Our Nanotechnology Future

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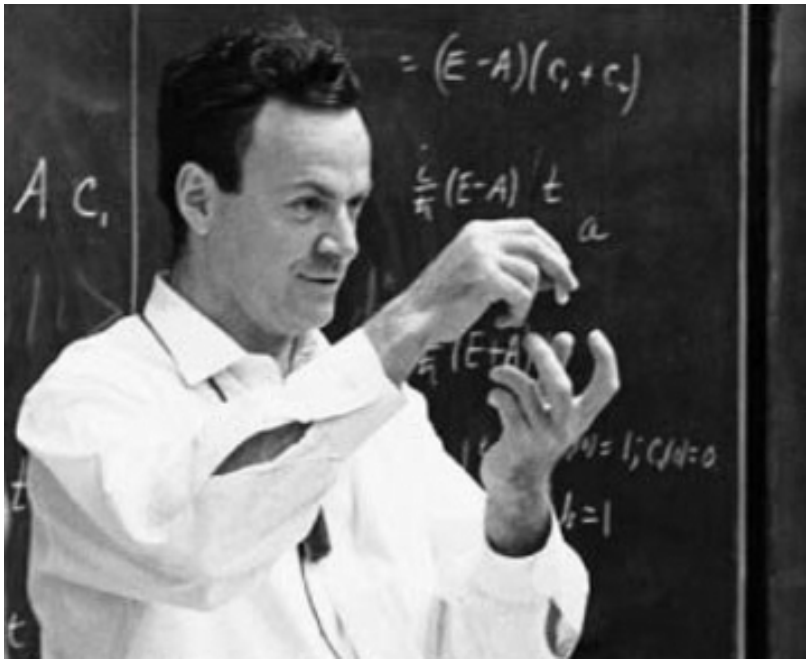
wikipedia

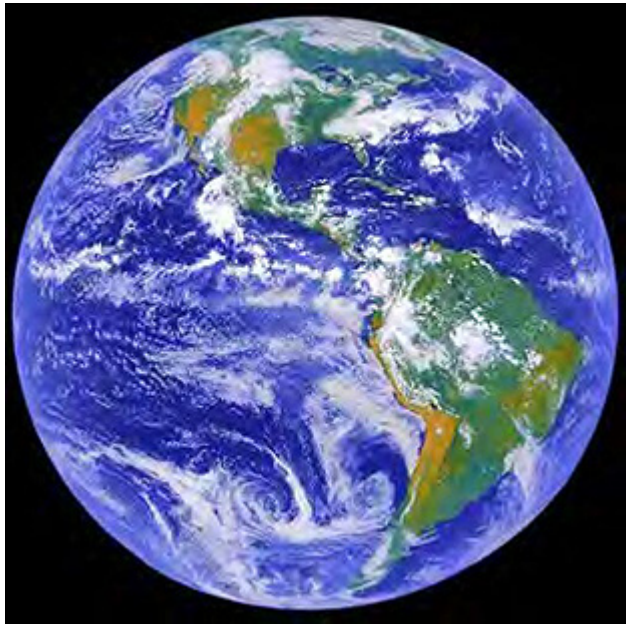
In 1959 Richard Feynman
Delivered a now famous lecture,
“There is Plenty of Room at
the Bottom.”
He predicted new discoveries
if one could fabricate materials
and devices at the atomic scale



For this to happen, he pointed out the necessity of a new class of miniaturized instrumentation to manipulate and measure the properties of these small structures—nanostructures.

Nano = one billionth = 10^{-9}

One nano-Earth



Is a marble!

Nanotechnology

Nanotechnology will build devices with structural features at the nanometer level.

Why?

Because

Nano is different than bulk

Nano is different than atomic.

Nano is something in between

Nano allows us to control the physical and chemical properties by varying the size of the structure.

Nanogold is not golden!

Single 5nm Particles

Aggregates

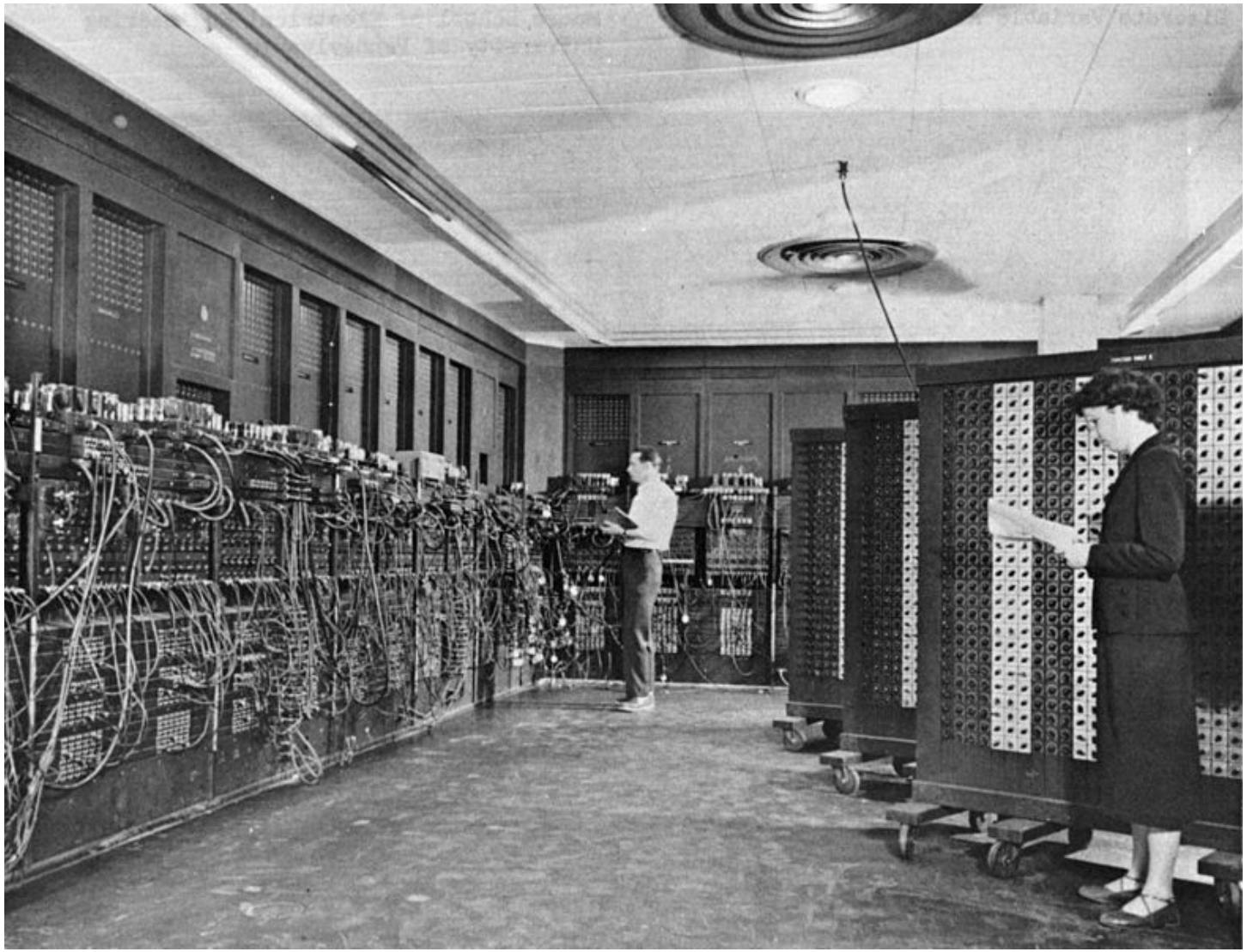
Nanotechnology will build from the bottom up, rather than the top down.

The canonical example of top down:
The computer

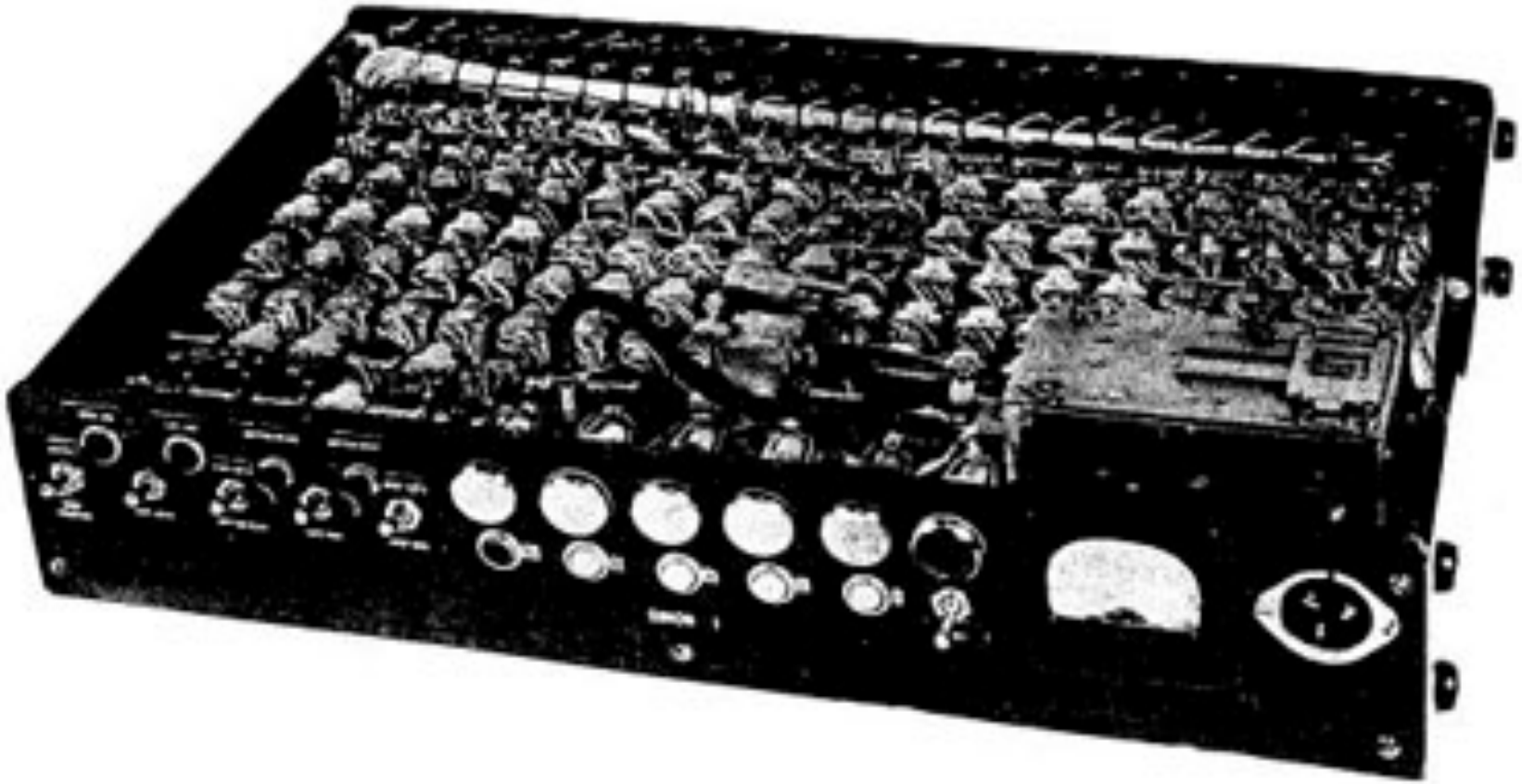
Electronic Numerical Integrator And Computer

The ENIAC, 1946

Vacuum tube technology

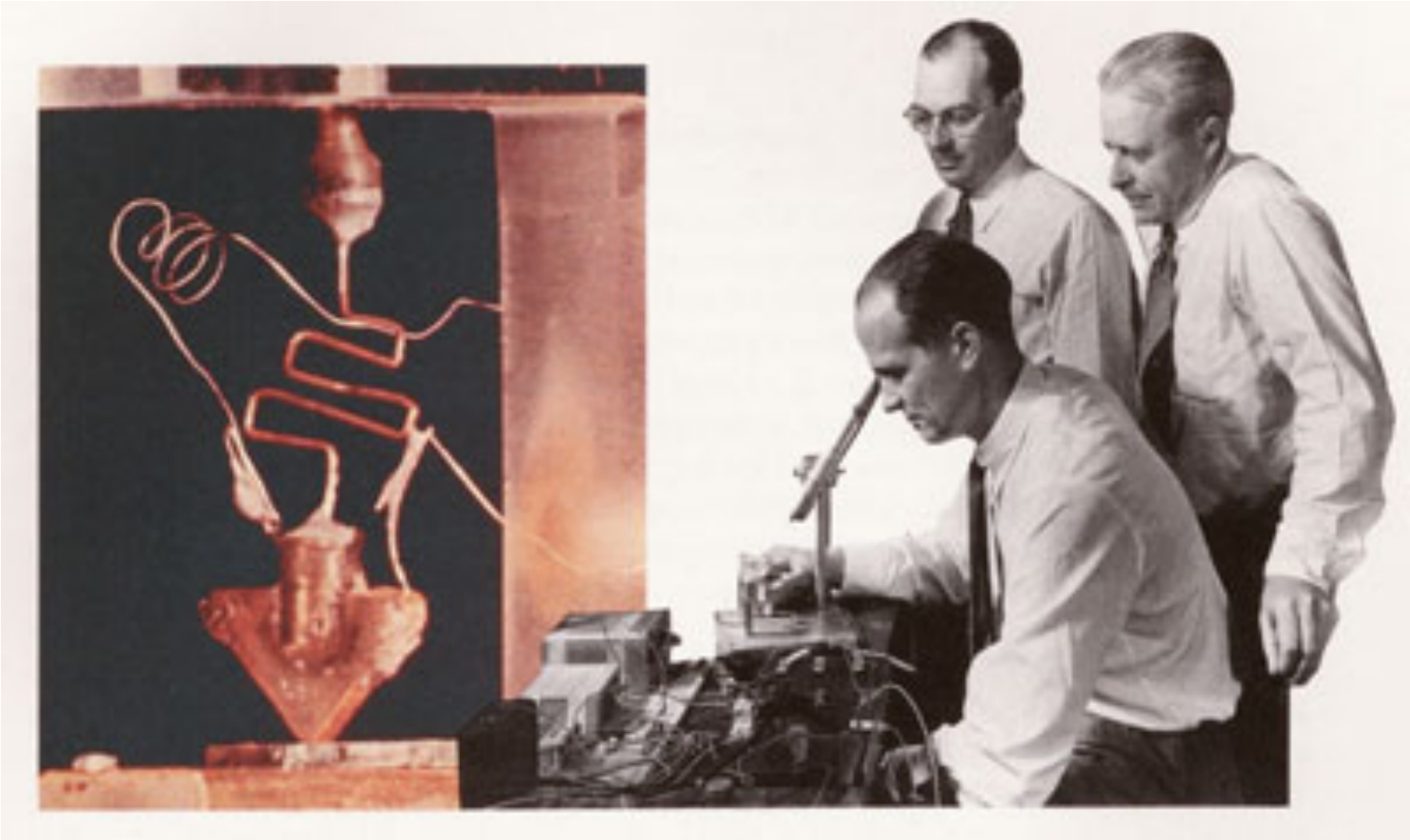


Electronic desktop calculator ca. 1950

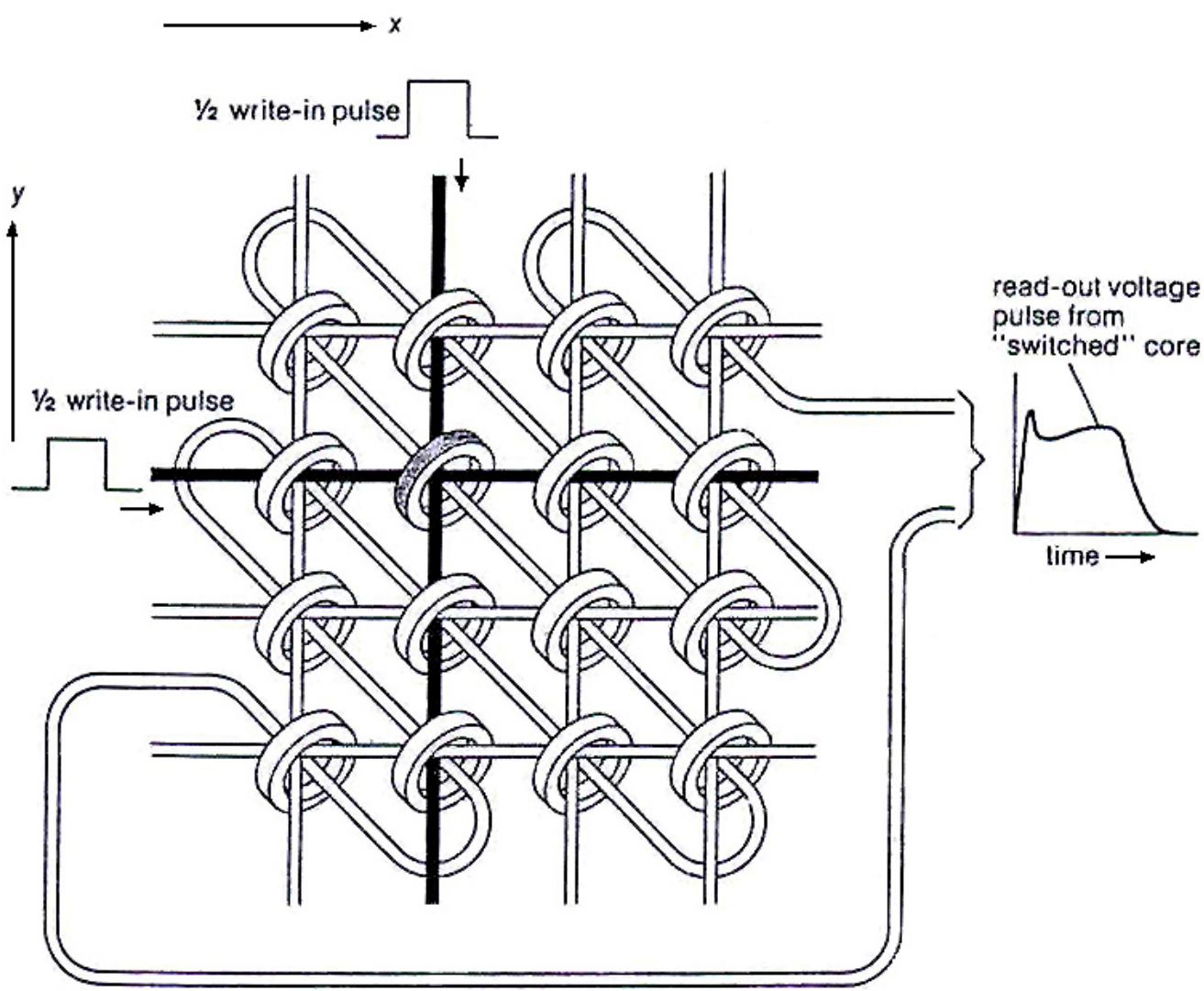


The transistor

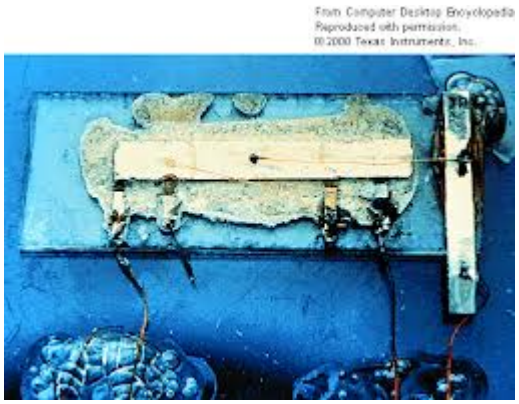
John Bardeen, William Shockley and Walter Brattain at Bell Labs, 1948

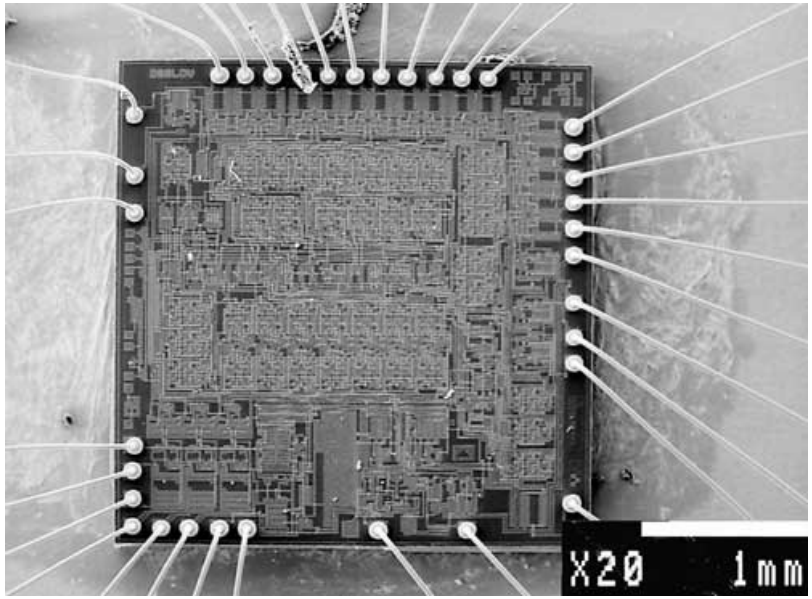


Magnetic core computer memory ca. 1970

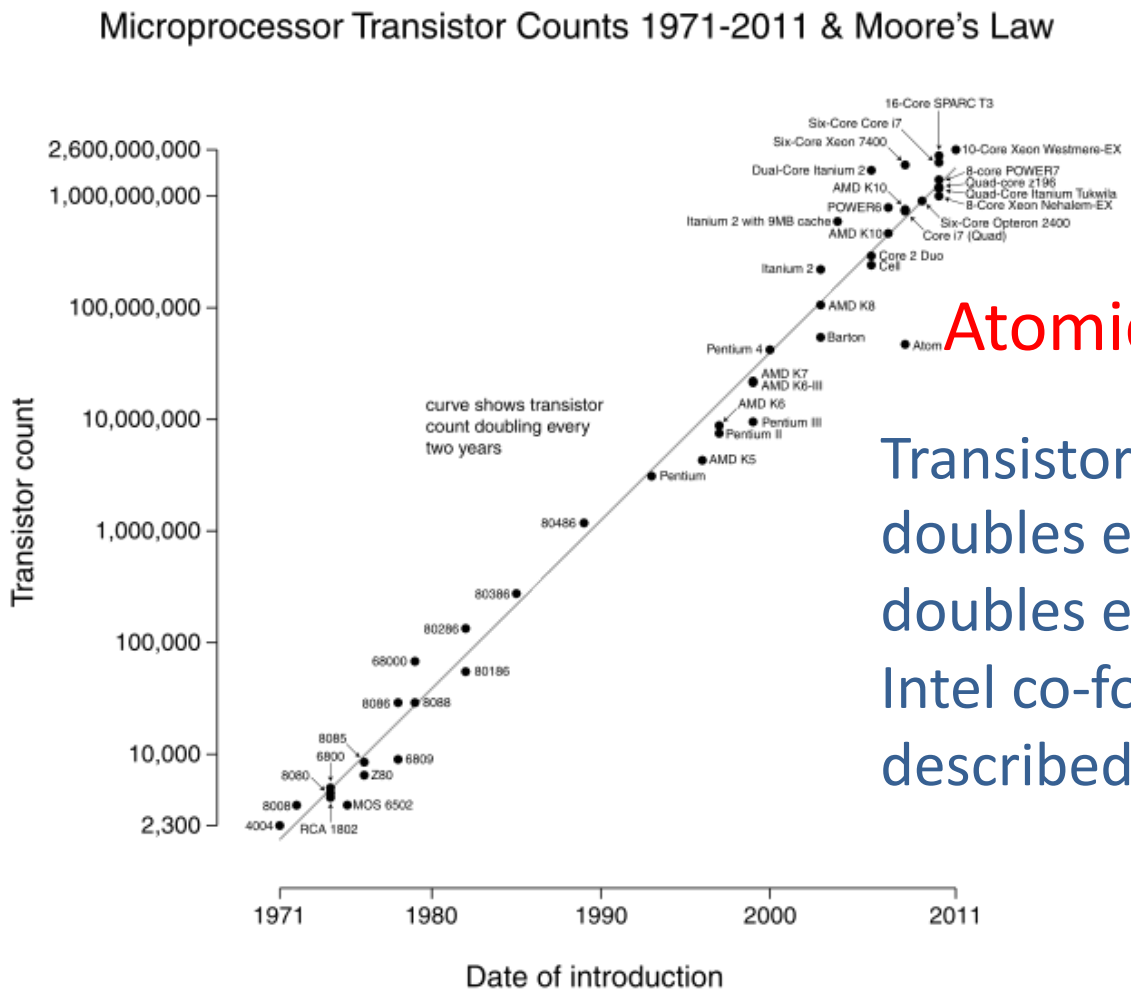


Jack Kilby and the integrated circuit





Moore's Law



One transistor
200nm by 200nm

Atomic dimensions in 20 years

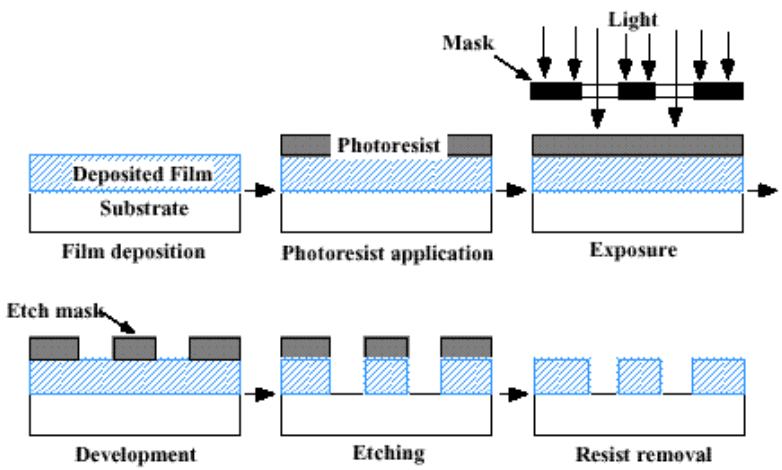
Transistors/integrated circuit doubles every 2 years (speed doubles every 18 months).
Intel co-founder Gordon Moore described this trend in a 1965 paper.

wikipedia

Lithography

photons (light, UV, X-rays)

electrons



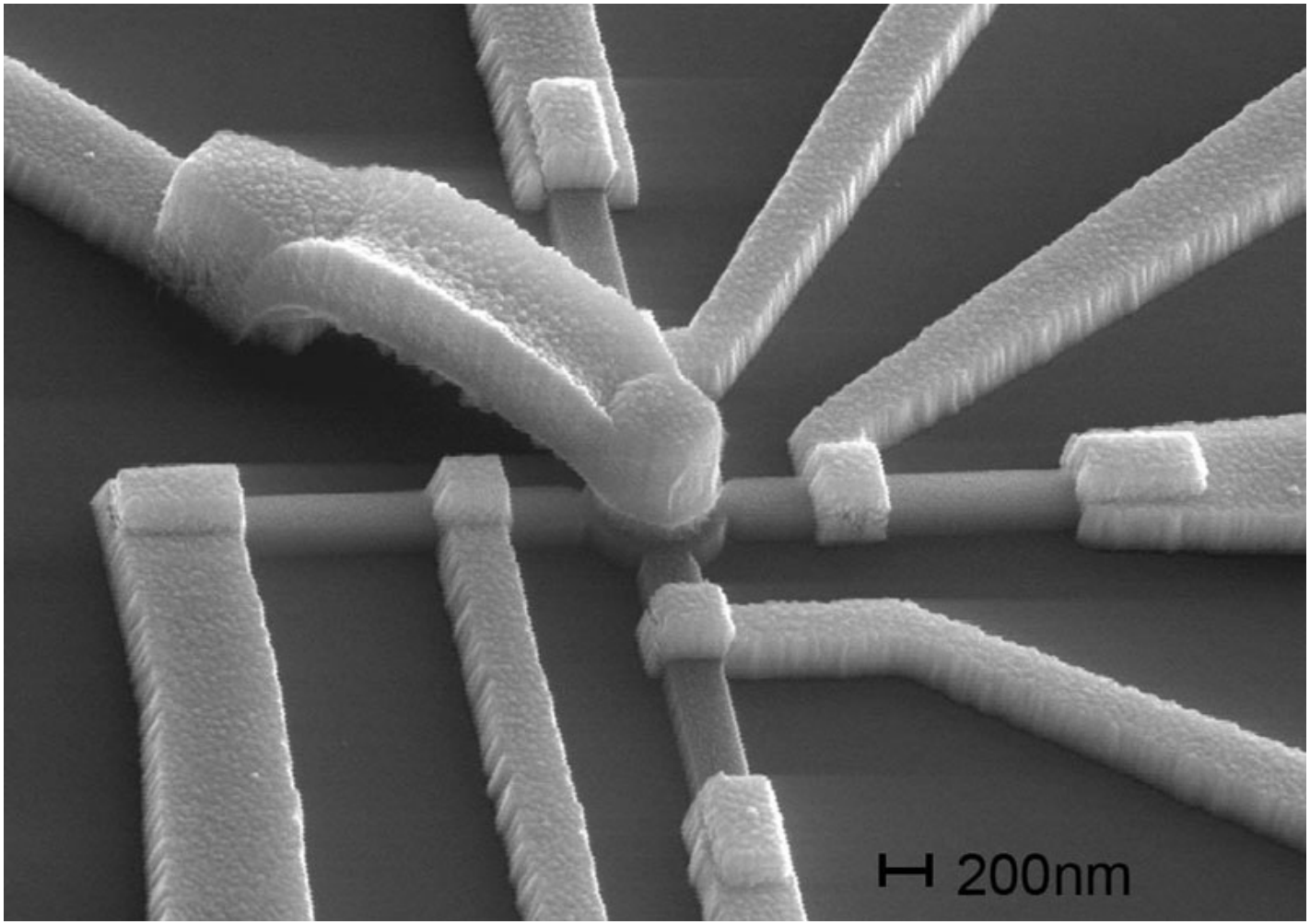
A-Silicon+Wafer+Patterned

Using photons or electrons to draw a pattern in an etching resist either:

1. directly with a projected image, or
2. using an optical mask.

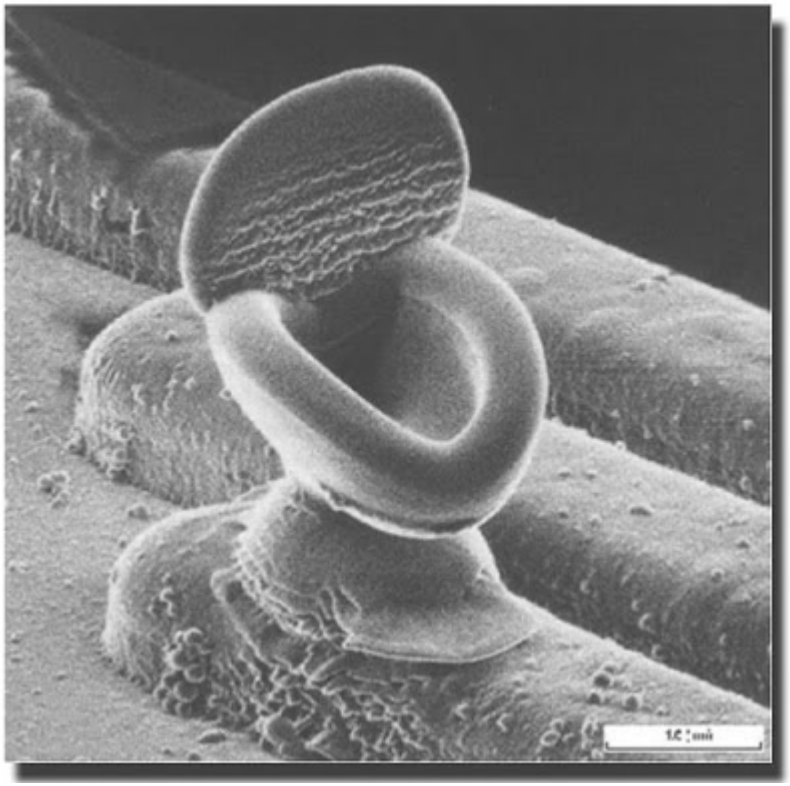
Extremely small patterns can be made, ~ 100 nanometers

Logic/memory device made via Lithography



physicsworld

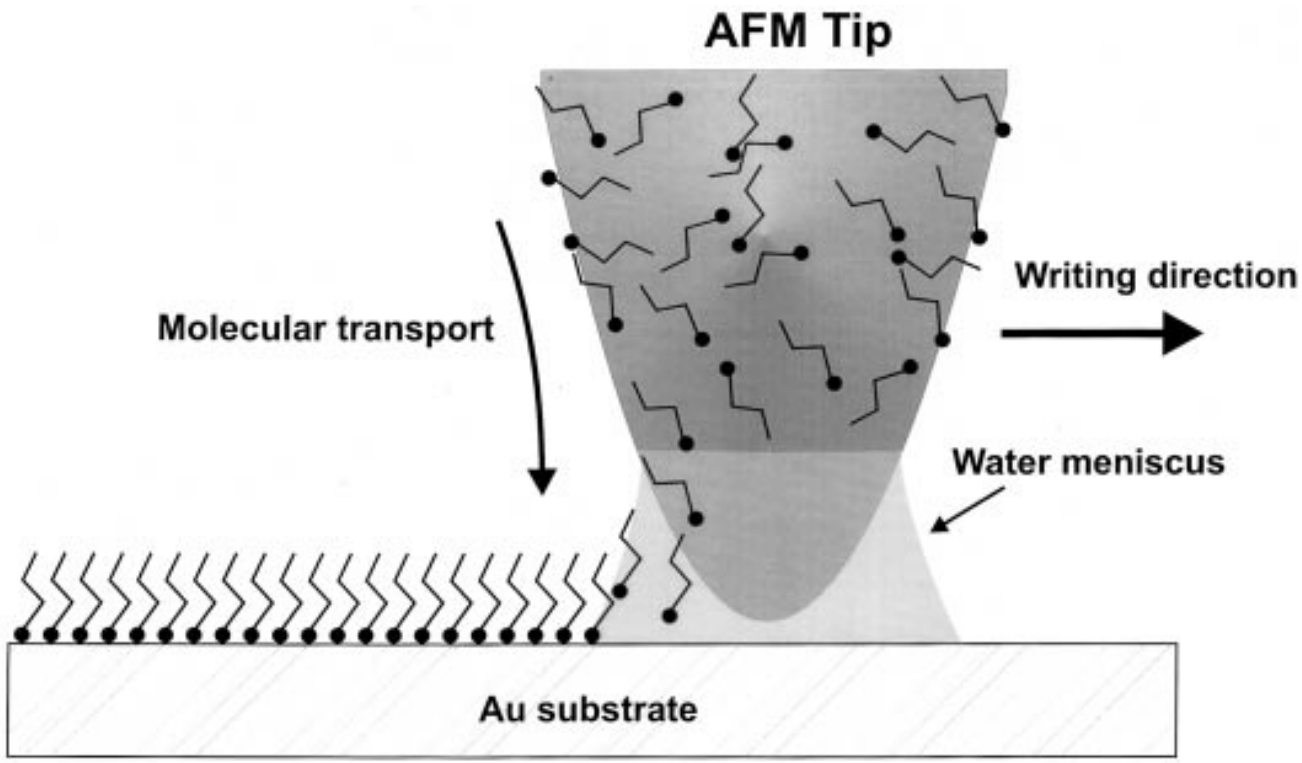
Another important device



Kaito, SII Nanotechnology Inc

“Bottom up” Example

Dip-Pen Nanolithography (DPN)

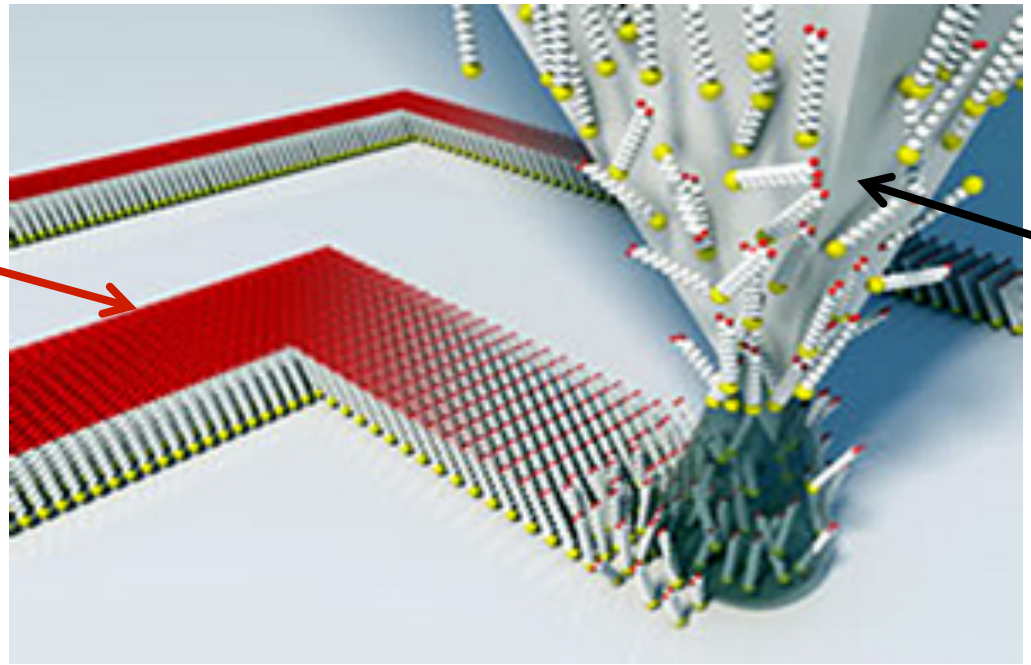


C A Mirkin et al.

Dip-Pen Nanolithography (DPN)

"Bottom up"

Surfactant molecules

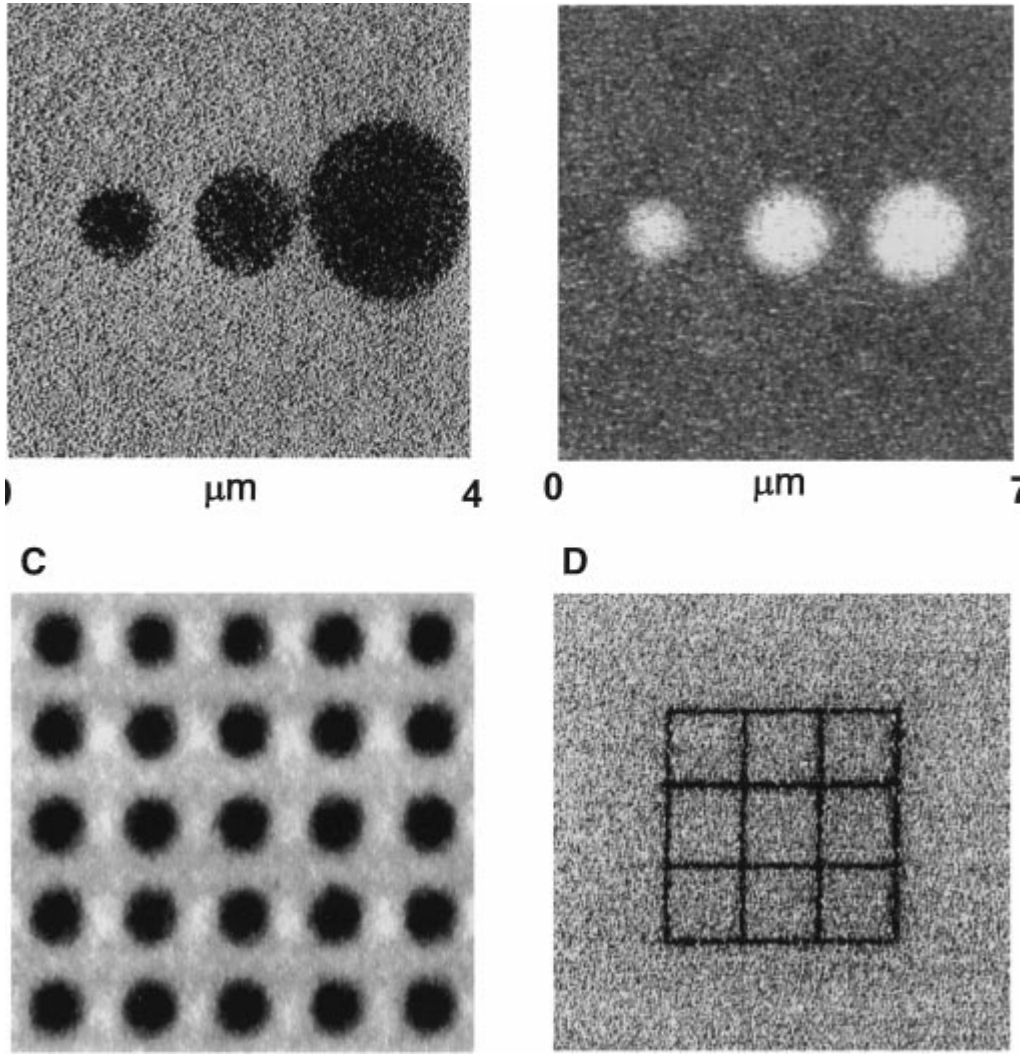


STM/AFM tip

Mirkin Nanoink

Resolution to ca. 30 nm

Dip-Pen Nanolithography (DPN)



Science 283 661 (1999)

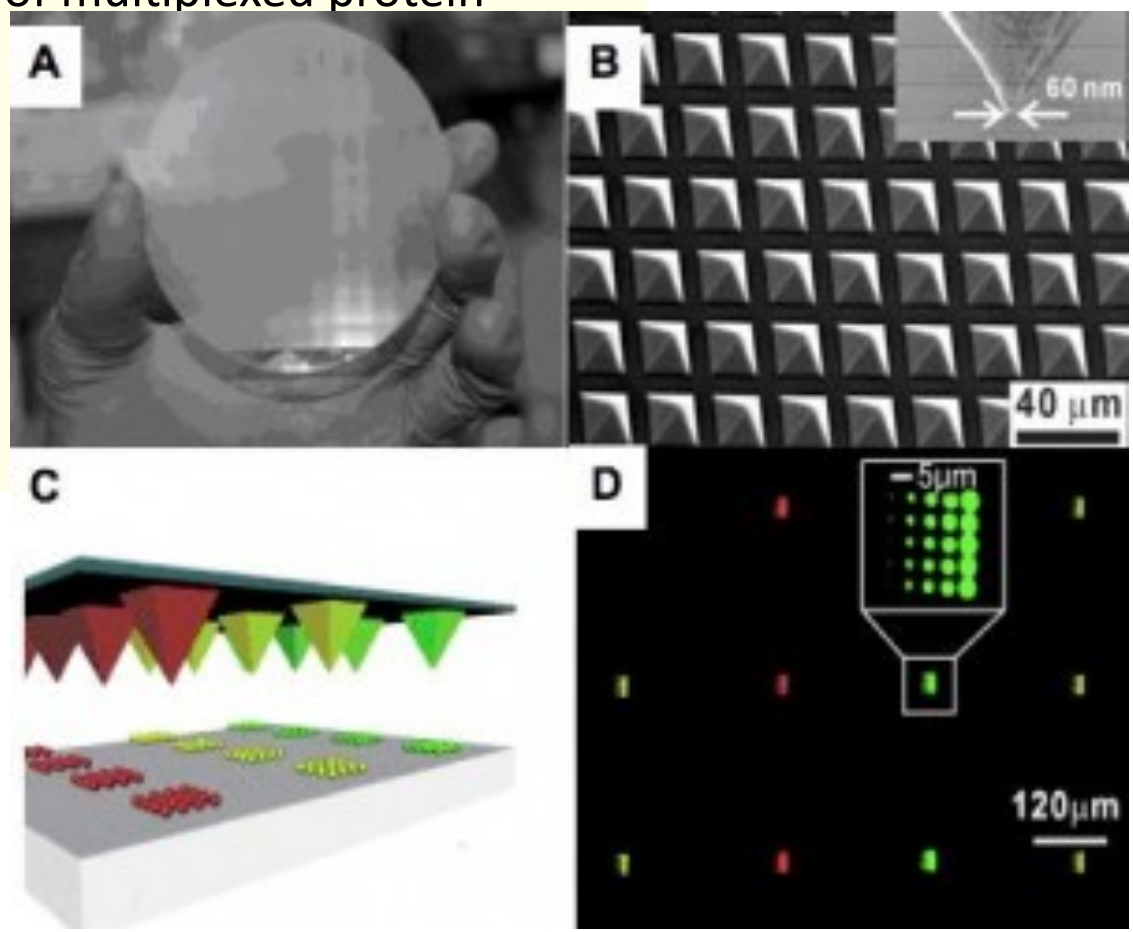
Multiplexing DPN

(A) Photograph of a 4-inch the Polymer-Pen Lithography (PPL) array with 11 million pens.

(B) A scanning electron micrograph image of the nanometer-scale pen tips within the array.

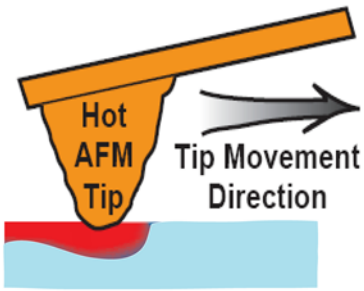
(C) A schematic representation of multiplexed protein printing by PPL.

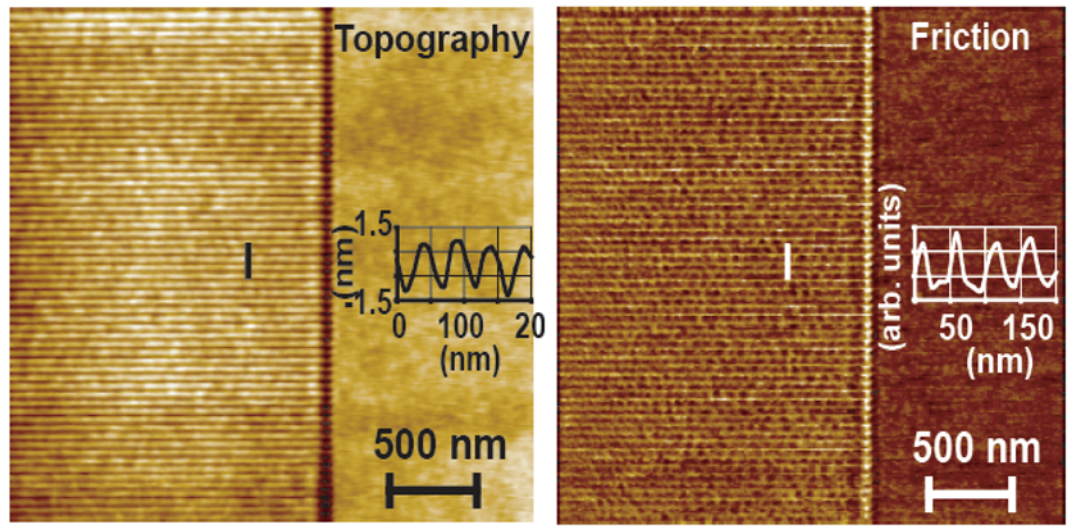
(D) A fluorescence optical micrograph image of the resultant multiplexed PPL patterns.



ThermoChemical Nanolithography (TCNL)

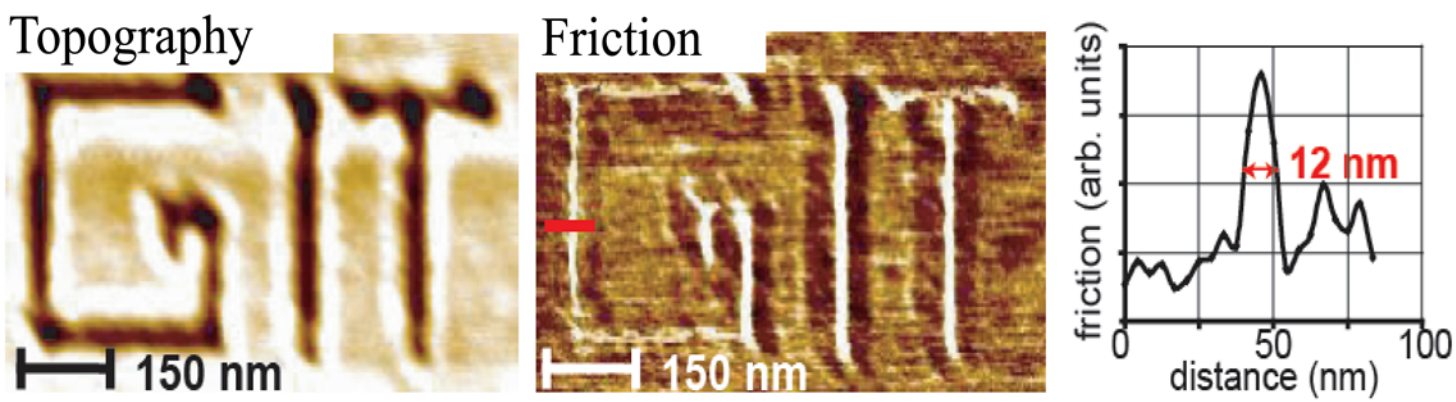
By locally heating a polymer with a hot AFM tip a chemical reaction is induced and nano-lines can be drawn.





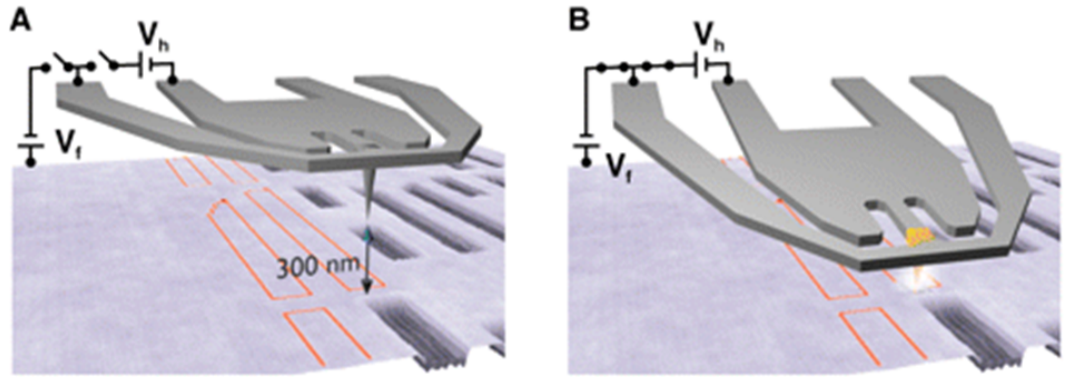
Fast writing speeds > 1 mm/s

Sub-15 nm feature size

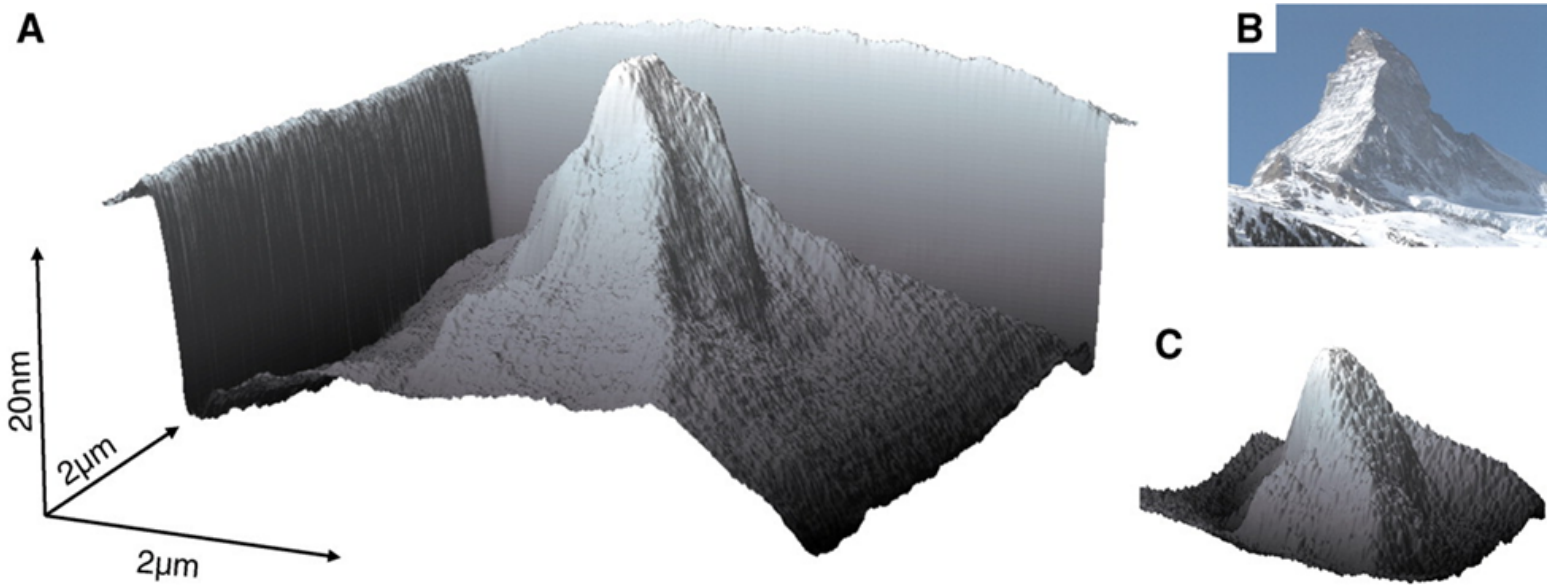


R. Szoszkiewicz, et al., Nano Letters, 2007

3D TCNL

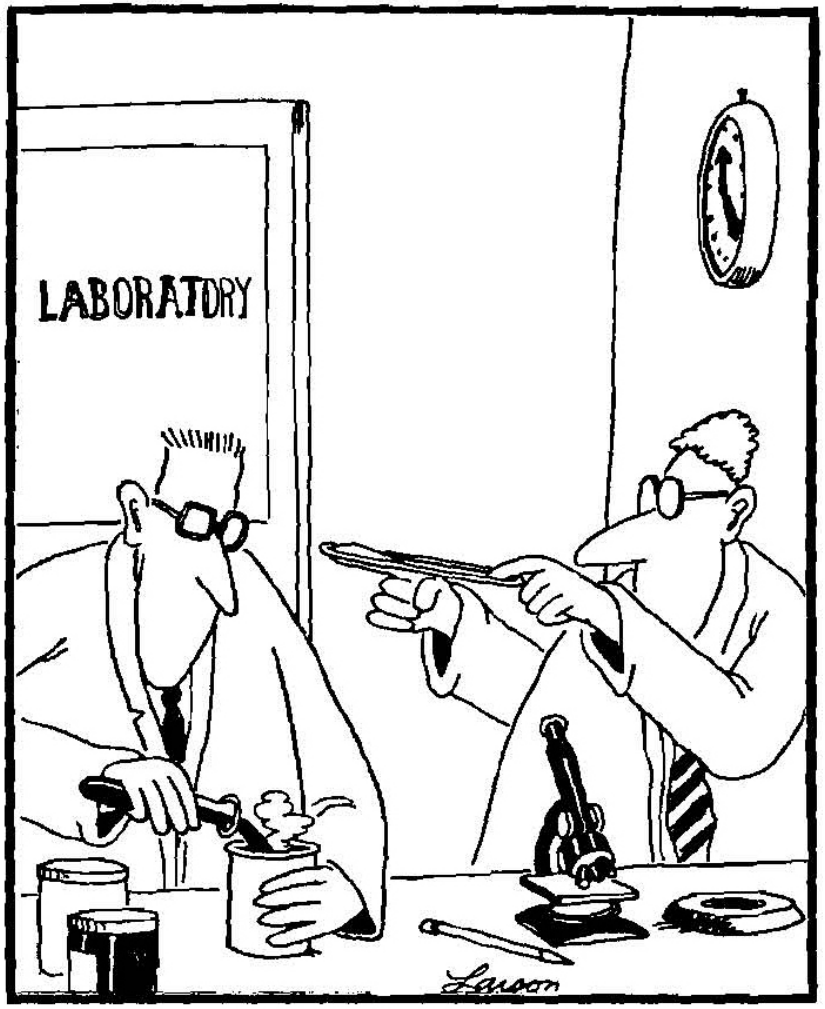


Tip has
x, y, z motion



D Pires et al., Science. 2010

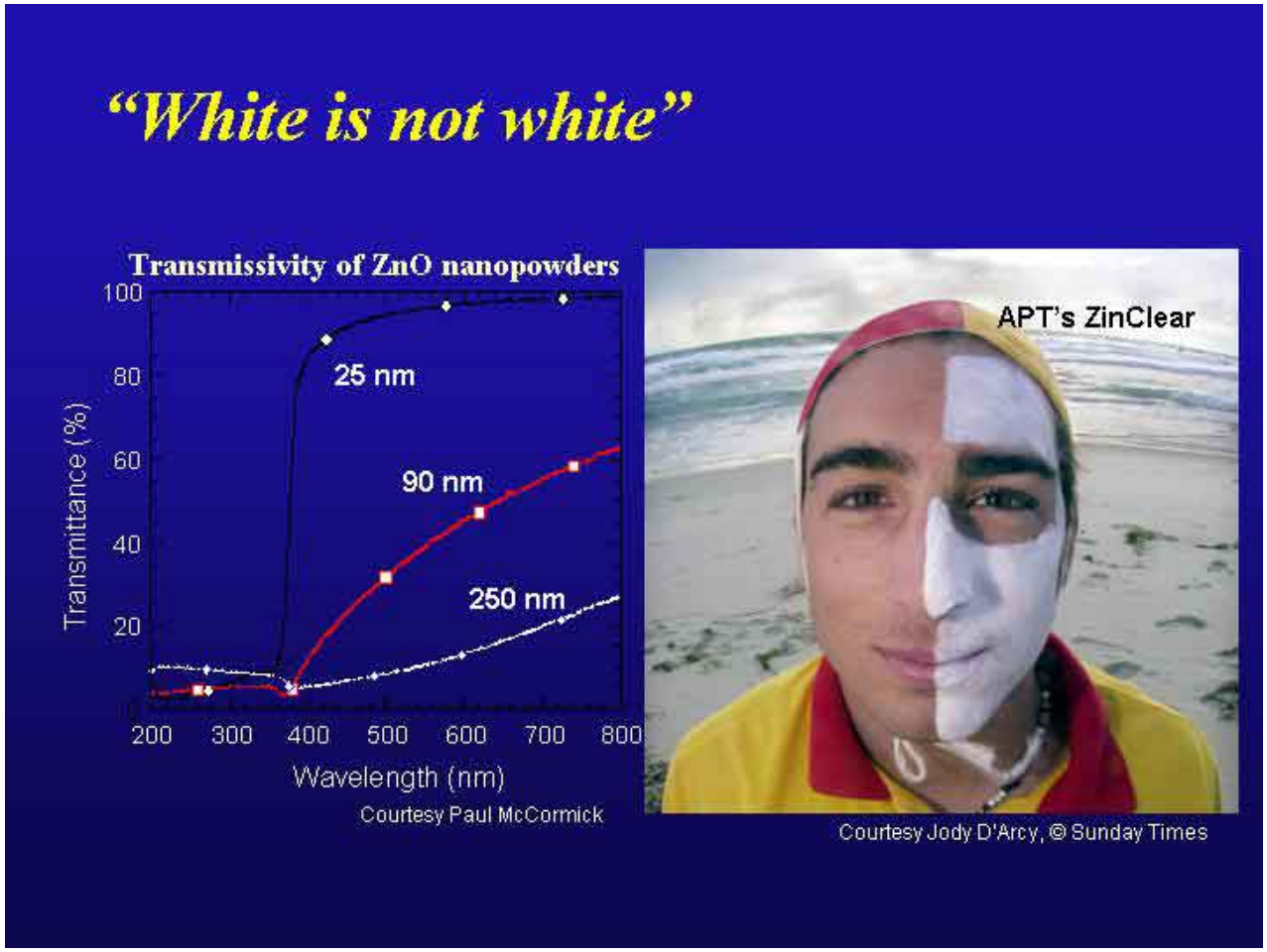
Clever things from the lab



Applications of Nanoparticles

(a small subset)

Invisible Sun Screen

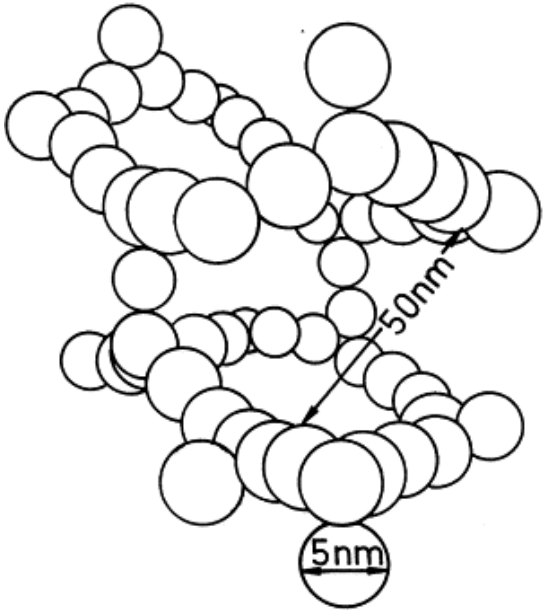


Scat ~ NV^2

~ $NV \cdot V$

Abs ~ NV

Aerogels



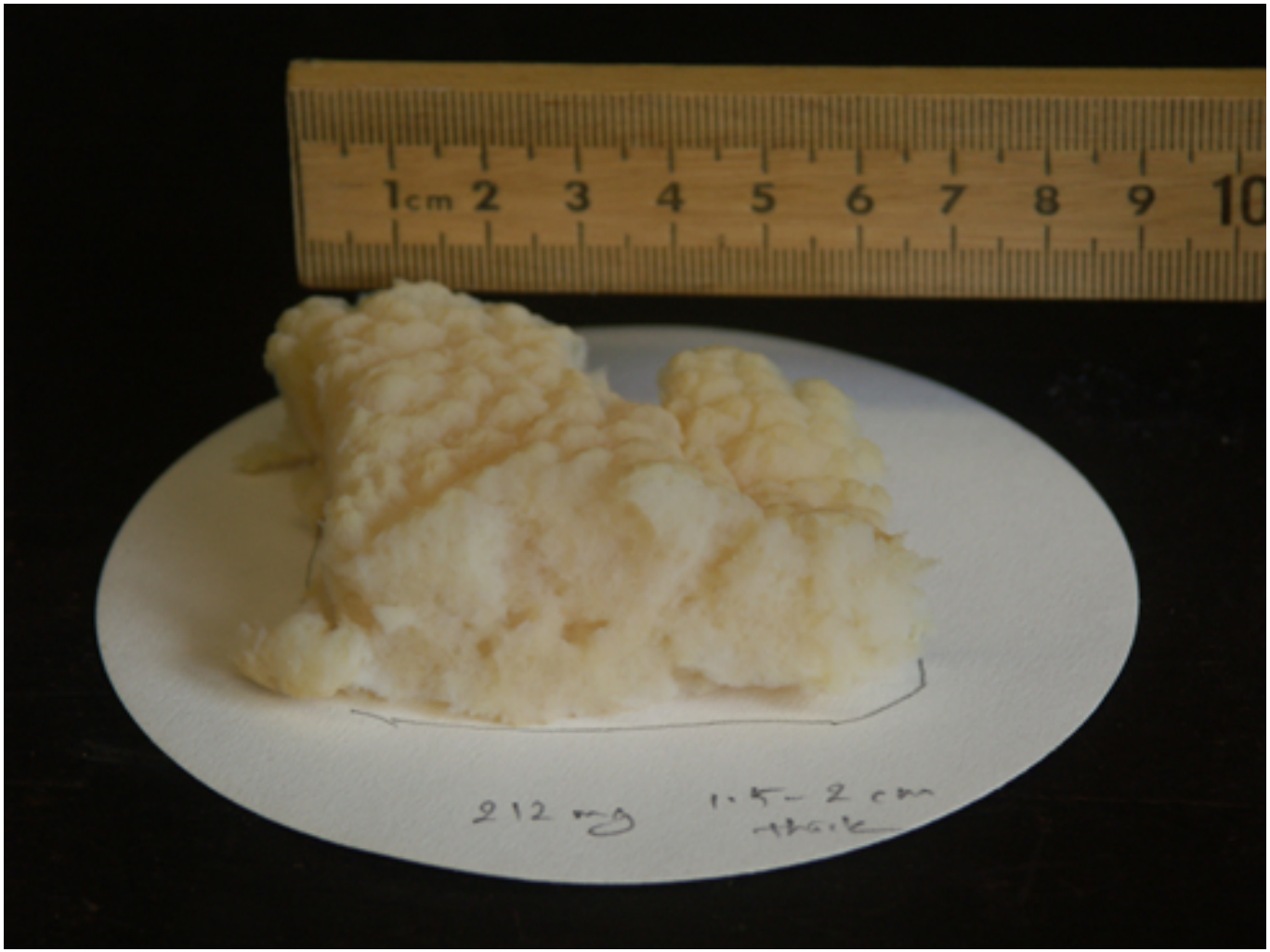
Liquid phase

$$Si(OCH_3)_4 + H_2O \longrightarrow SiO_2 \text{ particles}$$

Particles randomly aggregate, gel forms.
Density ~ 0.01 g/cc,
surface area ~ 500 m^2/g

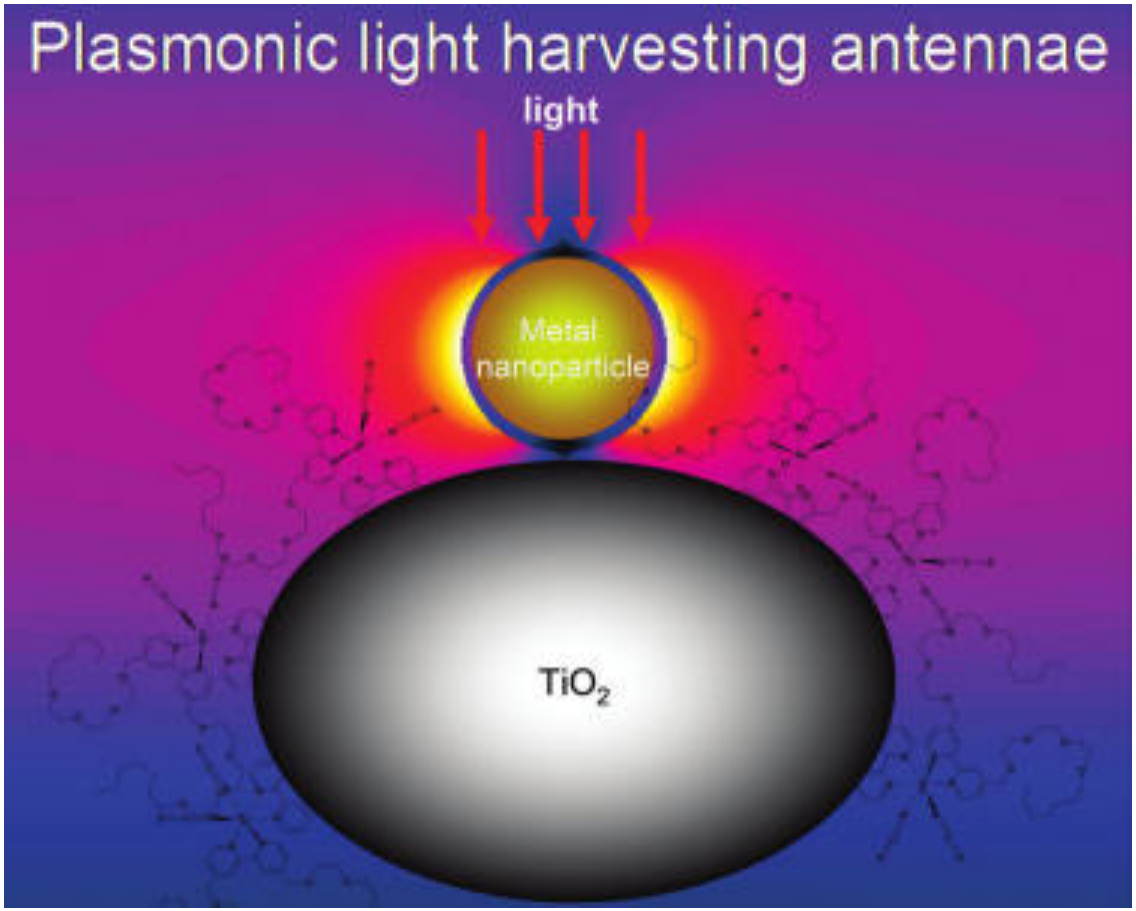
Aerosol Gels

Gas Phase $SiH_4 + O_2 \longrightarrow SiO_2$

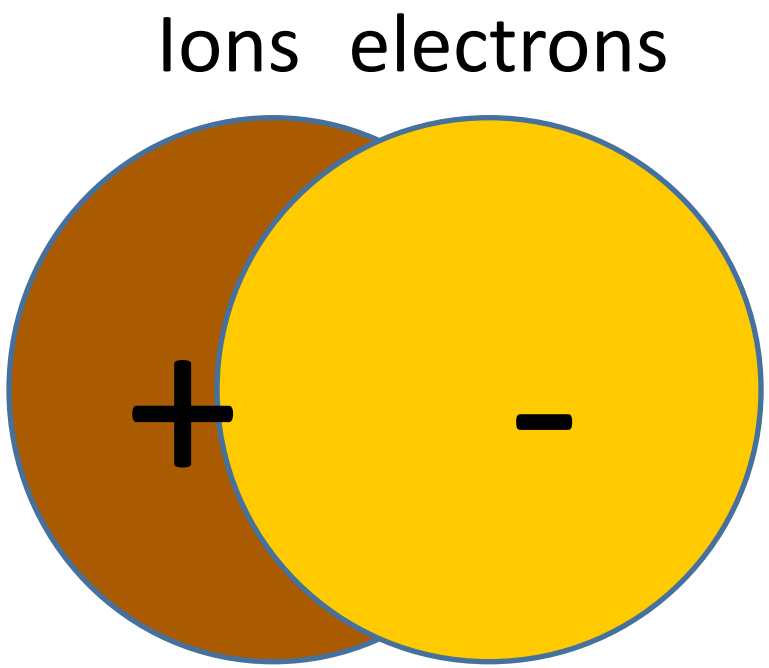


Photocatalysis

H_2O to H_2 and O_2 with sunlight



Plasmon resonance

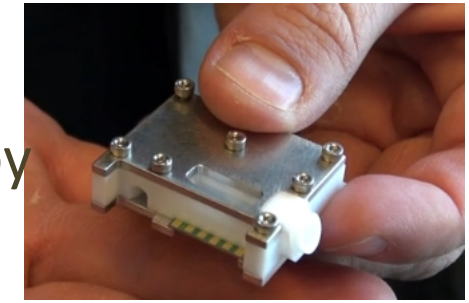


Puppies!

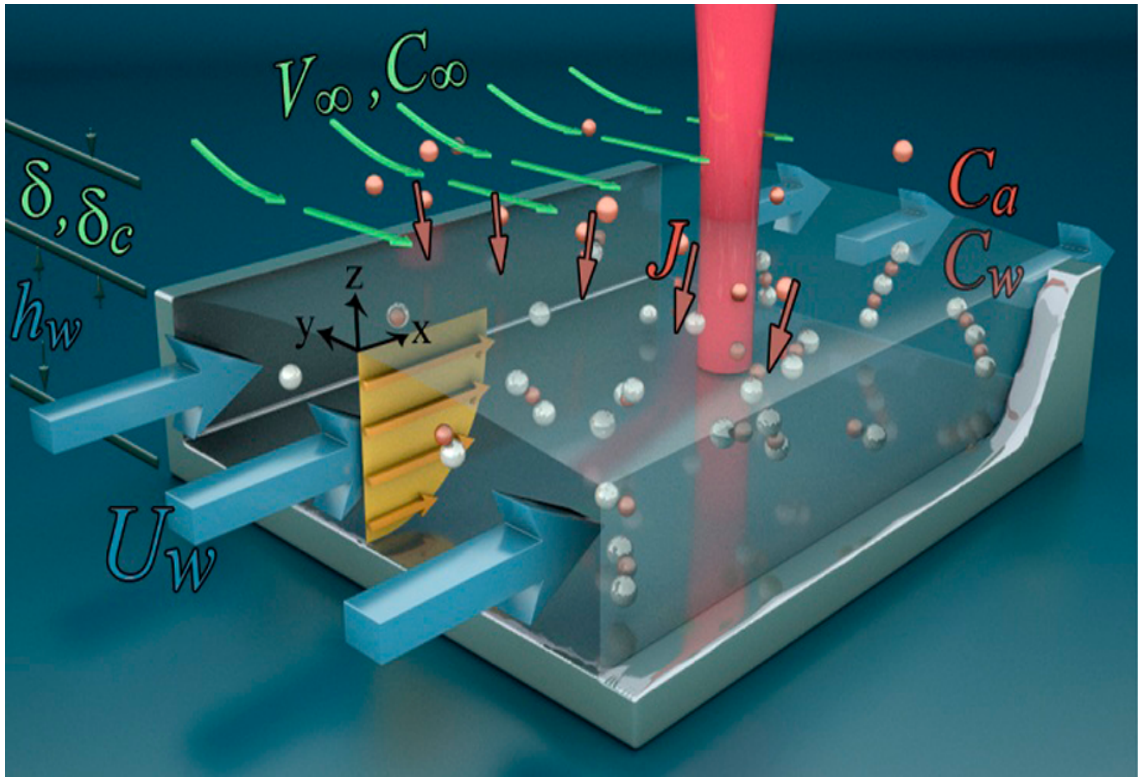
With noses!


05.13.2012 15:40

Artificial Dog Nose

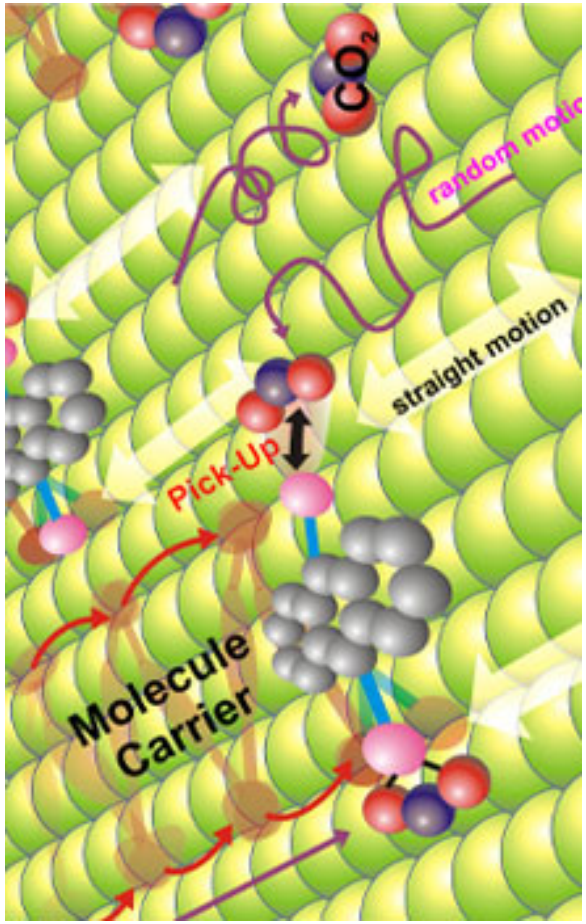


Nanoparticles enhance light for spectroscopy
Surface Enhanced Raman Spectroscopy
SERS



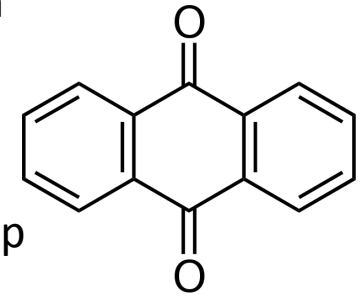
The aqueous microfluidic phase flows from left
to right (blue arrows). The gas phase flows from back to front (green arrows). Analyte molecules (red spheres) diffuse from the gas into the liquid (red arrows). Nanoparticles (white spheres) in the aqueous phase adsorb analyte molecules where 658 nm laser light (red vertical beam) excites SERS.

Piorek et al. Anal. Chem. 2012, 84, 9700–9705



Nanotruck

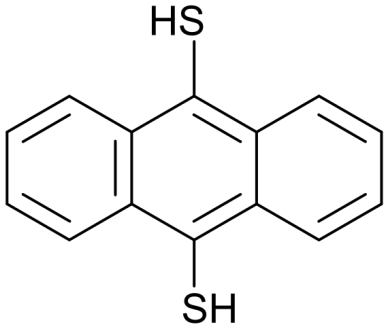
With STM nudging anthraquinone molecules move in a straight line on a copper surface, while carbon dioxide moves randomly. But when the two molecules get close together, the anthraquinone picks up the carbon dioxide and keeps walking.



anthraquinone

Nanowalker

9,10-Dithioanthracene has taken as many as 10,000 spontaneous steps on a copper surface.
The thiol groups (SH) are its feet.

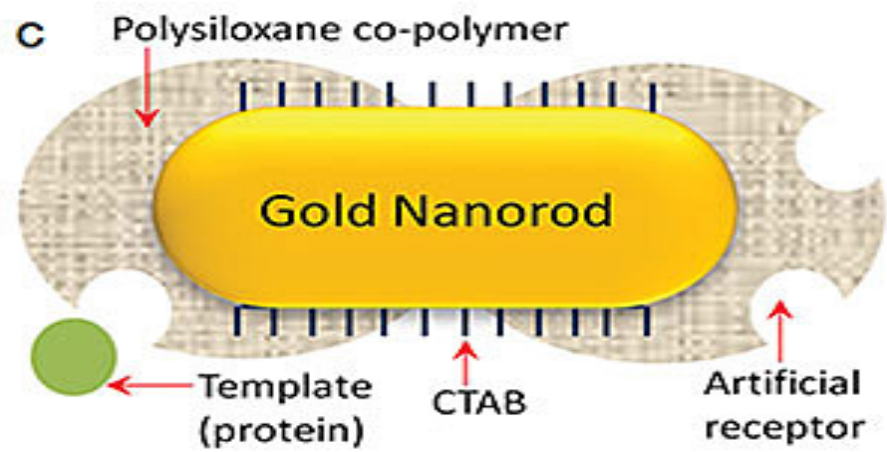


9,10-Dithioanthracene

Ludwig Bartels, University of California, Riverside

Plasmonic biosensor/biomolecular imprinting

1. Attach target proteins and polymer layer around the nanorods.
2. Then remove target proteins to leave cavities, which act as artificial antibodies.

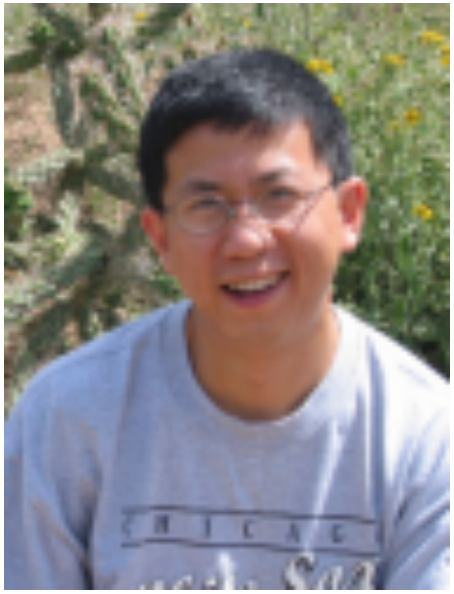


When exposed to a substance, such as urine, that contains the target protein, those proteins settle into the cavities, and the nanorod changes color.

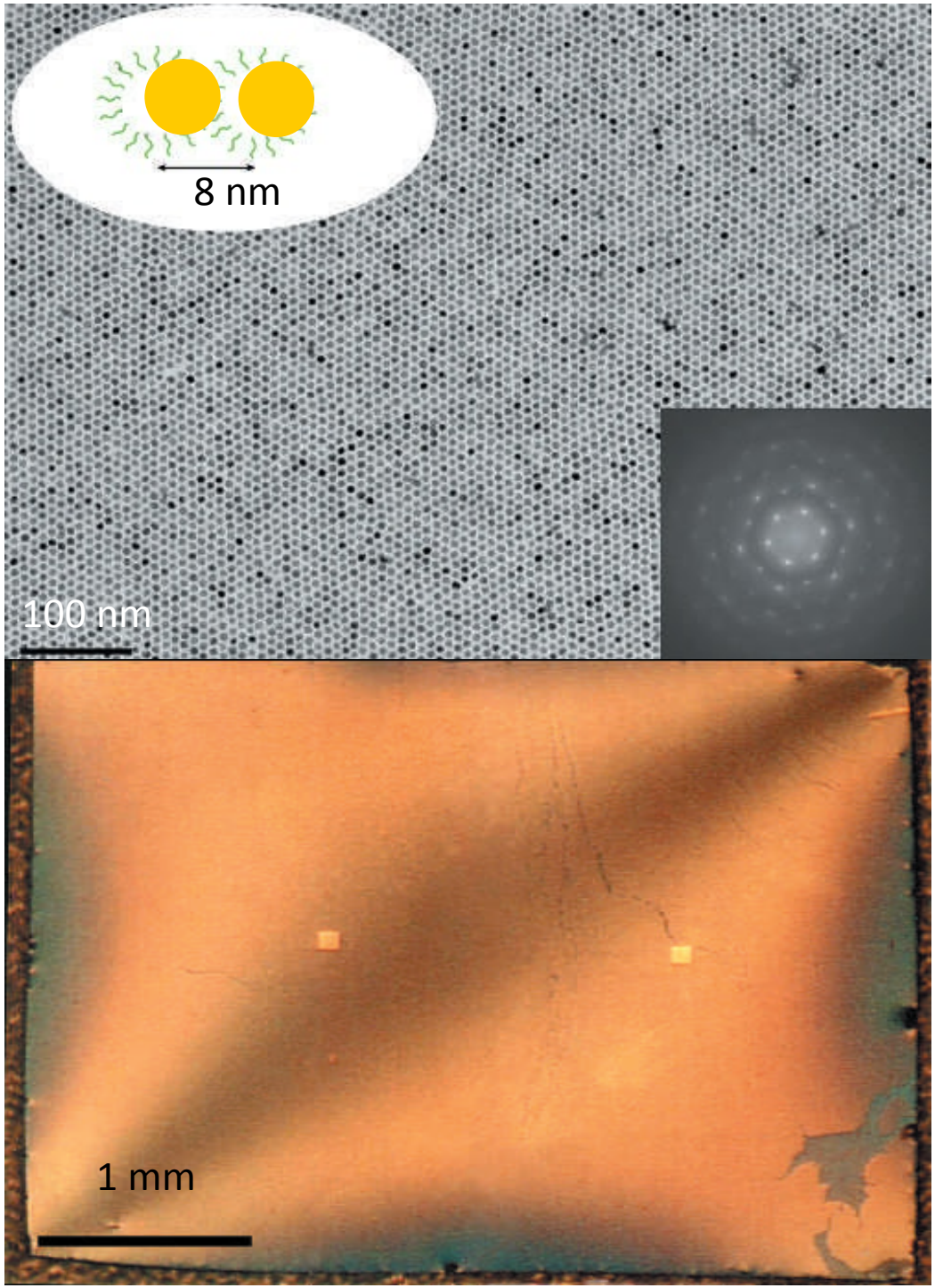
Washington University School of Medicine

Two dimensional Superlattice Membranes

NATURE MATERIALS **5** 265 (2006)



Xiao-min Lin



Ultra-Fast Synthesis

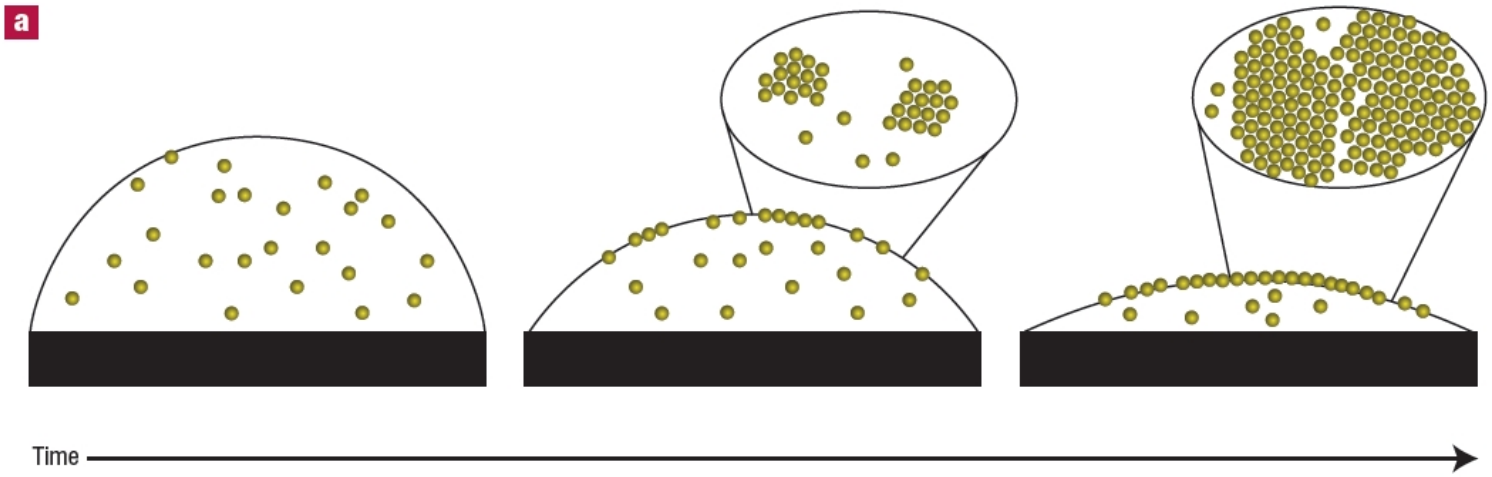
&

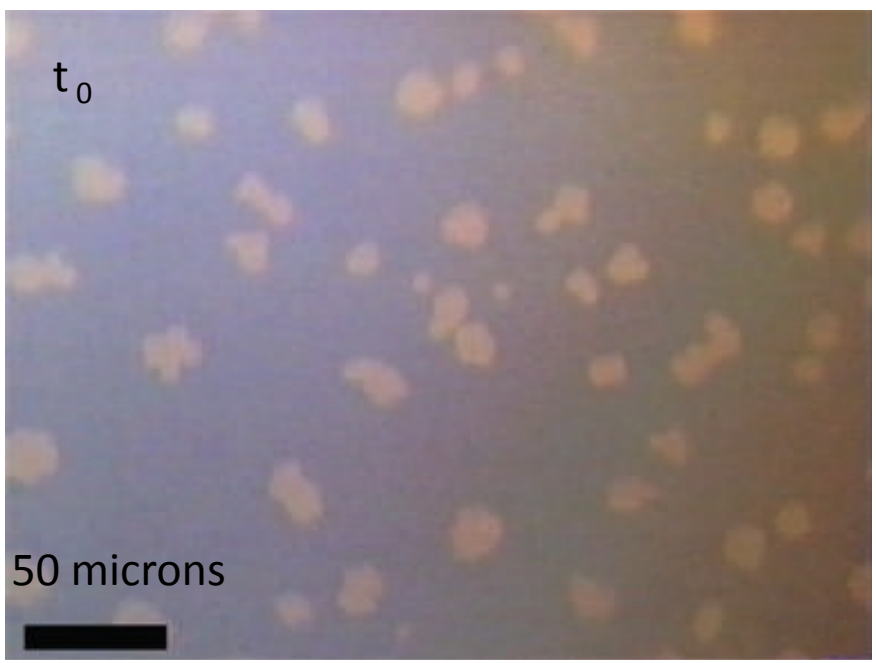
Ultra-Simple 2D Self-Assembly

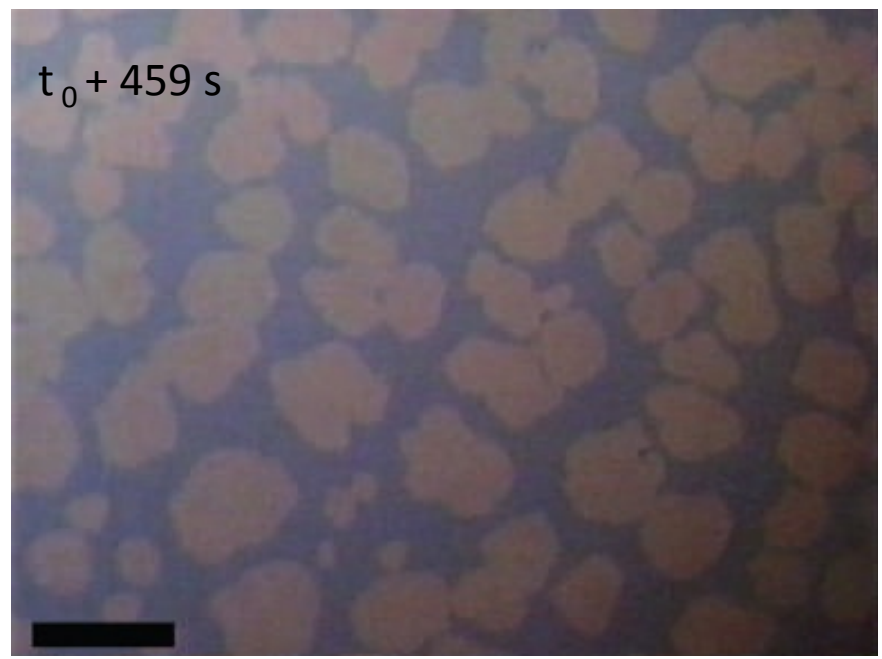
of

Monolayer-Protected Gold Nanoparticles

Films grow during evaporation

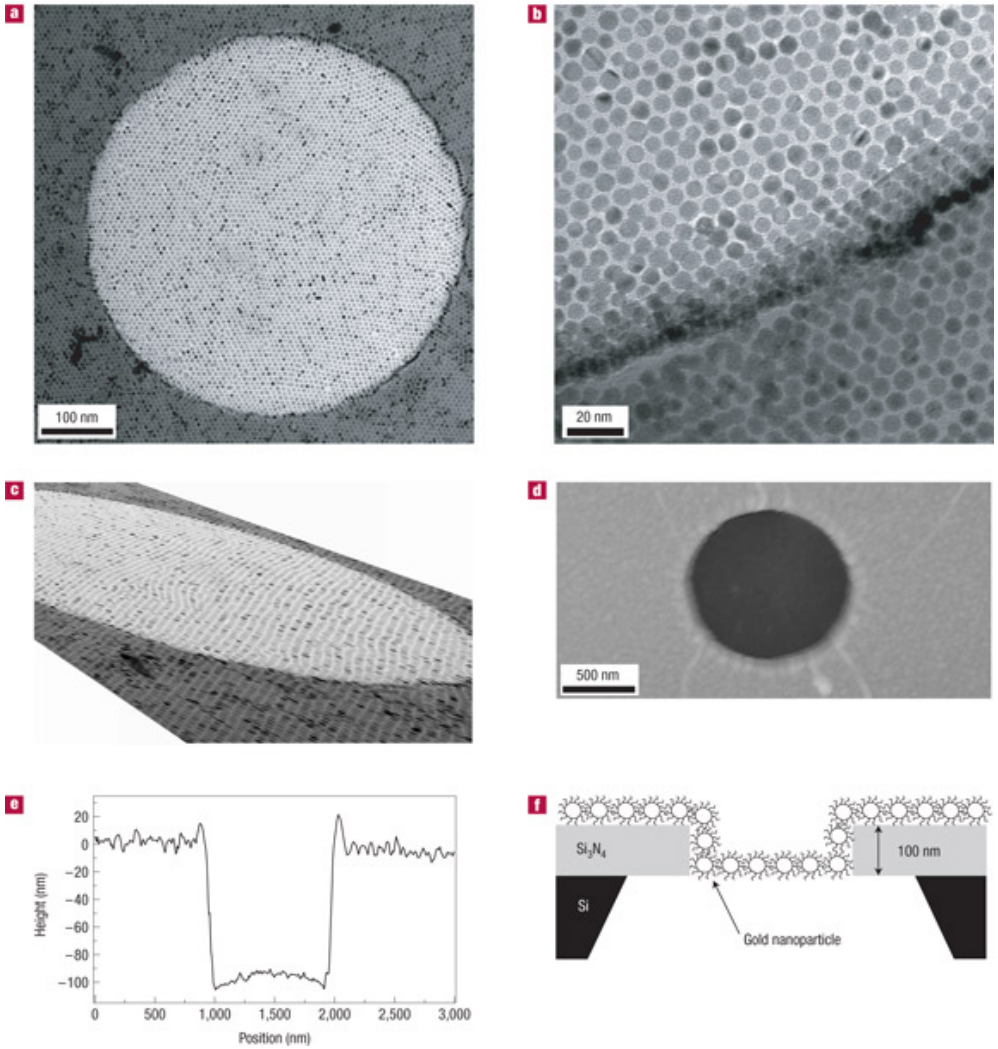


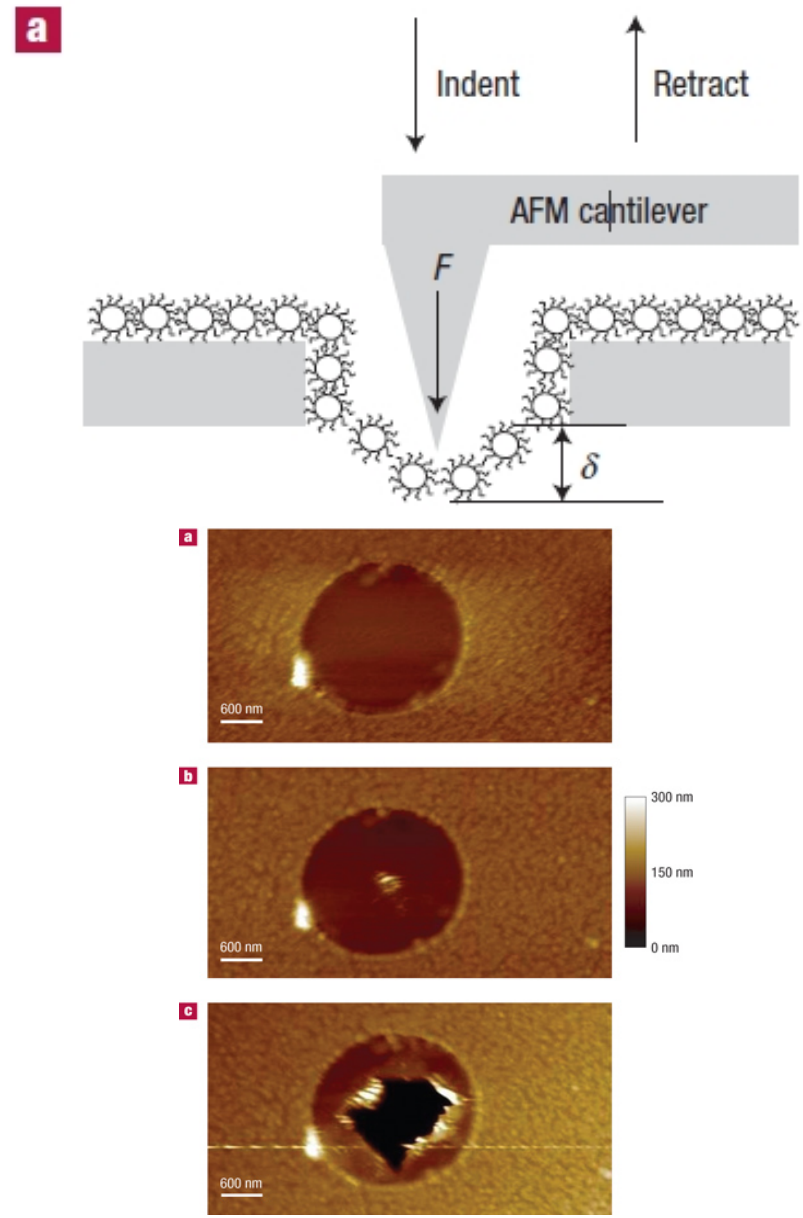




NATURE MATERIALS **5** 265 (2006)

Tough, elastic films like drum heads





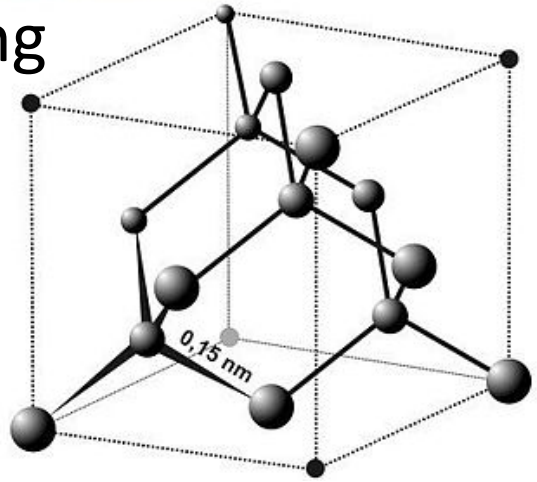
nature materials 6, 656 (2007)

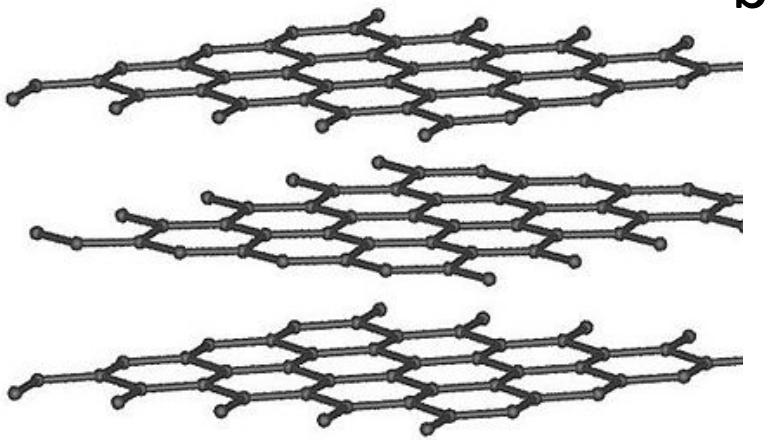

SEBRING
TOURING
KANSAS
OCT
11
74AQL
WILDCATS

carbon

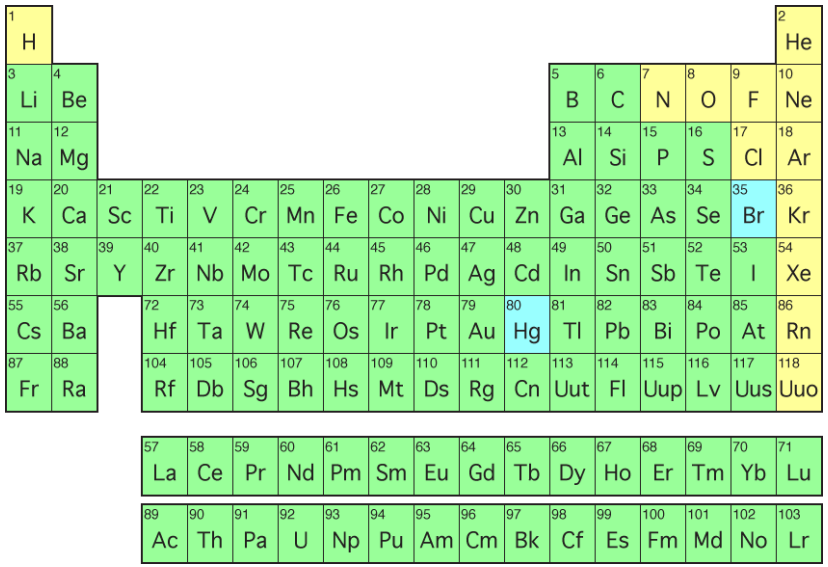
The allotropes of carbon
Diamond and Graphite
Before 1986

sp^3 bonding





sp^2 bonding



Carbon

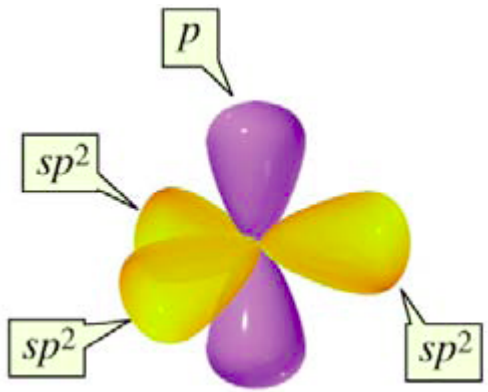
4 valence electrons

2 s-orbitals, 2 p-orbitals.

These can “hybridize” to

3 electrons in sp^2 hybrid, or

all 4 electrons in sp^3 hybrid



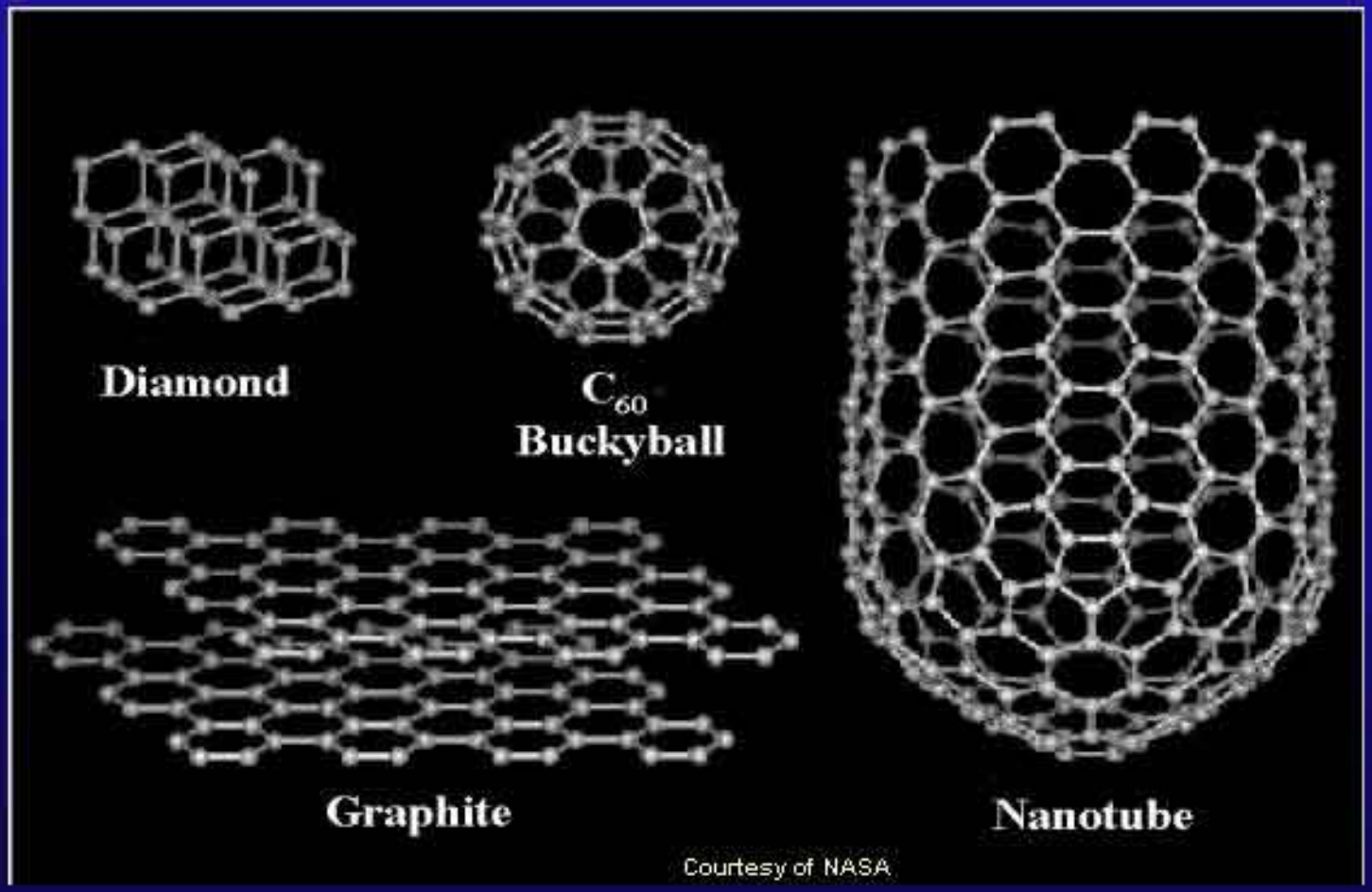
“extra” electron in the p-orbital

All 4 electrons are busy

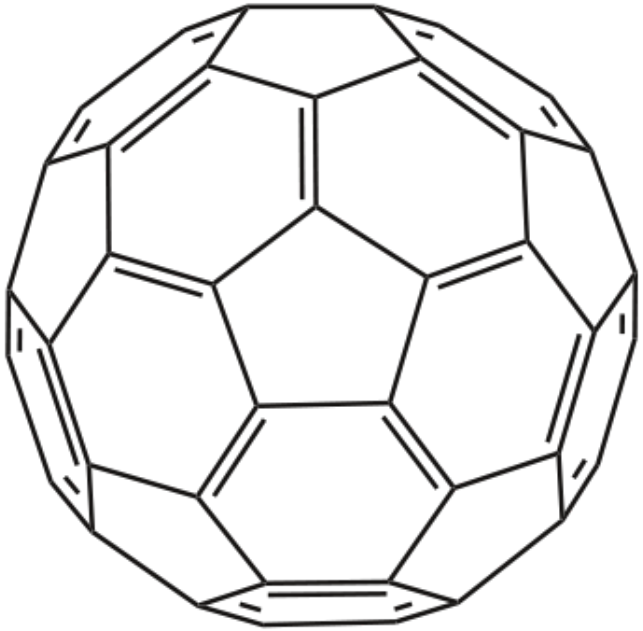
Graphite is a **black** conductor

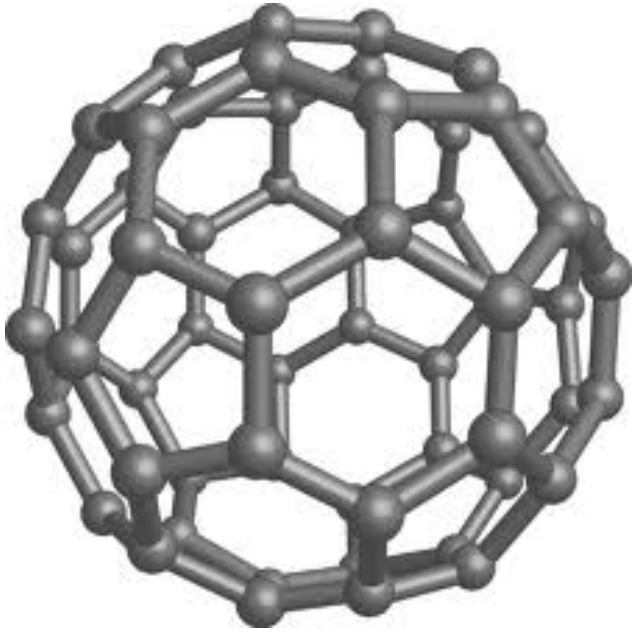
Diamond is a clear insulator

New forms of carbon



C60, Buckminsterfullerene

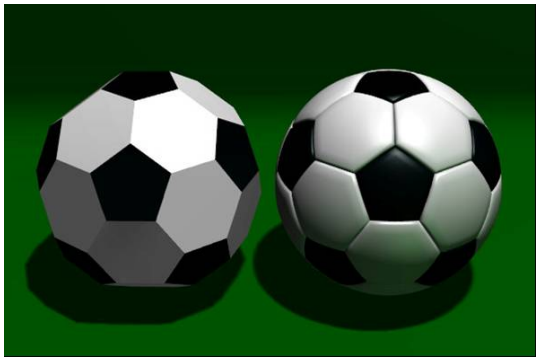




Robert F. Curl Jr.

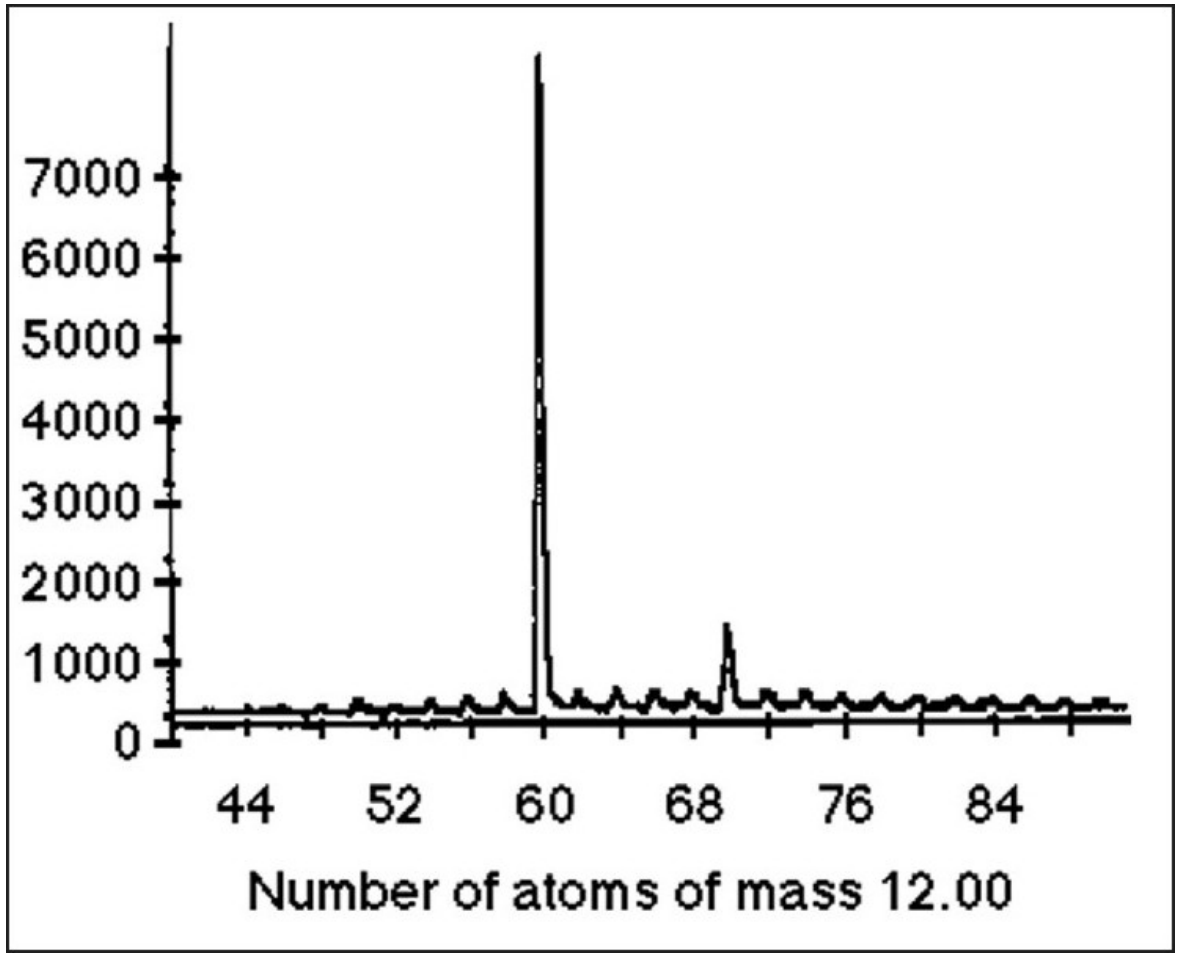
Sir Harold W. Kroto

Richard E. Smalley



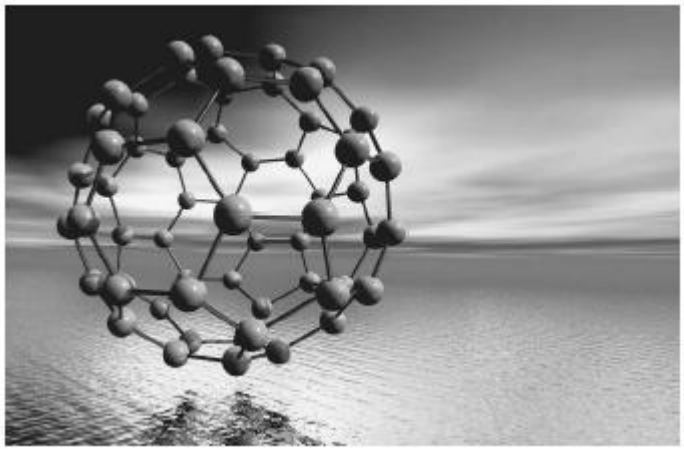
Source: Wikipedia

Synthesis via laser ablation of graphite under low pressure He.
The discovery mass spec



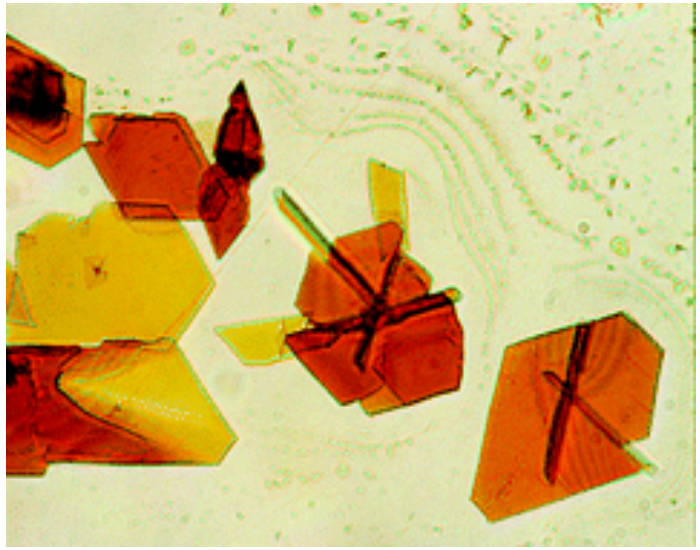
Krätschmer/Huffman Process

Gram quantities via the electric arc evaporation of graphite in a helium atmosphere



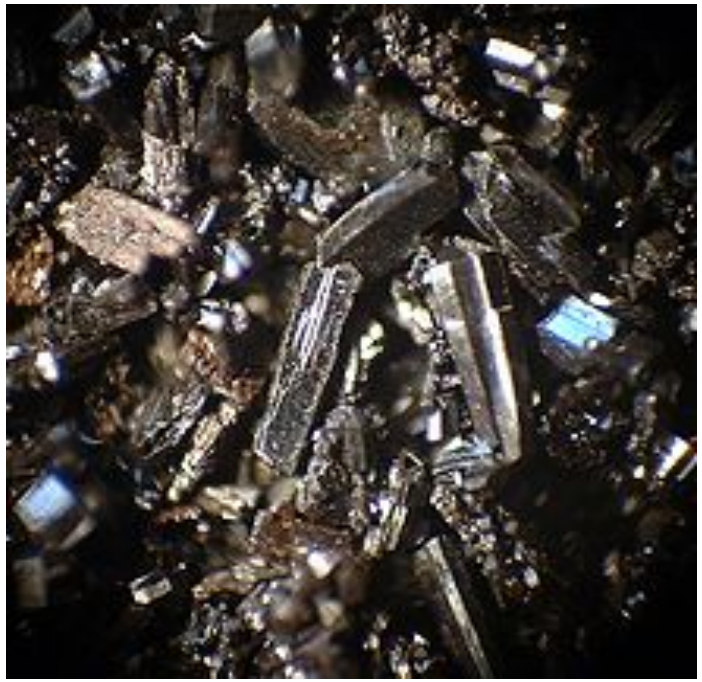
C60 developments:

- doped solid can be made superconducting,
- large nonlinear optical effects
- room temperature conversion via non-hydrostatic compression of C60 into diamond powder.



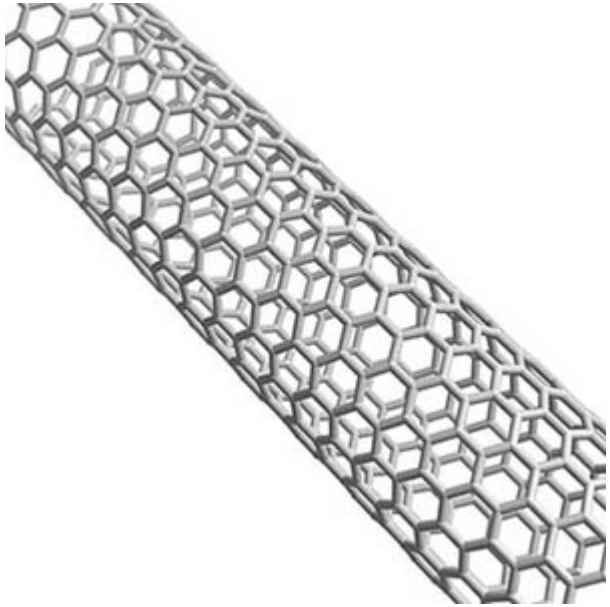
Each of these discoveries could lead to entire fields of commercial applications in the future.

C60 solution (in toluene) and solid

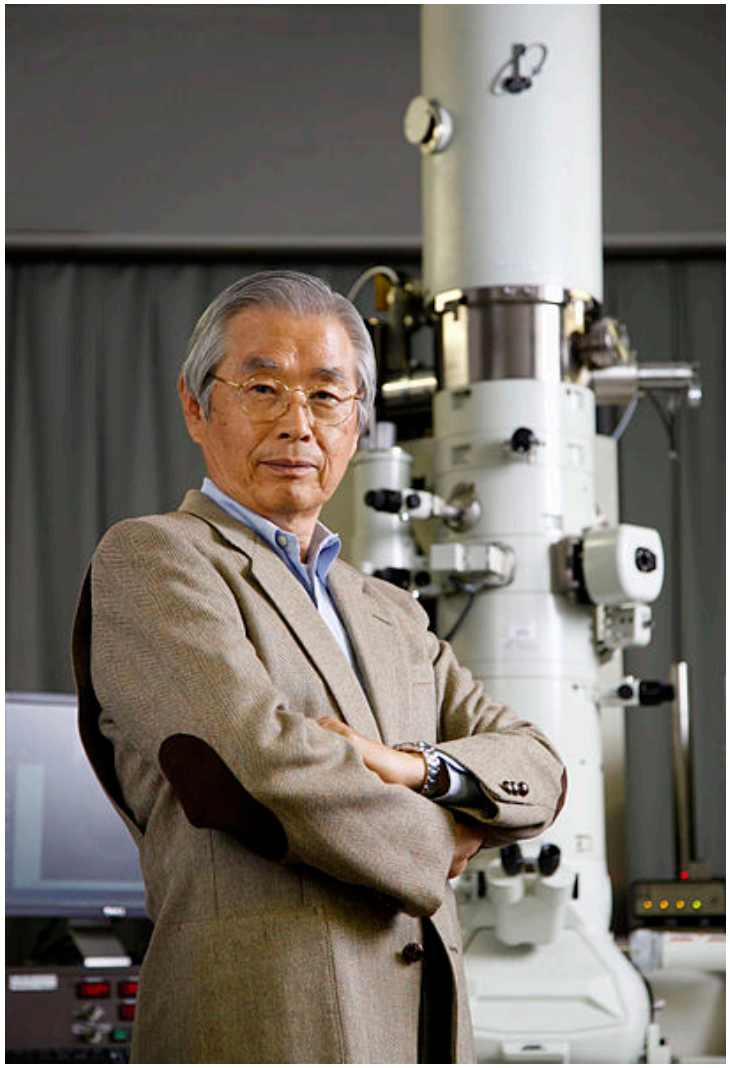


Source: Wikipedia

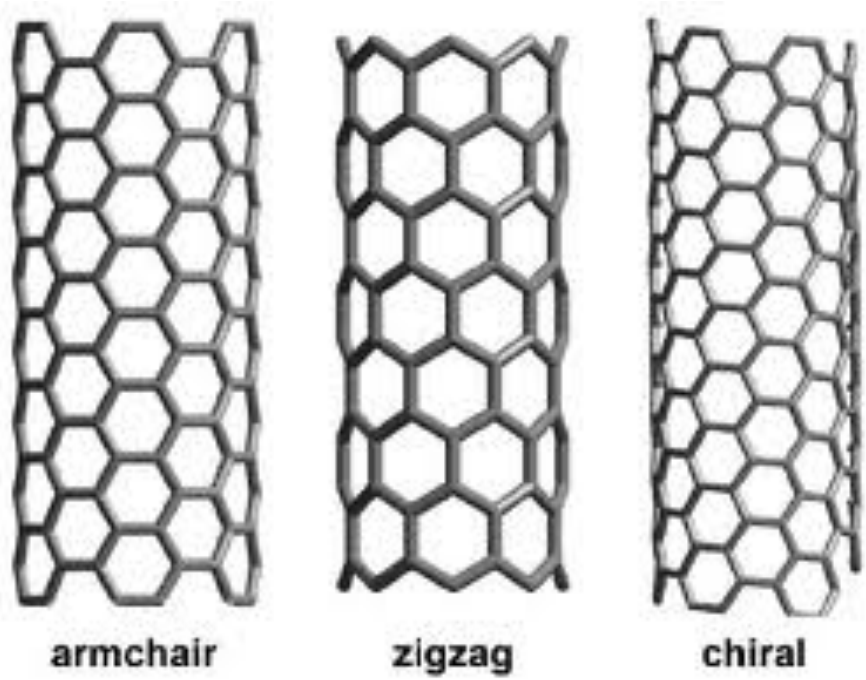
Carbon nanotubes (CNT)



Sumio Iijima, 1991

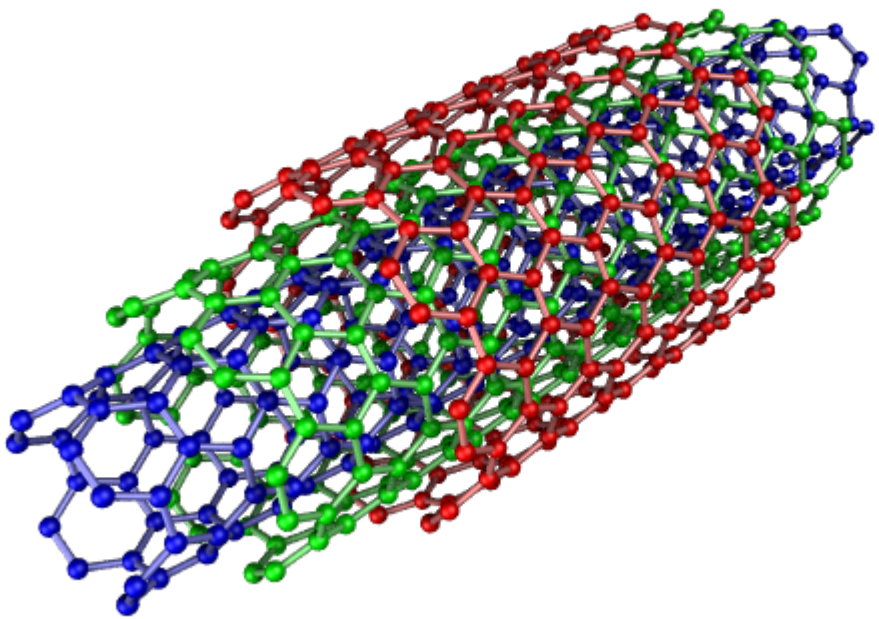


Single-walled nanotubes (SWNT) properties controlled by helicity



From metallic to semiconductor of various band gaps

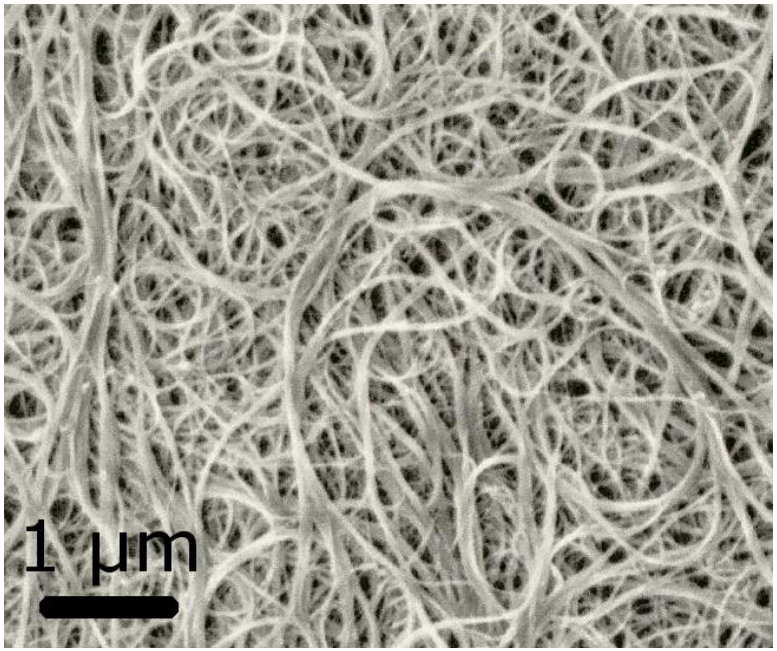
Multi-walled nanotubes (MWNT)

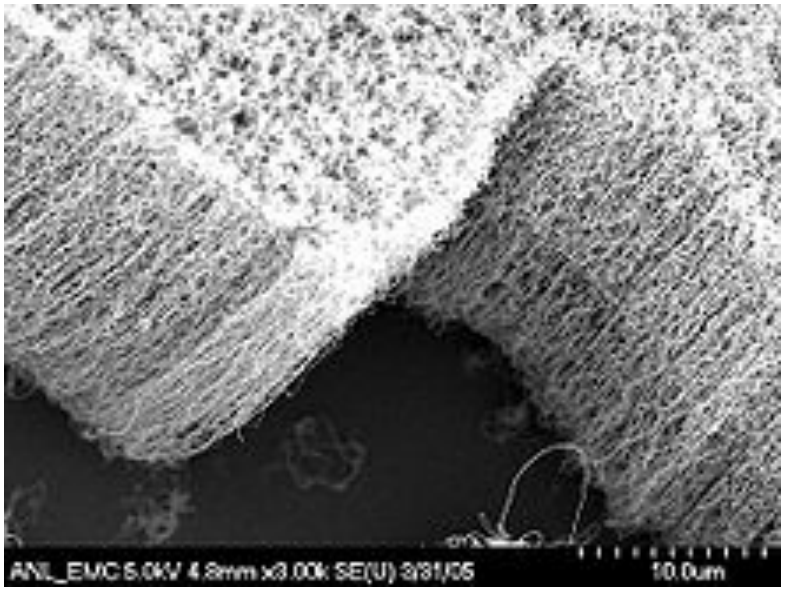


Typically metallic

Wikipedia

Multi-walled nanotubes (MWNT)





CNT Synthesis

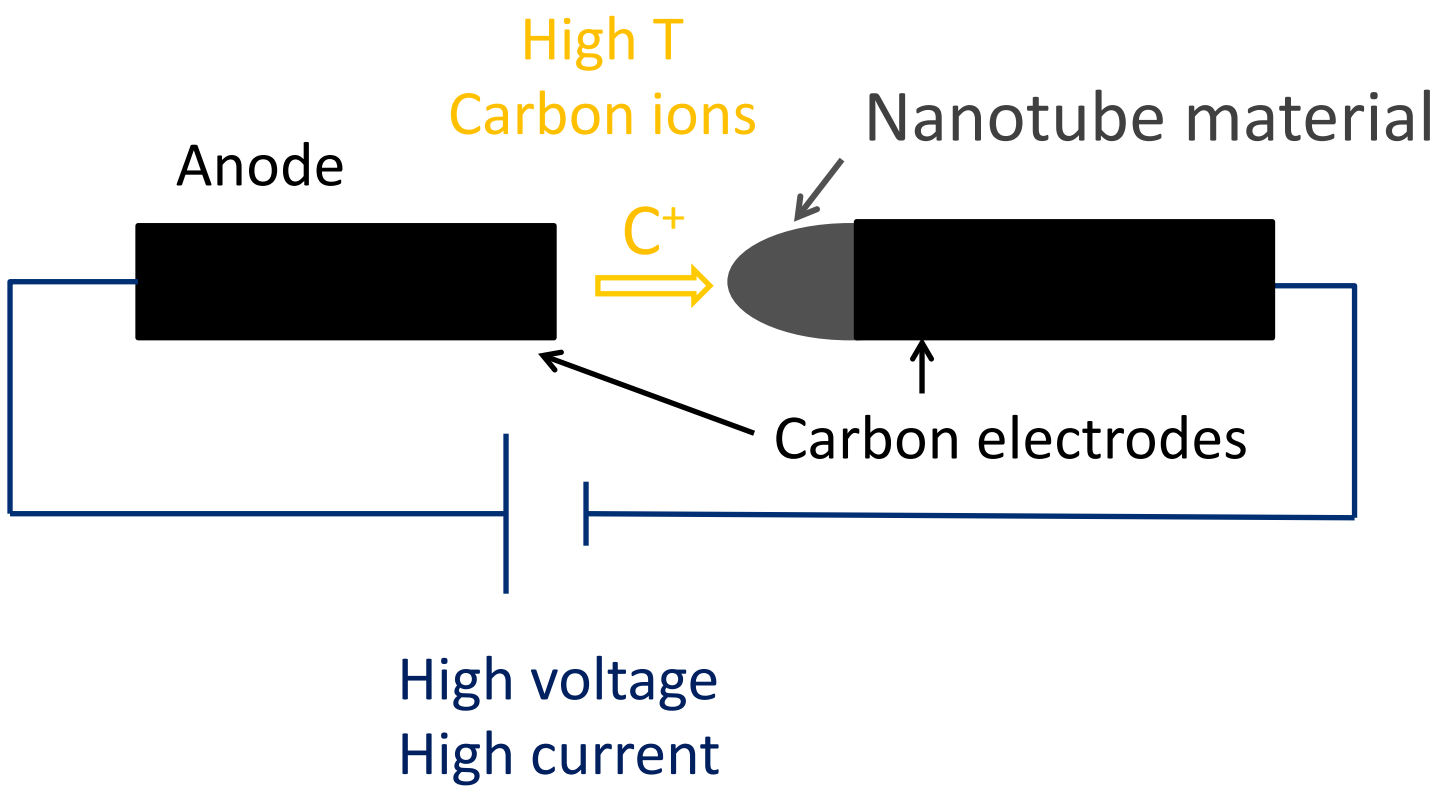
Arc discharge
Laser ablation
Chemical vapor
depostion (CVD)

All very high T.

CVD reactor to make
Carbon nanotubes

wikipedia

Arc Discharge Method



CNT Remarkable Properties

Variable band gap, it can be an insulator, semiconductor or a metal.

Tensile strength 10 to 100 times and elastic modulus 5 to 10 times that of steel at 1/5 the weight.

Harder than diamond, better thermal conductivity.

Black! Good absorber of electromagnetic radiation.

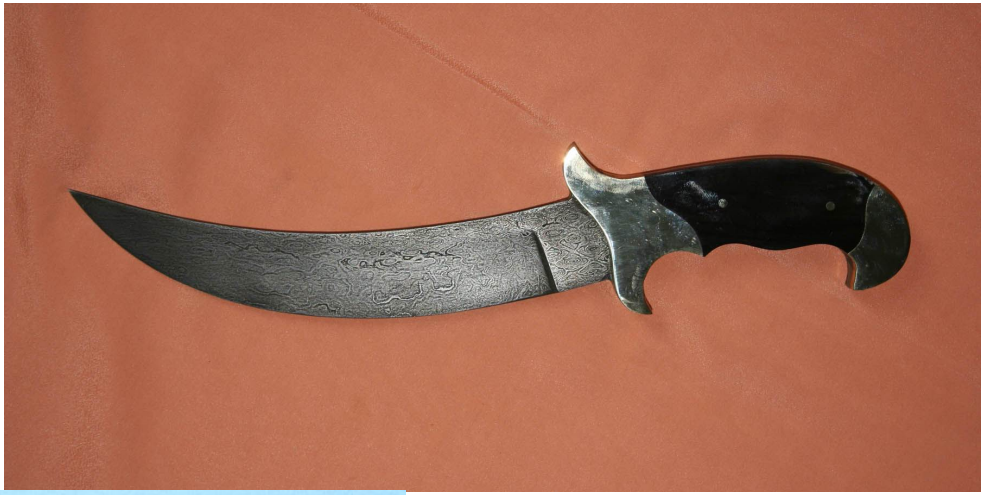
Airless bicycle tire

Britek tire and rubber

Stealth

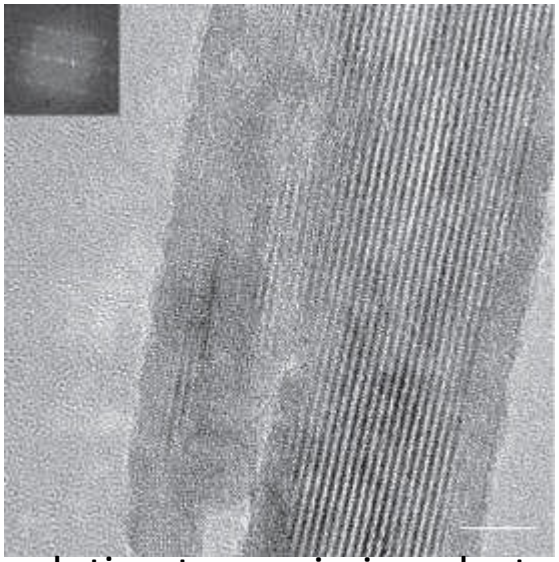
CNT coatings totally absorb
and do not scatter any electromagnetic radiation
e.g. light and radar

Damascus Steel



Detail of the “damask”

tomastomas180.worldpress.com



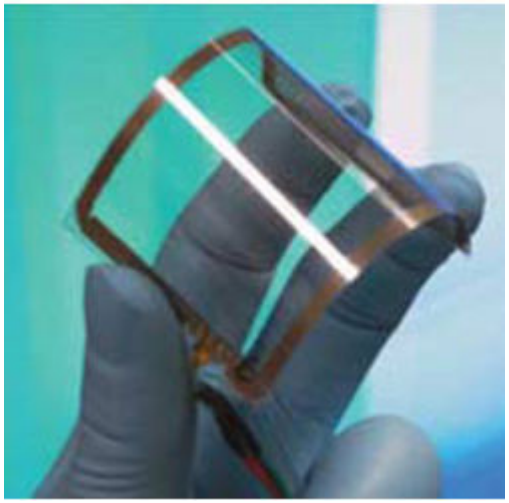
High-resolution transmission electron microscopy image of carbon nanotubes in a genuine Damascus sabre after dissolution in hydrochloric acid. Scale bar 5 nm.

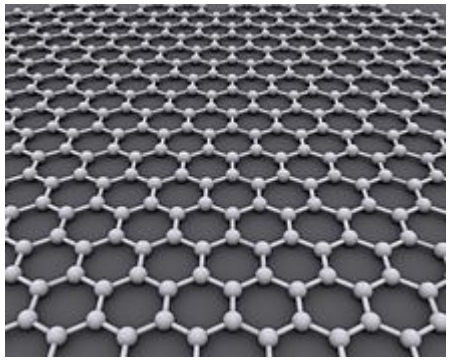
NATURE|Vol 444|16 November 2006

Graphene. A single layer of graphite

Geim and Novoselov, 2004

Nobel Prize 2010.



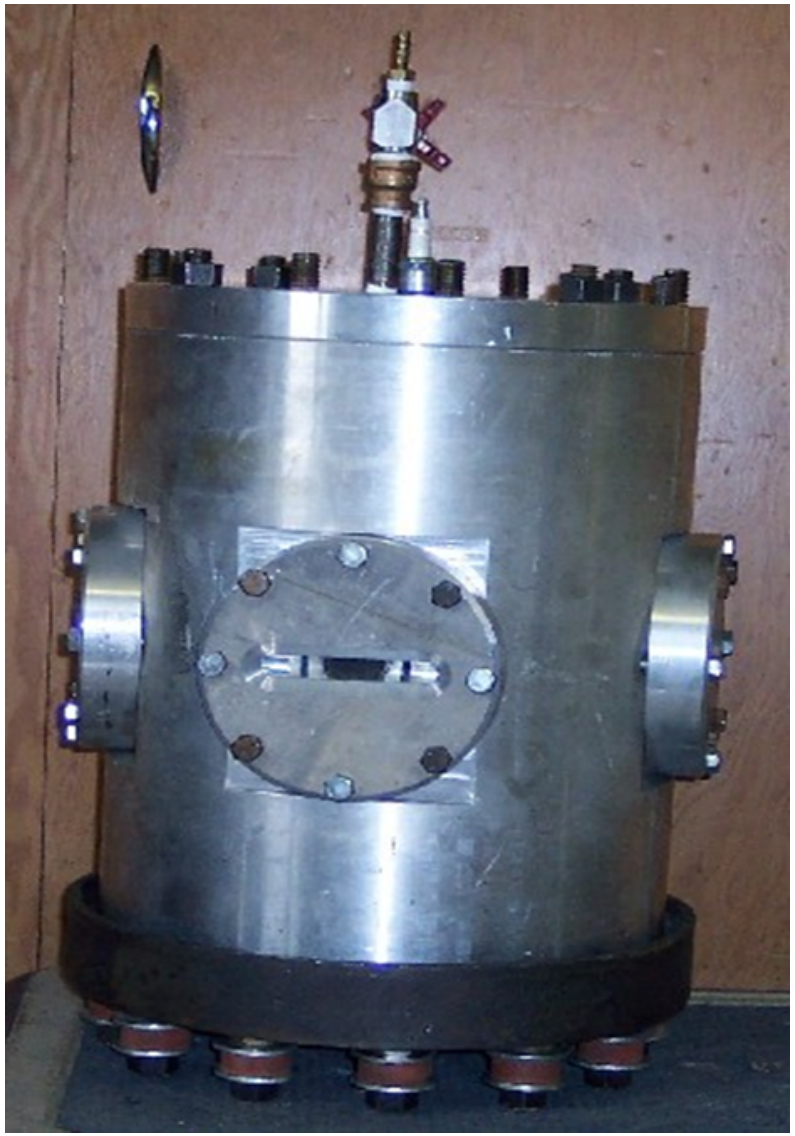


A lump of graphite, a graphene transistor and a tape dispenser. Donated to the Nobel museum in Stockholm by Andre Geim and Konstantin Novoselov.

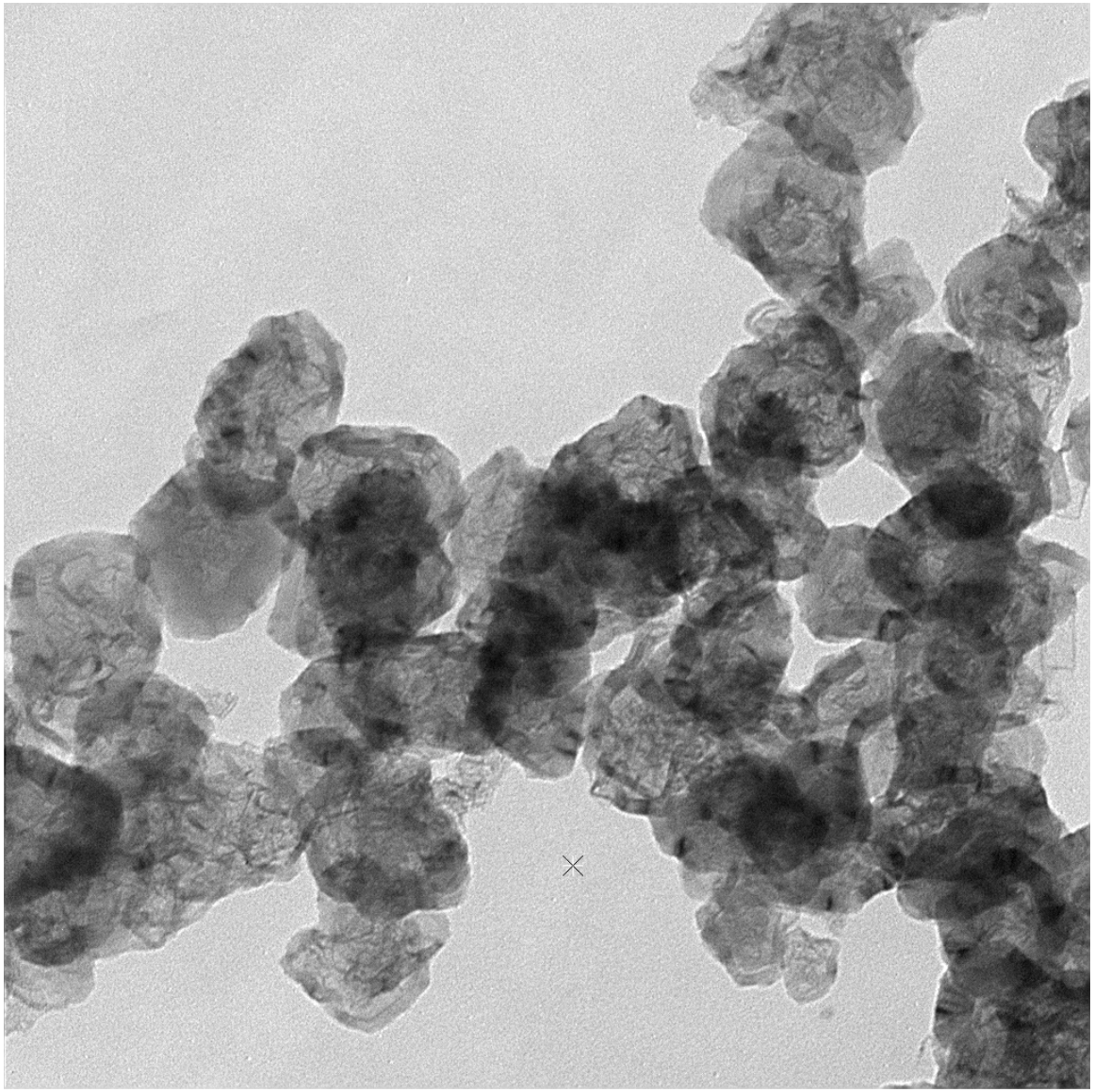
Graphene Production

- micro-mechanical exfoliation
  - Very small quantities
- Epitaxial growth on metal substrates
  - E.g. Cu, Ni with hydrocarbons, T ≈ 1000K
    Large transparent sheets, but small quantities
- Graphite oxide reduction
  - Graphite (from mines), treat with $KMnO_4 + H_2SO_4$ to GO, then reduce with N_2H_2 to graphene. Large quantities, but poor quality
- **Detonation carbon**

The KSU Detonator



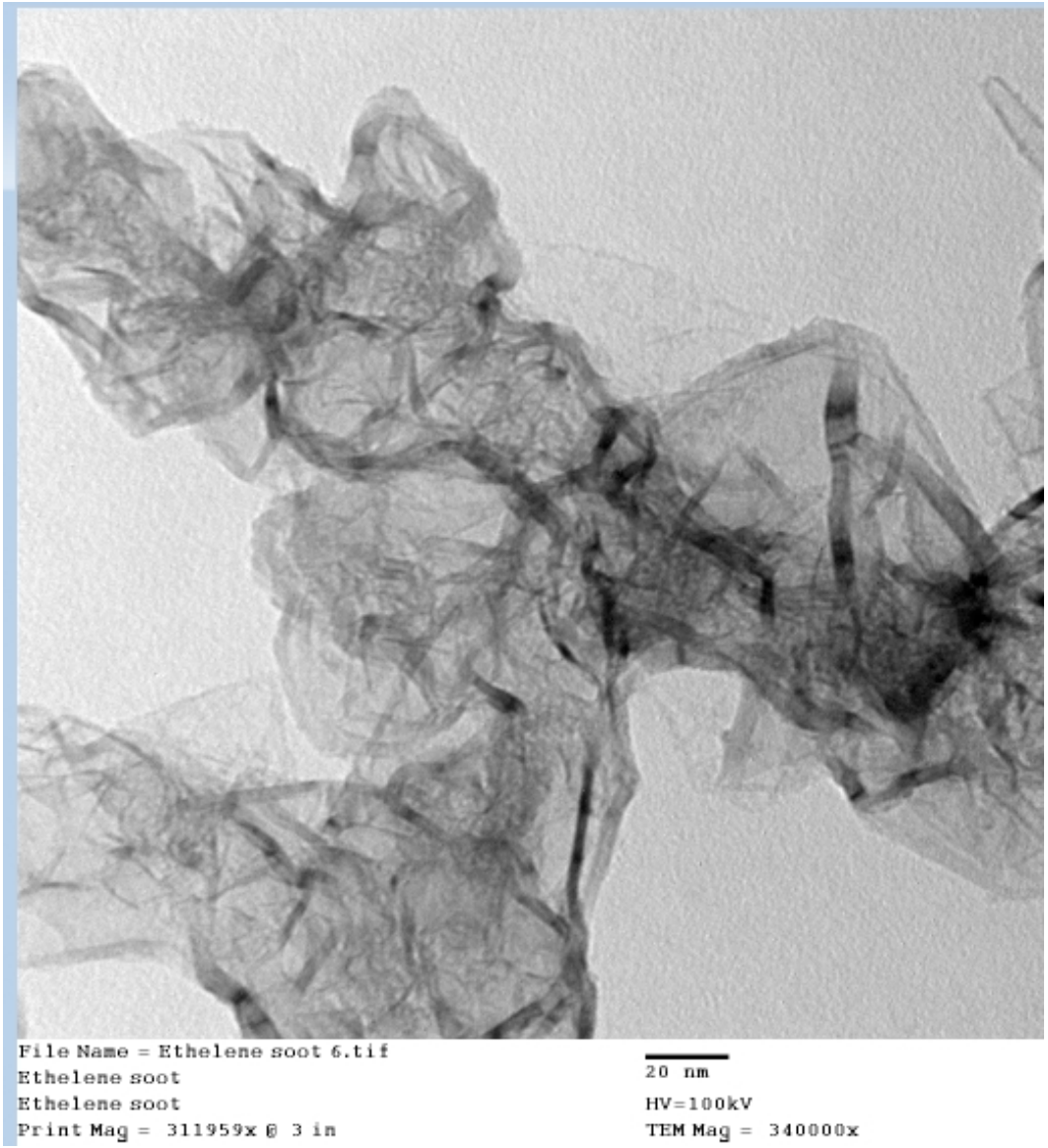
Detonation Graphene



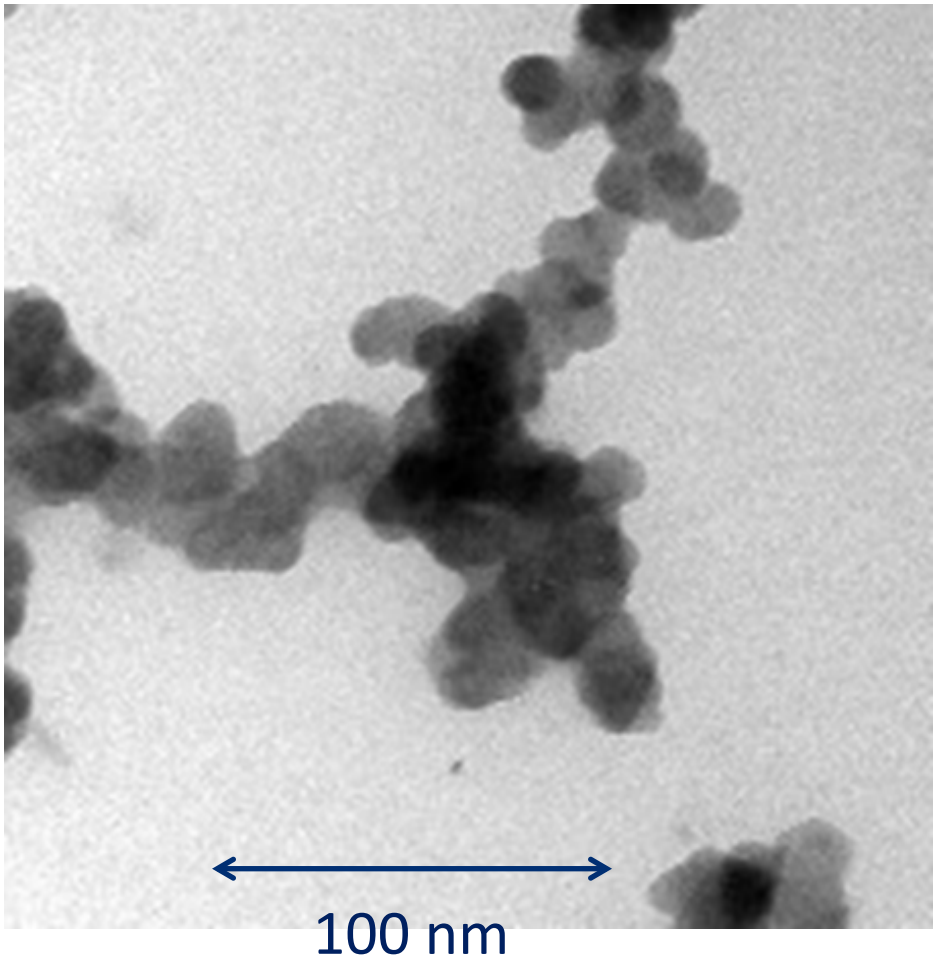
Low vol frac 1.tif
low vol frac
Print Mag: 118000x @ 3. in
11:37 04/04/05

100 nm
HV=100kV
Direct Mag: 92000x
AMT Camera System

Detonation Graphene



TEM picture of acetylene open flame soot.
T ≈ 2000K



Detonation Carbon

Pyrometer indicates T ≈ 4000K
Simple, cheap precursors, e.g. acetylene
No catalyst needed
Eco-friendly
5 grams/detonation lab scale, easily scaled up
to metric tons.

Has my ship come in …


… or not?


Thank you