Nanomaterials

There is plenty of room at the bottom

Richard Feynman December 29th 1959

- I would like to describe a field, in which little has been done, but in which an enormous amount can be done in principle….. What I want to talk about is the problem of manipulating and controlling things on a small scale….
- 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 fact---that enormous amounts of information can be carried in an exceedingly small space---is, of course, well known to the biologists, and resolves the mystery which existed before we understood all this clearly, of how it could be that, in the tiniest cell, all of the information for the organization of a complex creature such as ourselves can be stored.
- I don't know how to do this on a small scale in a practical way, but I do know that computing machines are very large; they fill rooms. Why can't we make them very small, make them of little wires, little elements---and by little, I mean little. For instance, the wires should be 10 or 100 atoms in diameter, and the circuits should be a few thousand angstroms across. Everybody who has analyzed the logical theory of computers has come to the conclusion that the possibilities of computers are very interesting…….

There is plenty of room at the bottom

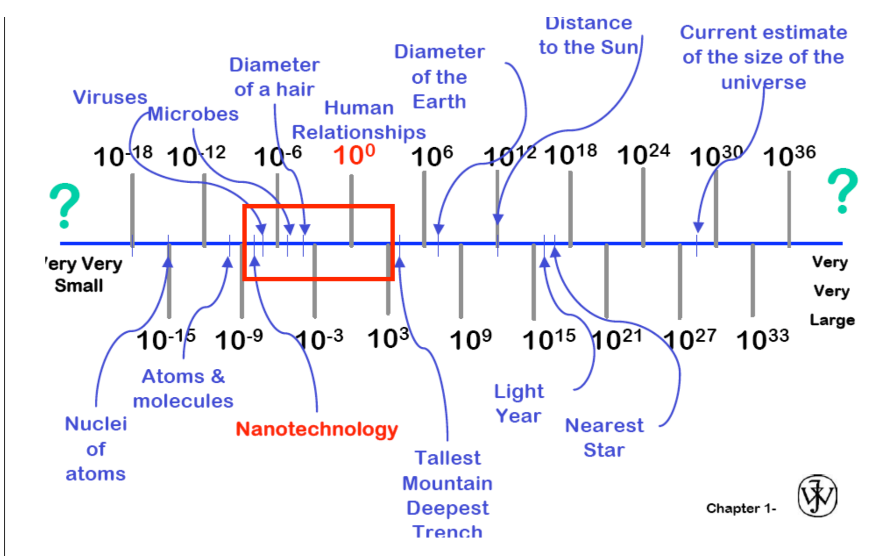
•A friend of mine (Albert R. Hibbs)…. says that, although it is a very wild idea, it would be interesting in surgery if you could swallow the surgeon. You put the mechanical surgeon inside the blood vessel and it goes into the heart and ``looks'' around. (Of course the information has to be fed out.) ….. Other small machines might be permanently incorporated in the body to assist some inadequately-functioning organ.

•But I am not afraid to consider the final question as to whether, ultimately---in the great future---we can arrange the atoms the way we want; the very atoms, all the way down! What would happen if we could arrange the atoms one by one the way we want them (within reason, of course; you can't put them so that they are chemically unstable, for example).

•Ultimately, we can do chemical synthesis. A chemist comes to us and says, ``Look, I want a molecule that has the atoms arranged thus and so; make me that molecule.'' The chemist does a mysterious thing when he wants to make a molecule. He sees that it has got that ring, so he mixes this and that, and he shakes it, and he fiddles around. And, at the end of a difficult process, he usually does succeed in synthesizing what he wants. By the time I get my devices working, so that we can do it by physics, he will have figured out how to synthesize absolutely anything, so that this will really be useless.

•Perhaps this doesn't excite you to do it, and only economics will do so. Then I want to do something; but I can't do it at the present moment, because I haven't prepared the ground. It is my intention to offer a prize of $1,000 to the first guy who can take the information on the page of a book and put it on an area 1/25,000 smaller in linear scale in such manner that it can be read by an electron microscope.

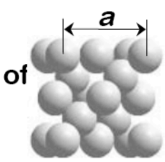
Length Scales



Perspective of Size

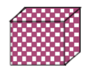
Si has a diamond structure with a = 5.43 Å

A Si nanocube 10 nm on a side is composed of
- ~6250 unit cells
- ~50,000 atoms



Diamond unit cell

Each nanocube face is composed of:
- ~340 unit cells per face
- ~680 surface atoms per face


Si nanocube

Total surface area is:
- ~4080 atoms (~10% surface atoms)

A bulk Si film 1 μm thick on a 10 cm square:
- ~6.3×10^{19} unit cells
- ~5×10^{20} atoms
- ~1.4×10^{17} surface atoms (~0.03% surface atoms)

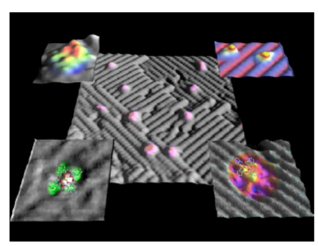
Bulk Si film

In a nanoscale material, the surface/boundary/interface plays an important role!

Not Just Length Scale…

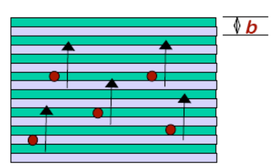
Interesting phenomena:

Chemical – take advantage of large surface to volume ratio, interfacial and surface chemistry important, systems too small for statistical analysis


STM of dangling bonds on a Si:H surface

Electronic – quantum confinement, bandgap engineering, change in density of states, electron tunneling

Magnetic – giant magnetoresistance by nanoscale multilayers, change in magnetic susceptibility



Electron tunneling

Not Just Length Scale…

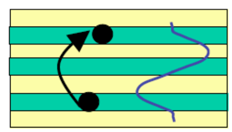
Interesting phenomena:

Mechanical – improved strength hardness in light-weight nanocomposites and nanomaterials, altered bending, compression properties, nanomechanics of molecular structures

Fluorescence of quantum dots of various sizes

Optical – absorption and fluorescence of nanocrystals, single photon phenomena, photonic bandgap engineering

Fluidic – enhanced flow properties with nanoparticles, nanoscale adsorbed films important

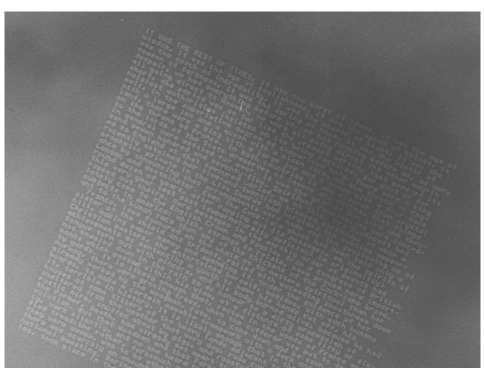


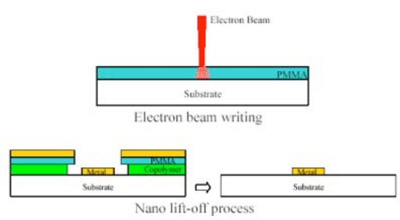
Phonon tunneling

Thermal – phonon confinement, increased thermoelectric performance of nanoscale materials, interfacial thermal resistance important, systems too small for statistical analysis, phonon tunneling

Chapter 1-

Writing the 24 volumes of the encyclopedia Britannica on a pin head





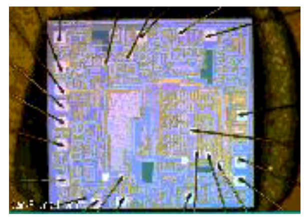
http://www.itrc.org.tw/Research/Nano-e/nanostructuring.jpg

40 nm line-width 1985
From Prof. Pease- Stanford University

Chapter 1 - 8

Making computers small

- Semiconductors
  - **Silicon and Germanium**
  - **III-V Compounds (e.g. GaAs)**
  - **Photonic materials**
  - **(solid-state lasers, LEDs)**



Moore's Law

In 1965 Gordon Moore, Intel cofounder, stated the self fulfilling prophecy that transistors per chip will double their number every two years.