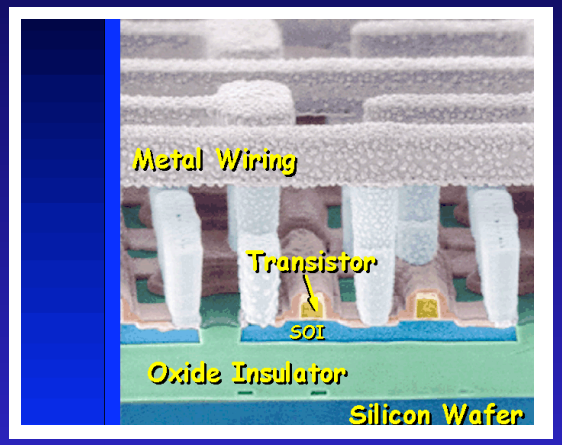
Thomas N. Theis
Director, Physical Sciences
IBM Research
Almaden - Yorktown - Zurich

Nanoscience and the Future of Information Technology

Topics ...

- Why is IBM pursuing research in nanoscale scienc and technology?
- Self-assembly - the challenge to do it better
- Outlook

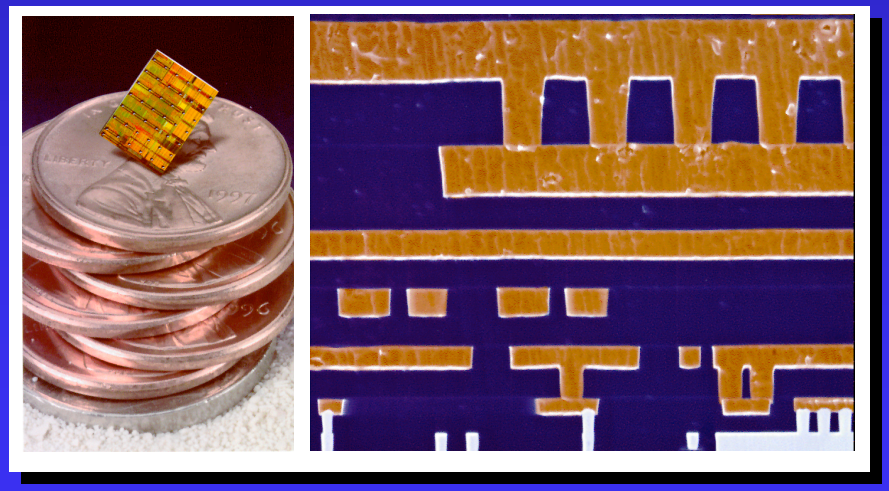
Some Recent Announcements



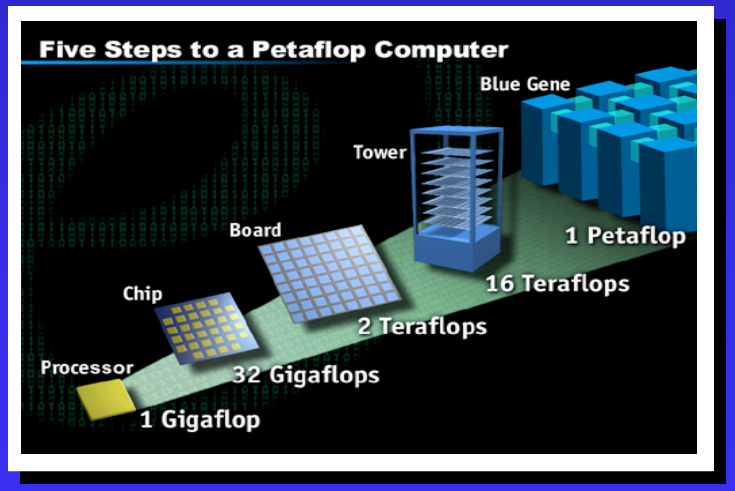
Silicon on Insulator (SOI)

Microdrive

SiGe



Copper Wiring



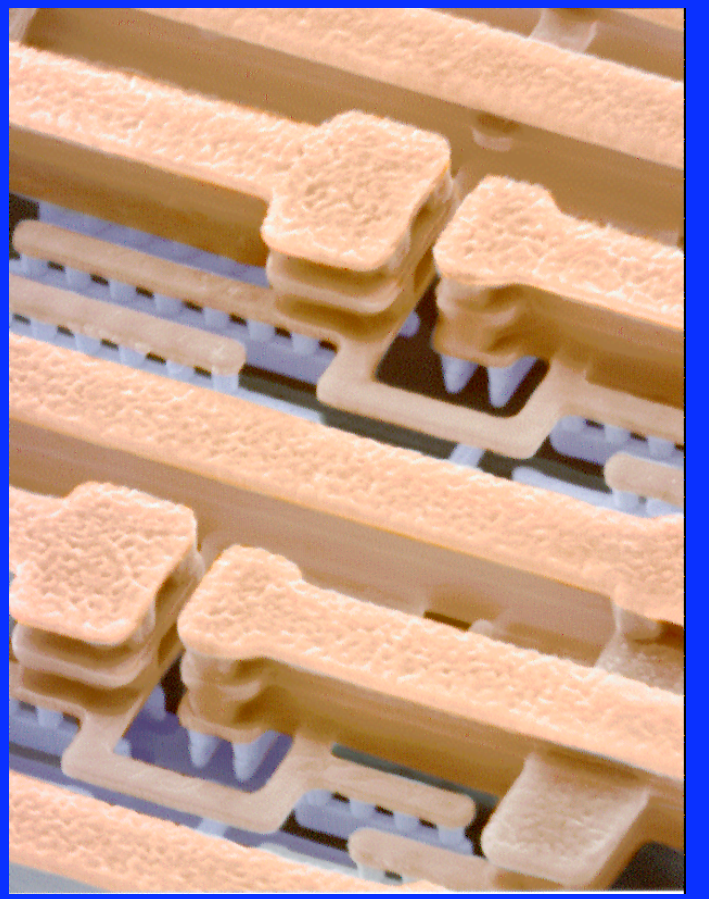
Blue Gene

What does it take to integrate a new material or device into a complex system?

An Example: Copper Interconnects

The benefits ...

- Performance
  Improved 10 – 20%
- Process Cost Reduction
  Fewer Process Steps
- Reliability
  Reduced Electromigration
- Extendability
  Scalable to future technology nodes



What we did to achieve those benefits…

Mfg. Qualifications

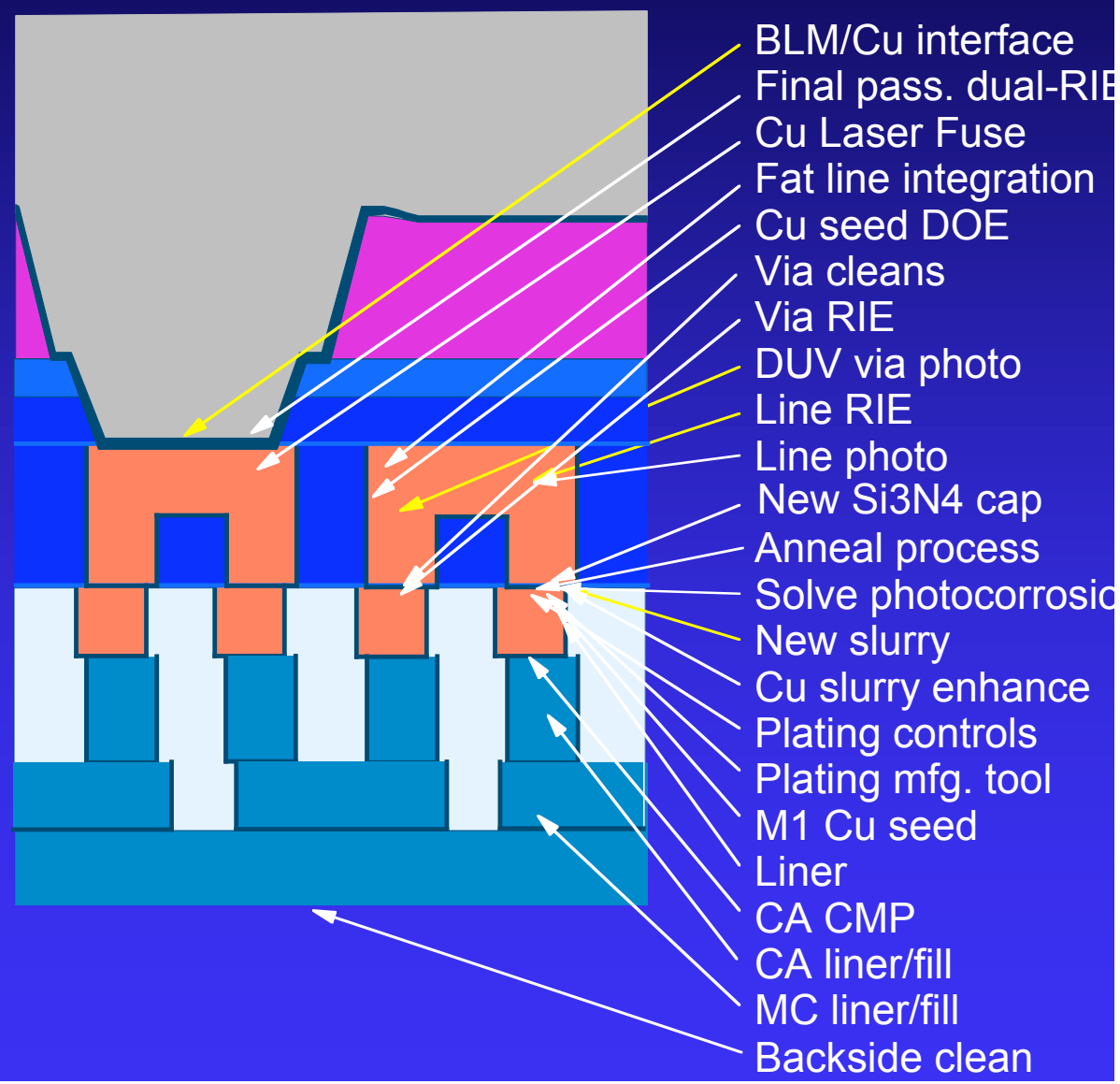
Design Rules

Product Specifications

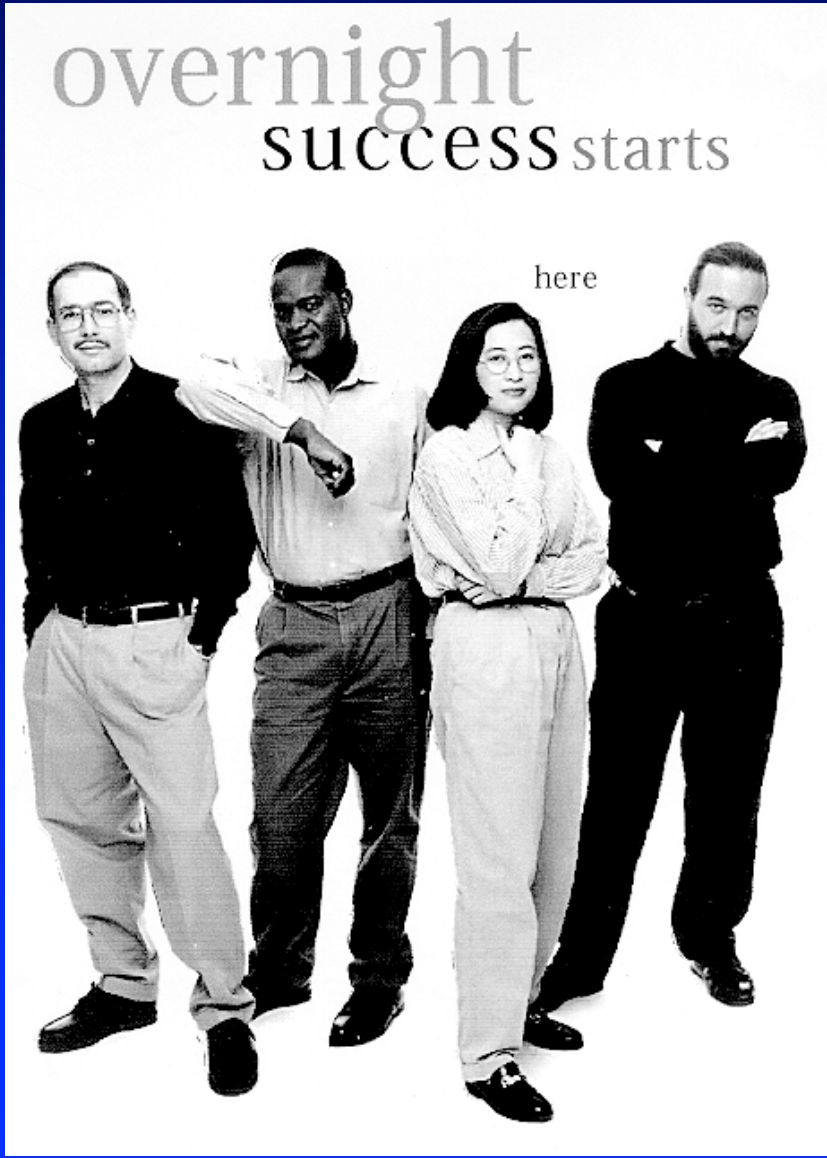
Mfg. Process Flow

Process Documentation

Transfer to Mfg.



On the cover of the annual report...



Behind the scenes…

Some Cu team members from 1 of the 3 sites involved

The Environment

- Rapid pace of hardware technology development undiminished, with increased global competition.

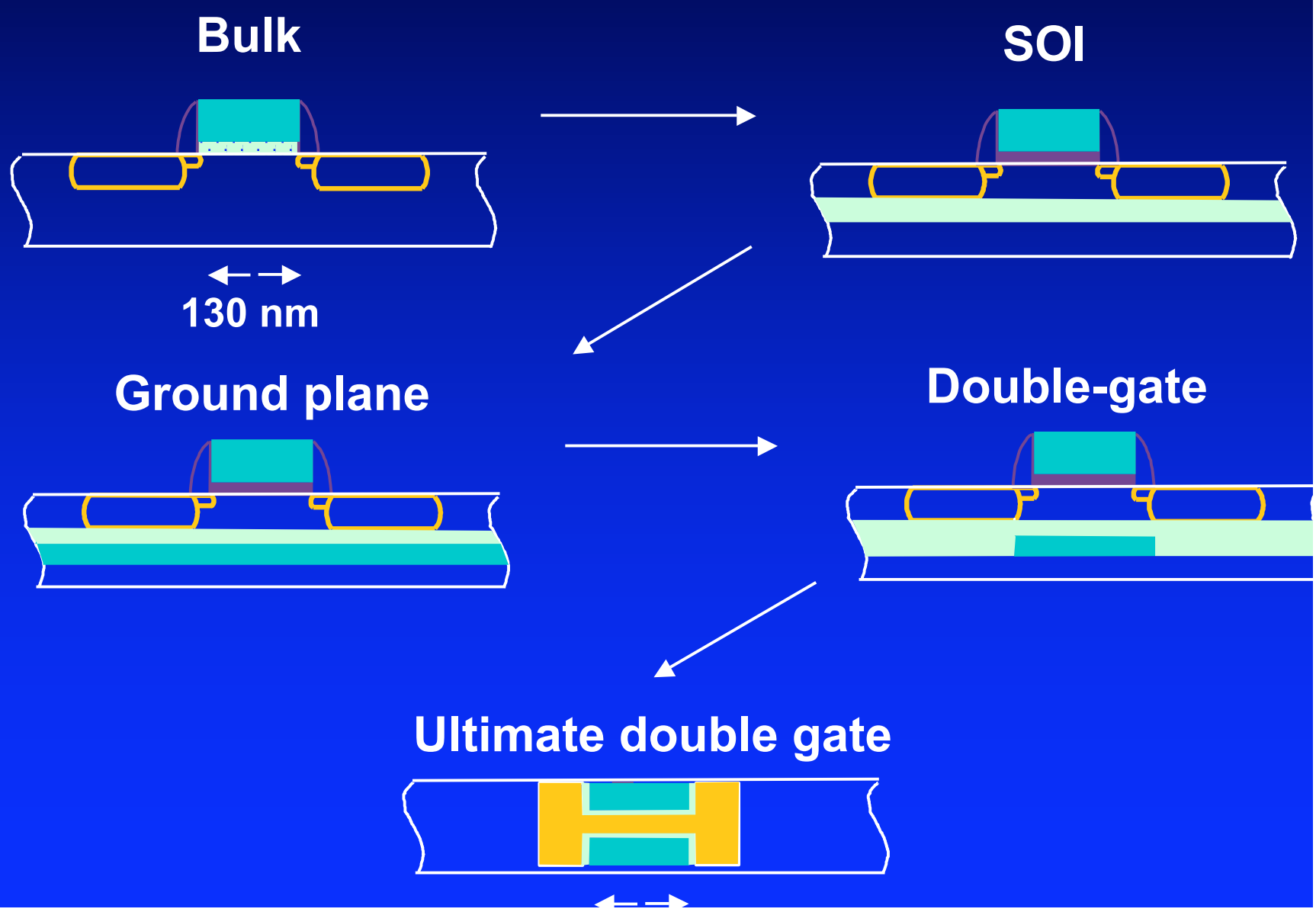
- Two key technology engines - silicon and magnetic storage - perceived to be reaching limits of extendibility within next 10 years or less.

  (But there is STILL plenty of room at the bottom!)

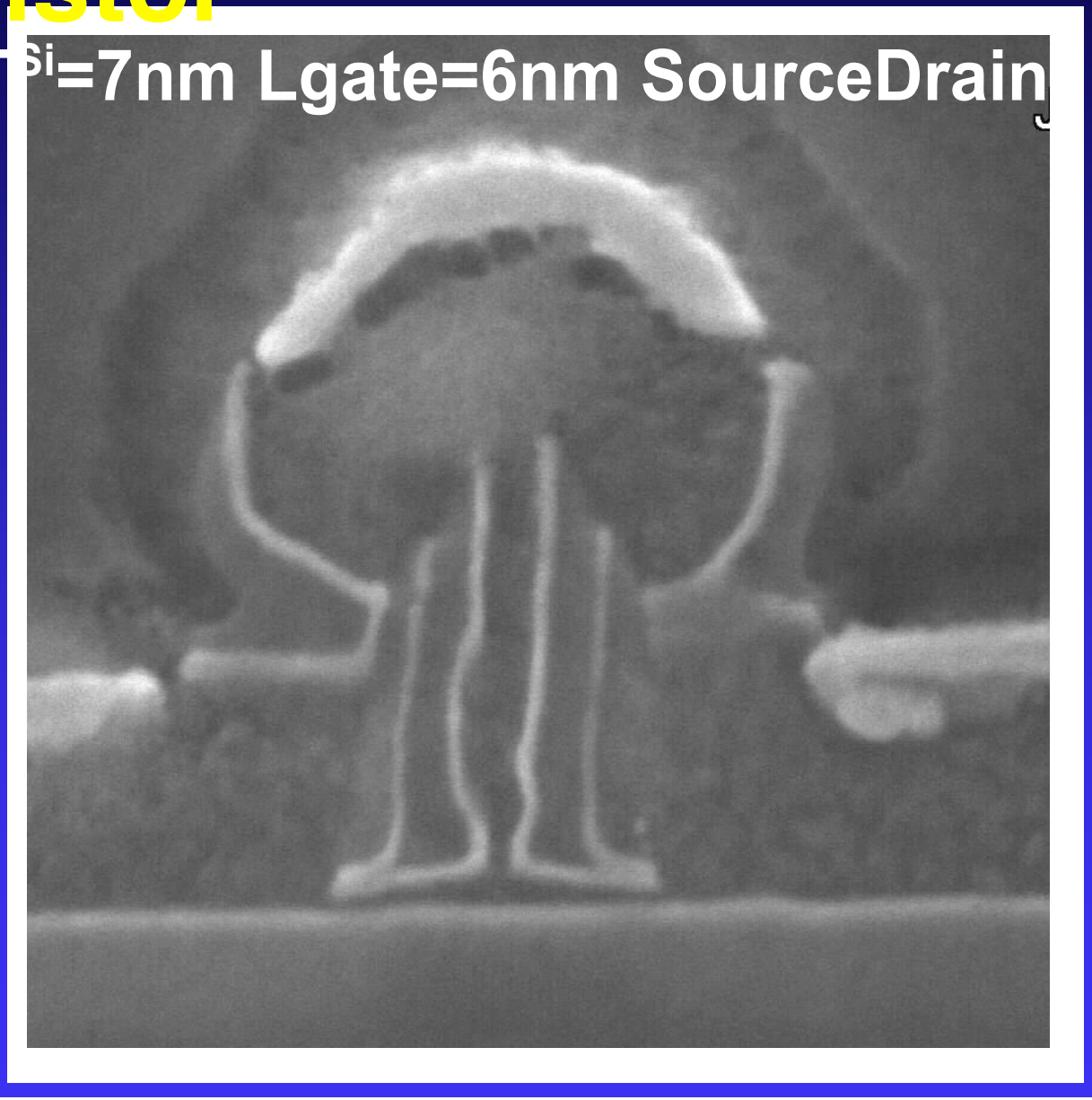
Some Basic Assumptions

- **The history of information technology is a history of making "bits" smaller.**
- **Nanotechnology is an emerging engineering field. It will integrate relevant knowledge from various scientific and engineering disciplines in the service of building very small structures.**
- **Nanotechnology is the future of I/T hardware.**

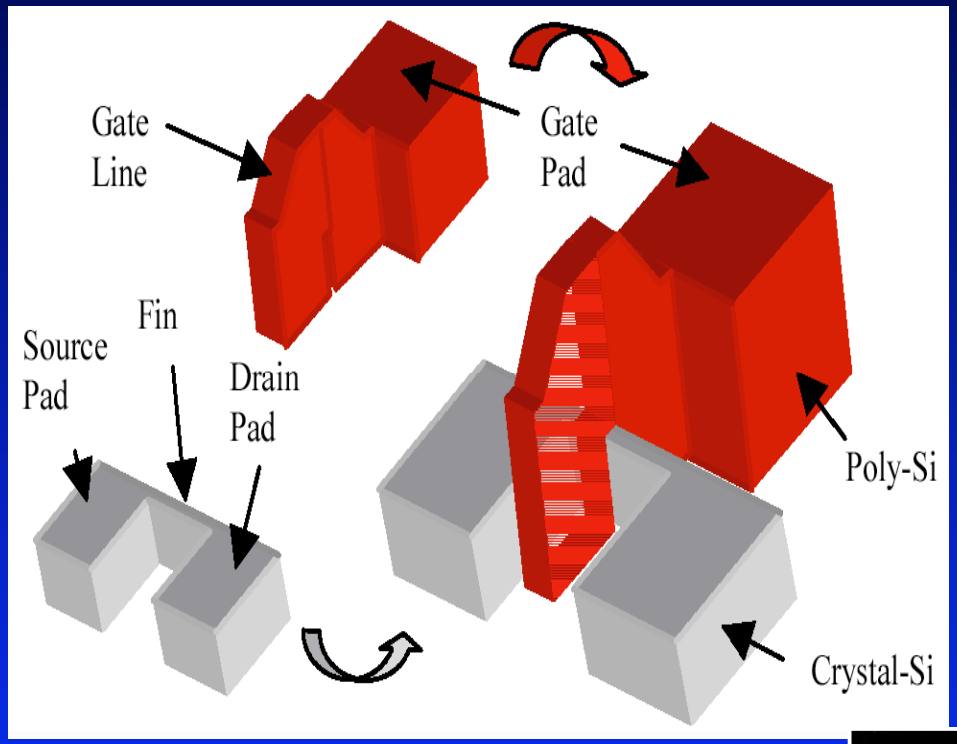
The silicon transistor has become a nanodevice.



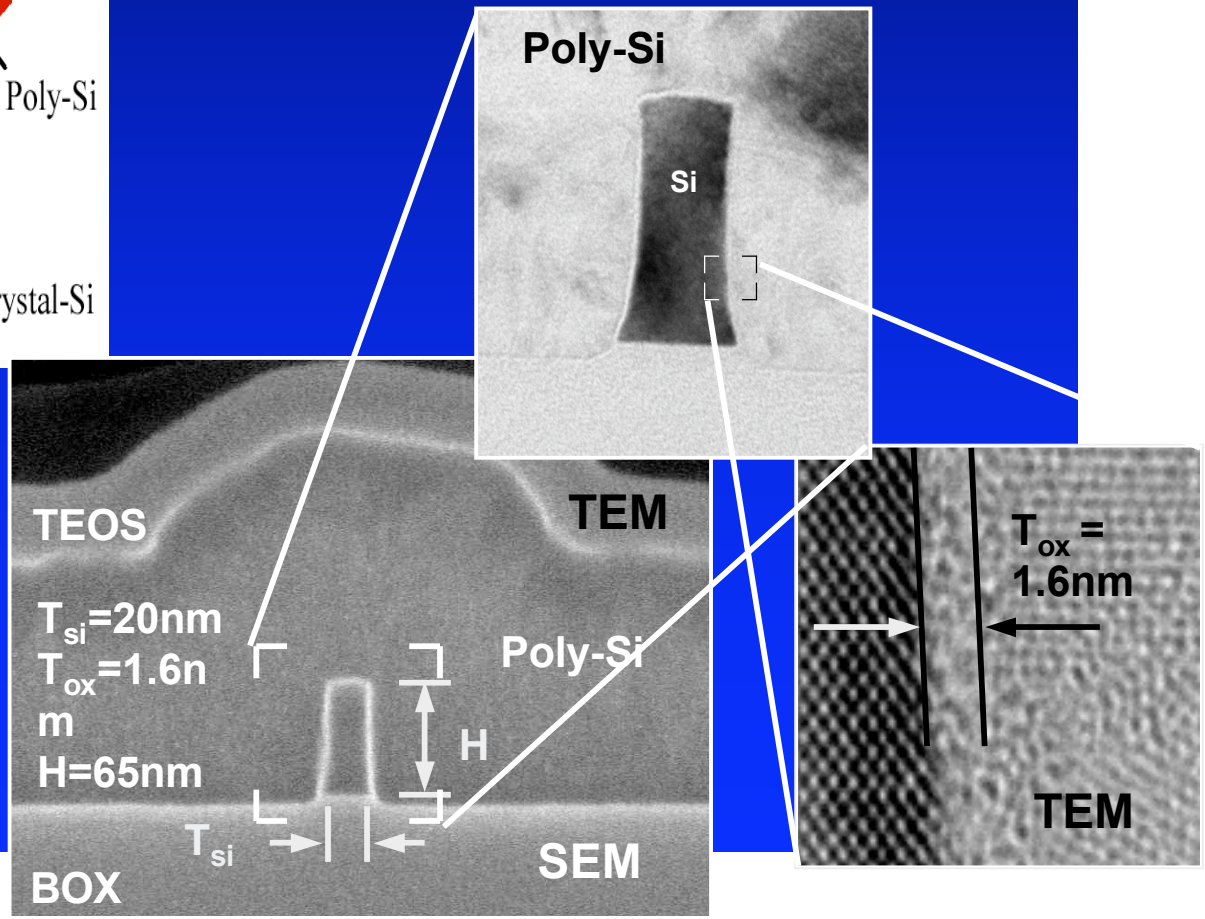
An Experimental Silicon Transistor



Approaching the ultimate silicon nanodevice (a double-gate Transistor or FinFET)

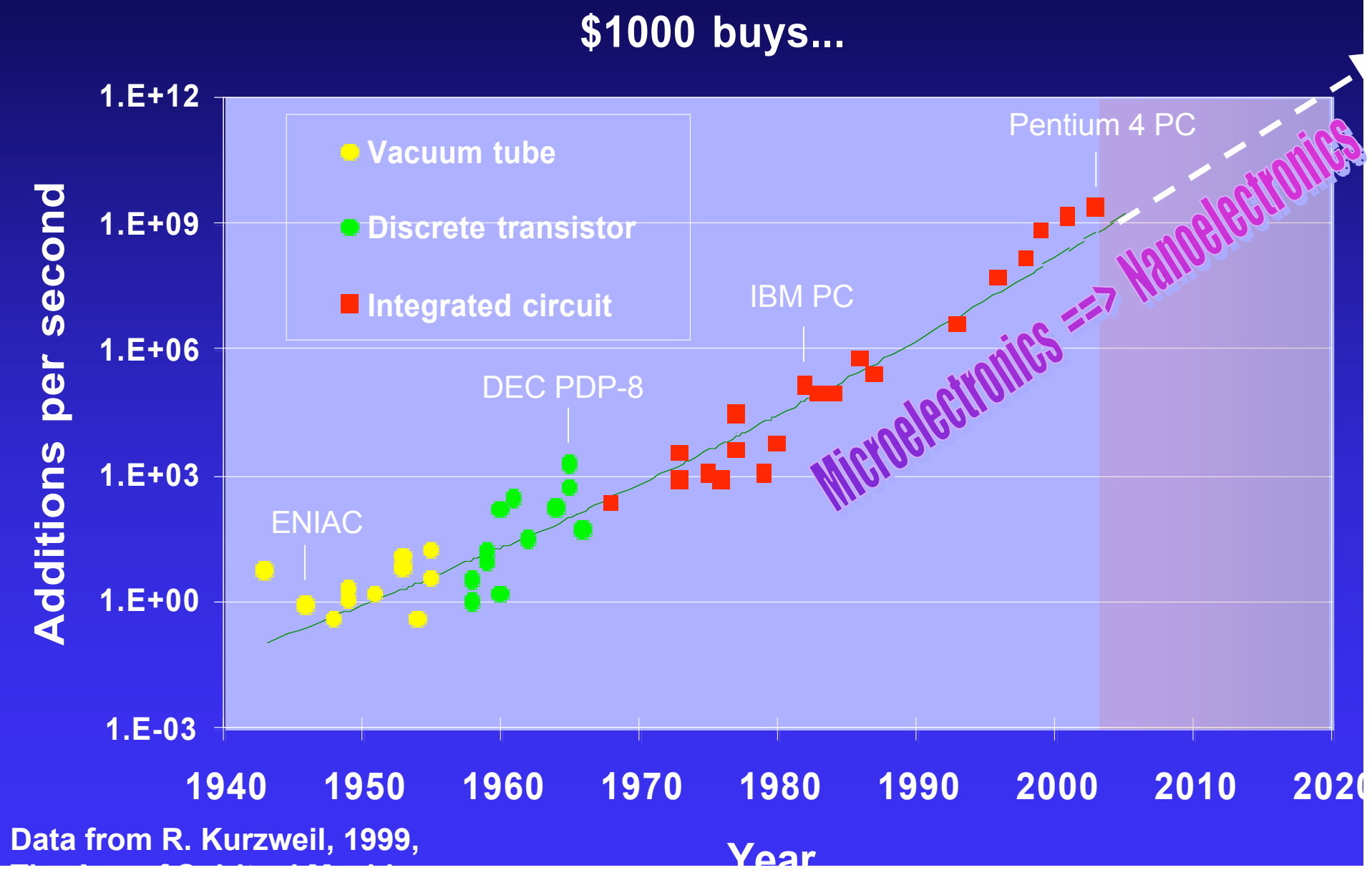


60 nm channel length FET



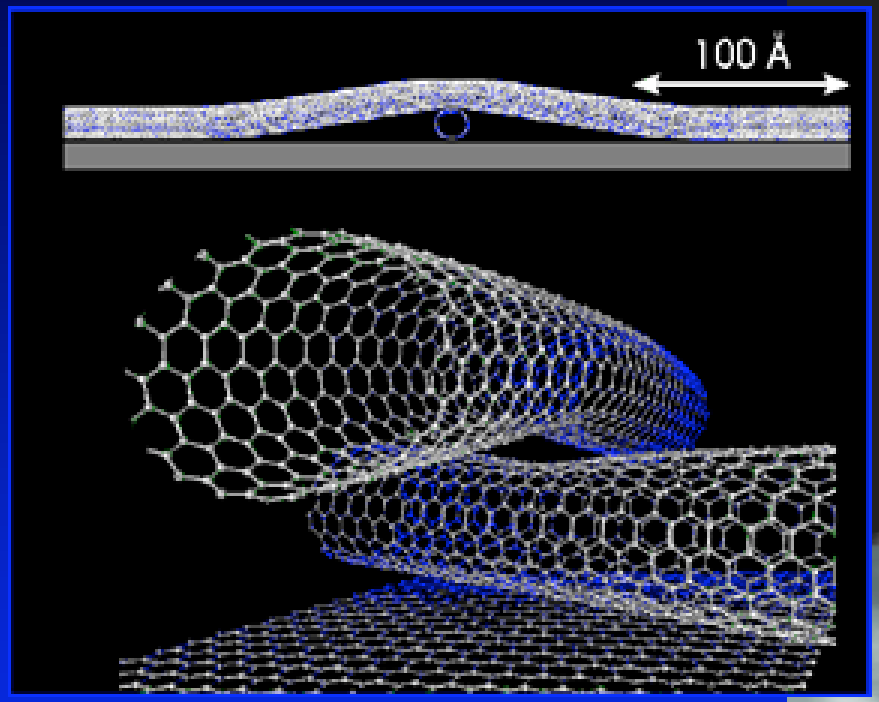
Cross-section

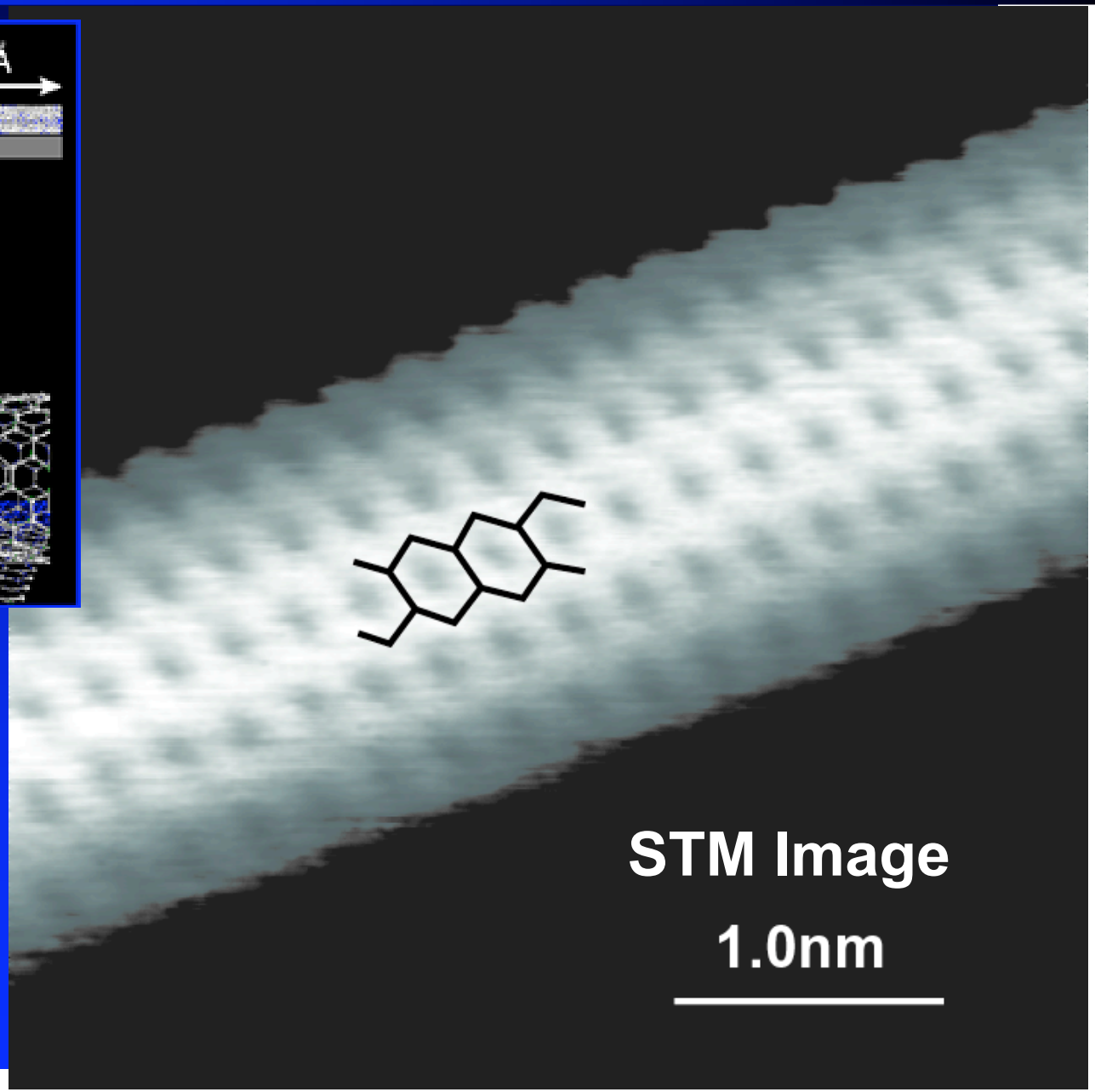
Is there a successor to the silicon transistor?



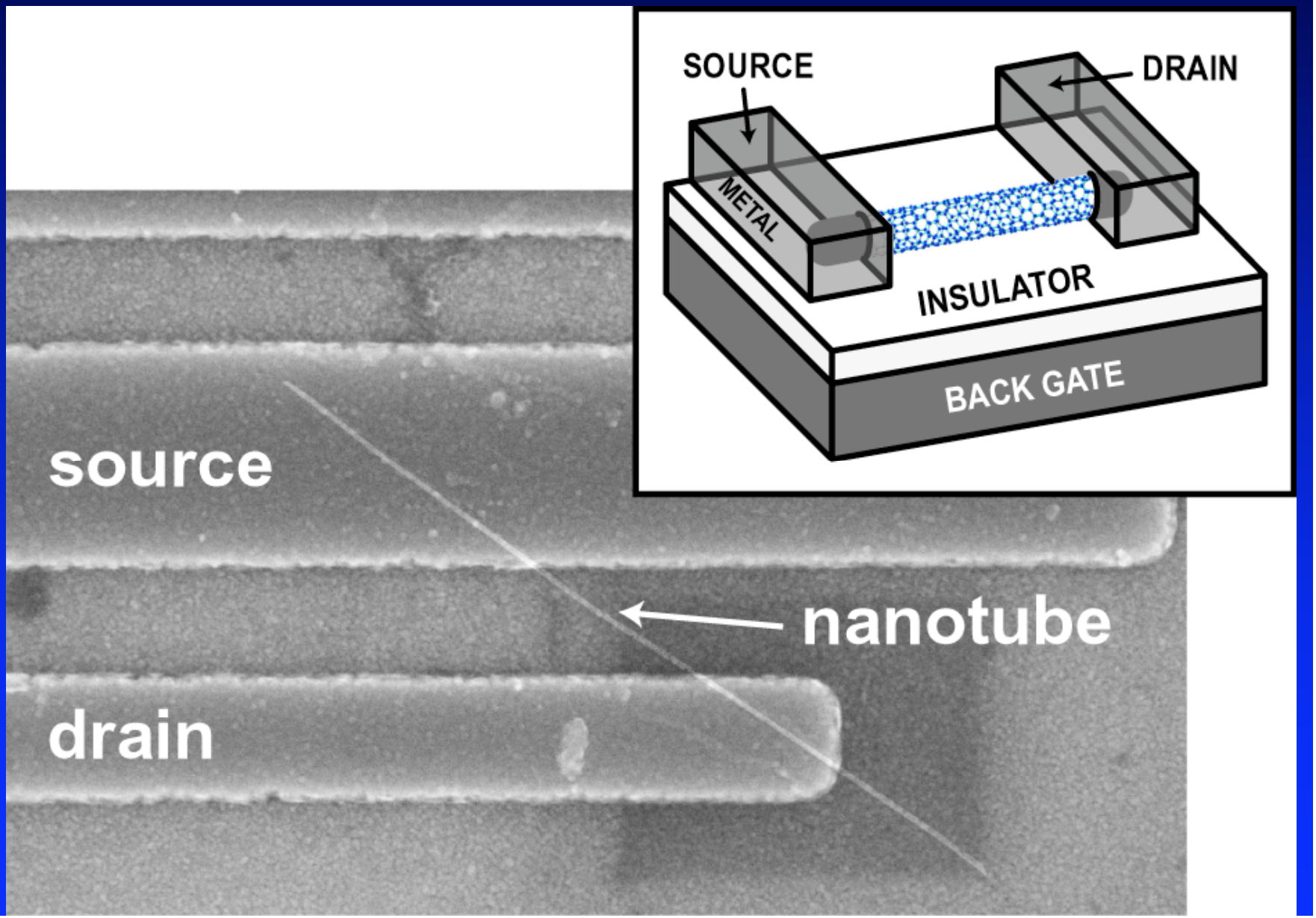
Data from R. Kurzweil, 1999,

Carbon Nanotubes

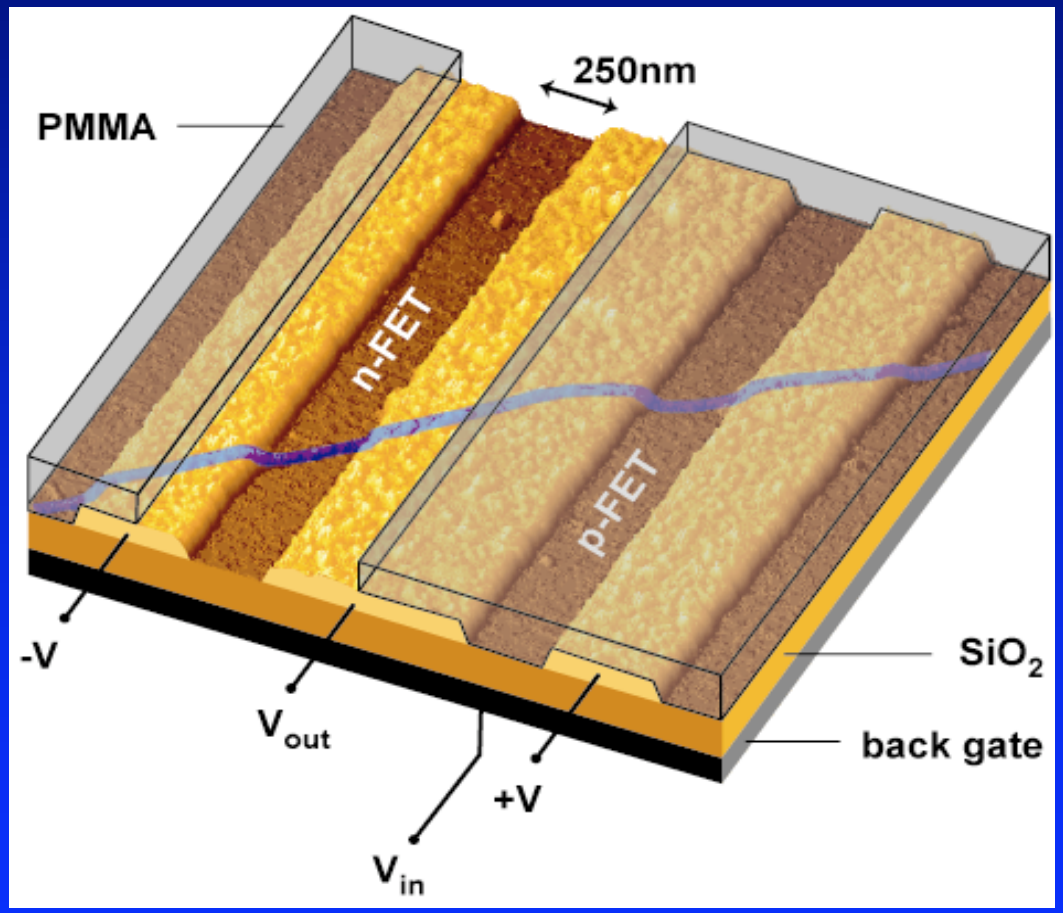


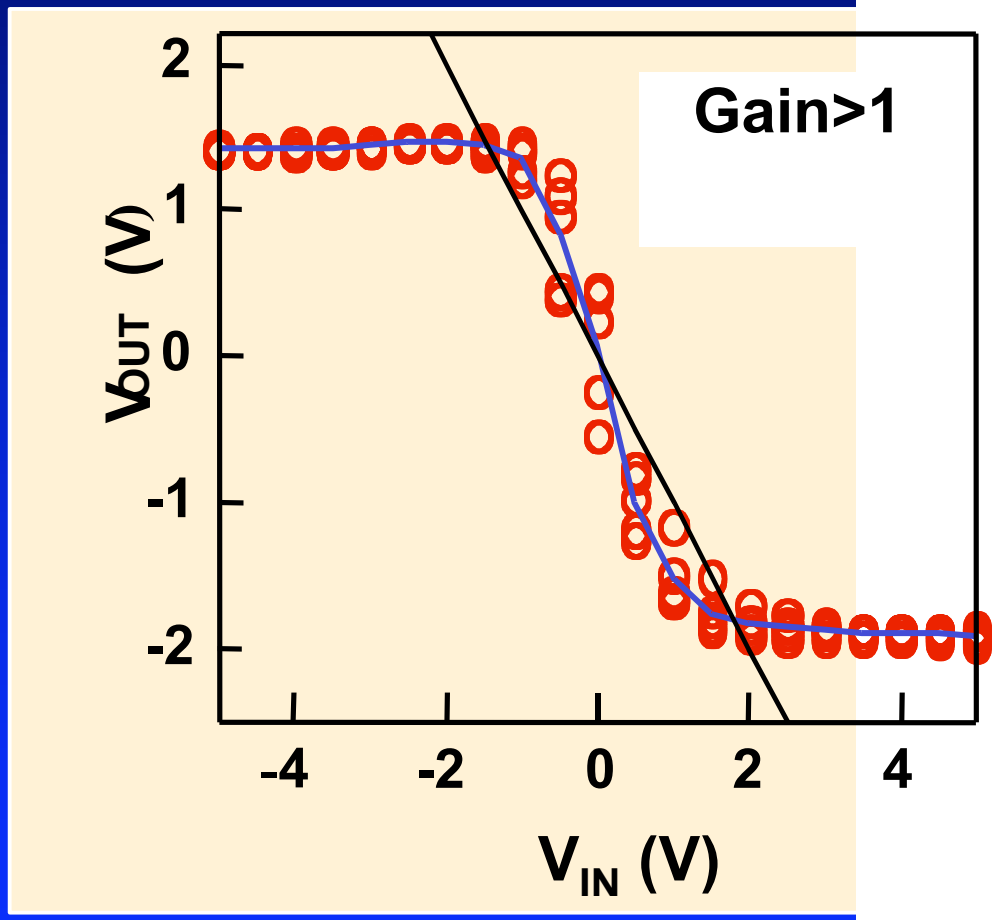


An alternative logic switch -- A simple Carbon Nanotube Transistor

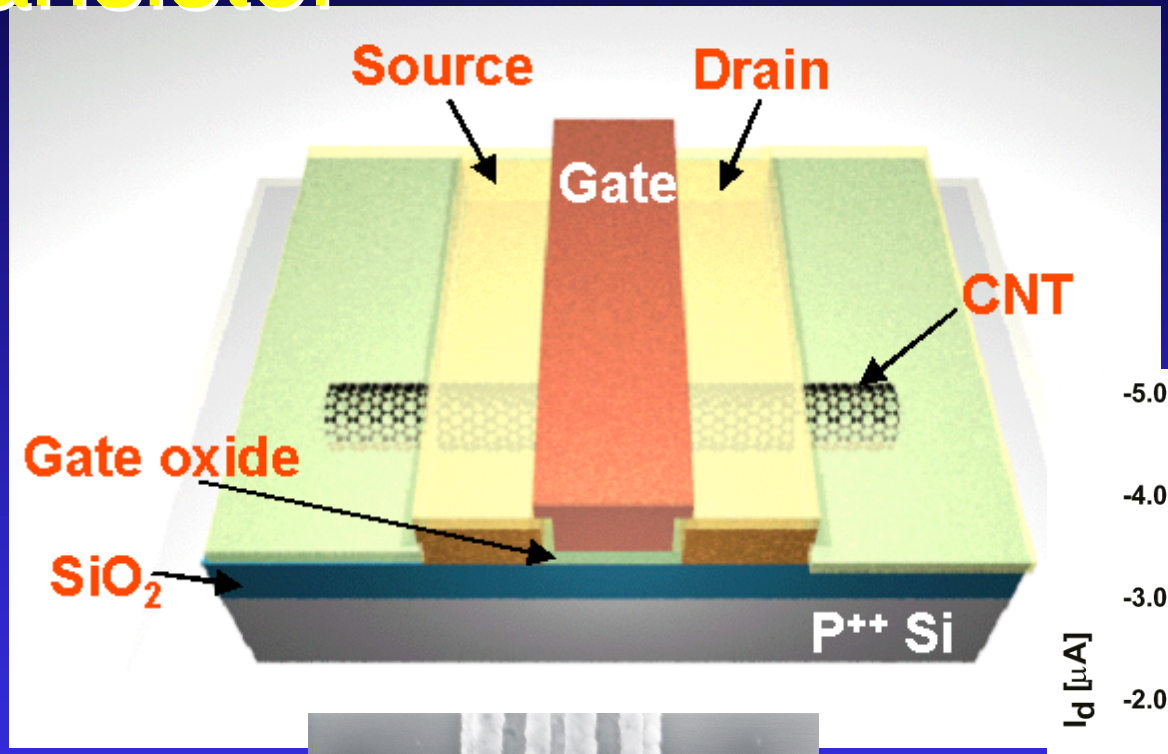


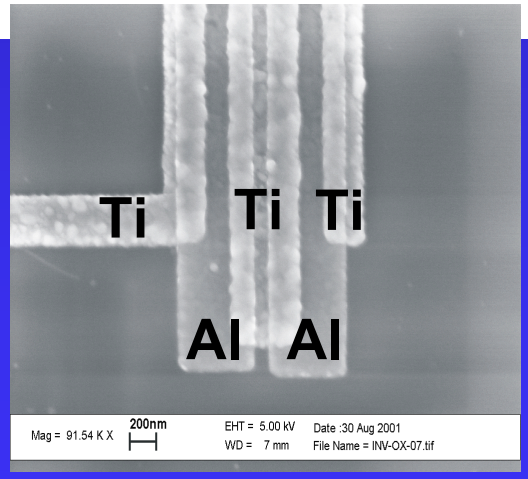
gate
(NOT gate, voltage inverter)

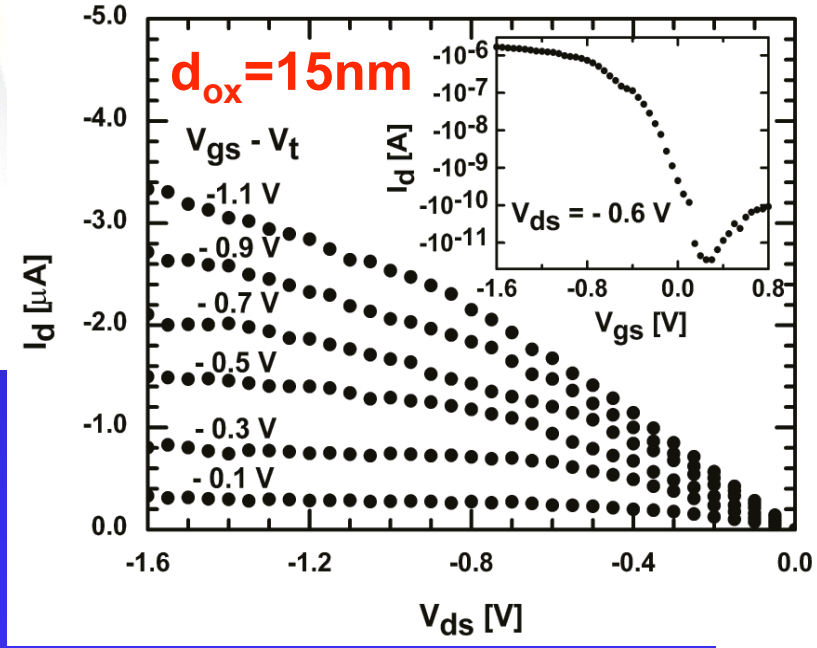




Top-gate carbon nanotube transistor







Appl. Phys. Lett. **80**, 3817 (200

Comparison with silicon

	p-MOSFET [a)]	p-CNFET
channel length	50nm	260nm
gate oxide thickness	1.5nm	~15nm
transconductance	650mS/mm	2300mS/mm
drive current$_{(Vg-Vt=-1.0V)}$	650mA/mm	2100mA/mm
threshold voltage	-0.2V	-0.5V
I_{On}/I_{Off}	10^6 - 10^7	~10^6
subthreshold slope	70mV/dec	130mV/dec

[a)] R. Chau et al. Proceedings of IEDM 2001, p.621

IBM

"Revolutionizing" a large, complex, stratified industry is not easy.

- Sphere of *successful* influence: +/- one layer

Application

Architecture

System

Circuit

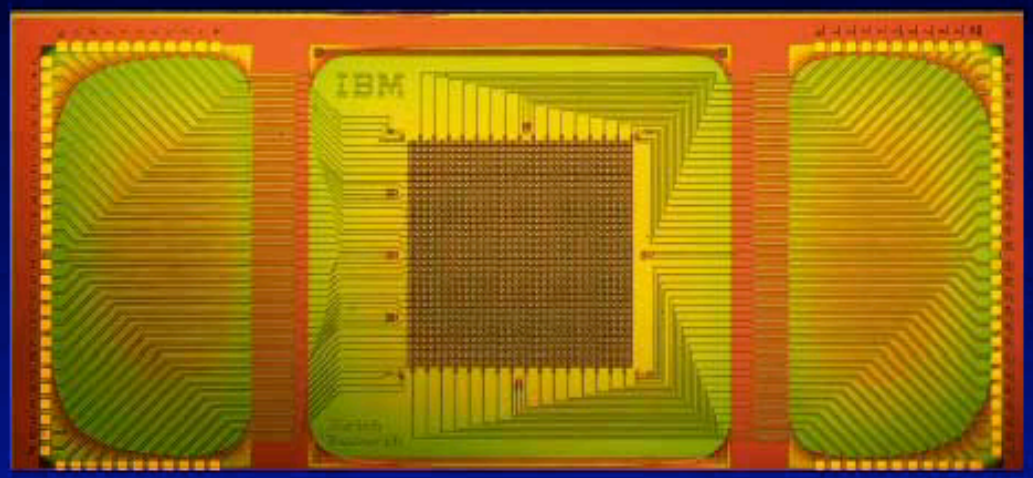
Device

Materials

Physics/chemistry

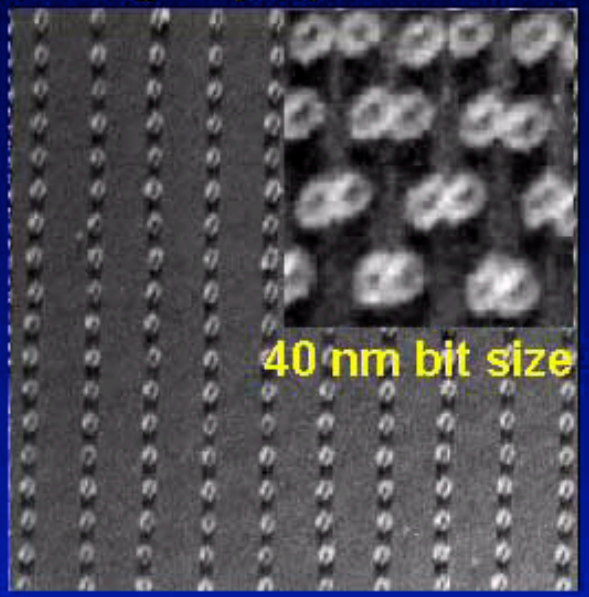
Adapted from M. Horowitz, in *Focus Center Research Program (MARCO) MSD-C2S2 Topical Workshop,* Nov. 12,

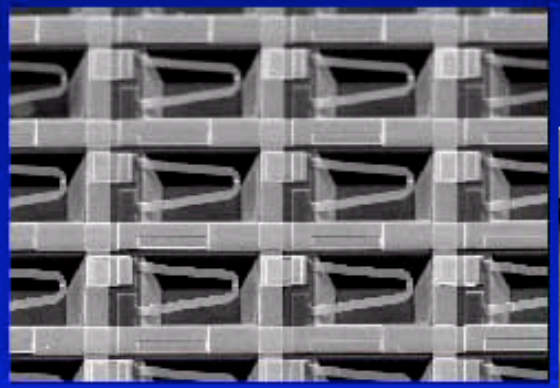
Millipede: A nanomechanical approach to storing information

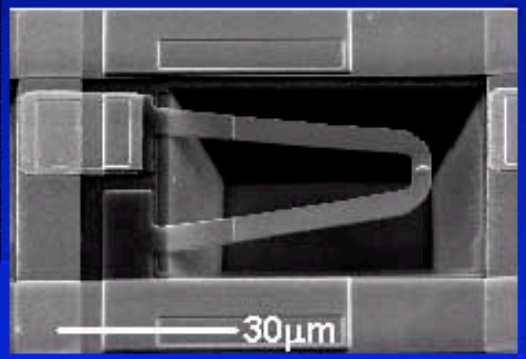


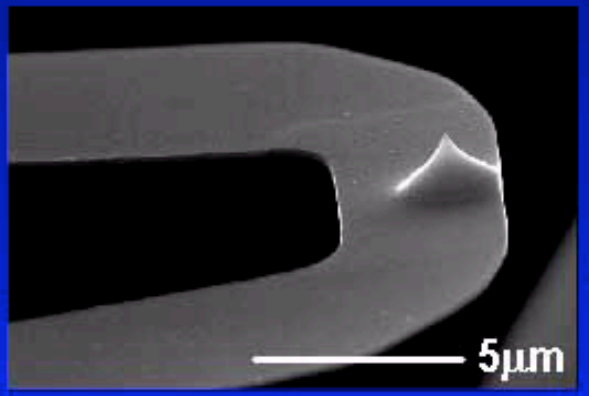
32 x 32 (1024) Cantilever Array

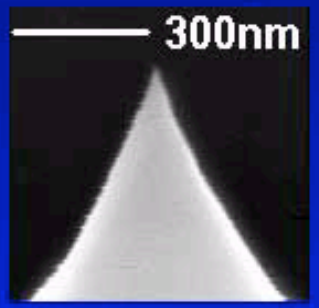
Thermomechanical writing in polymer media







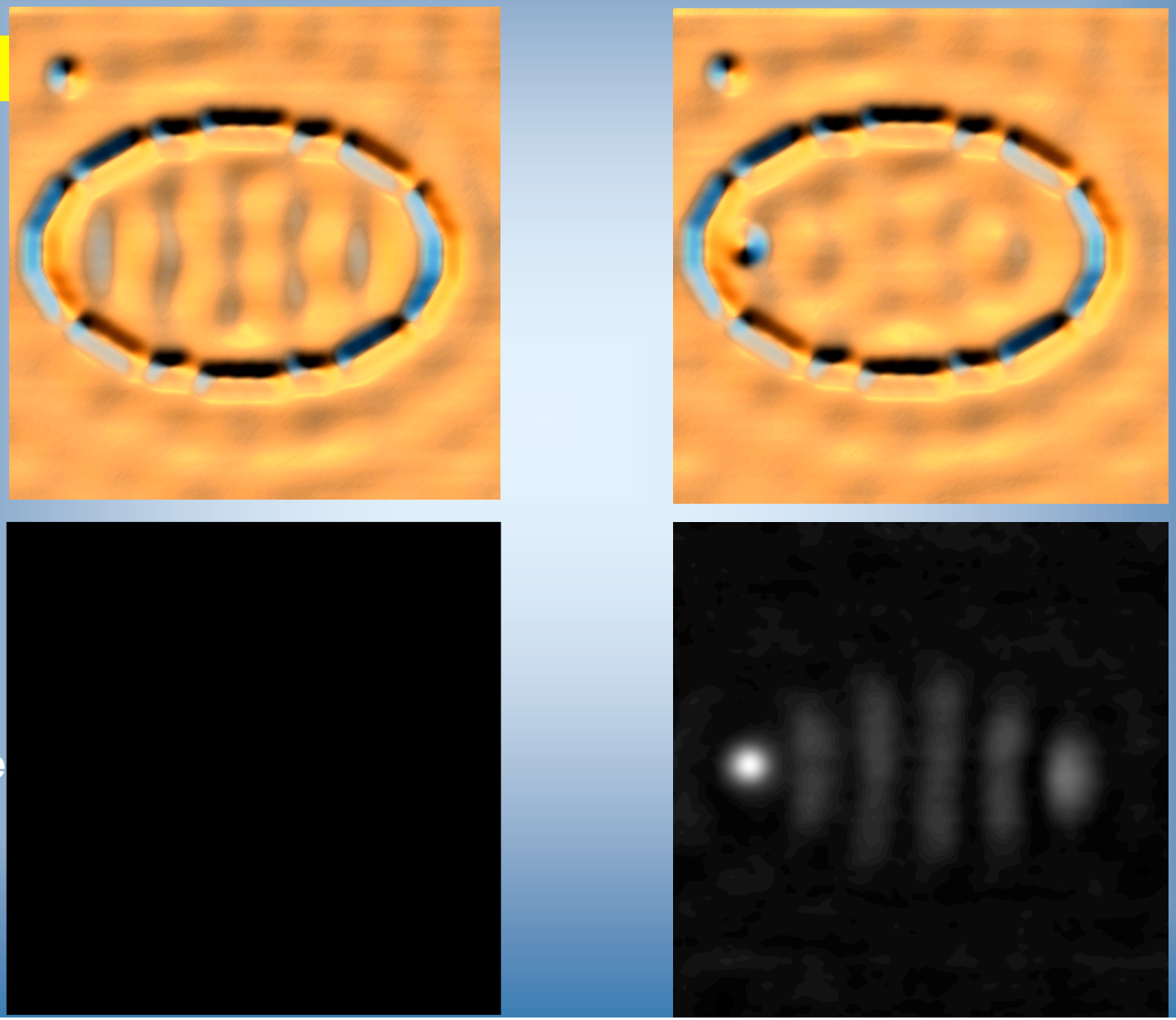




The Quantum Mirage: Single Channel Information Transp

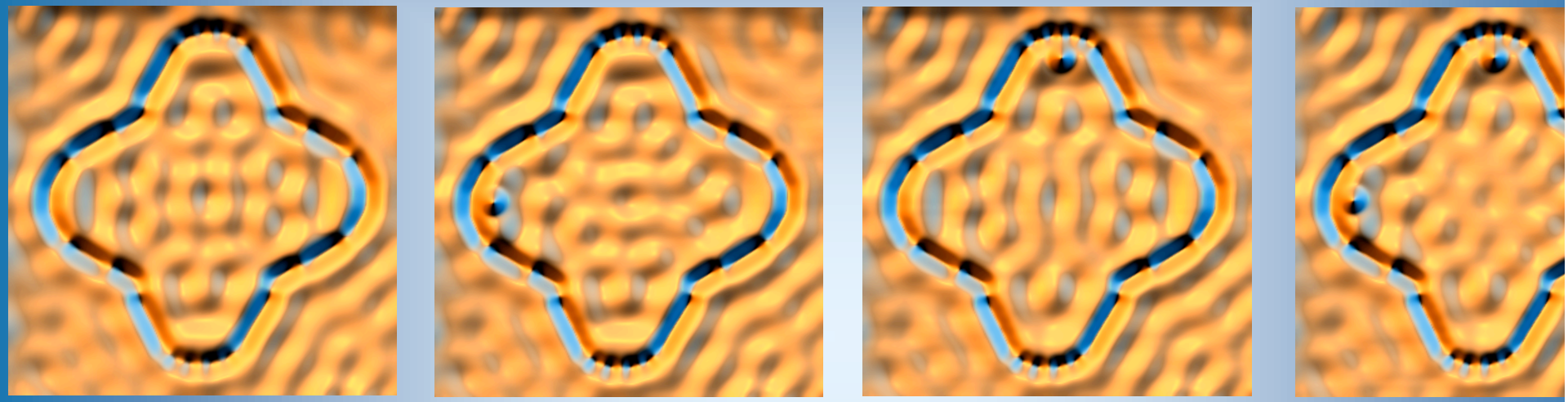
Topograph

dI/dV difference

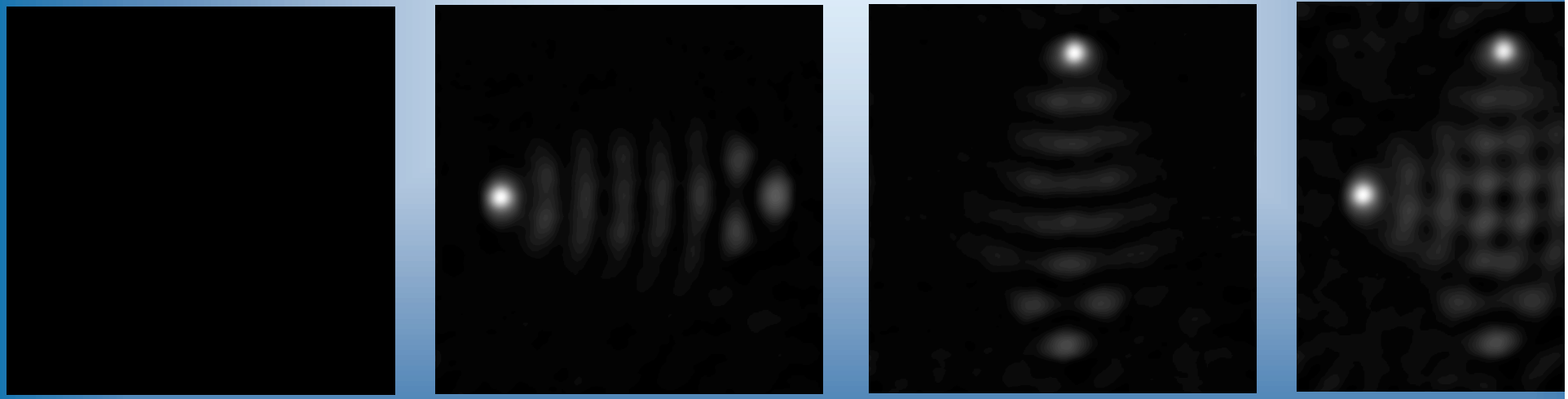


Multi Channel Information Transport

Topograph



dI/dV difference



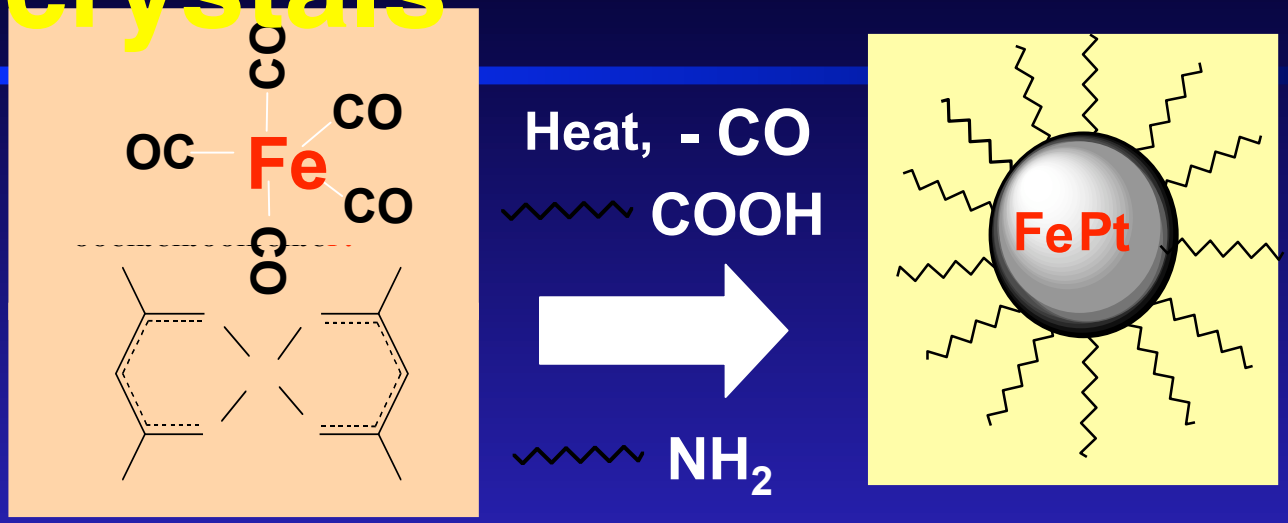
But how can we position atoms cheaply?

Persuade them to assemble themselves!

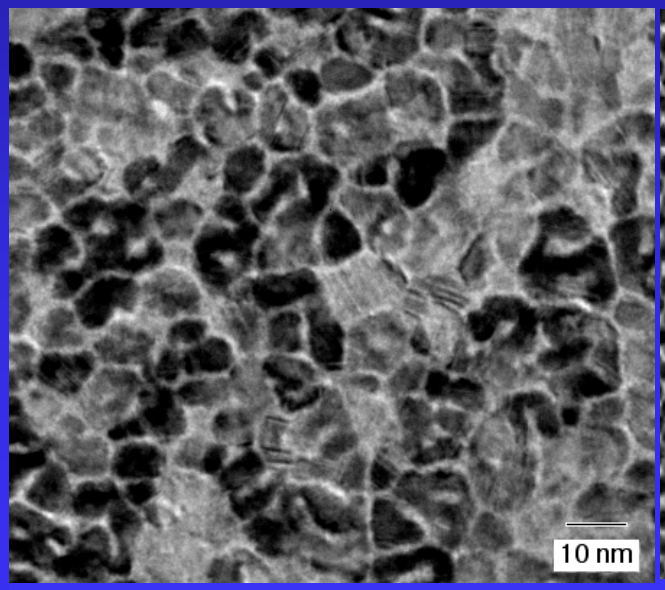
http://www.its.caltech.edu/~atomic/snowcrystals/photos/WWick/wwick.htm

Nature's Self-Assembly

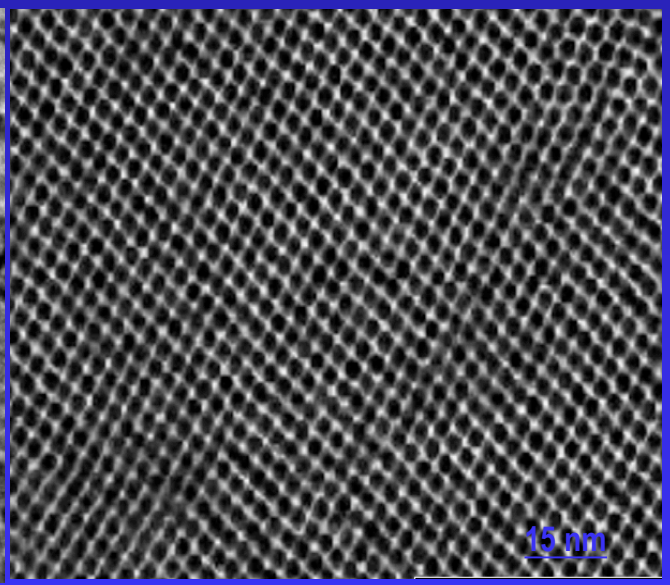
Self-assembled Magnetic Nanocrystals



35 Gbit/in^2 media



FePt Nanoparticle Arrays

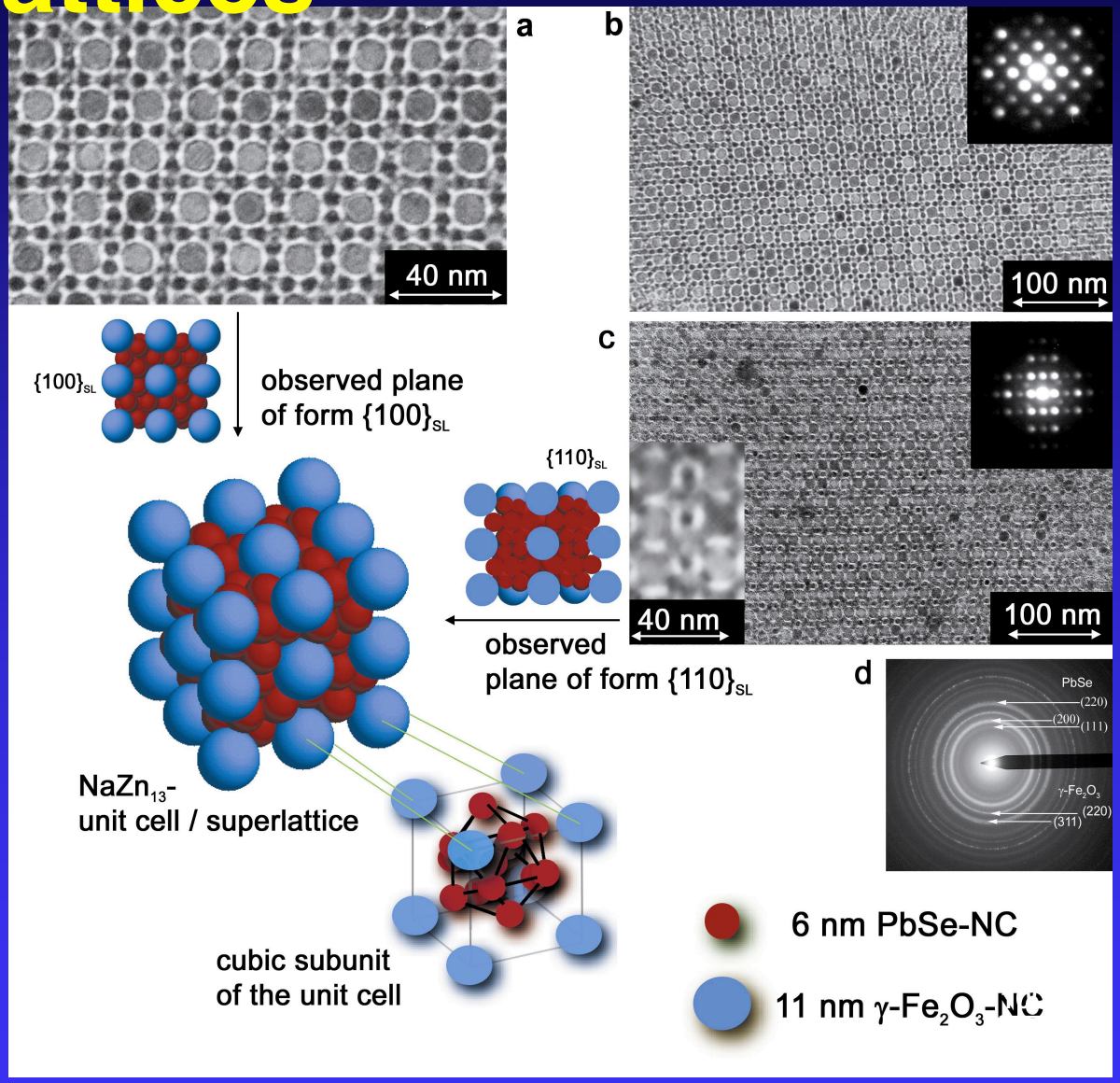


8.5nm grains $\square_{area}$ $\square$ 0.5

4 nm FePt NPs $\square_{area}$ $\square$ 0.05

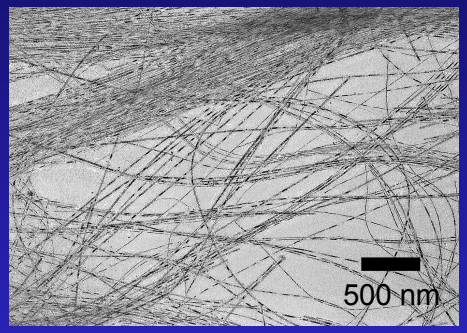
S. Sun, C. B. Murray, D. Weller, L. Folks, A. Moser, Science, 287, 1989-2000

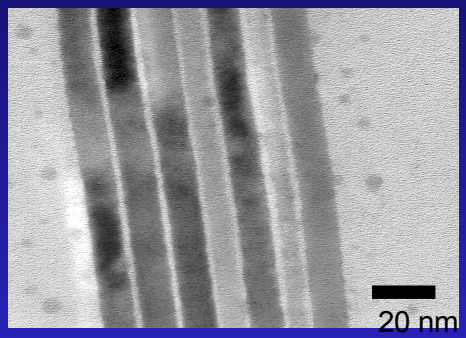
Multi-Component Nanocrystal Superlattices



AB_{13} binary Nanocrystal Superlattice of PbSe and Fe_2O_3

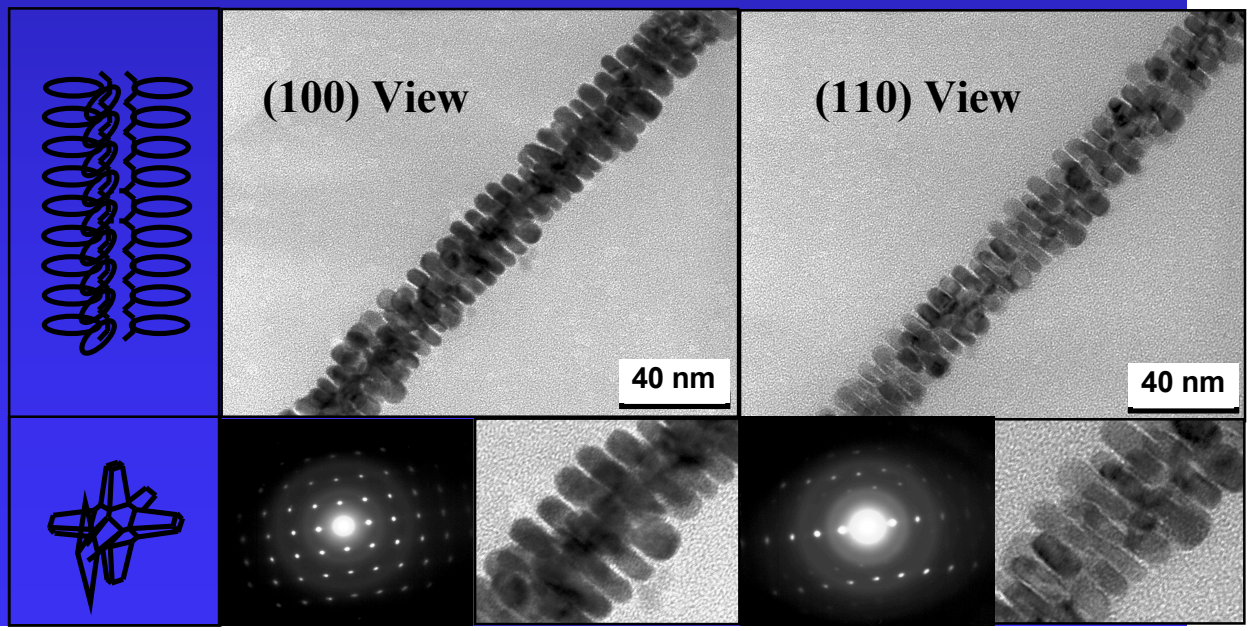
Semiconductor Nanowires



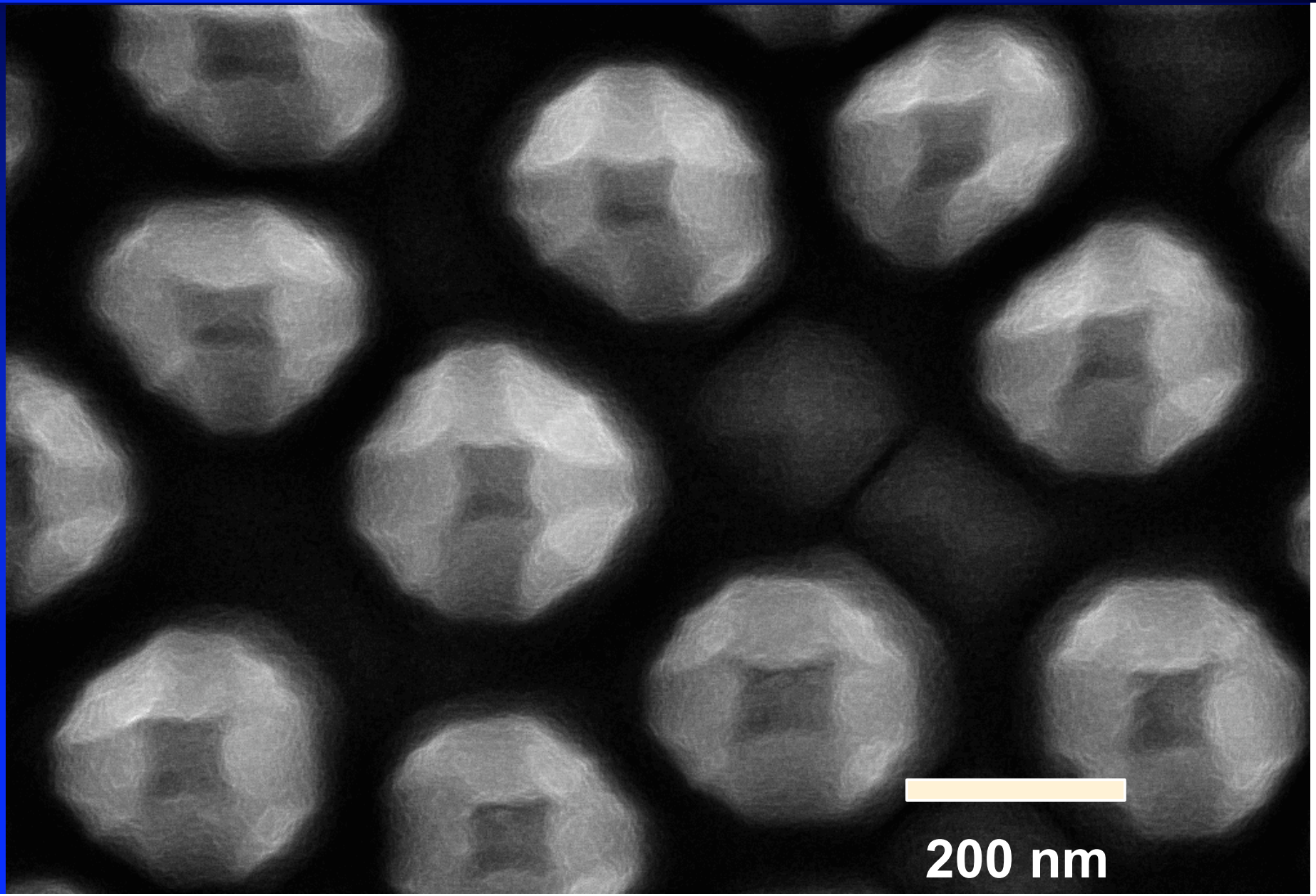


Straight PbSe Nanowires

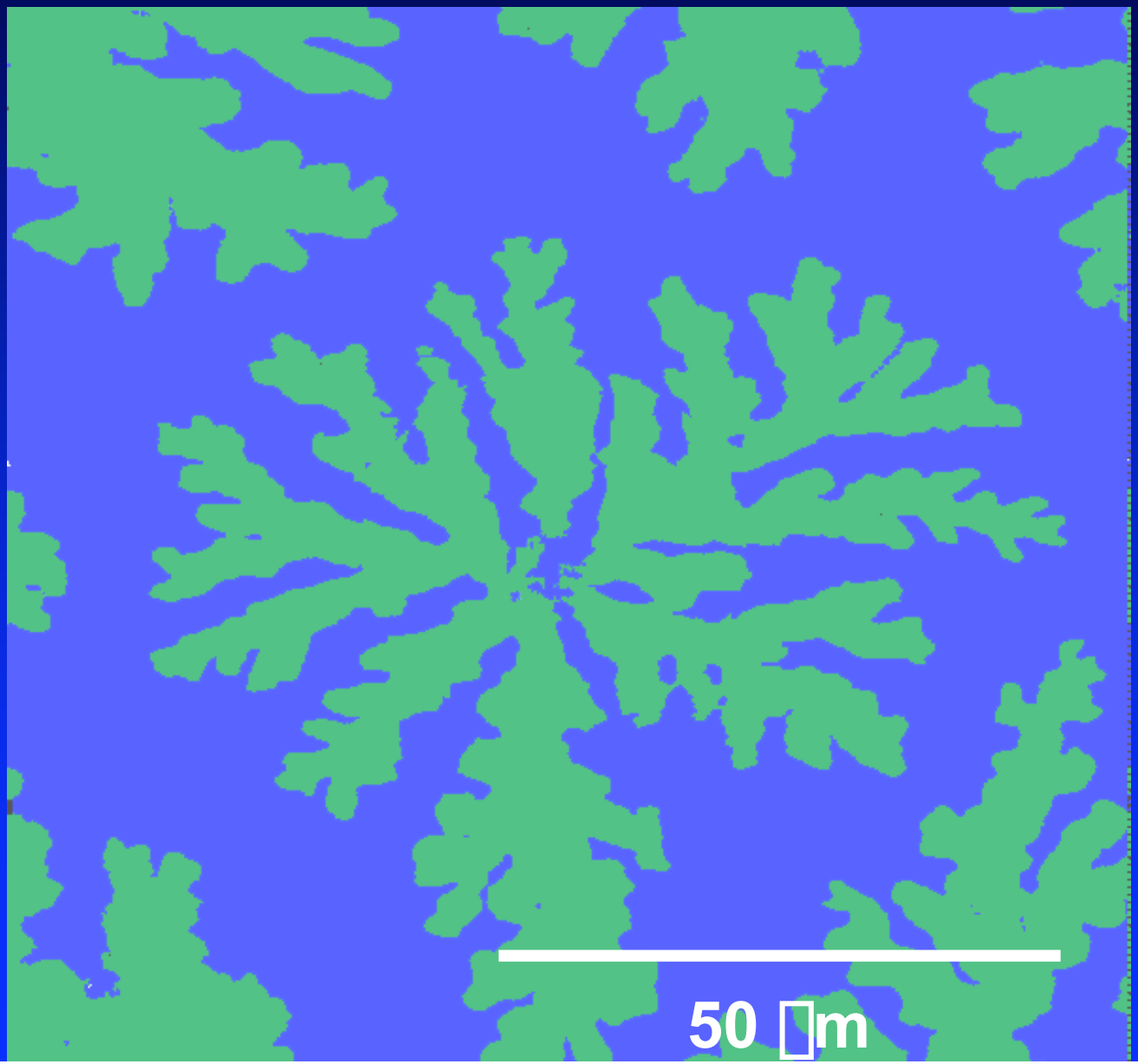
Branched PbSe Nanowires with High Surface Area



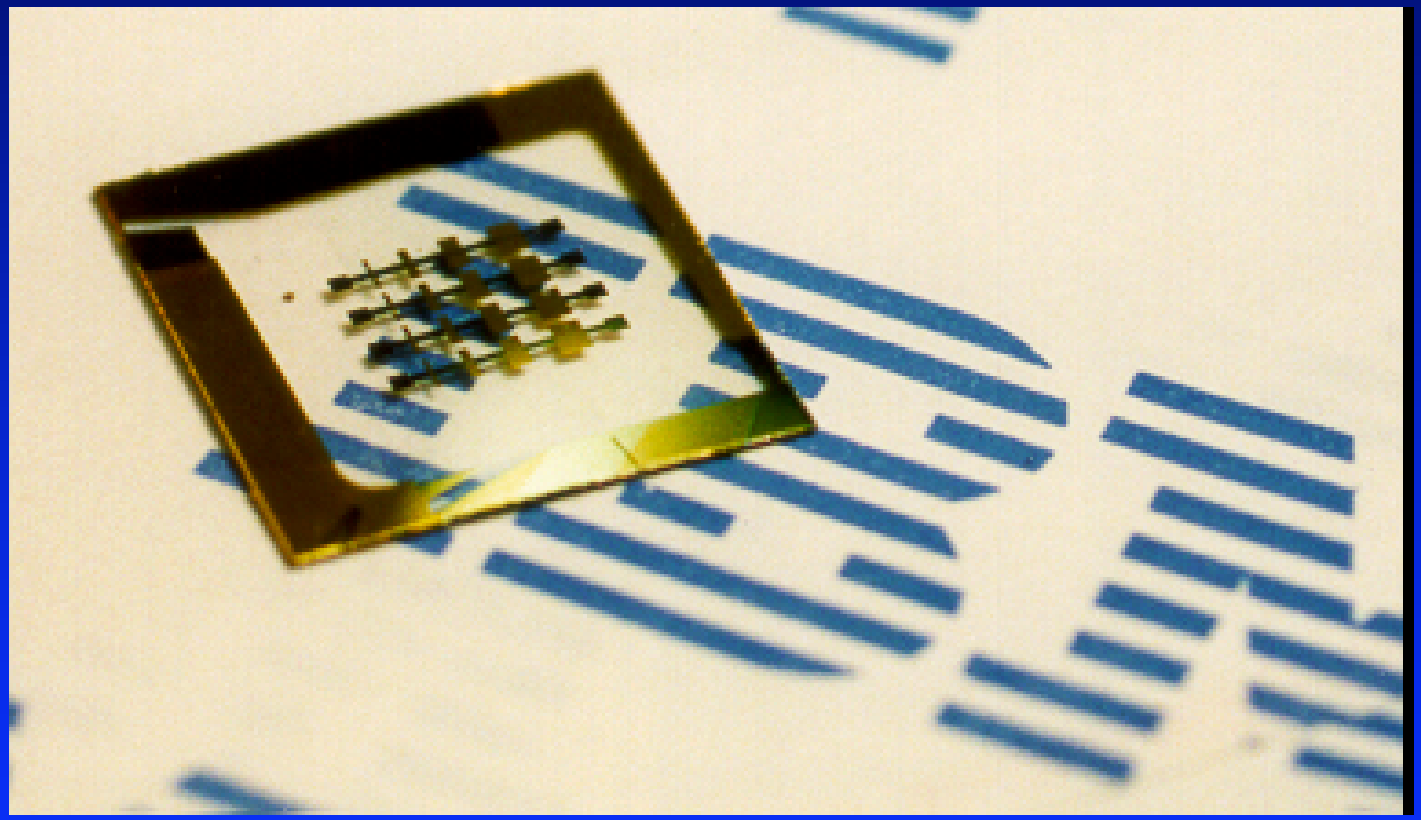
Self-assembly: SiGe Quantum Dots



Self-Assembly: A One-Monlayer-Thick Pentacene "Snowflake"

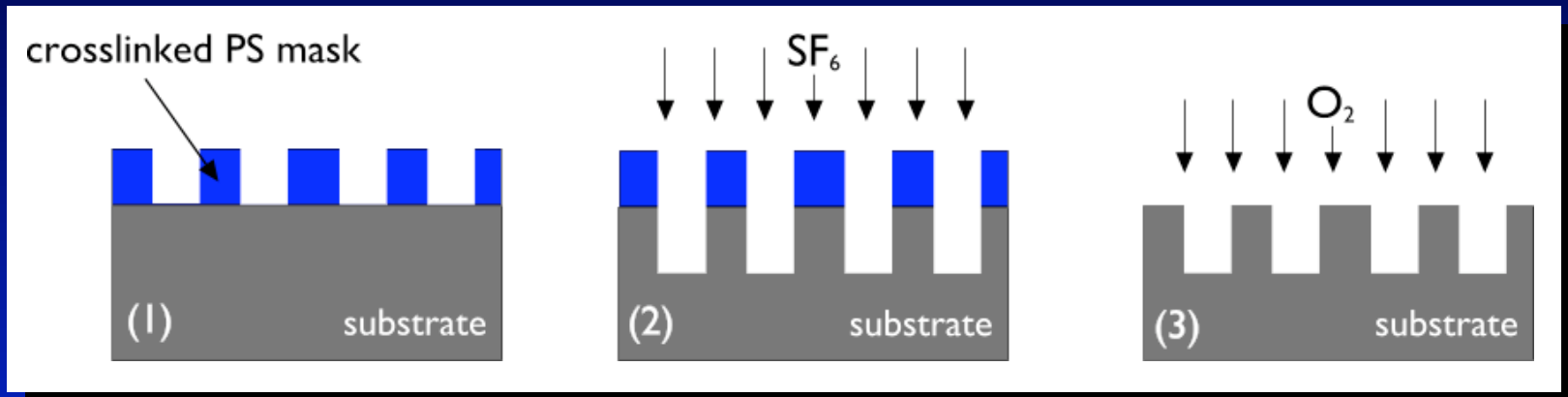


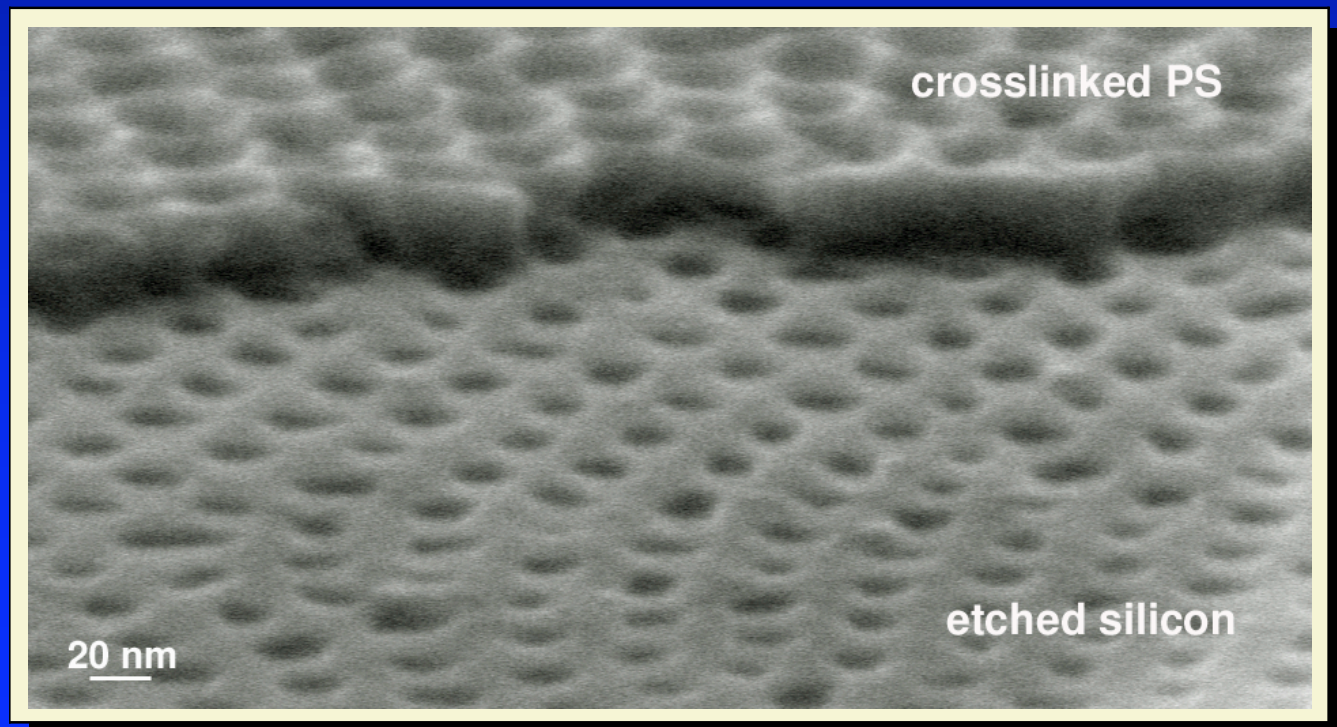
Thin Film Transistors on Transparent Plastic:



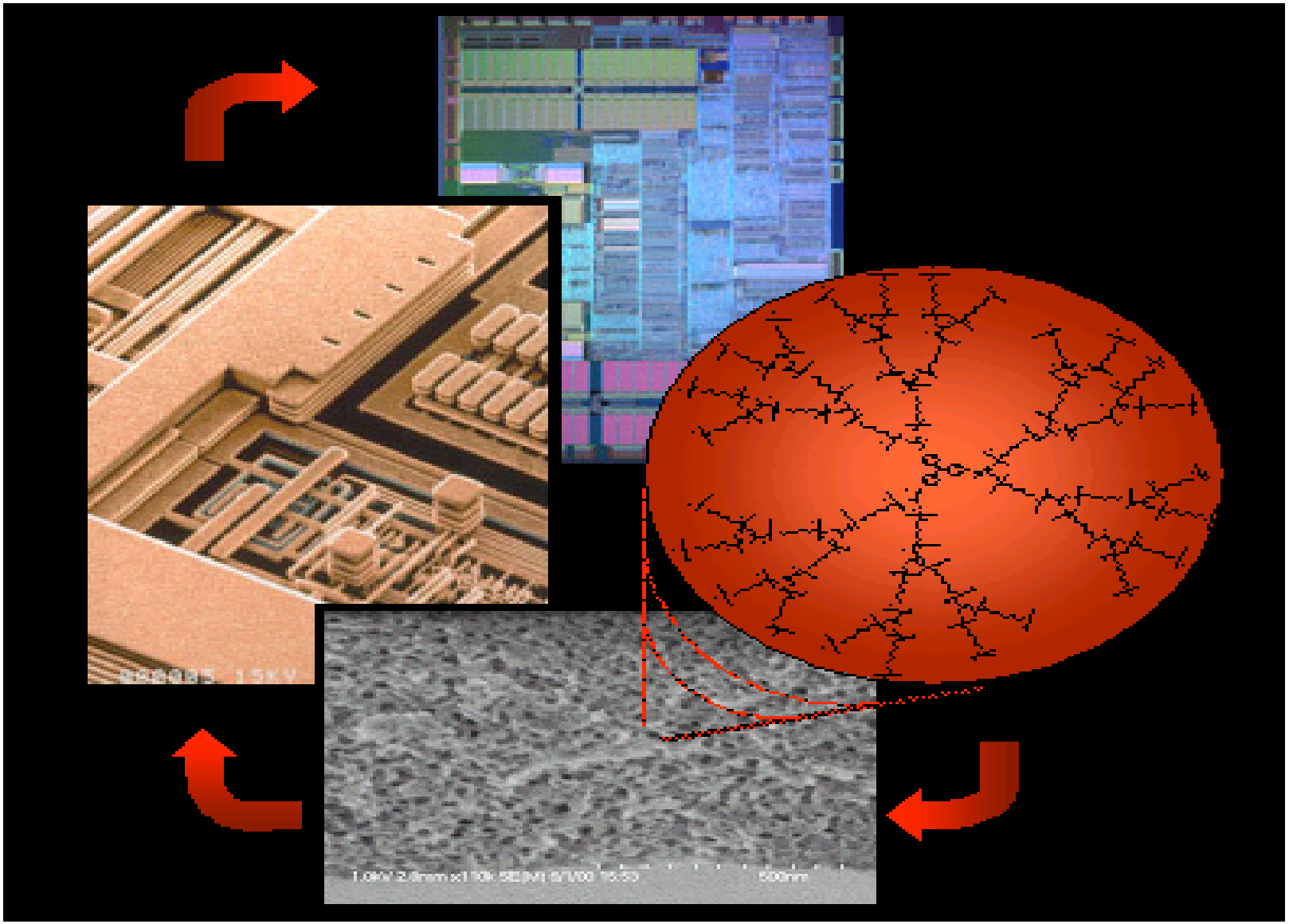
μ = 0.2 to 0.4 $cm^2 V^{-1}s^{-1}$, operating voltage 0 to 4 V.
All fabrication processes done at room temperature.

Patterning Silicon with Block Co-polymers

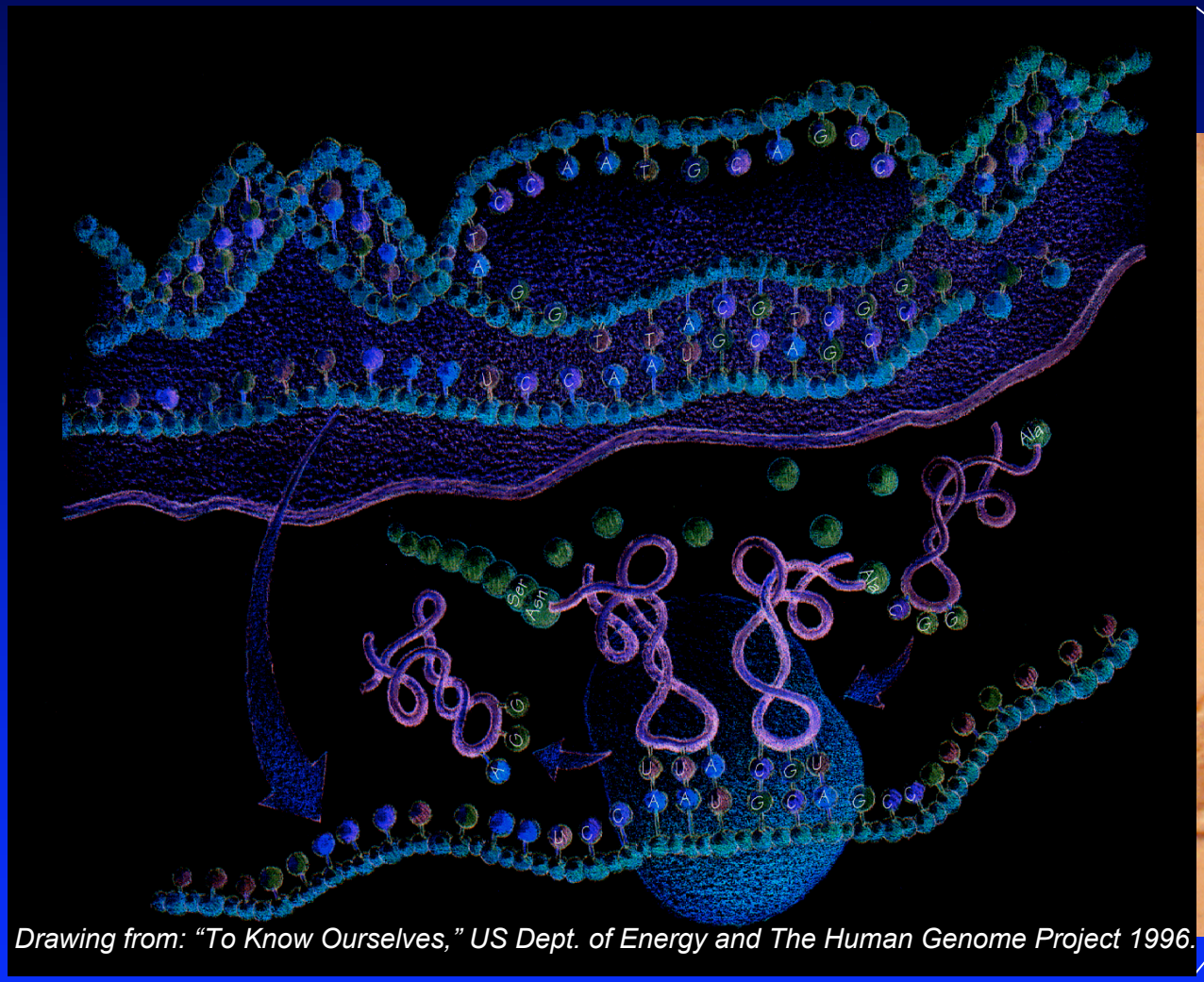




Pourous Dielectrics for On-Chip Wiring



How much digital information will specify the structure?



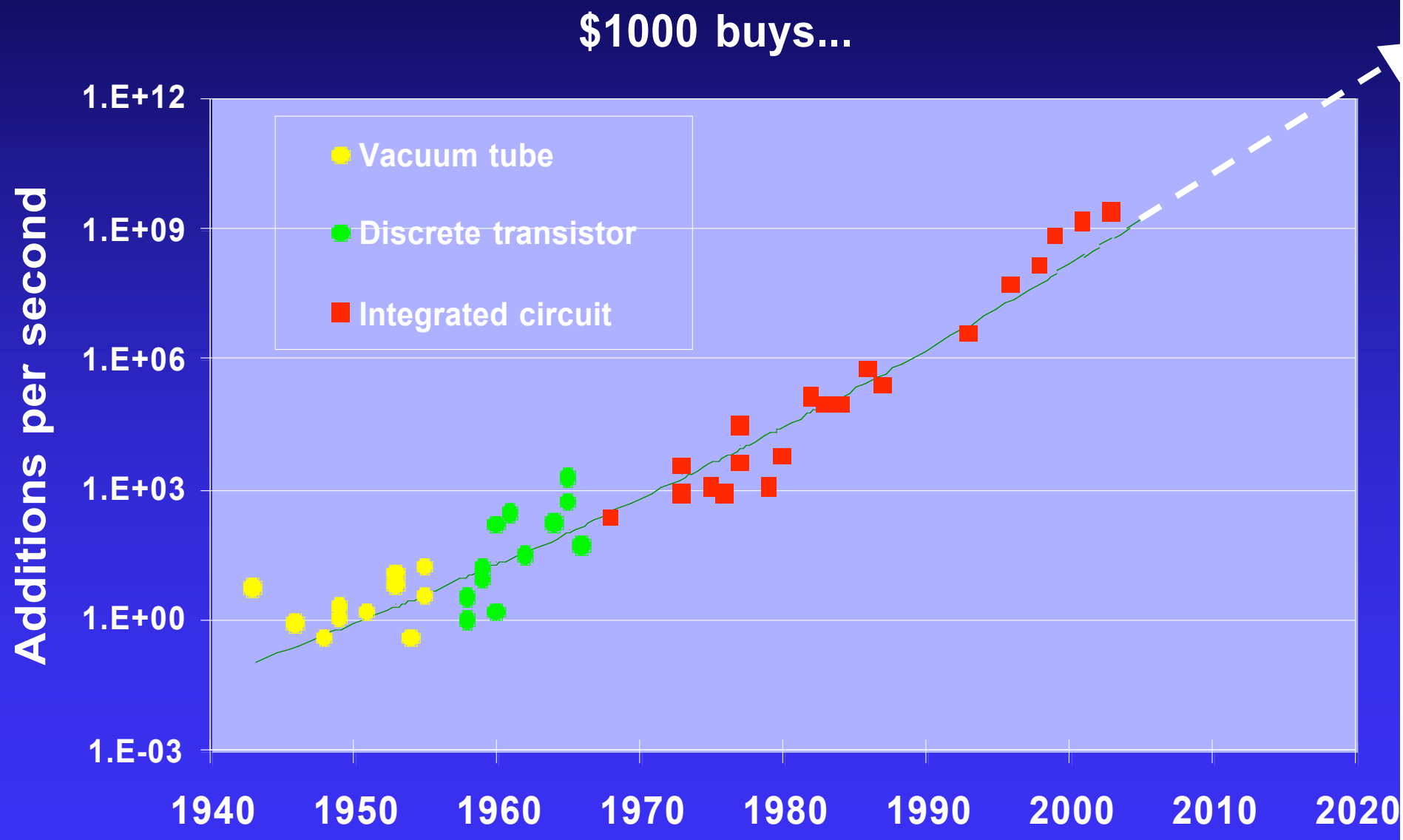
Drawing from: "To Know Ourselves," US Dept. of Energy and The Human Genome Project 1996.

A living thing
(Paramecium)

How much digital information is needed to BUILD the structure?

- Microprocessor – Gigabytes
- Living Thing – Megabytes!

Nanotechnology ...

The ability to design and control the structure of an object on <u>all</u> length scales, from the atomic to the macroscopic.

Nanotechnology: Were just getting started.