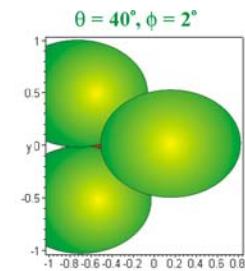
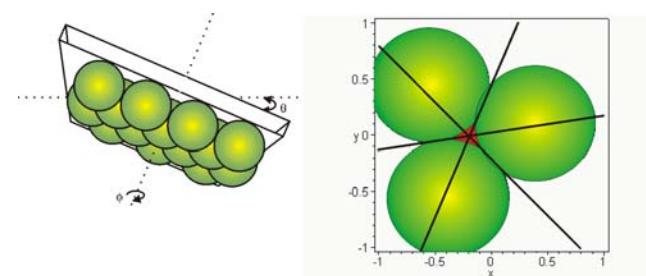
- More than just miniaturization with higher density
- New opportunities for biodetection and studying biorecognition



# Bench-top Nanoscale Patterning: *Nanosphere Lithography*

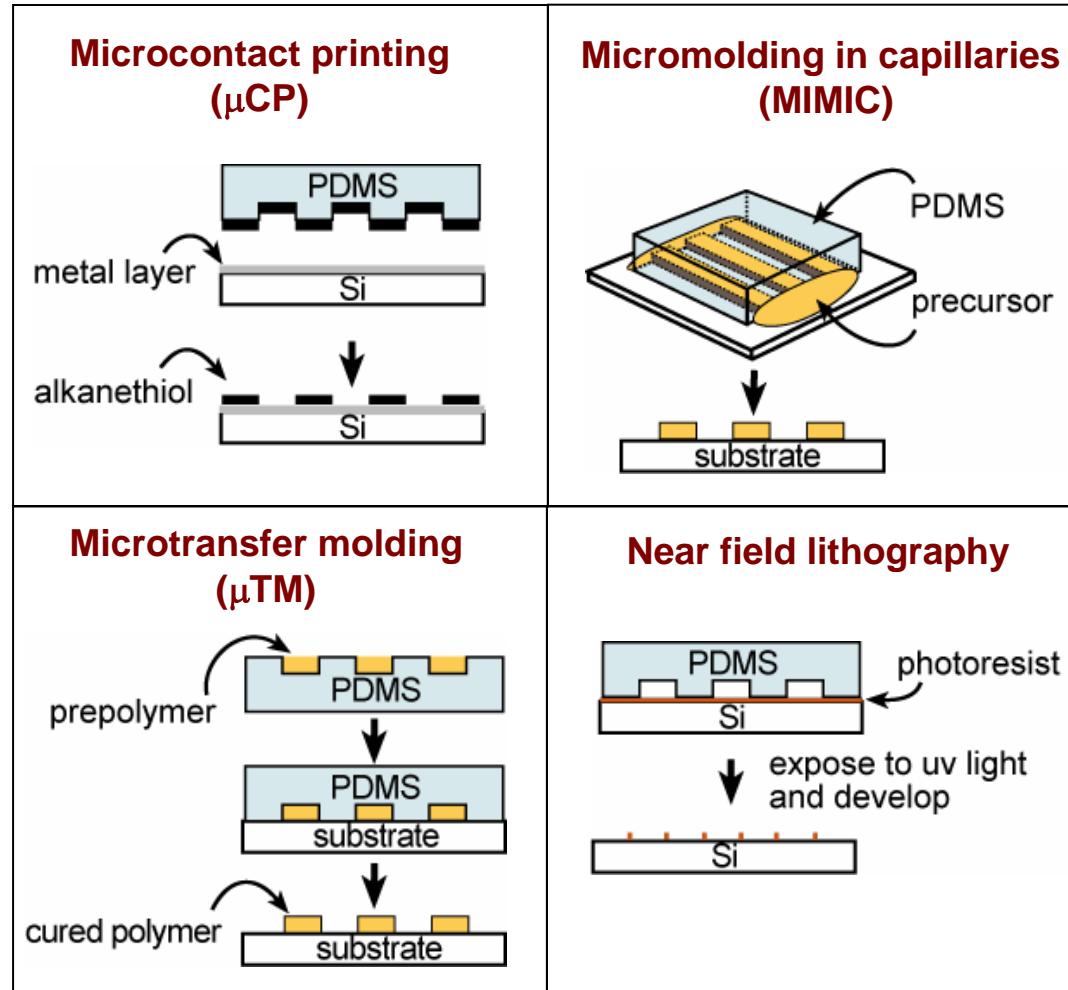
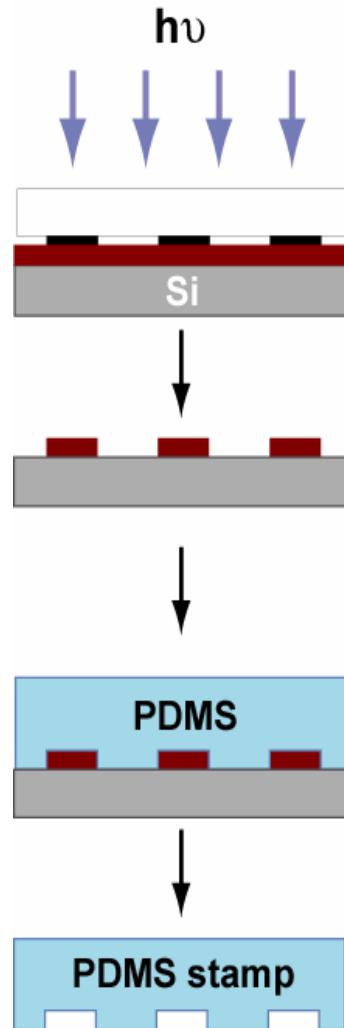


Angle Resolved Nanosphere Lithography: Reduction of in-plane nanoparticle Size by a factor of 3 - 4



Rick Van Duyne, Northwestern

# Bench-top Nanoscale Patterning: *Soft Lithography*



# ***Nanoscience and Nanotechnology***

Science

Technology

Patterning

**Societal implications**



# Issues in Policy

- **Research: What (and How) to Support?**
  - Balancing applied, fundamental, and exploratory research and development; National Initiatives
  - Nanobots/“Grey Goo”/Assemblers
  - Emphasis on “nano” may detract from “micro” ( $\mu$ -fluidics, MEMS,  $\mu$ -optics,  $\mu$ -TAS...)
- **Commercialization: Involving Business**
  - Small Start-ups: Innovation
  - Large Businesses: Development, manufacturing, distribution
- **Education**
  - Can one pour new wine from old bottles?
- **Public Perception**
  - Hyperbole and Reality; Risk

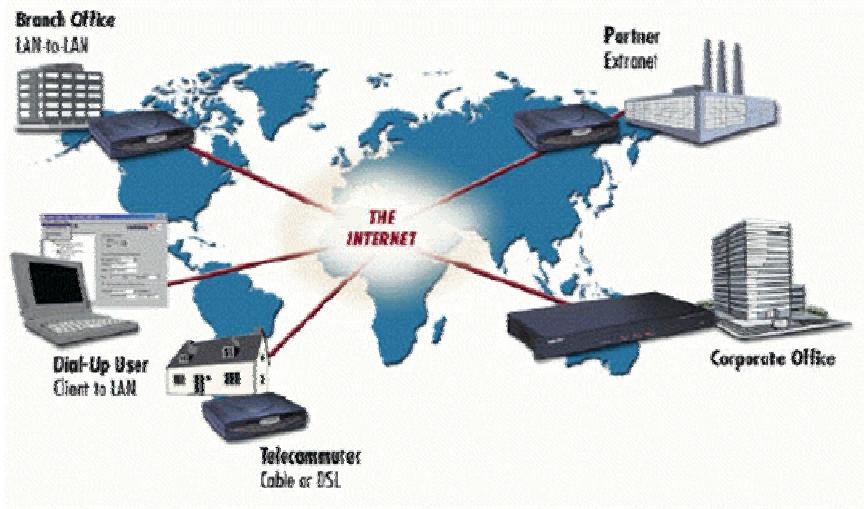


# Impacts on Society

- **Portable Technology**
- **Strengthened Capitalism**
  - high-quality jobs — for better or worse
- **Improved National Security**
  - in an age of asymmetric warfare and terrorism: global surveillance; universal awareness
- **New Understanding of Nature**
  - complex systems, materials, biomachines, single molecules
- **Loss of Privacy**
  - very large databases; quantum computation; decryption; universal genomics.
- **Alienation**
  - “Any technology, if sufficiently advanced, is indistinguishable from magic”
- **Global Economic/Technological Segregation**



# A Culture of Connectivity

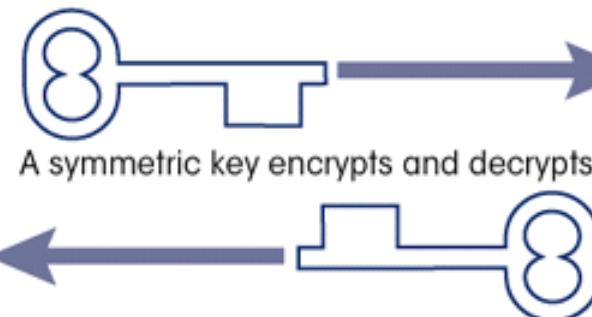


# Privacy and Information



## Plaintext

```
<html><head><title>  
Welcome to the NCSA  
</title></head>  
<body>Welcome to the  
National Center for  
Supercomputing  
Applications at the  
University of  
Illinois. <p><em>  
Administration and
```



## Ciphertext

```
MIIBKjCB5VQQKECBkTEL  
MAkkMRswBhMCVVMxEcTC  
1NNVBAgTCKNhG1mb3Ju  
aWExFDASBgNVBAcTC1Nw  
cmLuZ2ZpZWxkMRswGQYD  
VQQKExJSYW5kb20gQ29y  
cG9yYXRpb24xIzAhBgNV  
BhMCVVMxEcTC1NNVBAgT  
CkNhG1mb3JuaWExFDAS  
BguZpb24i02MRsZpZWxxk
```



# Information



- 2010: 15 Petabits ( $10^{16}$ ) / \$250,000
- Human Genome: 10 Gigabits ( $10^{11}$ )

*For a few million dollars, one could store the complete genome of every American and European*

*...for several more, could add credit card records, telephone logs, travel history, etc...*



# Where Does *Nano* Stand?

- **Exciting science**
  - New discoveries are the current push
  - “Life” may be the ultimate inspiration
- **A high level of hyperbole**
- **Nanotechnology is already developing**
  - Electronics and materials
  - Contributions from discovery **and** development
- **A high potential for eventual impact on society**
  - Information, genomics, privacy

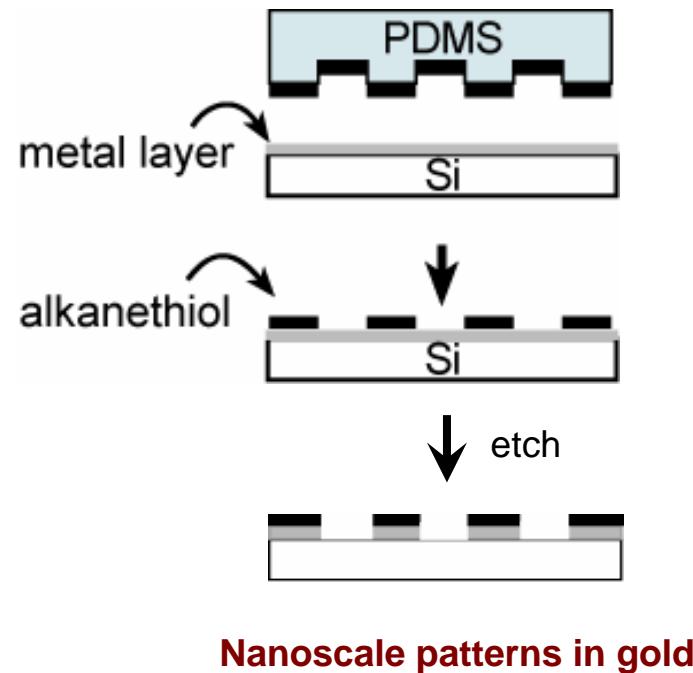
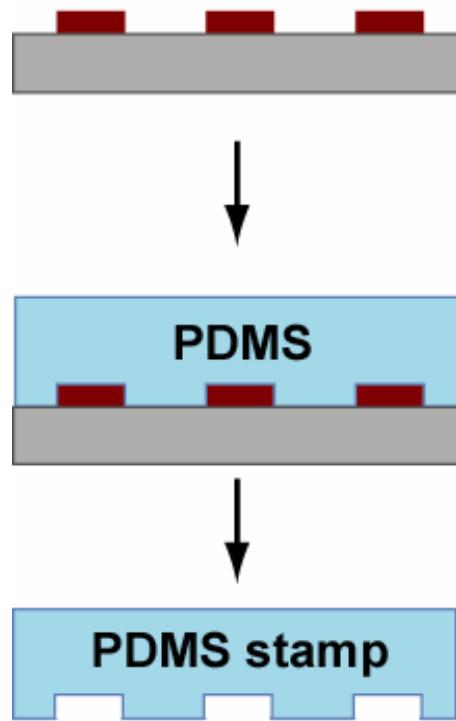


# **Lab 1: Introduction to Bench-top Nanoscale Tools**

- **Making Poly(dimethylsiloxane) stamps**
- **Handling tweezers**
- **Cutting silicon wafers**
- **Microcontact printing**
- **Wet chemical etching**

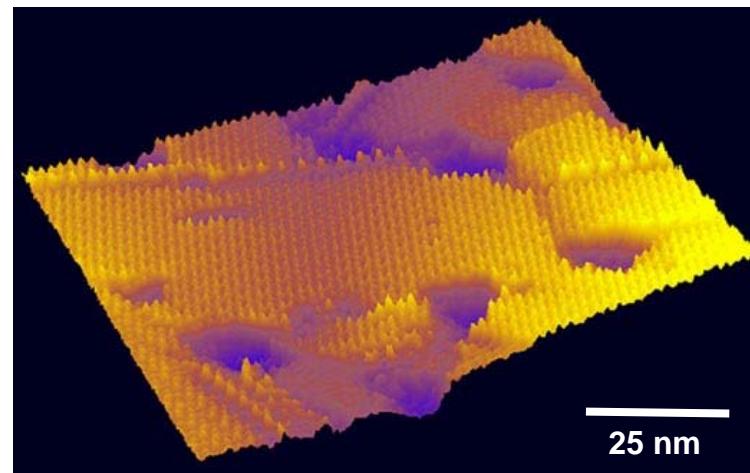
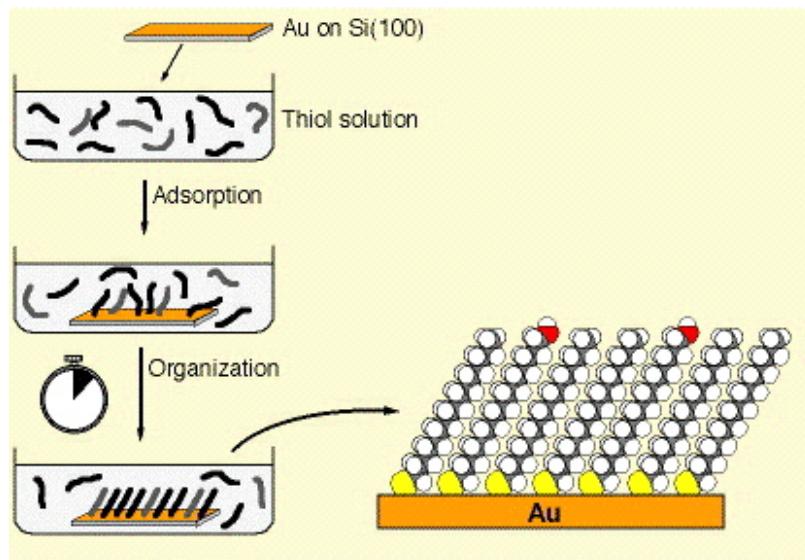


# Micro-contact Printing and Etching



# Self-assembled monolayers (SAMs)

- **Alkanethiols on Au, Ag, Cu**
  - Sulfur chemisorbs to noble metal surface
  - Chains with C<sub>16-18</sub> pack with fewer defects
- **Directed chemical assembly**



<http://www.ifm.liu.se/Appiphys/ftir/sams.html>



# Cutting Silicon Wafers

