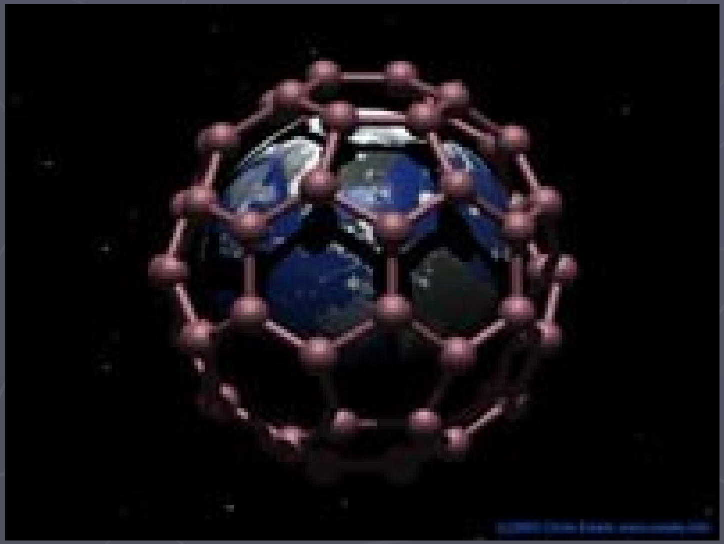
Nanotechnology

A big issue in a small world



What is Nanotechnology?

- It comprises any technological developments on the nanometer scale, usually 0.1 to 100 nm.
- One nanometer equals one thousandth of a micrometer or one millionth of a millimeter.
- It is also referred as microscopic technology.

WHAT IS NANOTECHNOLOGY?

The intentional manufacture of large scale objects whose discrete components are less than a few hundred nanometers wide.

Exploits novel phenomena and properties at the nanoscale.

Nature employs nanotechnology to build DNA, proteins, enzymes etc.

Nanotechnology – Bottom up approach

Traditional technology – Top down approach

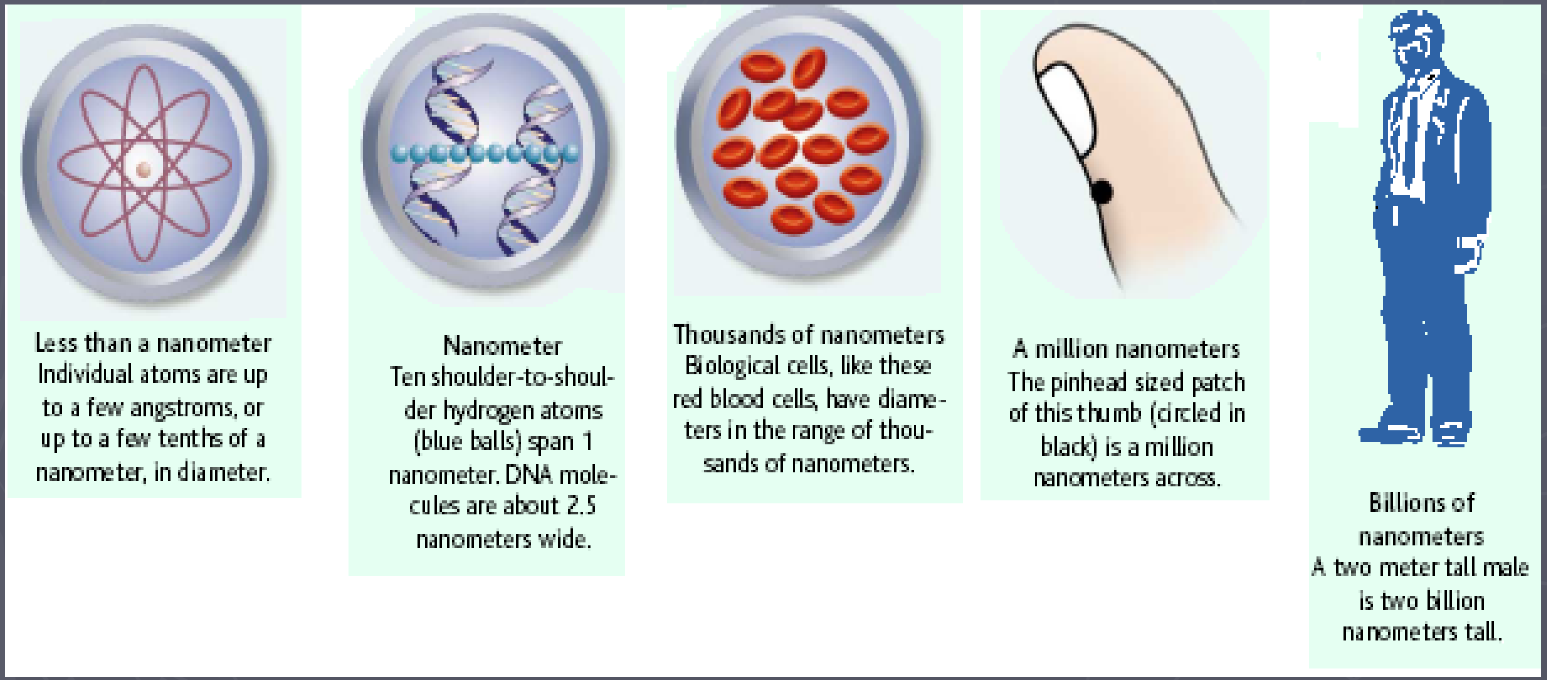
It is the ultimate technology.

What does Nano mean?

- “Nano” – derived from an ancient Greek word “Nanos” meaning DWARF.

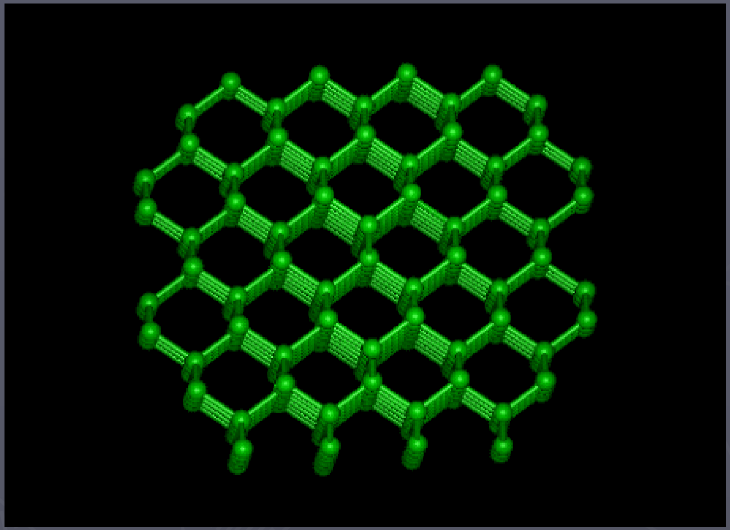
- “Nano” = One billionth of something
- “A Nanometer” = One billionth of a meter
- 10 hydrogen atoms shoulder to shoulder
- There are 25 million nms in a single inch.

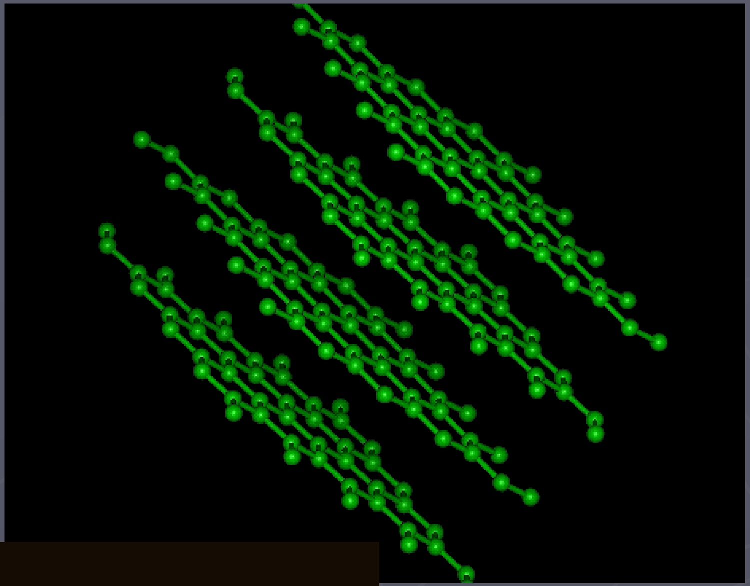
VARIOUS MATERIALS IN NANOMETER DIMENSION



< NM → NM → 1000's of NM's → Million NM's → Billions of NM's

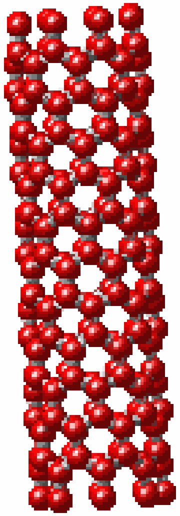
NANOMATERIALS WITH DIFFERENT ATOMIC ARRANGEMENTS

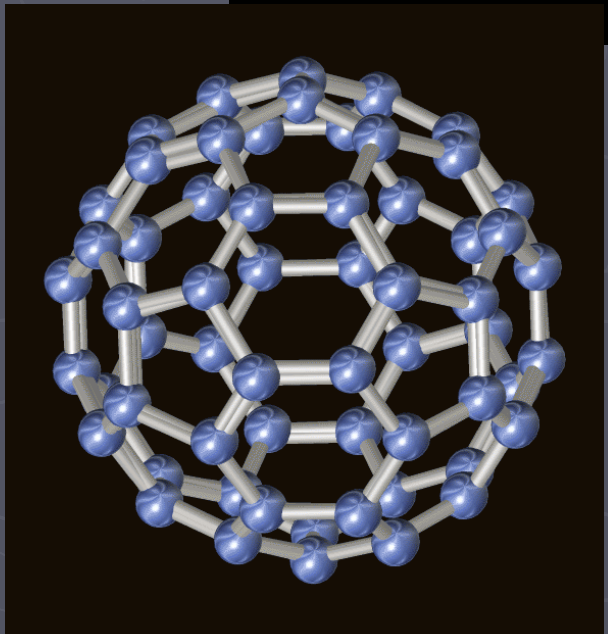




Carbon Nanotube

50,000 times Thinner than Human hair





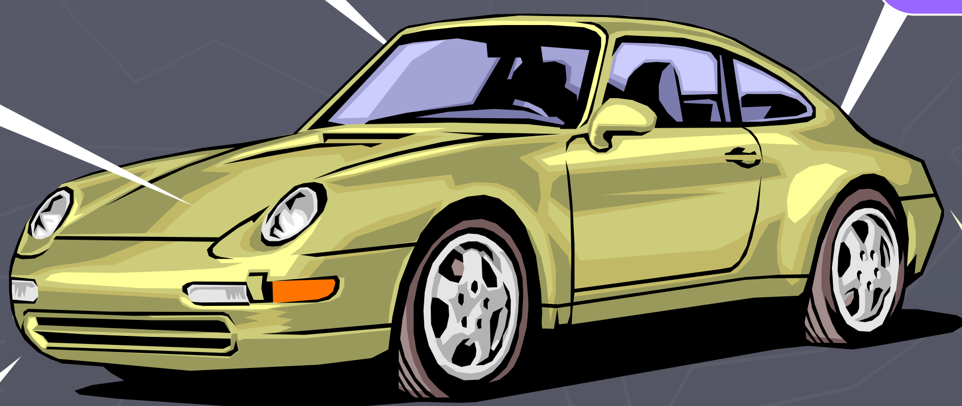
Buckyball

FUTURE AUTOMOBILE

Nano-scale metal oxide ceramic catalysts to almost eliminate emissions

Carbon nanotubes in windshields & frames to make them strong & lightweight

Nano-powders in paints for high gloss & durability



Nano polymer composites for lightweight high resistance bumpers

Fuel cells with nano-catalysts and membrane technologies

NANOMATERIALS IN CURRENT CONSUMER PRODUCTS

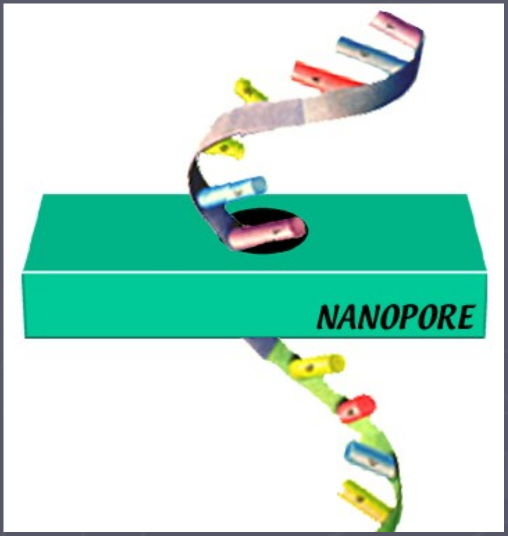
Cosmetics, sunscreens
Containing zinc oxide and
Titanium oxide
nanoparticles

Carbon nanotubes

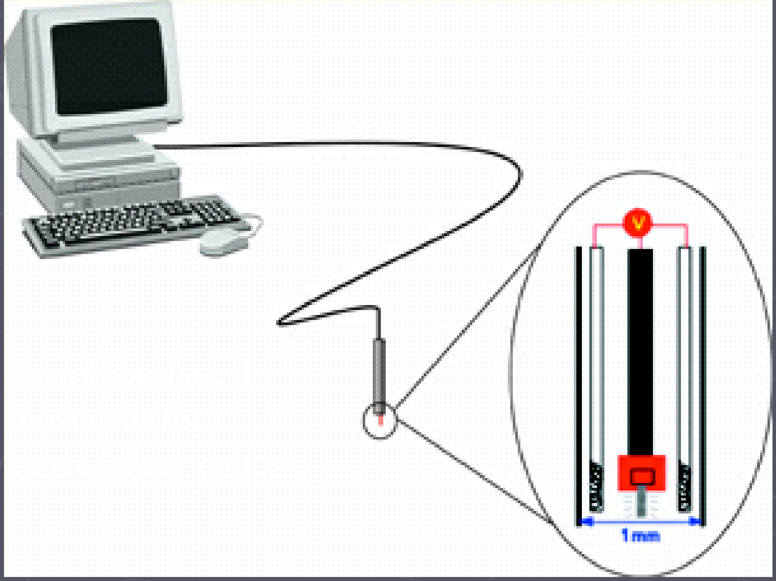
Nano polymer
Composites for stain
Resistant clothing

HEALTH AND MEDICINE

- Expanding ability to characterize genetic makeup will revolutionize the specificity of diagnostics and therapeutics
  - Nanodevices can make gene sequencing more efficient



- Effective and less expensive health care using remote and in-vivo devices



- New formulations and routes for drug delivery, optimal drug usage

- More durable, rejection-resistant artificial tissues and organs

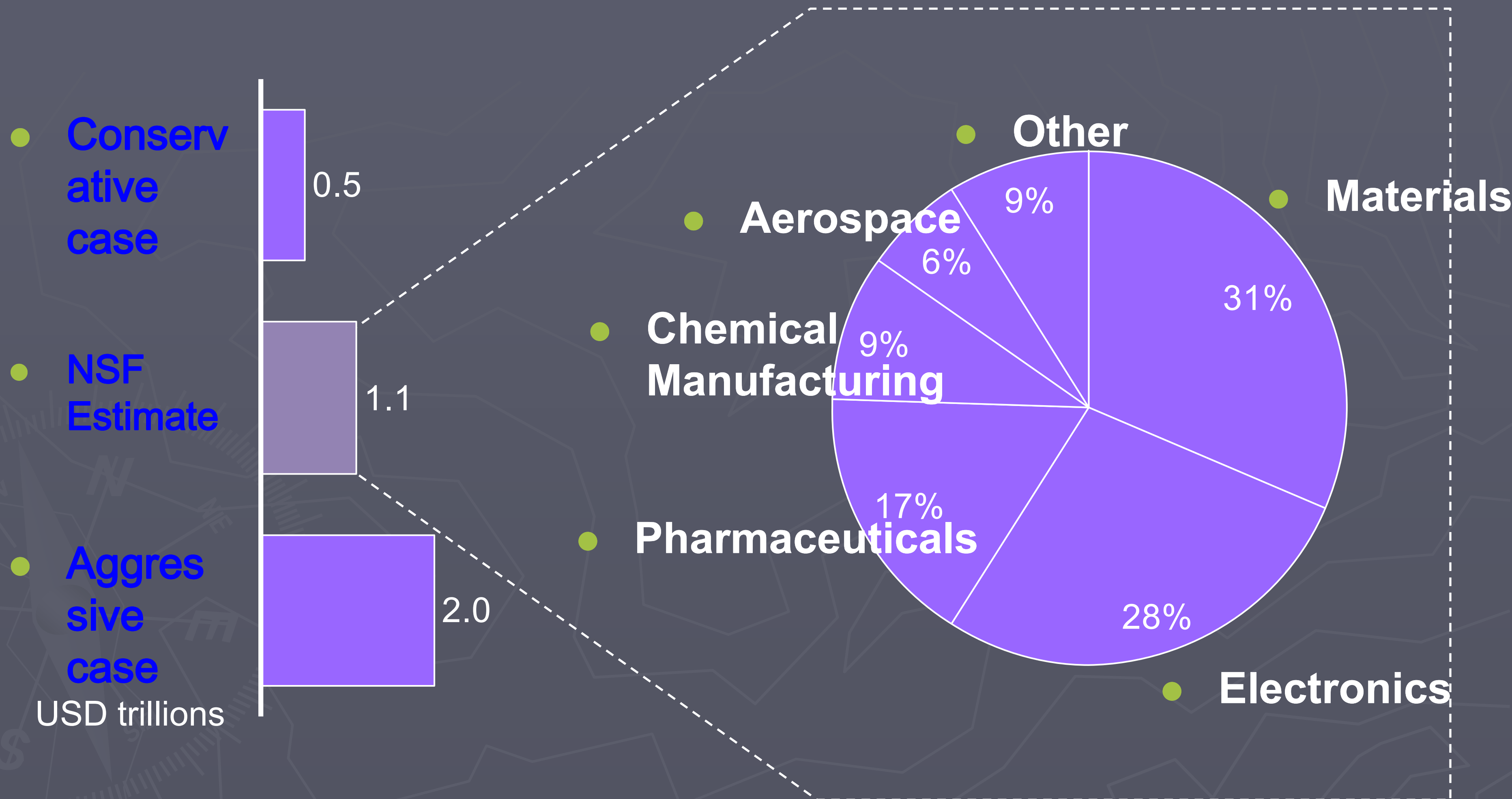
- Sensors for early detection and prevention

SECURITY

- Very high sensitivity, low power sensors for detecting chem/bio/nuclear threats
- Light weight military platforms, without sacrificing functionality, safety and soldier security
  - Reduce fuel needs and logistical requirements

- Reduce carry-on weight of soldier gear
  - Increased functionality per unit weight

ESTIMATES OF THE POTENTIAL MARKET SIZE



Nanotechnology related goods and services – by 2010-2015

Source: National Science Foundation

SAFETY OF NANOMATERIALS

- Environmental impact
- Absorption through skin
- Respitory ailments
- Evidence that carbon nanotubes cause lung infection in mice. Teflon nanoparticles smaller than 50 nm cause liver cancer in mice.

AREAS OF RESEARCH

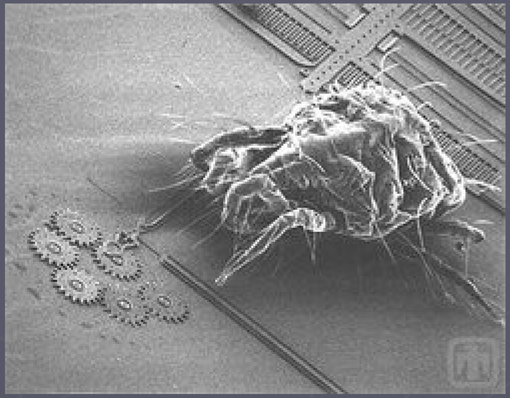
- Molecular Self-Assembly – organic, biological, and composites for molecular recognition, sensors, catalysis.
- Sensors – chemical, biological, and radiological agents;
  - biosensors; gases (O_2, H_2).
- Novel nanomaterial synthesis and characterization.
- Lab-on-chip and Lab-on-a-CD.
- Novel nanomaterials derived from biological molecules – protein nanotubes, viral scaffolds, bacteriophages.
- Quantum mechanical modeling of nanomaterials.
- Electronic structures and properties of nanoclusters.
- Fluid dynamics in micro- and nano-channels.
- Molecular electronics.
- Toxicity of nanoparticles.

Molecular Nanotechnology

- The term nanotechnology is often used interchangeably with molecular nanotechnology (MNT)
  - MNT includes the concept of mechanosynthesis.
  - MNT is a technology based on positionally-controlled mechanosynthesis guided by molecular machine systems.

Nanotechnology in Field of Electronics

- Miniaturization
- Device Density



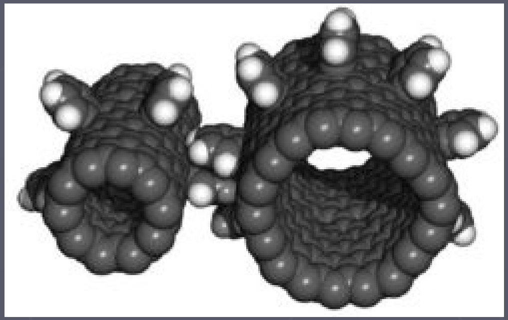
History

- Richard Feynman
  - 1959, entitled '*There's Plenty of Room at the Bottom*'
  - Manipulate atoms and molecules directly
  - 1/10th scale machine to help to develop the next generation of 1/100th scale machine, and so forth.
- As things get smaller, gravity would become less important, surface tension molecule attraction would become more important.

History

- Tokyo Science University professor Norio Taniguchi
  - 1974 to describe the precision manufacture of materials with nanometre tolerances.
- K Eric Drexler
  - 1980s the term was reinvented
  - 1986 book *Engines of Creation: The Coming Era of Nanotechnology*.
  - He expanded the term into *Nanosystems: Molecular Machinery, Manufacturing, and Computation*

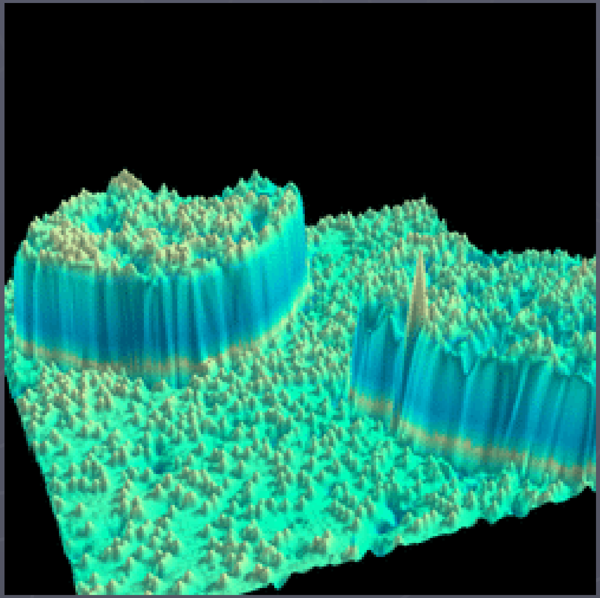
Nanomaterial and Devices



- Small Scales
  - Extreme Properties
  - Nanobots

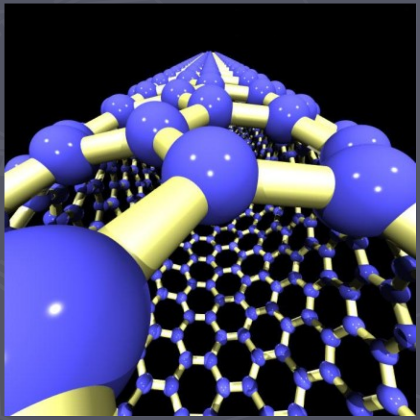
Self-Assemble

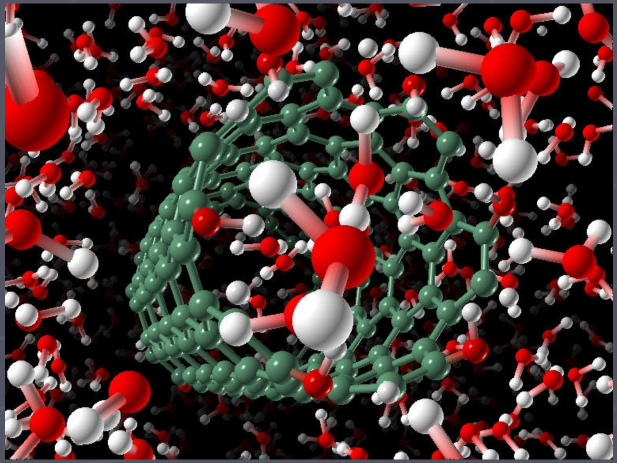
- Nanodevices build themselves from the bottom up.
- Scanning probe microscopy
  - Atomic force microscopes
  - scanning tunneling microscopes
  - scanning the probe over the surface and measuring the current, one can thus reconstruct the surface structure of the material



Current Nanotechnology

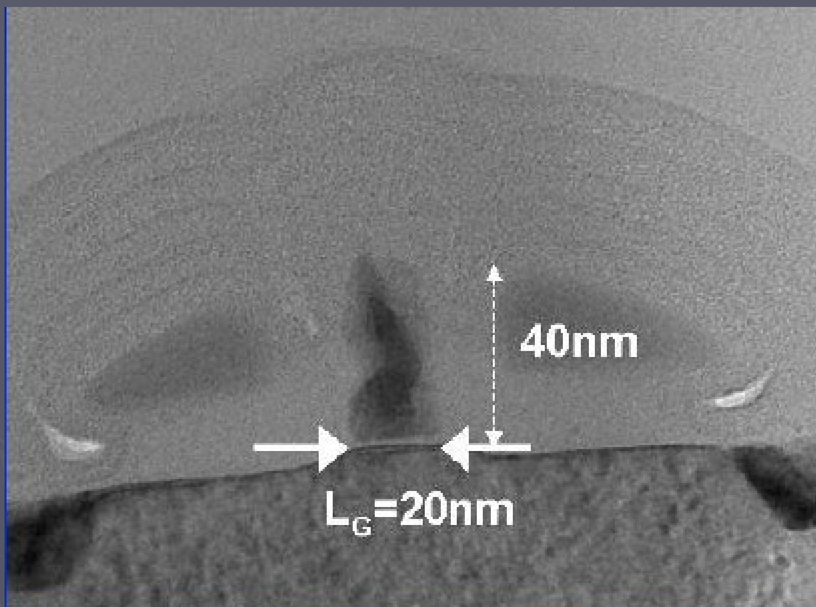
- Stanford University
  - extremely small transistor
  - two nanometers wide and regulates electric current through a channel that is just one to three nanometers long
  - ultra-low-power





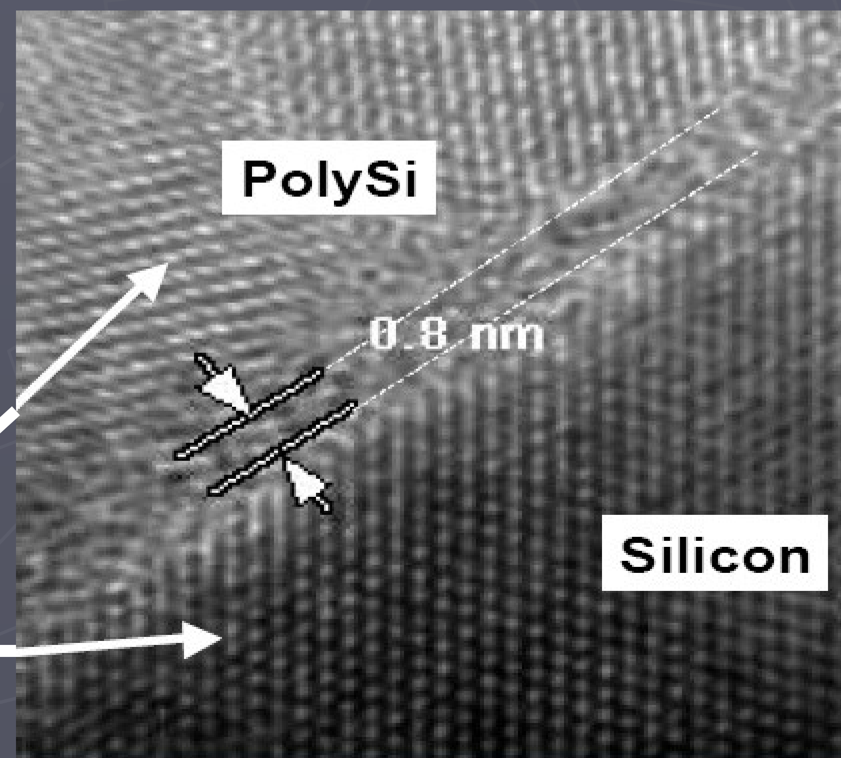
Intel

- processors with features measuring 65 nanometers



20 nanometer transistor

Gate oxide less than 3 atomic layers thick



Atomic structure

Plasmons

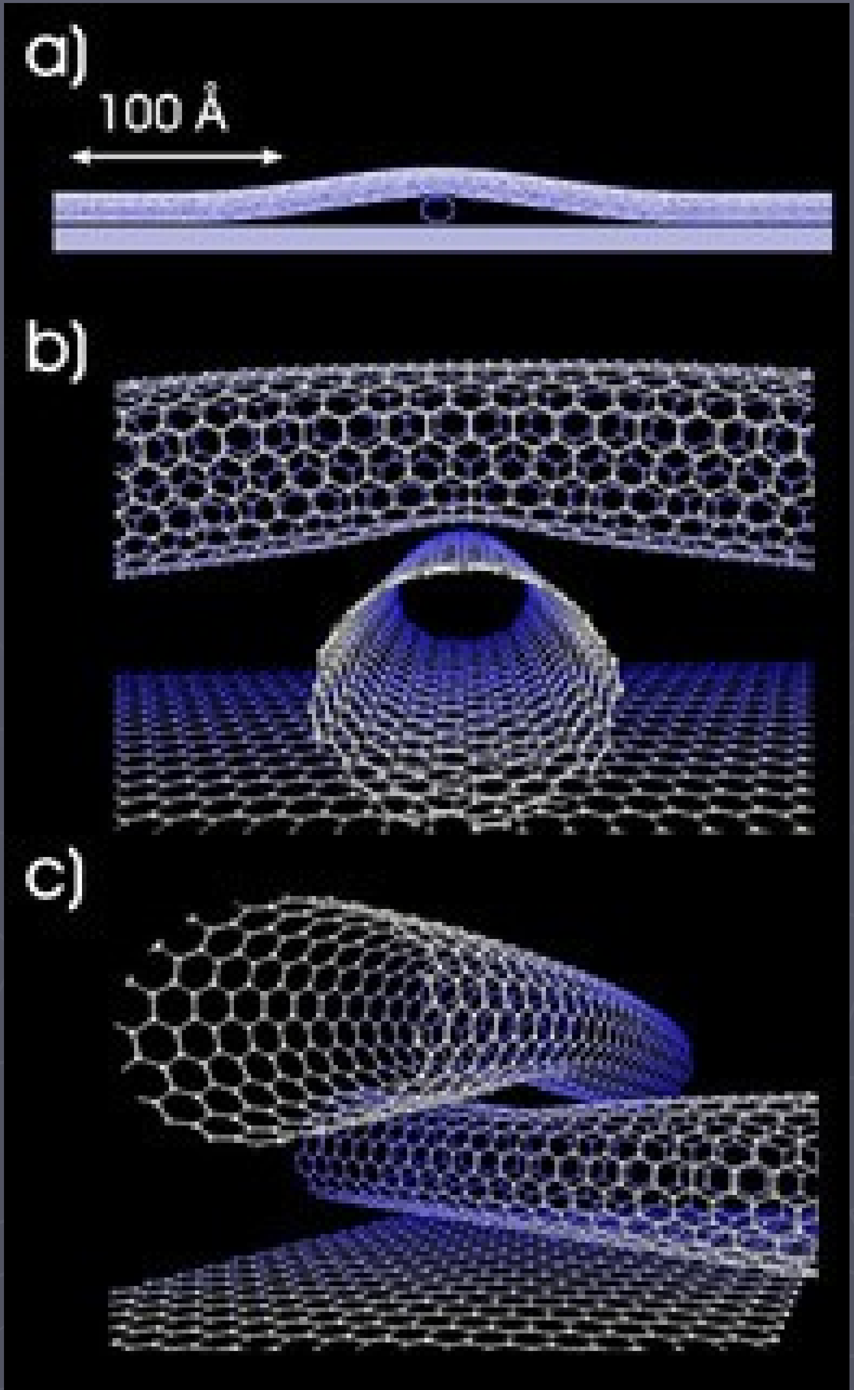
- Waves of electrons traveling along the surface of metals
- They have the same frequency and electromagnetic field as light.
- Their sub-wavelength require less space.
- With the use of plasmons information can be transferred through chips at an incredible speed

Nanomaterial modeling and simulation types

- Carbon Nanotubes

Carbon Nanotubes

- What are they?
  - Carbon molecules aligned in cylinder formation
- Who discovered them?
  - Researchers at NEC in 1991
- What are some of their uses?
  - Minuscule wires
  - Extremely small devices

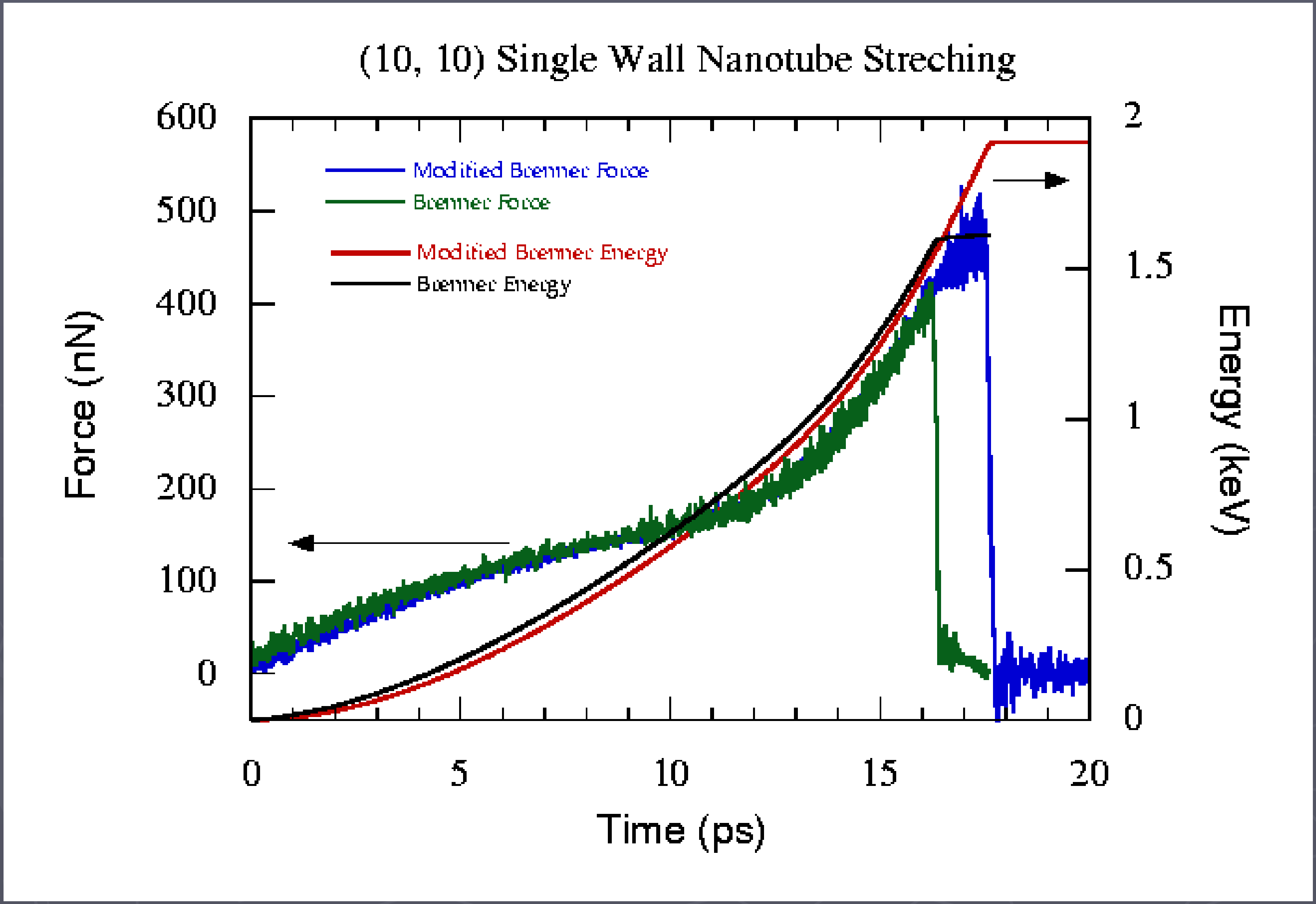

a)
100 Å
b)
c)

Carbon Nanotubes

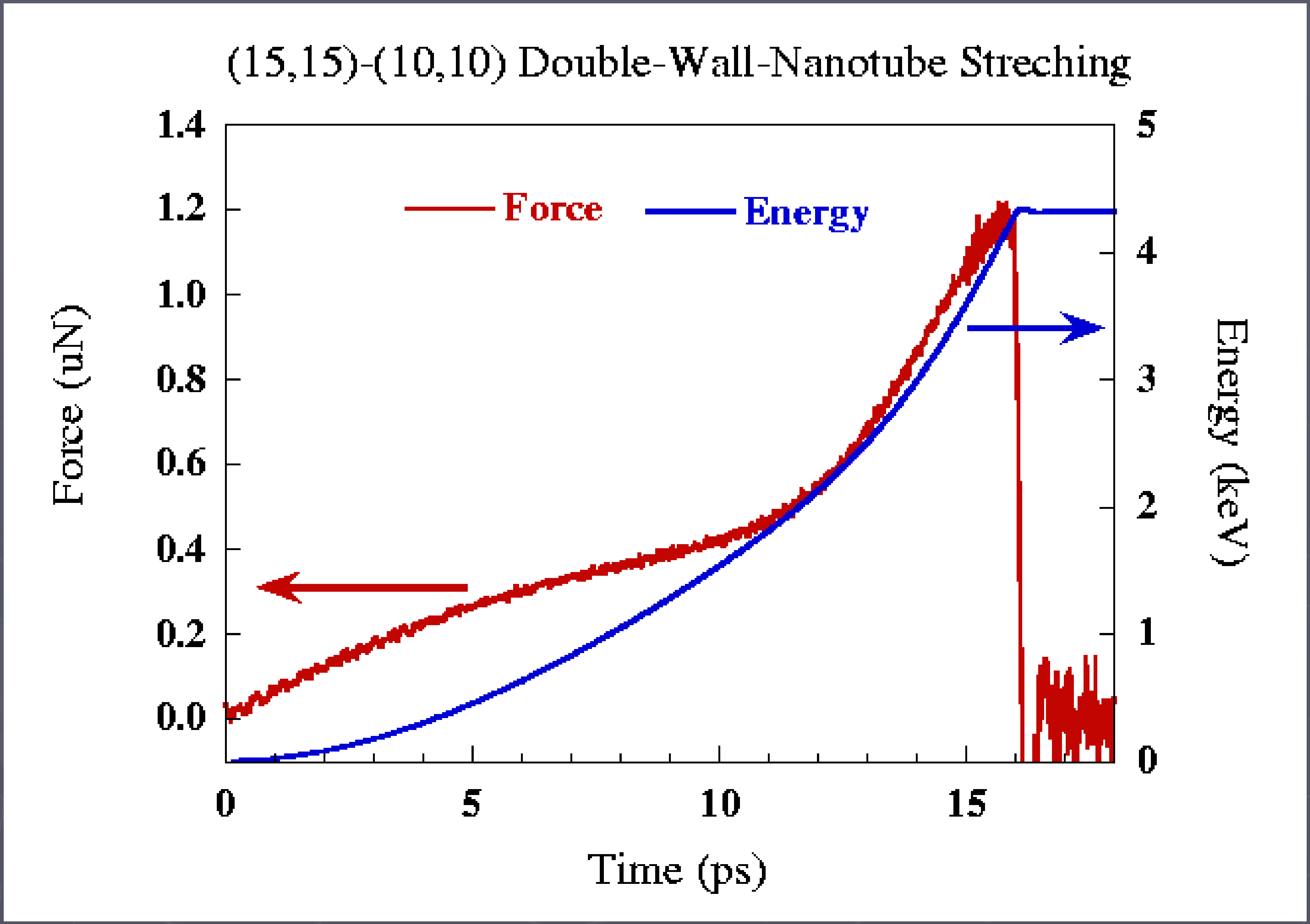
- $$\bar{B}_{ij} = \frac{B_{ij} + B_{ji}}{2} + F_{ij}\left(N_i^{(t)}, N_j^{(t)}, N_{ij}^{conj}\right). \qquad (5)$$
- $$V^{tot} = \sum_i \sum_{j>i} \left[V_{ij}^{B} + P_{ij} V_{ij}^{NB}\right], \qquad (6)$$
  - total potential of a system
- $$P_{ij} = f(V_{ij}^{B}, V_{ij}^{B}) \prod_{k \neq i,j} f(V_{ik}^{B}, V_{kj}^{B}), \qquad (7)$$
- $$f(x, y) = \begin{cases} \exp(-\gamma x^2 y^2), & if x < 0 and y < 0 \\ 1, & otherwise \end{cases}. \qquad (8)$$
  - Adds the NB contribution
- $$F_{\alpha\beta} = -\frac{\partial V^{tot}}{\partial r_{\alpha\beta}}. \qquad (9)$$
  - Force of interaction

Carbon Nanotubes

- $$V_{ij}^{NB} = \epsilon_0 \left[\left(\frac{\sigma}{r_{ij}} \right)^{12} - 2 \left(\frac{\sigma}{r_{ij}} \right)^{6} \right]. \qquad (10)$$
  - Leonard – Jones potential with von der Waals interaction
- $$\Lambda(T) = \frac{V}{k_B T^2} \int_0^\infty dt \, \langle \vec{j}(t) \vec{j}(0) \rangle, \qquad (11)$$
  - Geen - Kudo relation
- $$\vec{j}(t) = \frac{d}{dt} \sum_i \vec{r}_i(t) h_i(t), \qquad (12)$$
  $$h_i(t) = \frac{1}{V} \left(\frac{m_i v_i^2}{2} + \frac{1}{2} \sum_j u_{ij} \right). \qquad (13)$$



(10, 10) Single Wall Nanotube Streching
Modified Brenner Force
Brenner Force
Modified Brenner Energy
Brenner Energy
Force (nN)
Energy (keV)
Time (ps)
600
500
400
300
200
100
0
2
1.5
1
0.5
0
0
5
10
15
20



(15,15)-(10,10) Double-Wall-Nanotube Streching
Force
Energy
Force (uN)
Energy (keV)
Time (ps)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
5
4
3
2
1
0
0
5
10
15