나노 기술과 재료

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Syllabus

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주교재: G. Cao, Nanostructures & Nanomaterials

평가: 출석 및 과제 (10%), 중가고사 (30%), 기말고사 (40%),
term paper (20%)

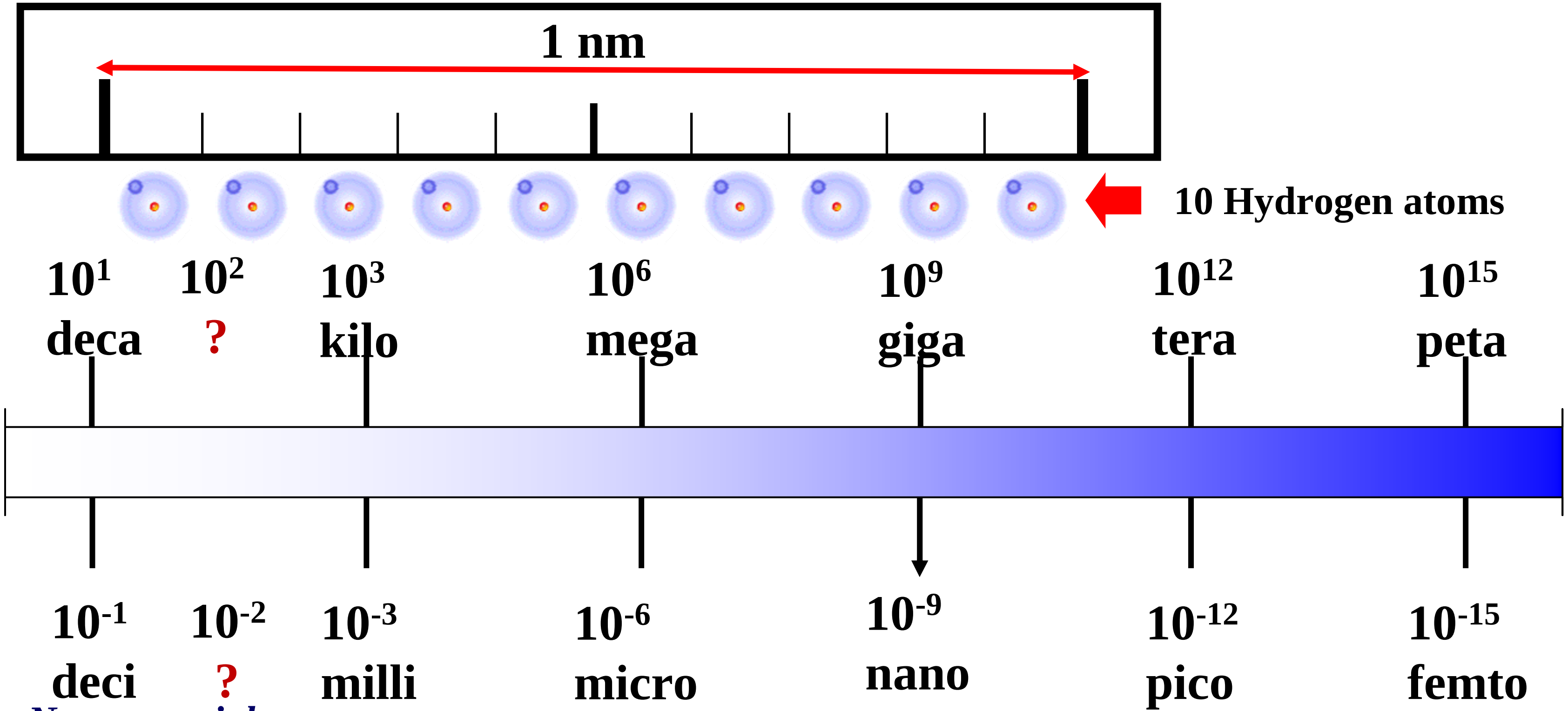
Contents

Introduction

- What's the nano?
- Effect of Nano Size
- History of Nano Science
- Fabrication of Nano Structure
  - Top-Down Approach
  - Bottom-Up Approach

Introduction- What is Nano ?

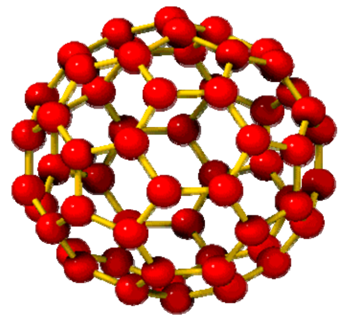
- A prefix (symbol n) of units denoting a factor of 10^{-9} and comes from the Greek nanos, meaning *dwarf* .
- One nanometer, which is on the scale of atomic diameters. For comparison, a human hair is about 100,000 nanometers thick!



Introduction- How small is nano-scale ?

about 10^7 m (radius)

about 10^{-2} m (radius)



Nano-meter: 10^{-9} m

- **Comparing nanometer scale to a 100 ₩ coin,**

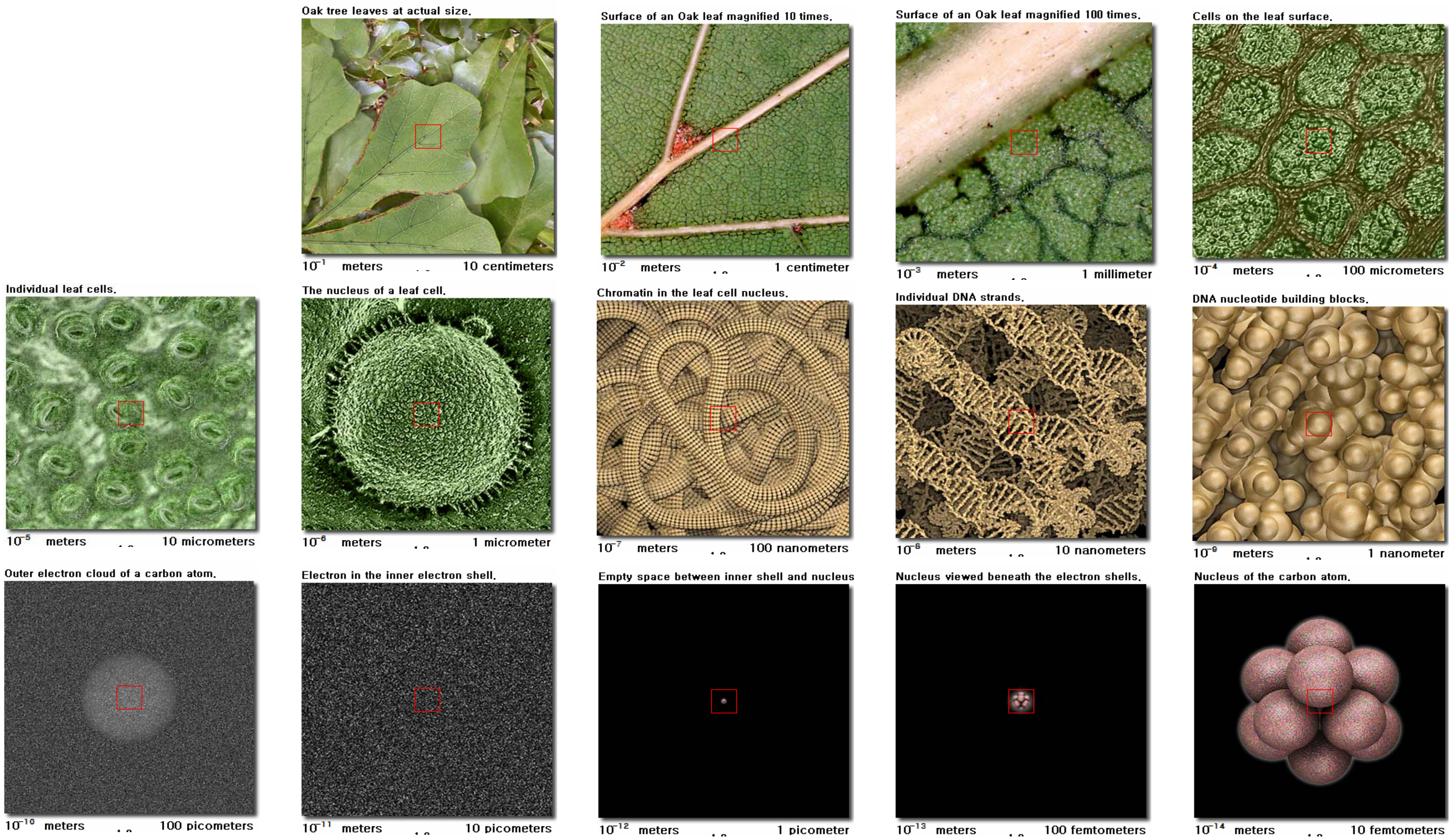
  ➡ **The coin becomes the Earth .**

- **100nm size Al nano powder 2 gram,**

  ➡ **Each one of 60 billion people have 300 thousand particles.**

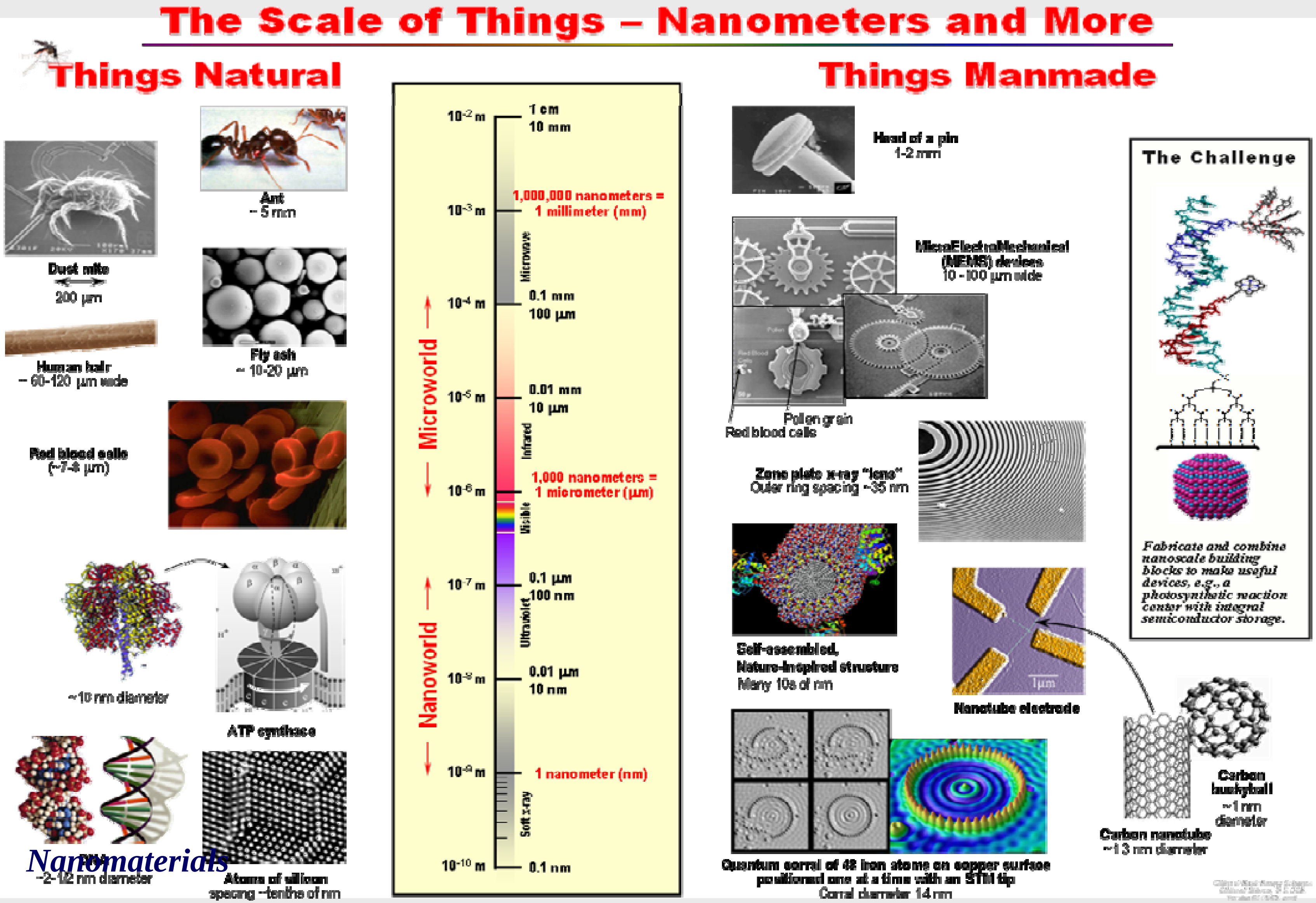
  & It covers a whole football field,

Introduction- Scaling to Nano



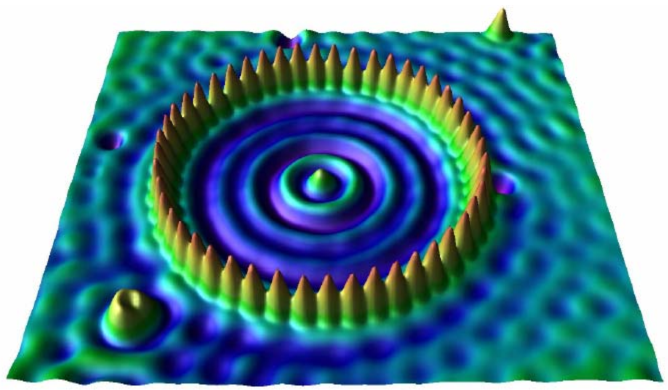
Ref*. http://micro.magnet.fsu.edu*

Introduction- What is nano-scale ?



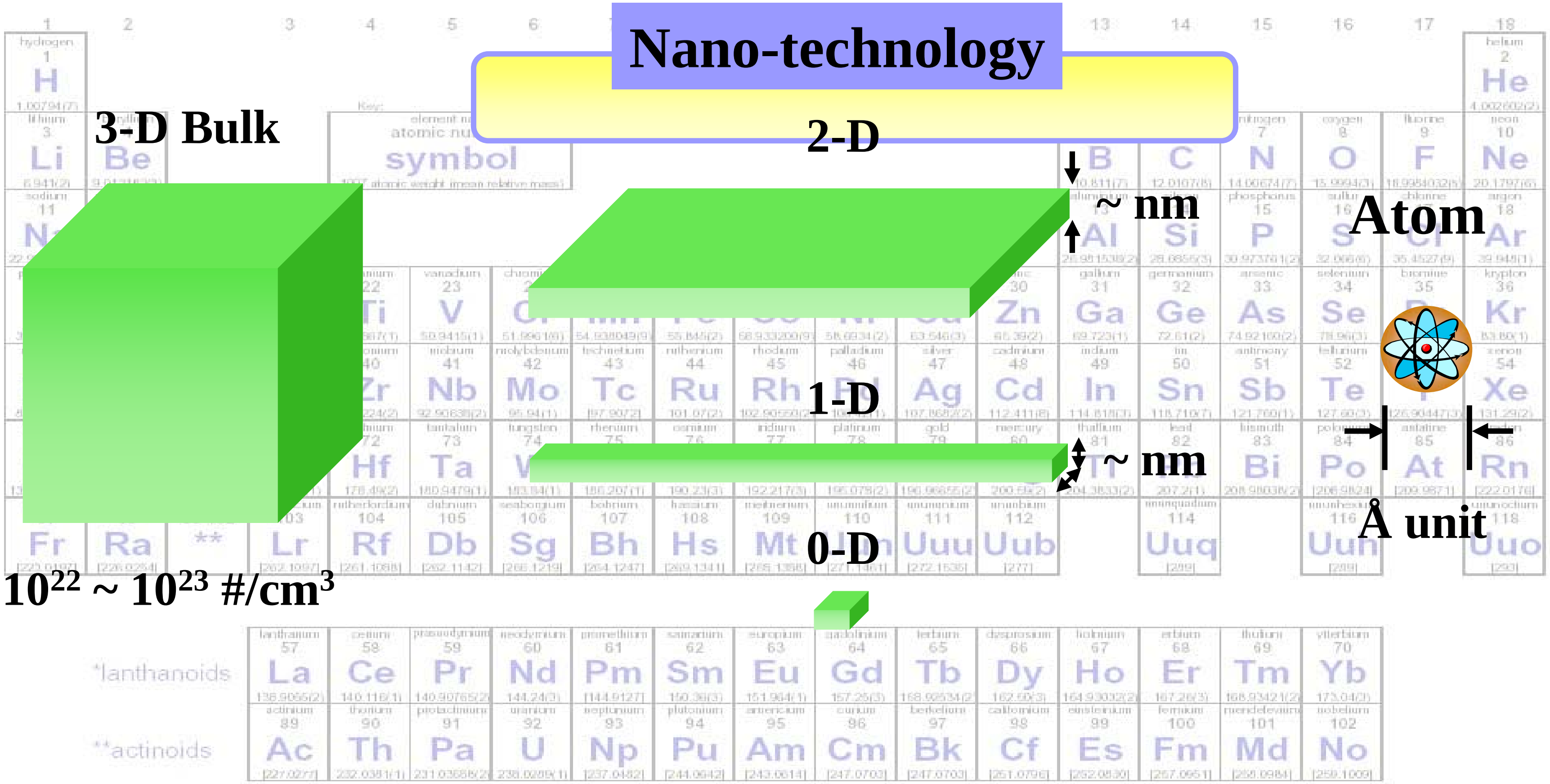
Introduction- Nano-science and technology

- **Nano-science : the study of the fundamental principles of molecules and structures with at least one dimension roughly between 1 and 100 nanometers.**
- **Nanotechnology : application of manipulation methods and knowledge acquired from nano-science.**



(*A report by the interagency working group on nanoscience, engineering and technology*, Feb., 2000)

Introduction- Nano-technology in materials



Introduction- A brief history

1959 : Richard Feynman

- Lecture titled “There’s plenty of room at the bottom:
- Considered as “Father of Nanoscience”
- Described molecular sized electronics, machines, and data storage

There’s Plenty of Room at the Bottom:

An Invitation to Enter a New Field of Physics

Richard Feynman
Cal Tech, 1959

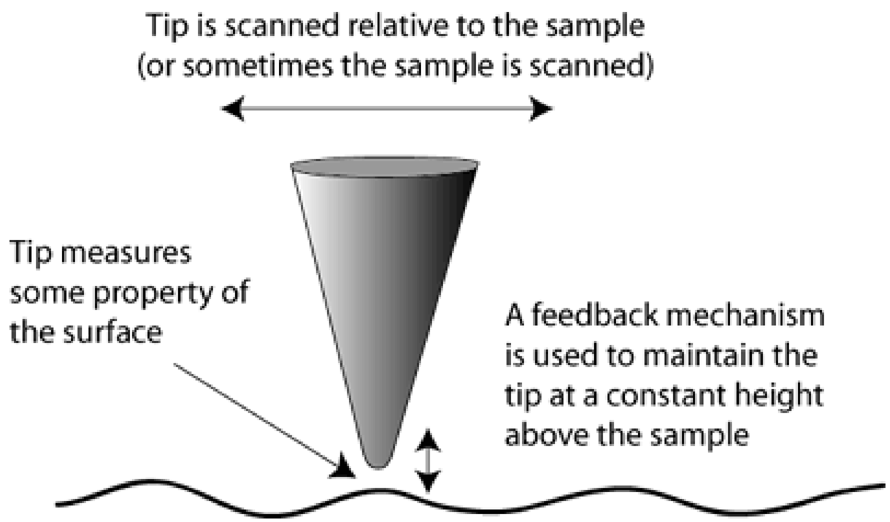
“People tell me about miniaturization, and how far it has progressed today. They tell me about electric motors that are the size of the nail on your small finger. And there is a device on the market, they tell me, by which you can write the Lord's Prayer on the head of a pin. But that's nothing; that's 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.

Introduction- A brief history

- **1981 : SPM (Scanning probe microscope) invented**

  - Allowed us to image surfaces at the nanometer scale
  - Small tip is scanned across conductive surfaces measuring electrical current by tunneling electrons to create the image

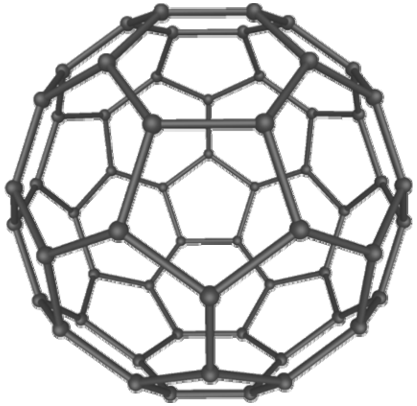


SPM tip

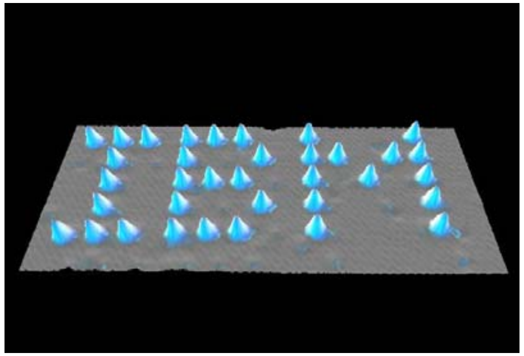
Atomic image by SPM

Nano-science : A brief history

- **1985 : C_{60} (Buckminster Fullerene, Bucky ball) is discovered. Stable molecule entirely made of carbon.**
- **1990 : With STM (Scanning Tunneling microscope) 's, IBM researchers positioned atoms on a surface**
- **1991 : Carbon Nano-Tube (CNT) is made entirely of carbon rings.**



Bucky ball



STM image

Carbon Nano-Tube

Introduction- Au nanoparticle

- **Ancient China (2500 BC)**
  - medicine- eating, wound healing
    potable gold (soluble) – alchemist Paracelsus (16th century)
    Aurum Potabile (Latin: potable gold).
    Danziger Gold
  - paint and printing silk and paper
- **Chinese ceramic porcelain**
  - An nanoparticle- inorganic dye- red color
- **Purple of Cassius (17th century)**
  − a purple pigment precipitated as a sol by the interaction of gold chloride and a solution of stannic acid and stannous chloride
  - ruby glass

H. Zhao and Y. Ning, Gold Bull. 33, 103 (2000)
M. Faraday, Phil. Trans. 11, 952, 1857

Introduction- Danziger Gold

- ***Danziger Goldwasser*** is the registered tradename of a strong (40%) root and herbal liqueur which has been produced since at least 1598 in Danzig (Gdańsk).
- The most prominent characteristic of this alcoholic beverage is small flakes of 22 karat gold suspended in it (thus *gold water*). Alchemy, which was at its high point in the 16th century when Goldwasser appeared, believed gold to have many desirable medical properties. Since the flakes are extremely small and thin, the price is not prohibitive. When used as food additive, Gold is labelled as E175 (List of food additives, Codex Alimentarius)

- http://en.wikipedia.org/wiki/Goldwasser

Introduction- Purple of Cassius

- Figure: 'purple gold' solution that I made on 23.5.05, using Rochelle salt, and on the right my attempt at purple of Cassius.'

- Ruby Glass

Beautiful glasses of pink and ruby red are made using gold, at about 10-15 parts per million

http://www.levity.com/alchemy/kollerstrom_purple_gold.html

Introduction- Au nanoparticle

- **Crysotype (or gold print) (John Herschel, 1842)**

  - photographic process using colloidal gold to record images on paper

  - Herschel's system involved coating paper with ferric citrate, exposing it to the sun in contact with an etching used as mask, then developing the print with a chloroaurate solution.

- **Michael Paraday (1857)**

  preparation and properties of colloidal gold

  colloidal dispersion- stable for almost a hundred years

http://en.wikipedia.org/wiki/Chrysotype

Introduction- Au nanoparticle

- **Arthritis**

  - primarily to reduce inflammation and to slow disease progression in patients with rheumatoid arthritis

  - Medical use:

  Auranofin (UK & U.S.)

  Aurothioglucose (Gold thioglucose) (U.S.)

  Disodium aurothiomalate

  Sodium aurothiosulfate (Gold sodium thiosulfate)

  Sodium aurothiomalate (Gold sodium thiomalate) (UK)

http://en.wikipedia.org/wiki/Gold_salts

Introduction- Au nanoparticle

❑ Electrical studies of single nanocrystals

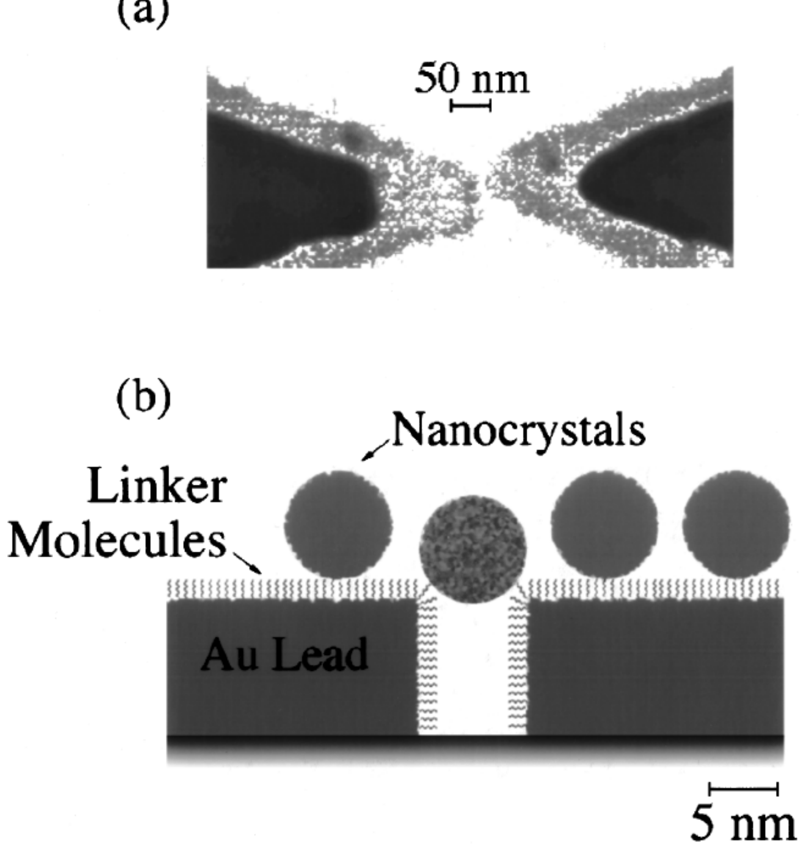


FIG. 1. (a) Field emission scanning electron micrograph of a lead structure before the nanocrystals are introduced. The light gray region is formed by the angle evaporation, and is ~10 nm thick. The darker region is from a normal angle evaporation and is ~70 nm thick. (b) Schematic cross section of nanocrystals bound via a bifunctional linker molecule to the leads. Transport between the leads occurs through the mottled nanocrystal bridging the gap.

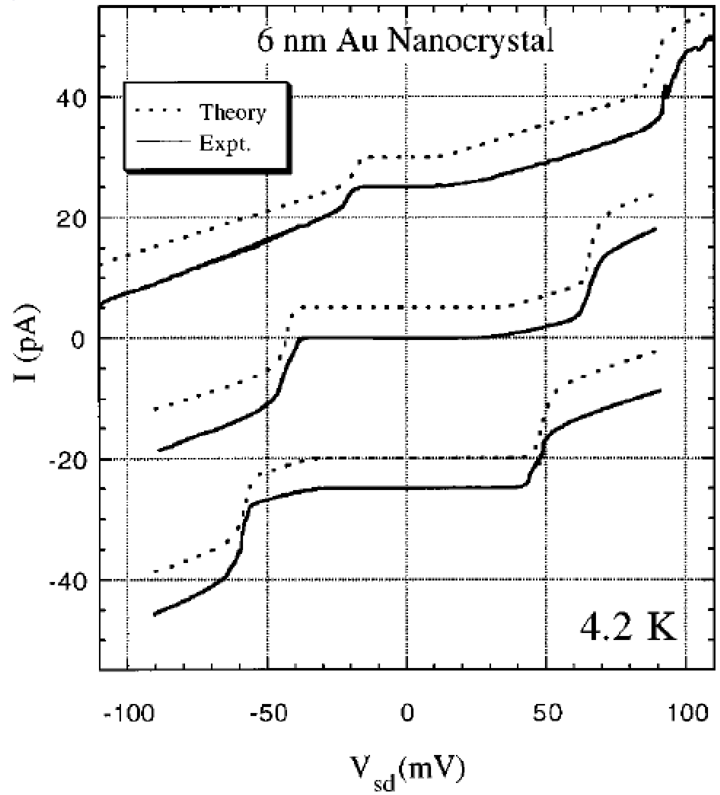


FIG. 3. $I-V_{sd}$ characteristic of a 5.8 nm diam Au nanocrystal measured at 4.2 K. The solid lines show three $I-V$ curves measured over the course of several days. Each is offset for clarity. These different curves result from changes in the local charge distribution about the dot. The dashed lines are fits to the data using the orthodox Coulomb blockade model as discussed.

D.L. Klein, Appl. Phys. Lett. 68 2574 (1996)

Introduction- Transistor

❑ Moore's law

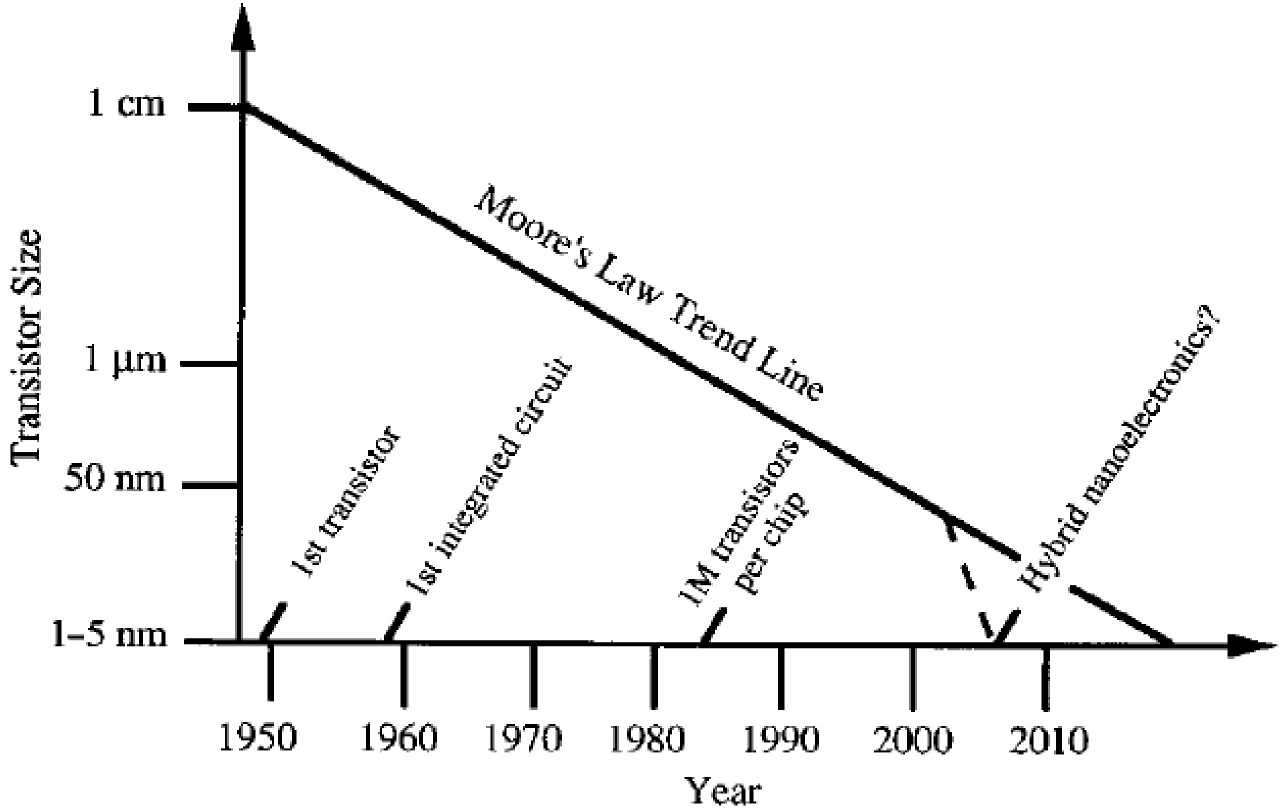


Fig. 1 "Moore's Law" plot of transistor size *vs.* year. The trend line illustrates the fact that the transistor size has decreased by a factor of 2 every 18 months since 1950.

D.L. Feldheim, Chem. Soc. Rev. 21, 1 (1998)

Introduction- Transistor

- MOSFET (metal oxide semiconductor field effect transistor)

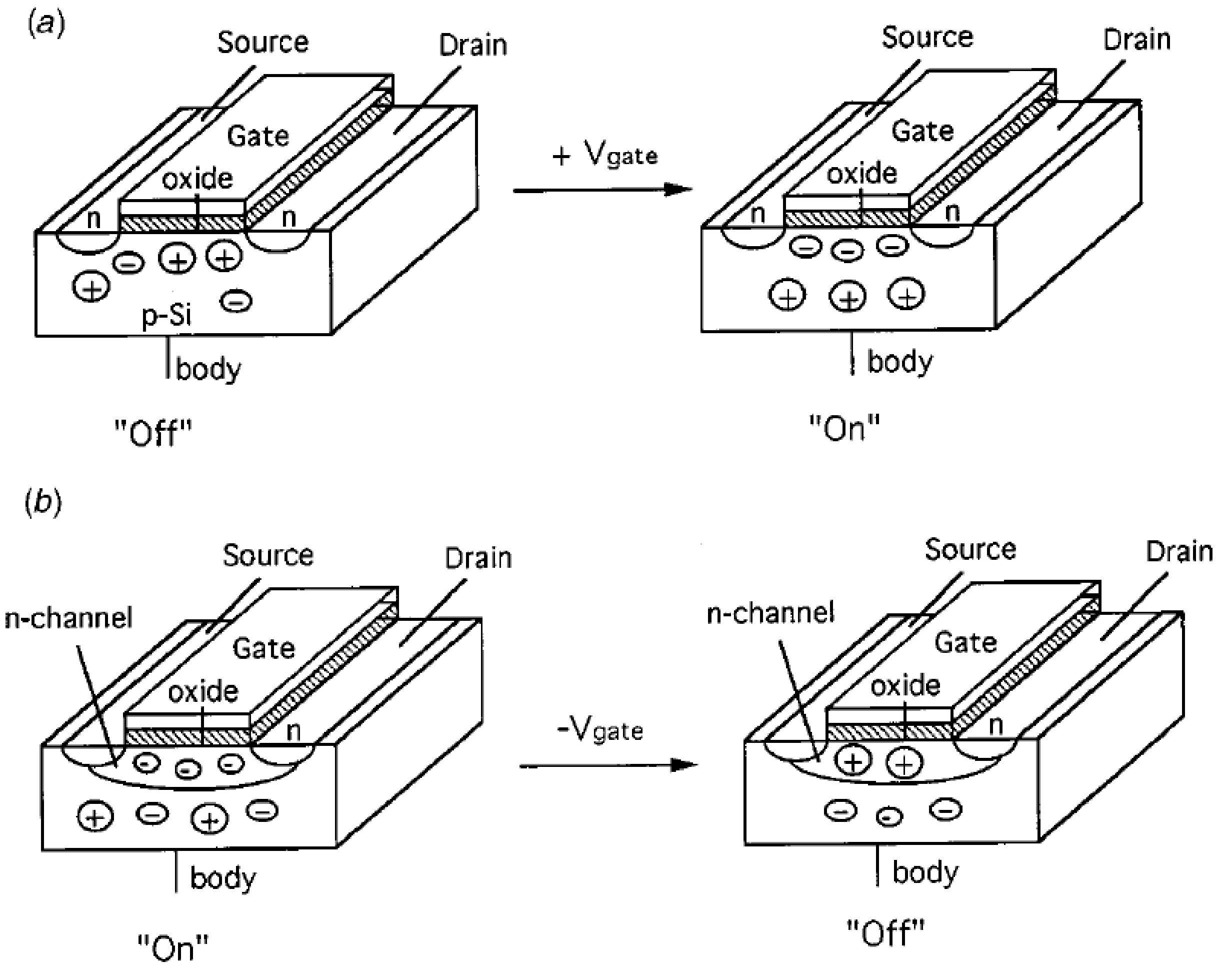


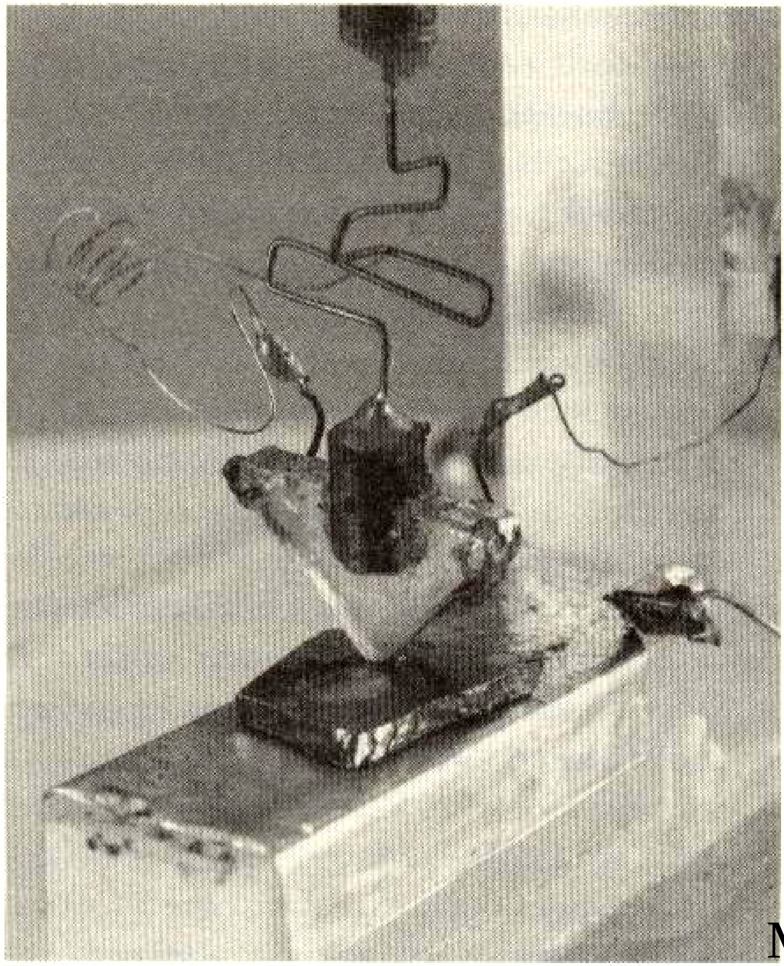
Fig. 2 Schematic illustration of (*a*) an NMOSFET and (*b*) an n-channel MOSFET

D.L. Feldheim, Chem. Soc. Rev. 21, 1 (1998)

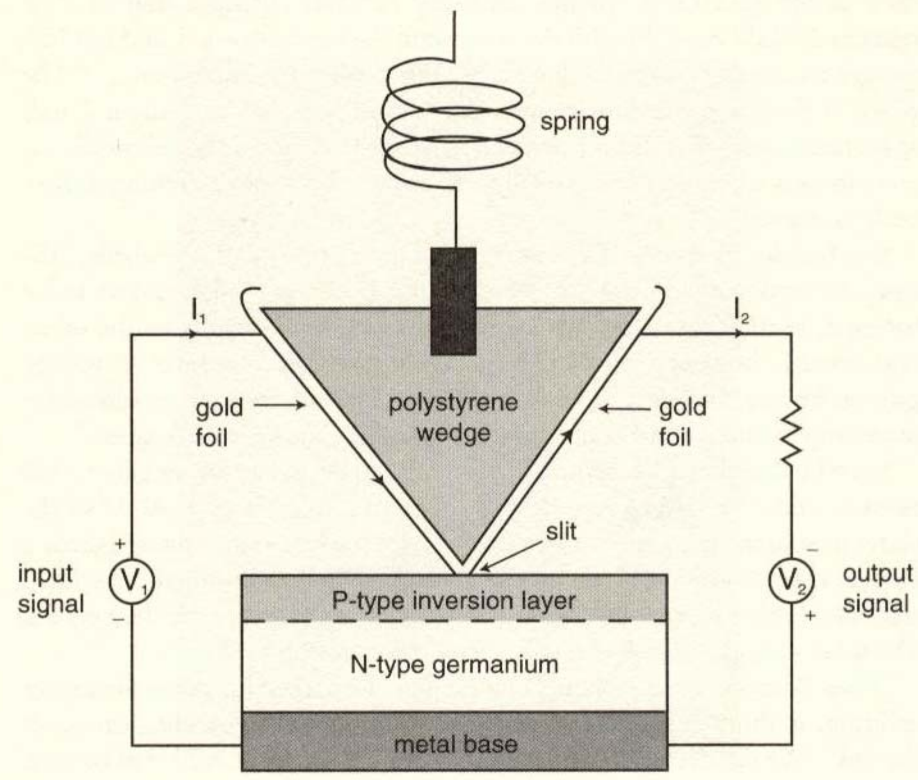
Introduction- Transistor

❑ Point contact semiconductor amplifier

Bardeen and Brattain's point-contact semiconductor amplifier.



Cross-sectional diagram of the original point-contact semiconductor amplifier.

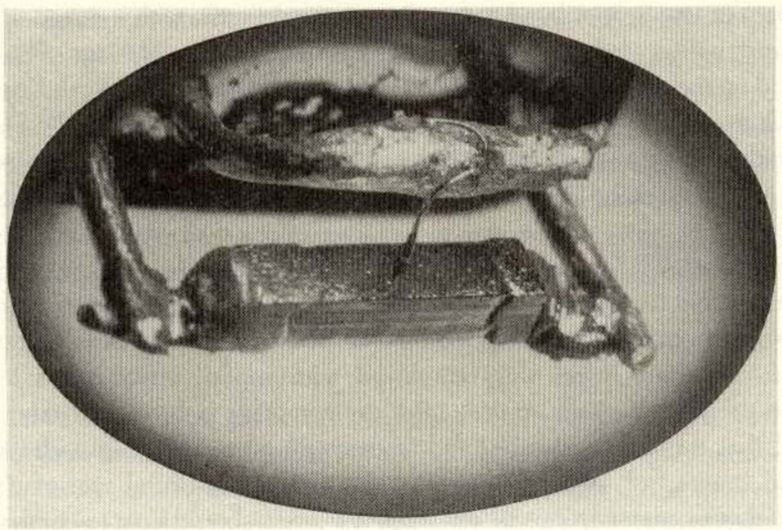


M. Riordan & L. Hoddeson, Crystal Fire, 1997

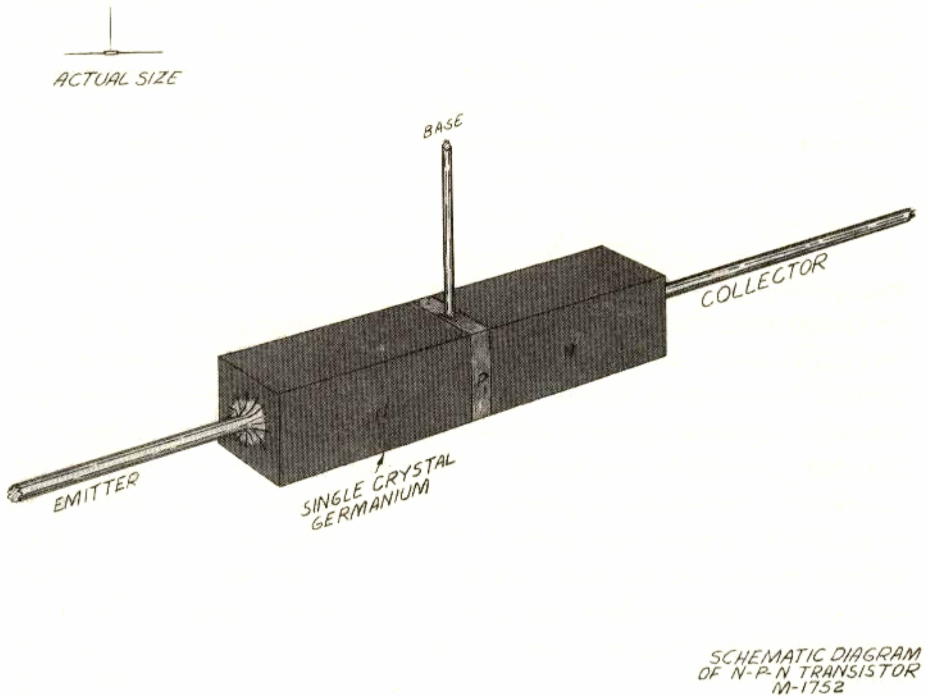
Introduction- Transistor

❑ First microwatt junction transistor

Photograph of one of the first microwatt junction transistors.



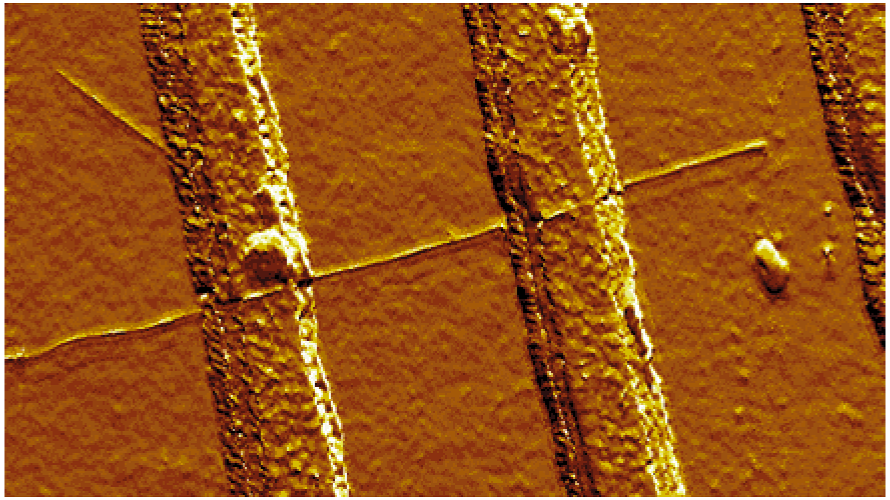
Drawing of an early microwatt junction transistor, March 1951. The base layer is only 1 to 2 mils thick.



M. Riordan & L. Hoddeson, Crystal Fire, 1997

Introduction- Transistor

❑ Single Molecular Transistor



▪Atomic force microscope image of a single carbon nanotube crossing two platinum strips, which are used as source and drain contacts. On the right, a part is seen of a third electrode which could be used as a gate. The distance between electrodes is 200 nm. In the upper left corner a short tube is seen. [Courtesy of S. J. Tans *et al.*, Delft University of Technology>

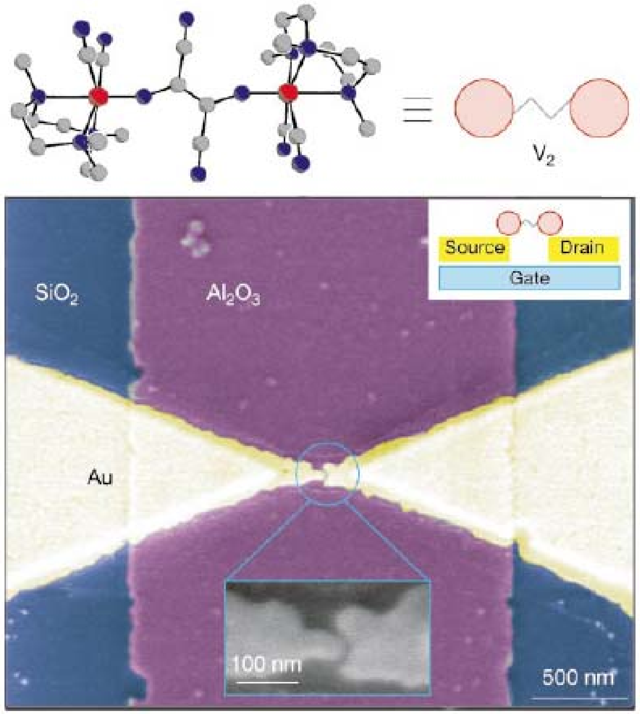


Figure 1 Fabrication of single-molecule transistors incorporating individual divanadium molecules. Top left, the structure of [(*N*,*N*′,*N*″-trimethyl-1,4,7-triazacyclononane)$_2V_2(CN)_4(\mu-C_4N_4)$] (the V_2 molecule) as determined by X-ray crystallography; red, grey and blue spheres represent respectively V, C and N atoms. Top right, the schematic representation of this molecule. Main panel, scanning electron microscope image (false colour) of the metallic electrodes fabricated by electron beam lithography and the electromigration-induced break-junction technique. The image shows two gold electrodes separated by ~1 nm above an aluminium pad, which is covered with an ~3-nm-thick layer of aluminium oxide. The whole structure was defined on a silicon wafer. The bright yellow regions correspond to a gold bridge with a thickness of 15 nm and a minimum lateral size of ~100 nm. The paler yellow regions represent portions of the gold electrodes with a thickness of ~100 nm. Main panel inset, schematic diagram of a single-V_2 transistor.

L. Kouwenhoven, Science, 275, 1896 (1997)

W. Liang, Nature, 417, 725 (2002)

Introduction- Transistor

❑ Single Molecular Transistor

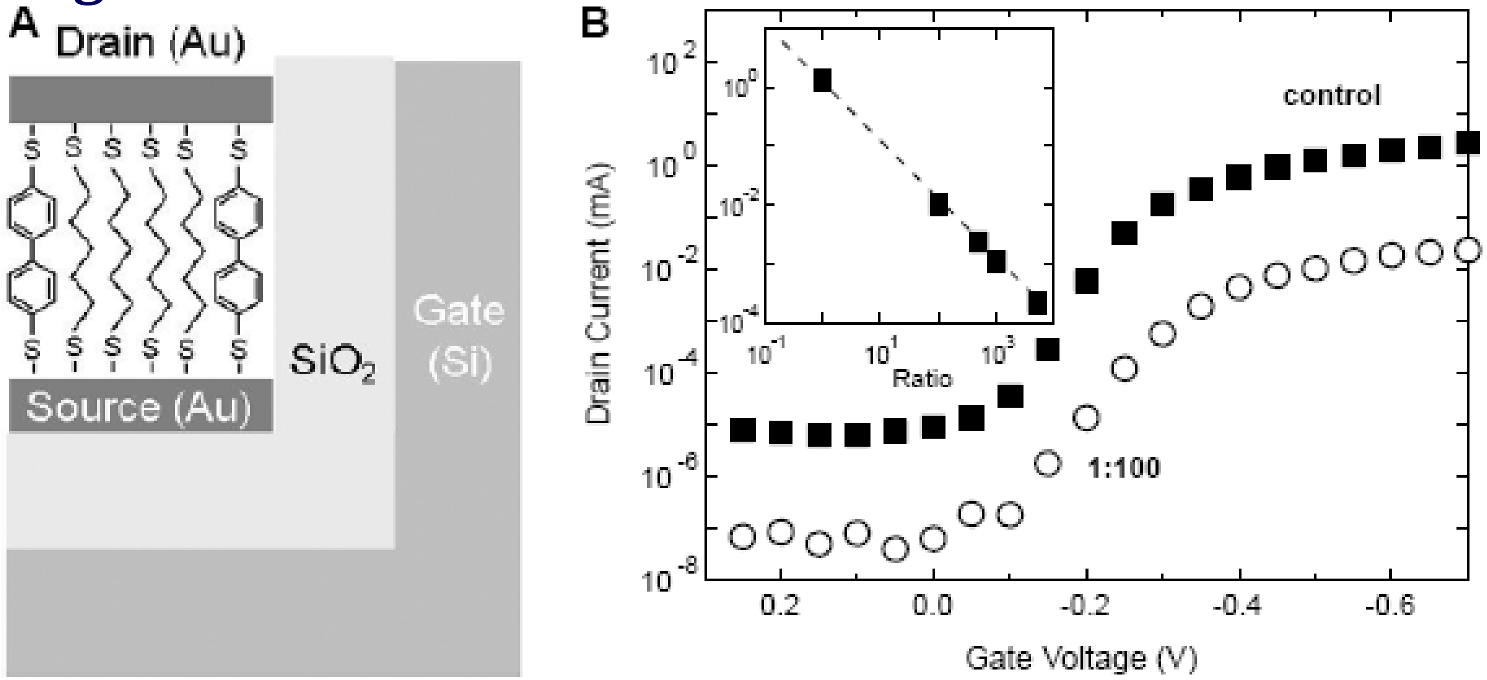
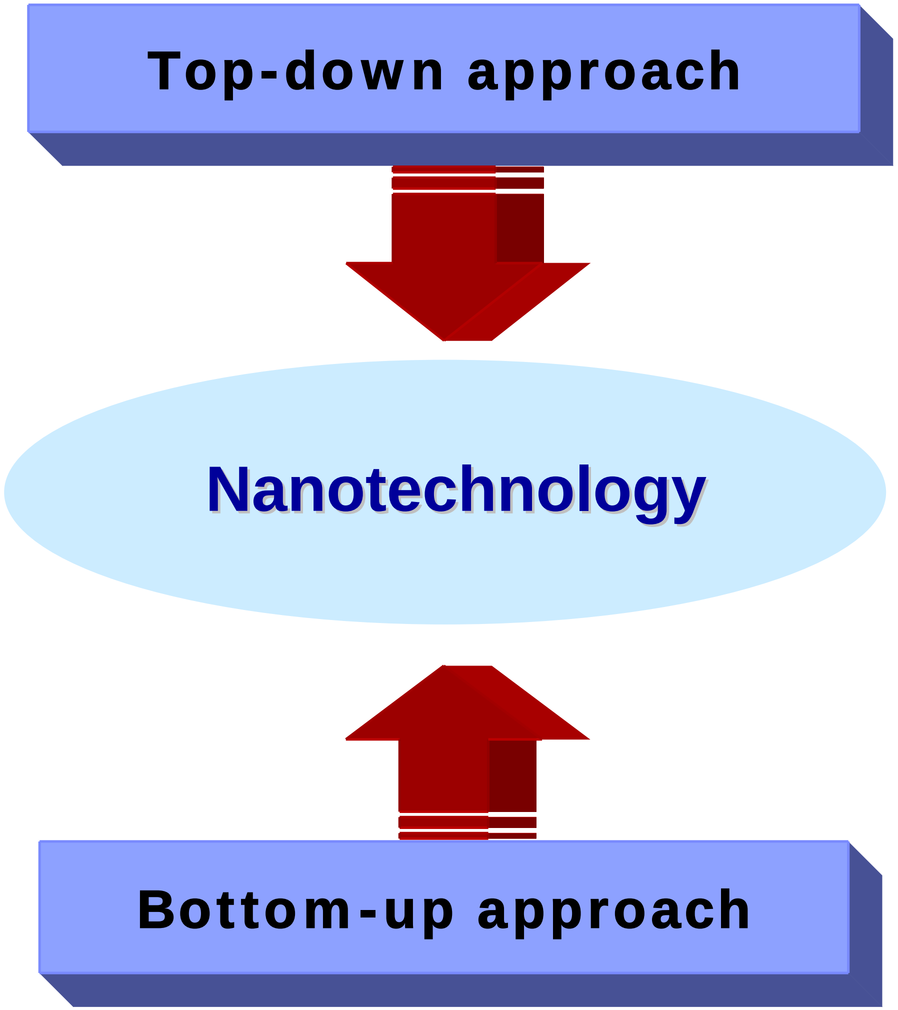


Fig. 1. (**A**) SAMFET structure. A highly doped Si substrate is used as the gate electrode, a thermally grown SiO_2 layer acts as gate insulator, the gold source electrode is deposited by thermal evaporation, and the active semiconducting material is a two-component SAM of alkanedithiols mixed with 4,4′-biphenyldithiol or 5,5′-terthiophenedithiol. The drain contact is defined by shallow angle shadow evaporation of gold. The active region of the device is magnified. (**B**) Transfer characteristics at room temperature of two SAMFETs (drain-source voltage of −0.5 V). The control corresponds to a "pure" 4,4′-biphenyldithiol SAM, whereas the second one is based on a two-component SAM (4,4′-biphenyldithiol to alkanedithiol ratio is 1:100). The inset shows the current at a gate and drain-source voltage of −0.5 V as a function of the mixture ratio.

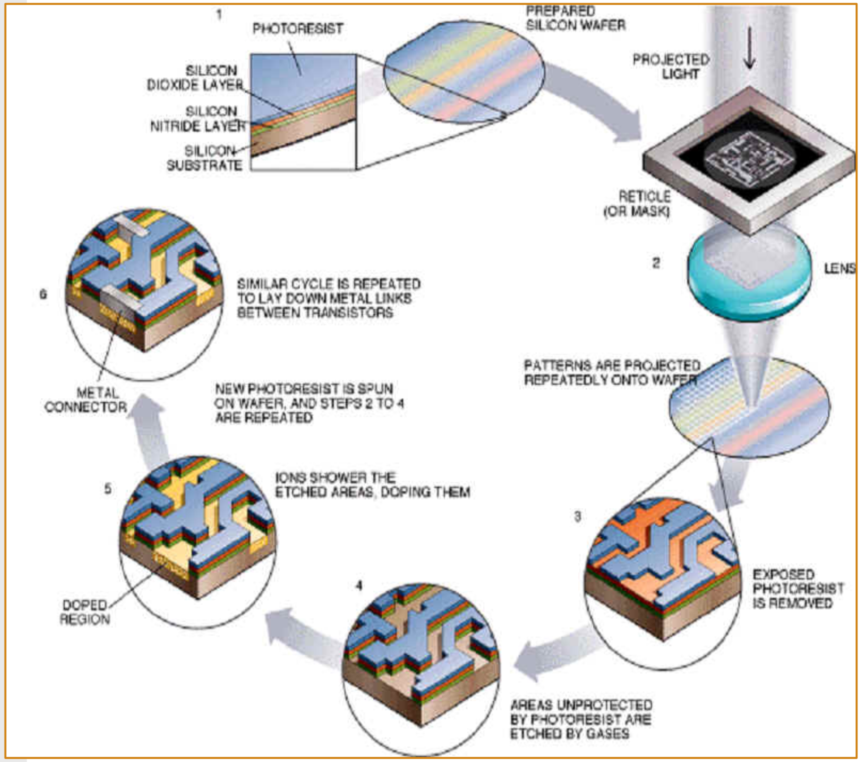
J.H. Schon, Science, 292, 2138 (2001)

Introduction- Nanostructure fabrication

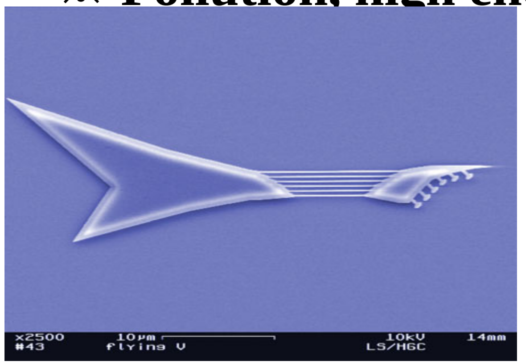


Introduction- Top-down Approach

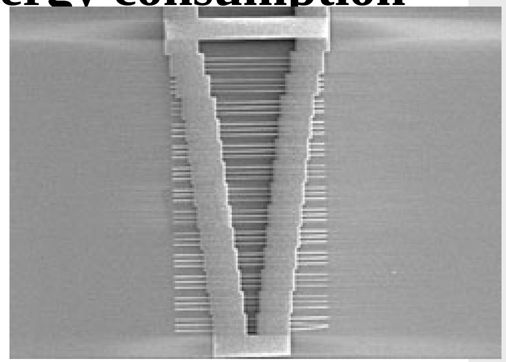
Compatible with Semiconductor Fabrication Process



– Nanostructure fabrication by patterning (lithography or etch process)
- ※ Precise, but limited to small area
- ※ Too expensive
- ※ Pollution, high energy consumption



Nano guitar



Nano Xylophone

Introduction- Bottom-up Approach

Self-assembly and Synthesis of atoms and molecules

: Imitation of an ecosystem

※ No pollution problem, low energy consumption

※ Technically difficult to achieve, but innovative on all processes if achieved