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Nanoscale Assembly  Functioning Device
What is Nanotechnology?

Function: noun
Date: 1974

: the art of manipulating materials on an atomic or molecular scale especially to build microscopic devices

There's Plenty of Room at the Bottom, December 29th 1959
Richard Feynman

I would like to describe a field, in which little has been done, but in which an enormous amount can be done in principle… Furthermore, a point that is most important is that it would have an enormous number of technical applications.

What I want to talk about is the problem of manipulating and controlling things on a small scale.
What is Nanotechnology?

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There's Plenty of Room at the Bottom, December 29th 1959
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…And it turns out that all of the information that man has carefully accumulated in all the books in the world can be written in this form in a cube of material one two-hundredth of an inch wide--- which is the barest piece of dust that can be made out by the human eye.

So there is plenty of room at the bottom!
How big is a Nanometer?

1 Meter = 1000 millimeters

Human Hand

Mark C. Hersam Northwestern University
How big is a Nanometer?

$1 \text{ mm} = 10^4 \text{ micrometers}$

White blood cell

Chromosome
How big is a Nanometer?

1 μm = 1000 Nanometers

Nanoscale Phenomena reveals itself at 100 → 1 nm length
How big is a Nanometer?
How big is a Nanometer?
How small can we make something?
Materials transform Culture

Stone tools
2,000,000 BCE

Oldowan tools

Copper and Bronze tools and jewelry
3,000 – 2,000 BCE
Materials transform Culture

Iron tools and weapons
~1,500 BCE

Iron and Carbon make Steel
1,300 BCE – industrial revolution

Damascus Steel is very strong and resilient
The steel of Damascus blades, which were first encountered by the Crusaders when fighting against Muslims, had features not found in European steels — a characteristic wavy banding pattern known as damask, extraordinary mechanical properties, and an exceptionally sharp cutting edge.


Single walled carbon nanotubes were found in Damascus Steel
Materials transform Culture

Single walled carbon nanotubes were first characterized by Iijima in 1991

- Strongest material  Young's moduli= ~1TPa  (stainless steel = 0.2 TPa)

- Highest thermal conductivity
  1000X better than metals

- Highest electrical conductivity
  10X better than Cu
Nanostructured Carbon

Graphite to graphene

SWNT

C$_{60}$

Graphene – Nobel Prize 2010

Geim and Novoselov

1991

Iijima

C$_{60}$ – Nobel Prize 1996

Curl, Kroto, and Smalley
Technology from Nano-Carbon

Pulling Carbon nanotubes into yarns and sheets


Dr. David S. Lashmore, Nanocomp Technologies
Nanotechnology depends on processing

DLVO Theory
Potential energy of interacting parallel cylinders

\[ \varepsilon(x) \approx \frac{64nkT}{\kappa} \gamma^2 e^{-2\kappa} - \frac{H_{121} L}{12\sqrt{2} x^{3/2}} \]

[coagulant] << CCC
Nanotechnology depends on processing

DLVO Theory

Potential energy of interacting parallel cylinders

Electrical Double layer (EDL) Repulsion

\[ \varepsilon(x) \approx \frac{64nkT}{\kappa} \gamma^2 e^{-2\kappa x} - \frac{H_{121} L}{12\sqrt{2} x^{3/2}} \]

vdW attraction

Condition for rapid aggregation

\[ \varepsilon(x) = 0 \quad \frac{\partial \varepsilon(x)}{\partial x} \bigg|_{x=1/\kappa} = 0 \]

Distance between Spheres (m)
Nanotechnology depends on processing

DLVO Theory

Potential energy of interacting parallel cylinders

Electrical Double layer (EDL) Repulsion

\[ \varepsilon(x) \approx \frac{64nkT}{\kappa} \gamma^2 e^{-2\kappa x} - \frac{H_{121} L}{12\sqrt{2} x^{3/2}} \]

[coagulant] > CCC
Novel Actuator – Force transducer
Vertically aligned SWNT arrays grown on micro-cantilevers

COMSOL modeling of electrostatically driven actuation

Mike Forney Ph.D. Nanoscale Science
mforney1@gmail.com
03/30/2010
(J.C. Poler Advisor)
New processes for old materials

When the size of a material is reduced to the nanoscale, its optical, electronic, magnetic, chemical, catalytic and mechanical properties can be affected by the particle’s size and or shape.
Nanotechnology is NOT new!

The optical properties of gold and silver particles are affected by their size and shape.

Lycurgus Cup ~300 CE

Chad Mirkin Northwestern University
Nanotechnology depends on processing

<table>
<thead>
<tr>
<th>Coagulant</th>
<th>Valence Charge</th>
<th>CCC (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaCl$_2$</td>
<td>+2</td>
<td>3.4 (± 0.2) x 10$^{-4}$</td>
</tr>
<tr>
<td>Monomer</td>
<td>+2</td>
<td>1.2 (± 0.2) x 10$^{-7}$</td>
</tr>
<tr>
<td>Dimer</td>
<td>+4</td>
<td>3.2 (± 0.2) x 10$^{-8}$</td>
</tr>
</tbody>
</table>
Technology from Nano-Gold

Functionalized Au-NPs can be used for sensing!

Pregnancy test

Pregnancy hormone hGC detected: Sensitive and reproducible!

Technology from Nano-Gold

Functionalized Au-NPs can be used for detect cancer!

Chad A. Mirkin et al.  PNAS  November 3, 2009  vol. 106  no. 44  18437–18442

Very sensitive PSA detection
Economics of miniaturization is driving Nanotechnology.

If you make it smaller, you can make more of it

If you make it smaller you can make it less expensive

If you make it smaller you use fewer natural resources

If you make it smaller you can make it more functional

If you make it small enough, you can make something completely NEW
Economics of miniaturization is driving Nanotechnology.
Computing performance has increased exponentially as device dimensions reach nanoscale.

1st Transistor
Bell Laboratories, 1947
John Bardeen
Walter Brattain
William Shockley

>50 million transistors running at ~3 million calculations per second
Computing performance has increased exponentially as device dimensions reach nanoscale.

IBM claims smallest working silicon transistor

**Diagram Labels:**
- **Region**
  - Gate: Polysilicon
  - Spacers: Dielectric
  - RSD: Silicon
  - Channel: Silicon
  - Box: Oxide

**Notations:**
- $T_{Si} = 4$–8 nm
- $L_{gate} = 6$ nm

*RSD stands for “Raised Source Drain”*
*Box stands for “Buried Oxide”*
Can Nanotechnology lead to new energy production?

Current worldwide annual energy consumption = ~4 TeraWatts (4 million Megawatts!)

Assuming no new interventions and current energy growth the total worldwide annual energy consumption in 2050 will be ~ 10 TeraWatts

How do we generate all this needed energy without destroying the environment?
Currently available Photovoltaic technology can do the job.

Currently available Photovoltaic technology is very expensive.

Boxes showing land area requirements to produce 3 TW or 20 TW of photovoltaic energy at 10% efficiency.
Currently available Photovoltaic technology is very expensive.

Bulk Materials like single crystal Silicon are costly and not very efficient

Nanoscale Materials are far more efficient
And can be produced less expensively.

~$3.00 / Watt

~$0.20 / Watt

Nanostructured Materials have advantages over Bulk solids

Bulk Materials
Only absorb light at the surface

Nanostructured Materials have a very high surface area and can be tuned to absorb many colors of light
Can Nanotechnology help the Environment?

Nanoscale Iron effectively reduces chemical contamination from ground water

\[ \text{Fe(nano)} + \text{Bad molecule} \rightarrow \text{Fe}^{2+} + 2e^- \rightarrow \text{Not so bad molecule} \]
Can Nanotechnology help the Environment?

Cr(VI) Reduction
COPR Samples from an industrial site in NJ
Aqueous Cr(VI) - 43.38 mg/L, Soil CrT - 7,725 mg/kg, pH = 11

Wei-xian Zhang, Lehigh University

Chlorinated Methanes
Chlorinated Ethenes
Chlorinated Ethanes
Chlorinated Benzenes
PCBs
Lindane (HCHs)
Cr(VI)
Pb(II)
Ni(II)
Cd(II)
Perchlorate
Arsenic
Nanoscale Science; what do we know and where do we go from here?

Materials exhibit novel properties at the nanoscale because:

1. When particles get very small, they have very few defects!

Bulk Graphite

Single Walled Carbon Nanotube
Nanoscale Science; what do we know and where do we go from here?

Materials exhibit novel properties at the nanoscale because:

2. When particles get very small, they have very high surface areas!

\[ N = 4096 \]
\[ n = 1352 \]

Surface atoms have more energy!

\[ N = 4096 \]
\[ n = 3584 \]
Nanoscale Science; what do we know and where do we go from here?

Materials exhibit novel properties at the nanoscale because:

3. When particles get very small, they are described by Quantum Mechanics and Quantum size confinement

- Electrons confined to 2D
- Electrons confined to 1D
- Electrons confined to 0D
Development of New Disciplines is Natural

- Geneticists
- Physicists
- Chemists
- Metallurgy
- Ceramics
- Polymers
- Algorithm theory
- Mathematical logic
- Biology
- Chemistry
- Physics
- Engineering

New discovery and manipulation of DNA → Molecular Biology
New Processing and Characterization Methods → Materials S&E
New Computing Technology → Computer Science
New Nanoscale experimental Methods → Nanoscale S&E
PSW: You made a comment in your talk at the Summit about the disappearance of disciplines with scale. Can you capture that thought for our readers?

Heine Rohrer: The nanoscale is the bifurcation point where the disciplines develop. That’s where materials have their properties and a cluster of 10 atoms does not yet have the same properties as 100 atoms. That is also where the disciplines emerge, and that’s why nano has to be completely interdisciplinary.

Inter-discipline AND/OR New Discipline?
NANOSCALE SCIENCE is a field of scientific investigation that addresses the development, manipulation, and use of materials and devices on the scale of roughly 1-100 nanometers in length, and the study of phenomena that occur on this size scale. As the highest priority funded science and technology effort since the space race, nanoscale science offers great potential for applications in materials, medicine, optics, electronics, data storage, advanced manufacturing, environment, energy, and national security.

Fundamental Concepts

Educate Students

Incentivize Investment

Develop Novel Nanotechnology

Lower costs and create new markets

Transform Cultures (for the better, we hope!)

www.nanoscalescience.uncc.edu (704) 687-6349
Thank You for your attention!

Questions?

Raith 150
Mag = 200.00 K X

100nm
EHT = 10.00 kV

WD = 6 mm
Signal A

2.24 nm
1.68 nm
1.88 nm
0.88 nm

12°