



Nanotechnology and Materials: Nanotechnology Impact on Materials Properties and Performance

The NACK Center was established at the Pennsylvania State College of Engineering, and is funded in part by a grant from the National Science Foundation.



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Nanotechnology Impact on
Materials Properties and
Performance

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In session for 1 hour, 21 minutes.

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Welcome to NACK's Webinar

Today's Presenter

Penn State University – Materials Science and Engineering



Dr. Allen Kimel

Assistant Professor

Associate Head for Undergraduate Studies

kimel@matse.psu.edu

Poll – Who is Joining us Today?

- A. K-12 Educator
- B. 2yr or Technical College Educator
- C. University Educator
- D. Industry Representative
- E. Other (please type your response in the Chat Box)

NanoScience and Nanotechnology: How the Smallest Building Blocks are Impacting Life Today and Tomorrow

**Dr. Allen Kimel, Assistant Professor
Materials Science and Engineering
Pennsylvania State University**

Overview

- **What is Materials Science and Engineering**
 - **Engineering versus Science**
 - **Example – Turkey Timer**
- **Impact now and in the Future**
 - **Interest in Nanotechnology**
 - **Products**
 - **Research**
- **Questions**

Ceramics in General

- **Bond metal to a non-metal**
- **Ionic and covalent bonding**
- **High stiffness with no toughness**
- **Insulators**
- **High temperature and chemical resistivity**

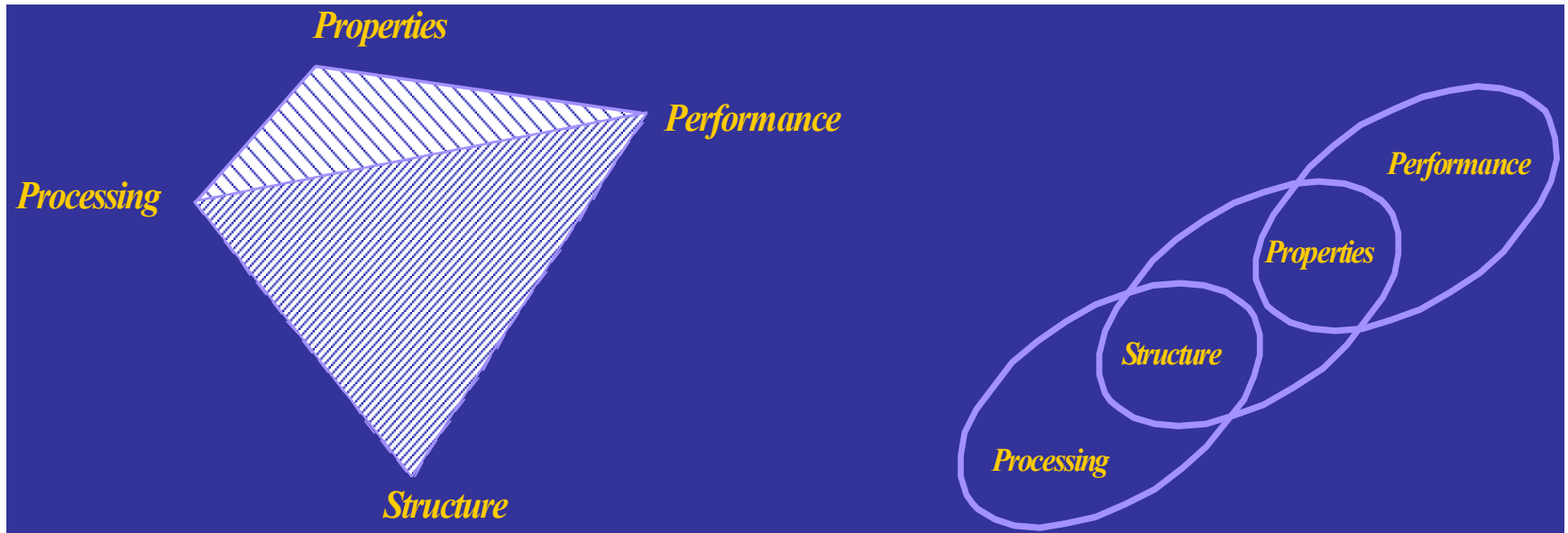
Metals in General

- **Metallic bonding – sharing of electrons**
- **Alloyed with addition of other elements**
- **High strength, tough/ductile**
- **Can engineer stiffness and toughness through both atomistic and microstructural manipulations**
- **Conductors**

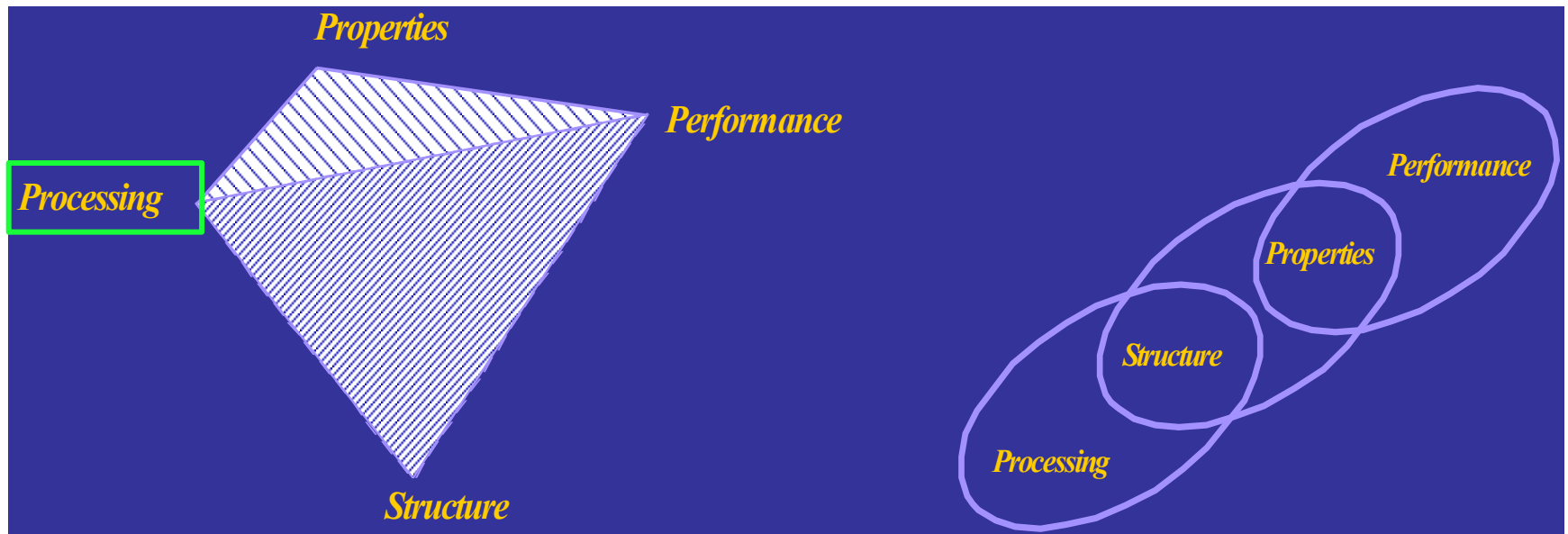
Polymers in General

- **Long carbon chains (does not have to be carbon)**
- **Covalent bonds within chains with covalent and van der Waals bonds between chains**
- **Low stiffness and high ductility/toughness**
- **Low temperature**
- **Performance highly dependent on molecular weight and degree of crystallinity**

THE MATERIALS' SCIENCE TETRAHEDRON

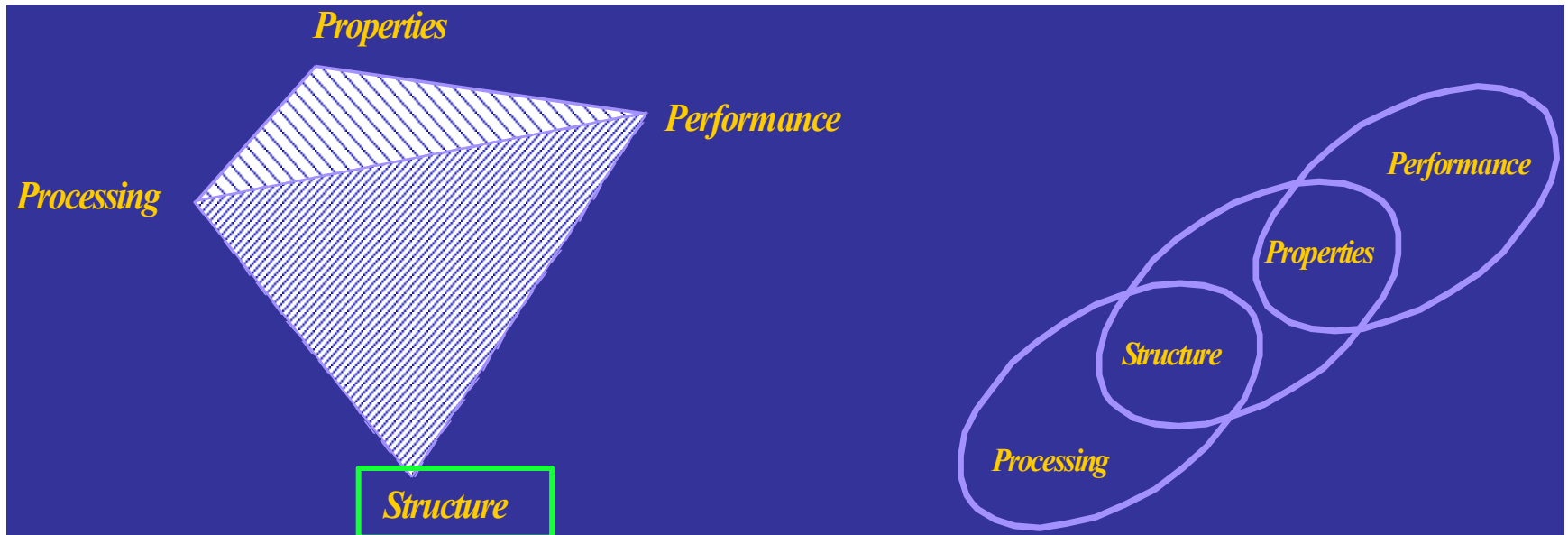


THE MATERIALS' SCIENCE TETRAHEDRON



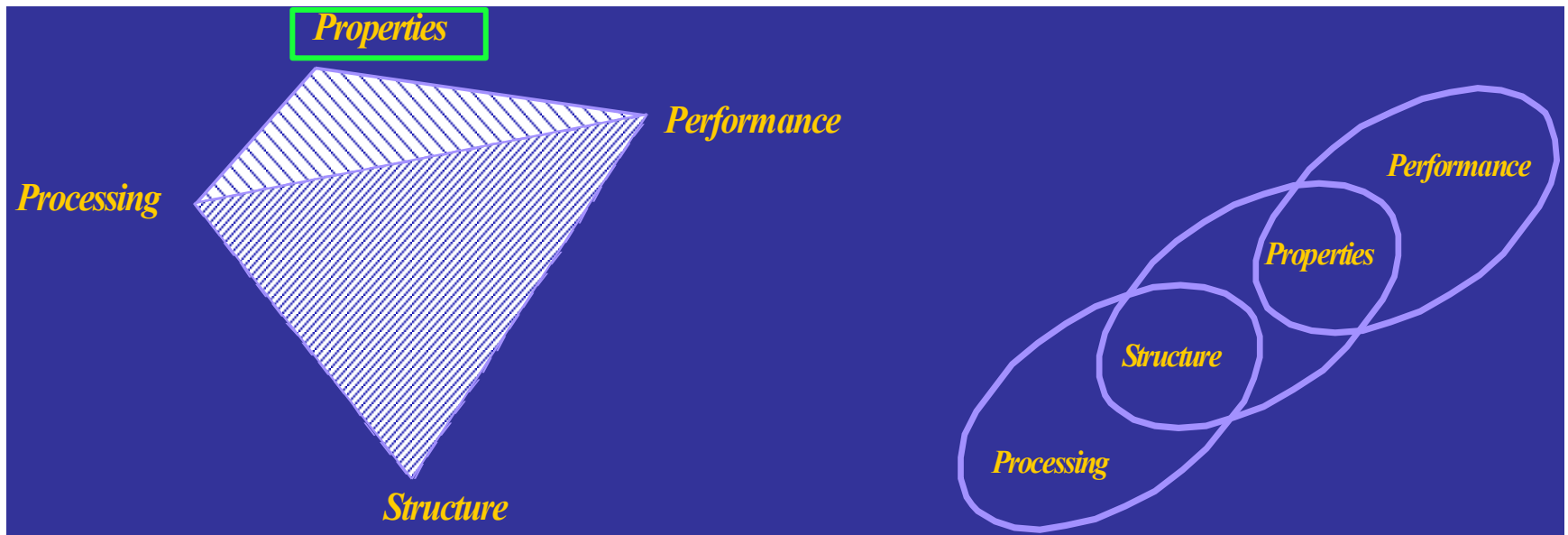
**chemistry, thermodynamics,
kinetics, transport phenomena**

THE MATERIALS' SCIENCE TETRAHEDRON



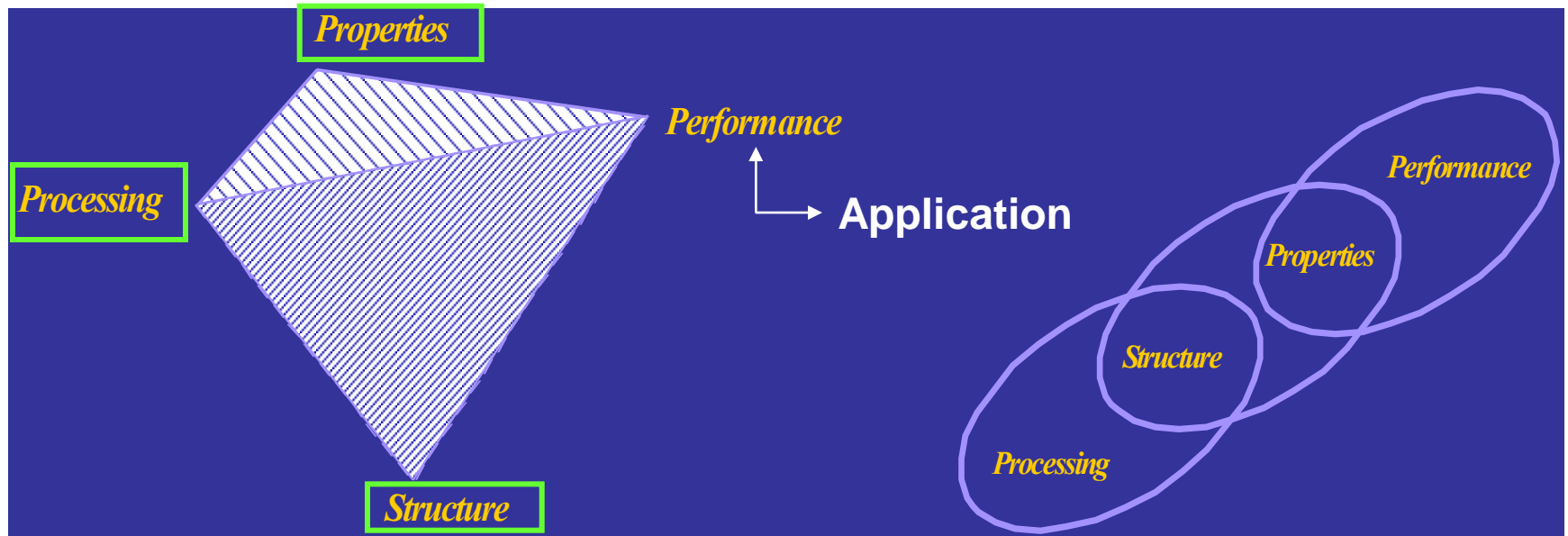
**crystallography, electron and x-ray
diffraction, analytical methods**

THE MATERIALS' SCIENCE TETRAHEDRON



**solid state physics, optics,
electromagnetics, mechanical
properties, chemical stability, etc.**

THE MATERIALS' SCIENCE TETRAHEDRON

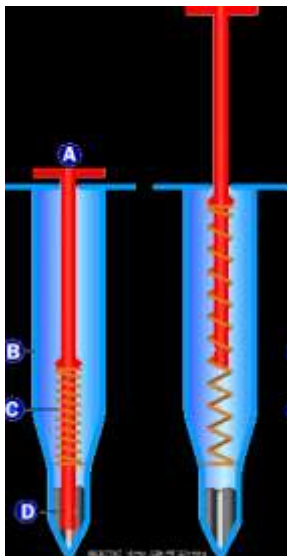
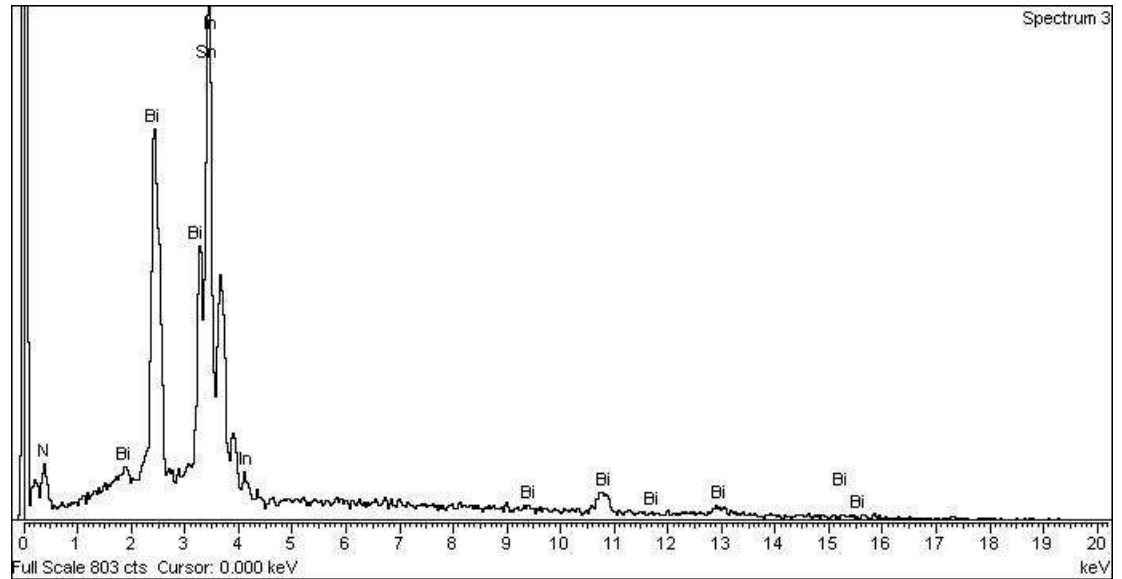
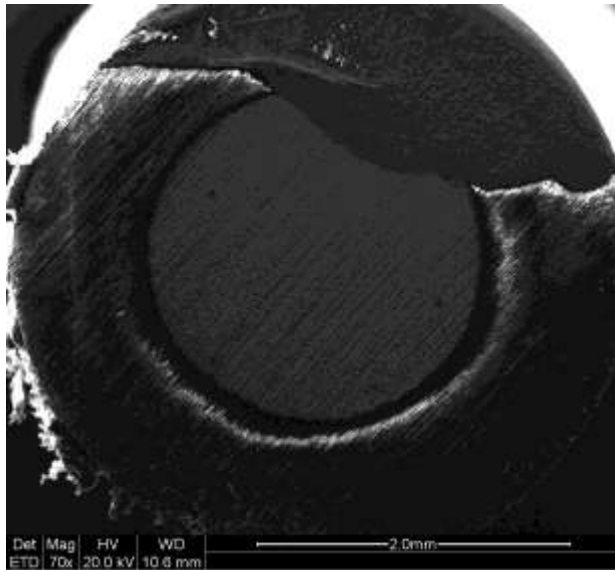


**solid state physics, optics,
electromagnetics, mechanical
properties, chemical stability, etc.**

Engineering versus Science

- **Engineering answers the question how**
- **Science answers the question why**
- **Example: creation of a hard surface to use to hit an object (hammer, golf club, tennis racket, etc.)**
- **Engineering chooses a metal and develops a setup to generate power**
- **Science asks what can we change within the components of the engineered system to exact improved properties for better performance**

Turkey Day Materials Science



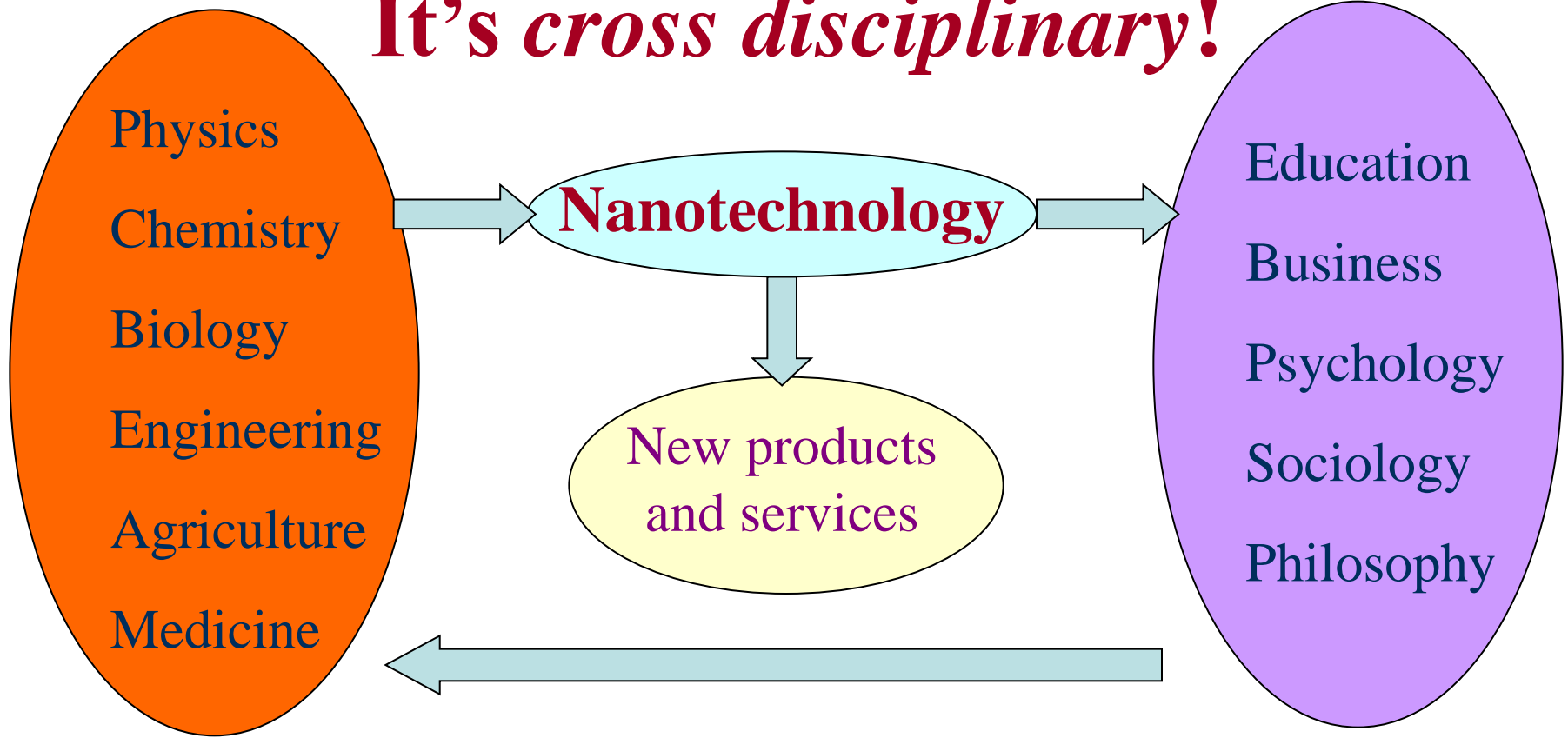
Element	Field's Metal Weight %	Turkey Timer Weight %
Bismuth (Bi)	32.5	32.5
Indium (In)	51	18.7
Tin (Sn)	16.5	48.5
Melting Point Celsius (F)	62 (144)	85 (185)

Nanoscience and Nanotechnology

- **Nano: 10^{-9} meters or 0.000000001 meters**
- **Essentially any material with a defining property determined by a structure at the nanometer scale**
- **Working definition for materials science and engineering is 0.1 – 100 nanometers**

What Makes Nanotechnology Development and Education Challenging and Exciting?

It's cross disciplinary!



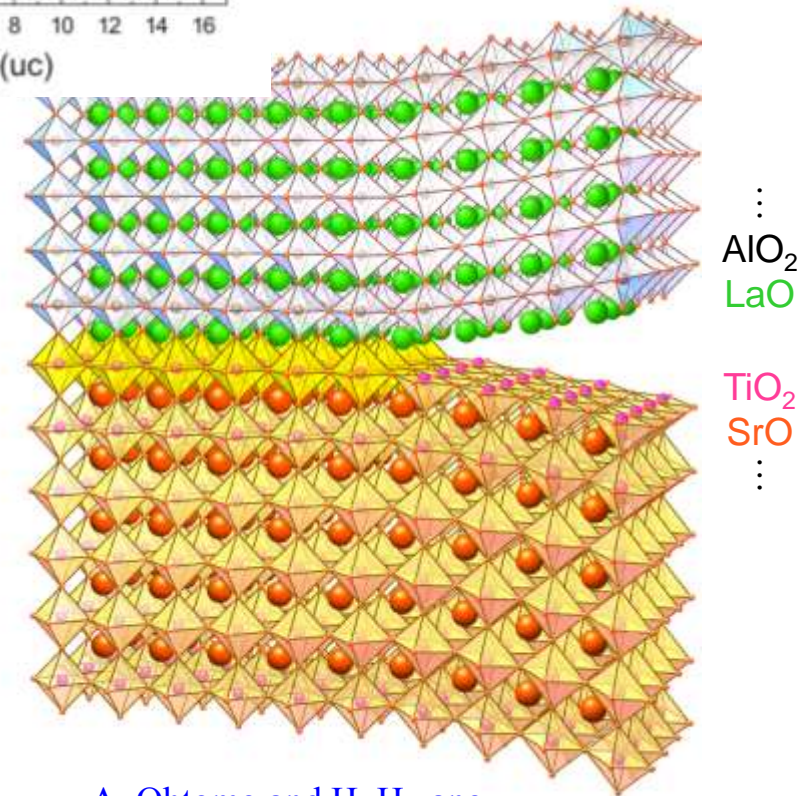
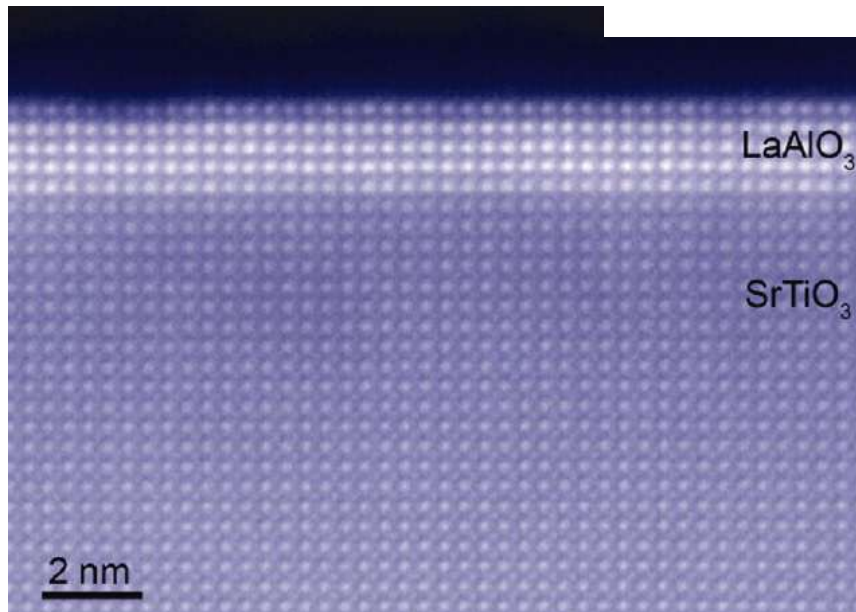
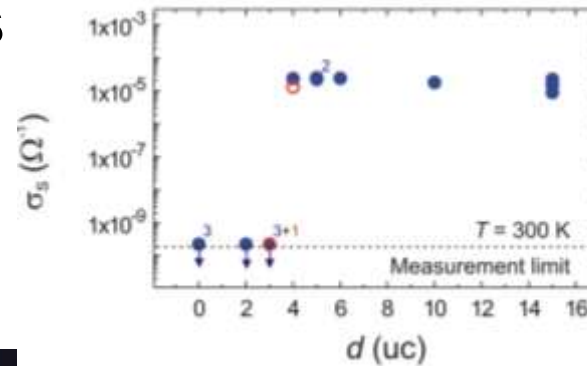
Career Pathways

- **Business**
- **Communications**
- **Human Services**
- **Engineering and Industrial**
- **Science**

Questions?

Please type all questions into the
Chat Box

Surprising phenomena at oxide-oxide interfaces: formation of a 2dimensional electron gas between two bulk insulators

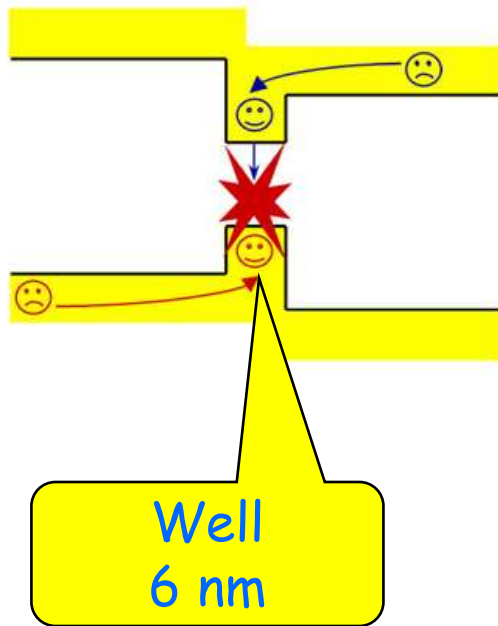


[J. Mannhart^{1,*}](#) and [D. G. Schlom^{2,*}](#)
Science 327, 1607 (2010)

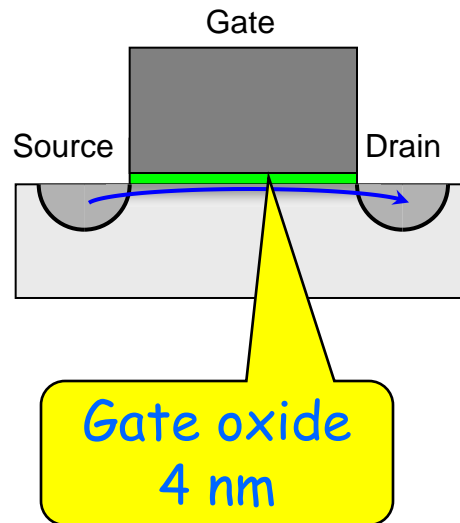
A. Ohtomo and H. Hwang
Nature **427** (2004) 423-426

Nanotechnology on our Desktops

Quantum Well Laser



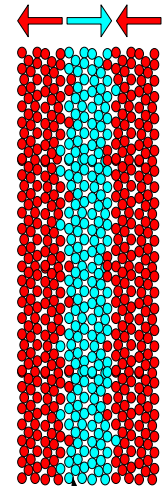
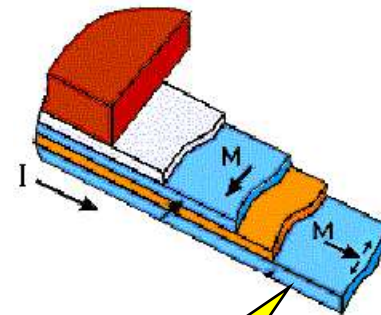
Transistor



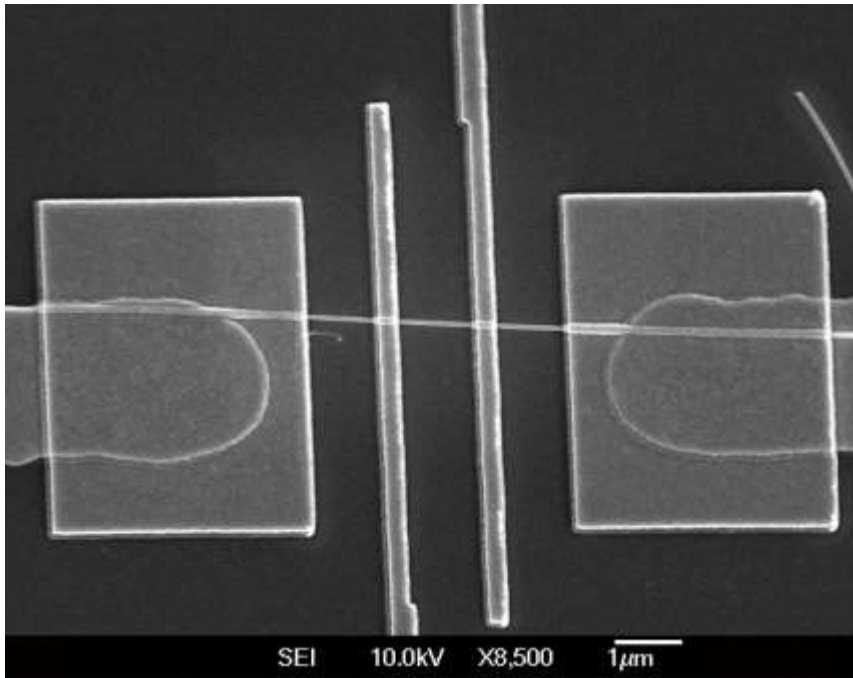
Hard Disk

Sensor

Medium



Semiconductor Nanowires



- Less than 5nm in diameter
- Increase speed of electrons in nanowires – faster computing, improve efficiency of solar cells
- Large surface area attractive for chemical sensing – homeland security

Nano-Sun block

- Keys incorporates nanosized ZnO particles into a cream
- ZnO nanoparticles adsorb UVA and UVB radiation wavelengths
- However, because of the small size of the ZnO particles (around 25 nm) the particles do not scatter visible light
- No white appearance

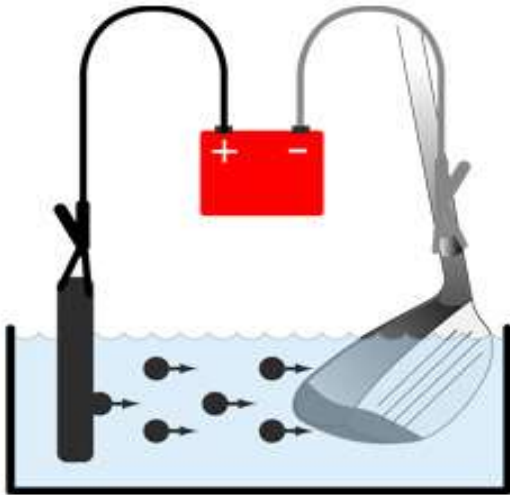


Easton Sports Stealth CNT Bat

- Combines carbon fiber technology with carbon nanotube (CNT) technology
- In between the carbon fibers is a polymer resin containing CNT
- Optimizes stiffness of bat for maximum energy transfer to the ball

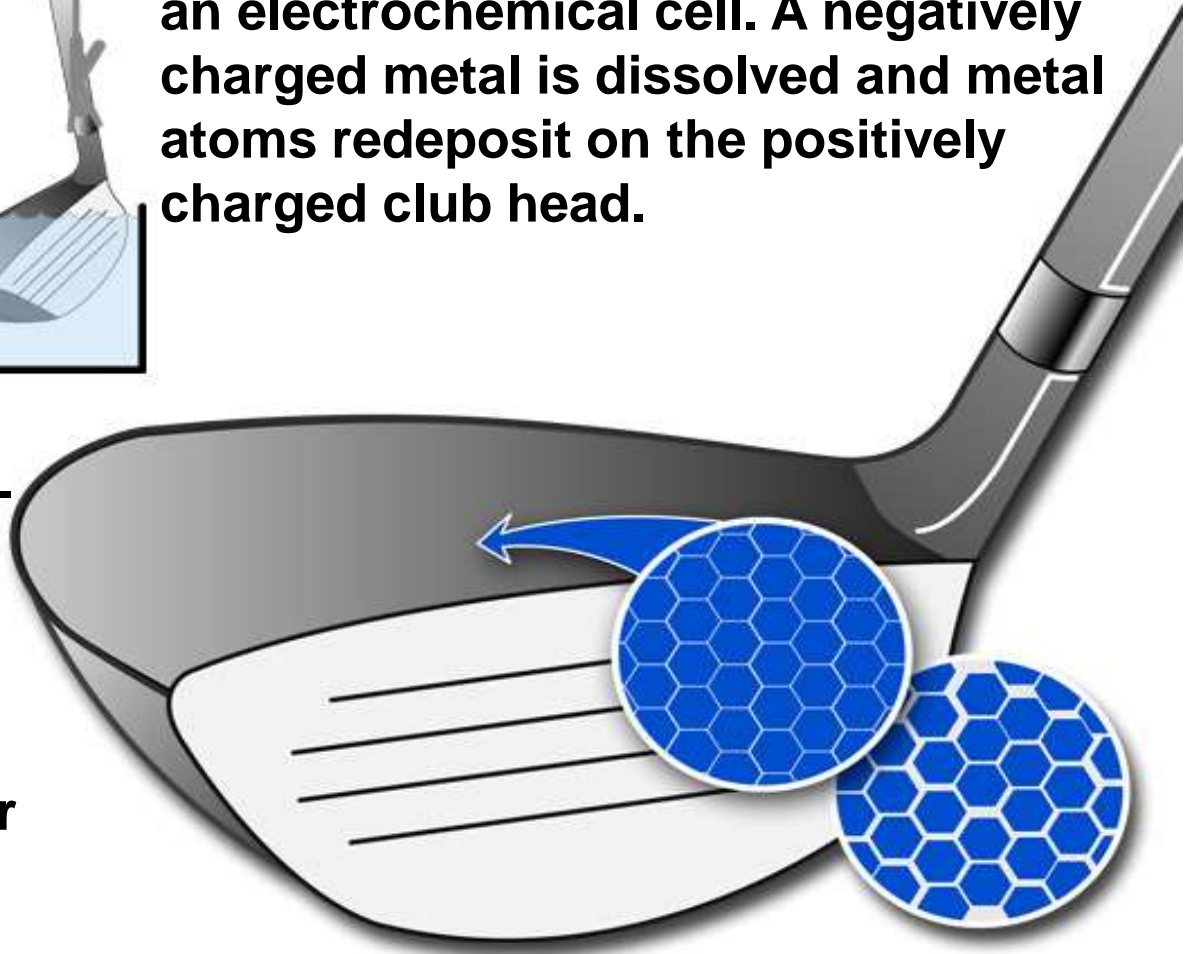


Nanotechnology in Golf



Electrodeposition is performed using an electrochemical cell. A negatively charged metal is dissolved and metal atoms redeposit on the positively charged club head.

Dense layer of a nano-grained metal on the surface of the club head. This leads to a lighter and stronger club face with a bigger “sweet spot”



The Result of Materials Improvements

- Distances are average drive lengths (in yards) for PGA Tour players over the last 25 years
- Note the substantial increase in the last decade (over 25 yards)



NEW TECHNOLOGY has helped golfers increase the distance a ball travels. Here is a look at the increase in PGA Tour driving distance from 1980 to 2004:

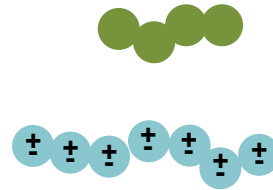
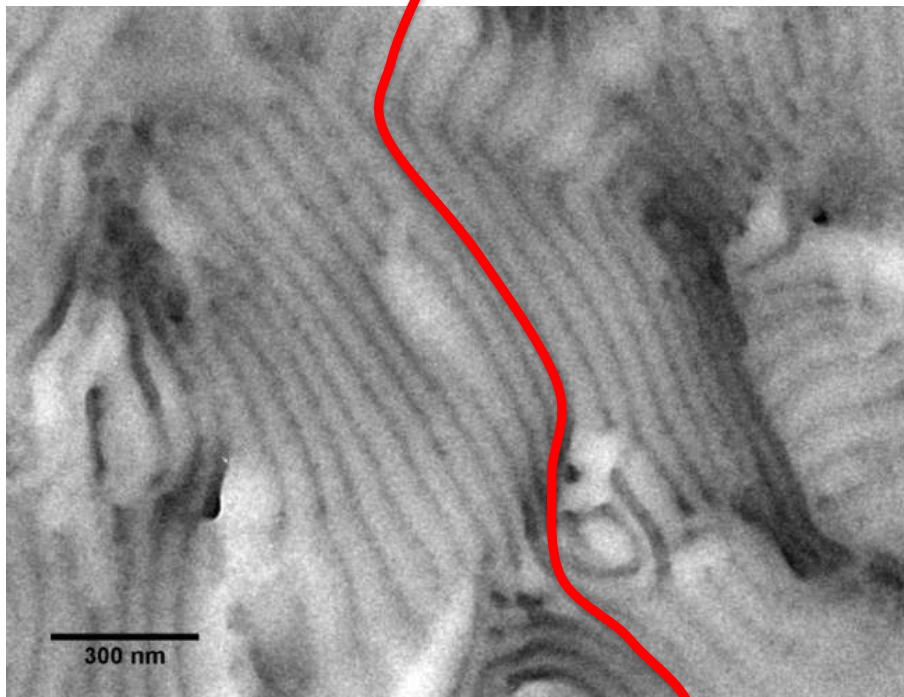
ARC Outdoors - ArcticShield Socks

- Silver is known for its antimicrobial properties
- Attempts have been made to incorporate silver into linen socks via metal threads
- Through the use of silver nanoparticles ARC has incorporated the silver into the polymer fibers
- ARC claims permanent resistance to odor or fungus



Block Copolymer Assemblies to Form Ionic Channels

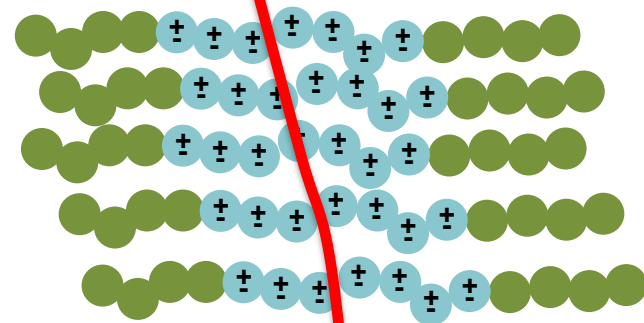
Transmission electron micrograph of a block copolymer with hydrophobic and ionic phases. The ionic phases for channels for transport of ions and water.



Hydrophobic part of the polymer provides mechanical strength.

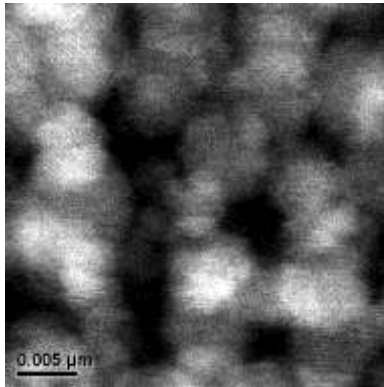
Ionic part of the polymer is hydrophilic and conducts ions and water.

Schematic of the self-assembly of like parts of the block copolymer.

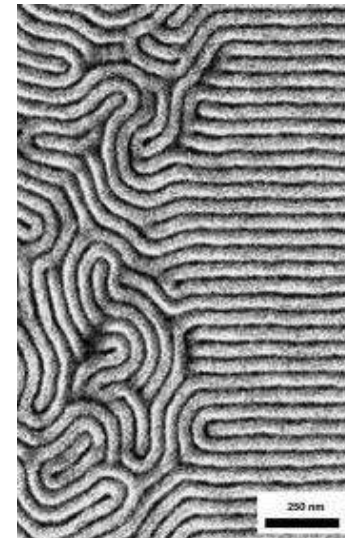


Block Copolymers can Form Many Different Structures

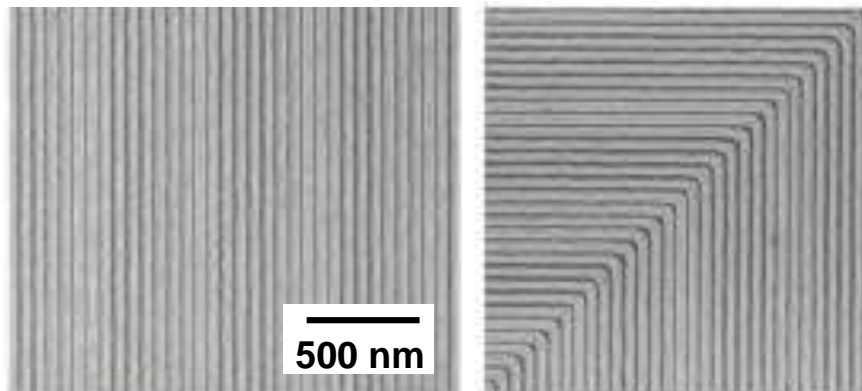
5 nm phases



Selective patterning

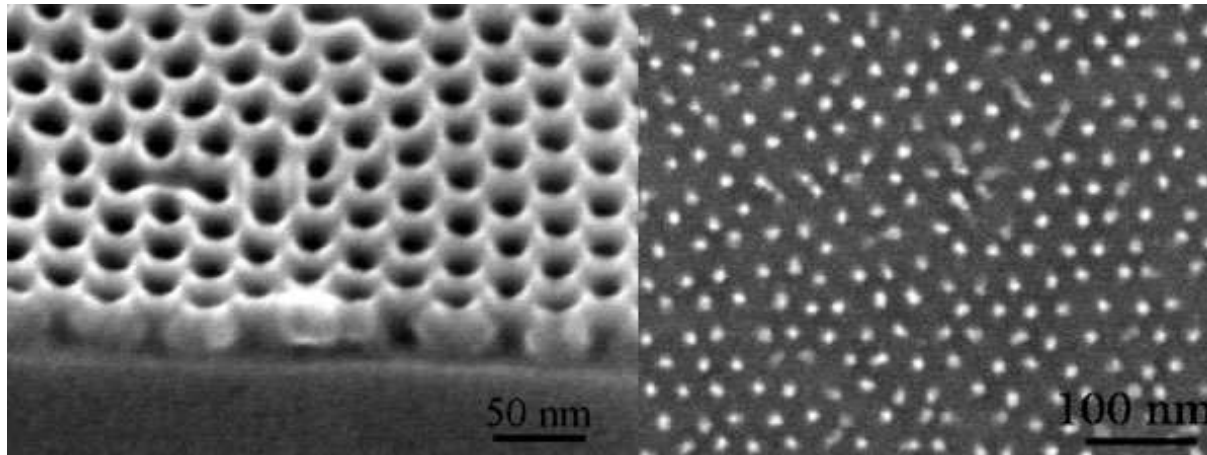


High aspect ratio lines and corners

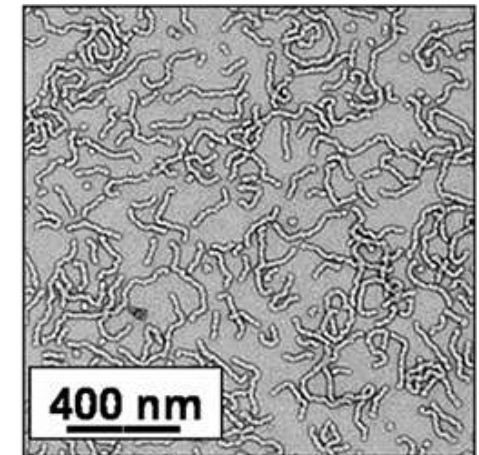


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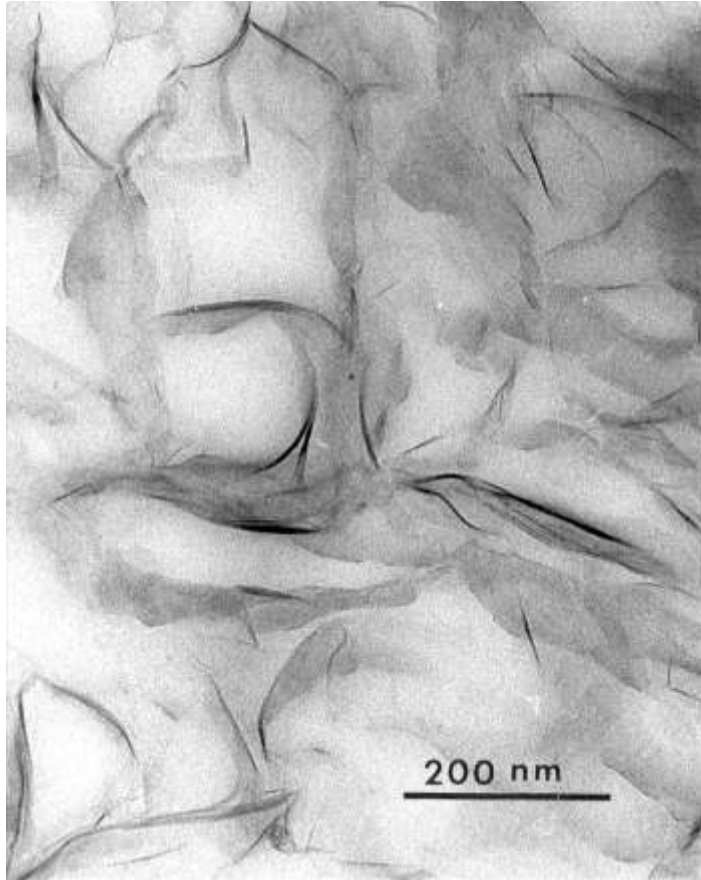
Holes and isolated dots



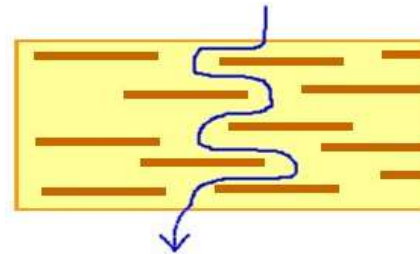
Wormlike micelles in solution



Polymer Nanocomposites



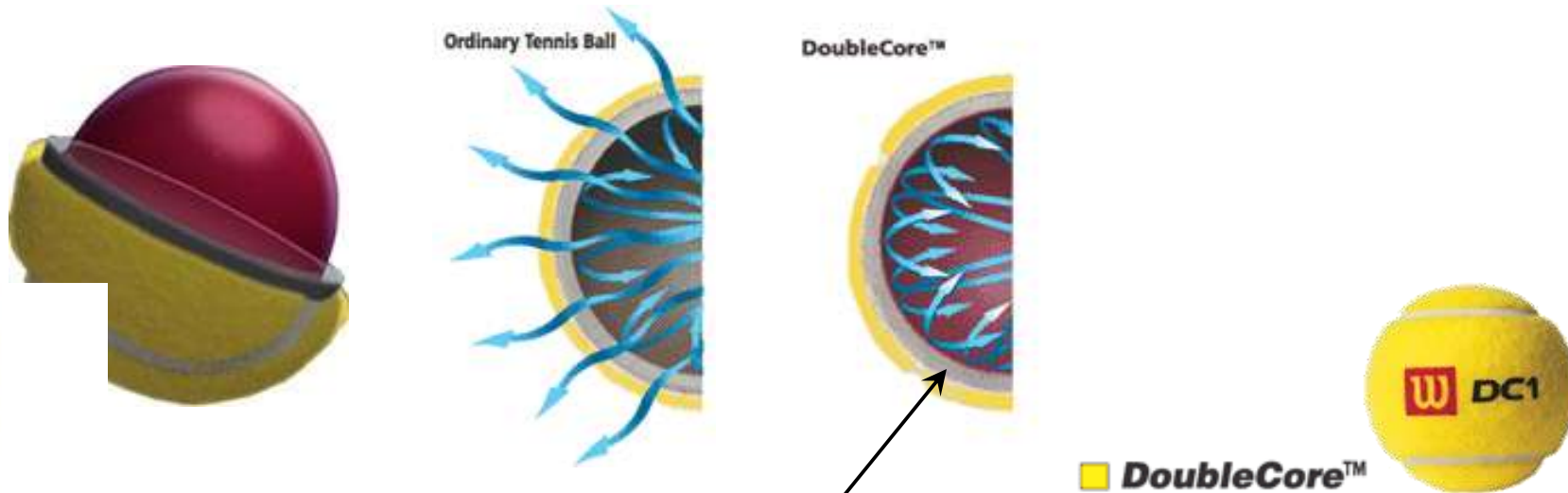
- Addition of a small amount of nanoparticles gives large change in properties of polymer



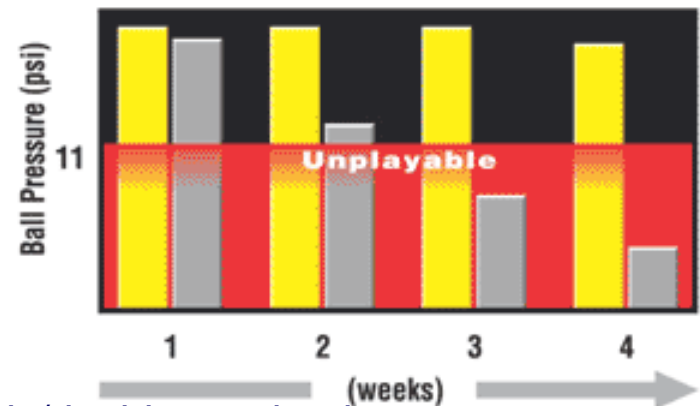
- However, important polymer properties such as optical transparency, flexibility, and low weight remain

Imagine this 10's of 1000's of times over

Wilson high performance tennis balls



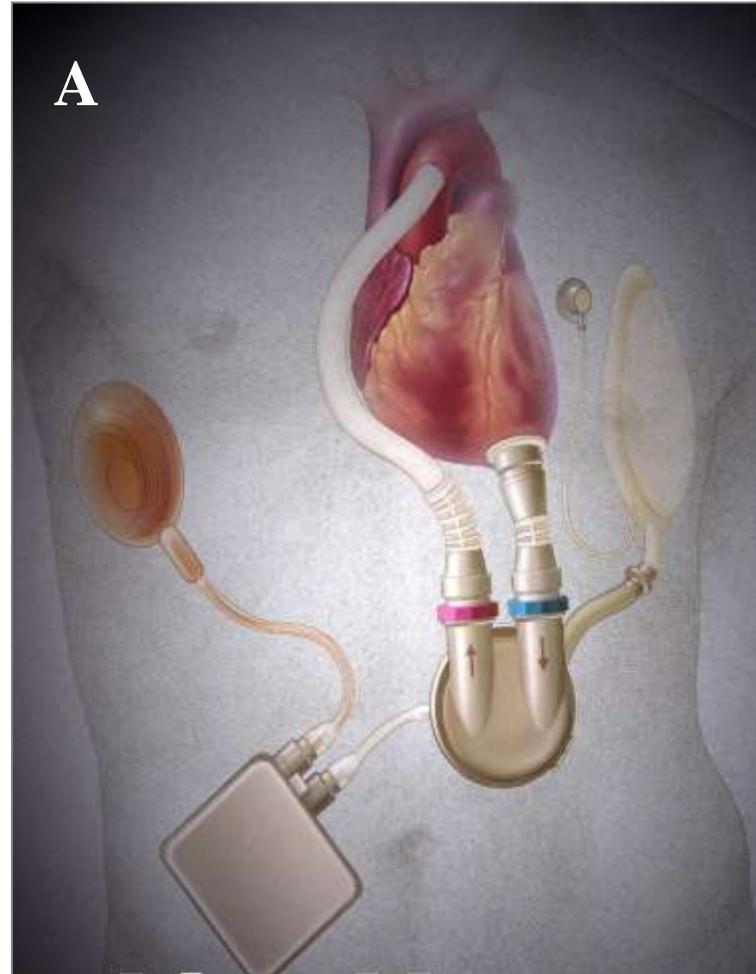
inner core (barrier)
butyl-rubber + clay



<http://www.wilsonsports.com.au/tennis/doublecore.html>

Application of Nanocomposite Polymer Materials

A. Pump for artificial heart



Application of Nanocomposite Polymer Materials

B. Decrease sneaker weight, increase response



Application of Nanocomposite Polymer Materials

C. Running boards and body panels for cars



Non-halogen, low flammability cables

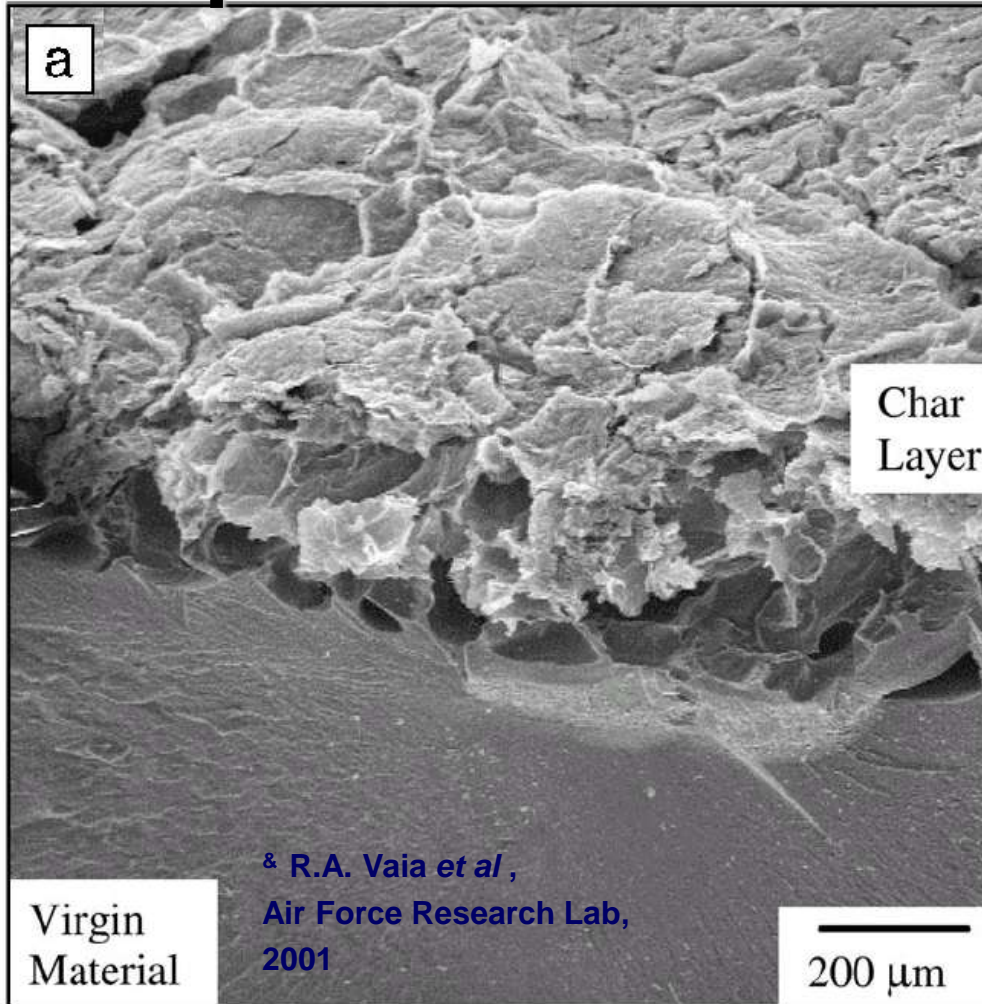
Char formation of a cable with nanocomposite



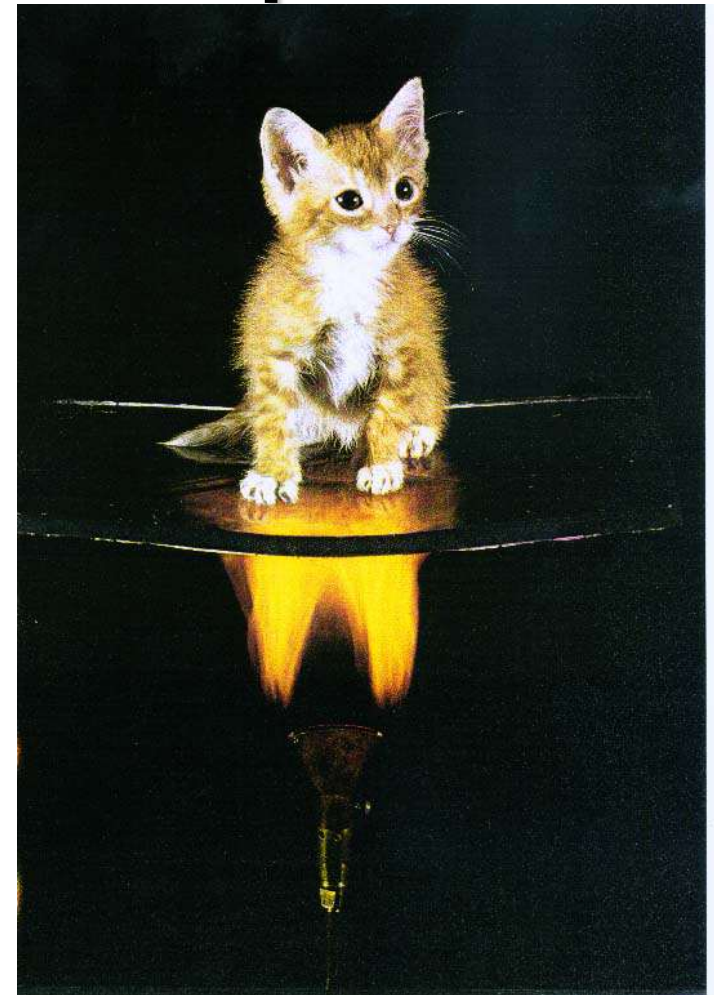
Addition
of organo-clay

Improvements
on fire performance
and smoke density

Improvement of Thermal Properties



**SEM of nylon-6/5wt% clay nanocomposite
after exposure to simulated solid-rocket
motor exhaust &**



**Thermal Conductivity
PC with 5wt% clay nanocomposite**

O'Lala Foods - Choco'la Chewing Gum

- Incorporating chocolate into chewing gum has actually been challenging because the cocoa butter fats in chocolate cause the gum to lose its elastic nature
- O'Lala has incorporated nano-crystals that change the surface characteristics of the gum allowing for the incorporation of chocolate flavoring



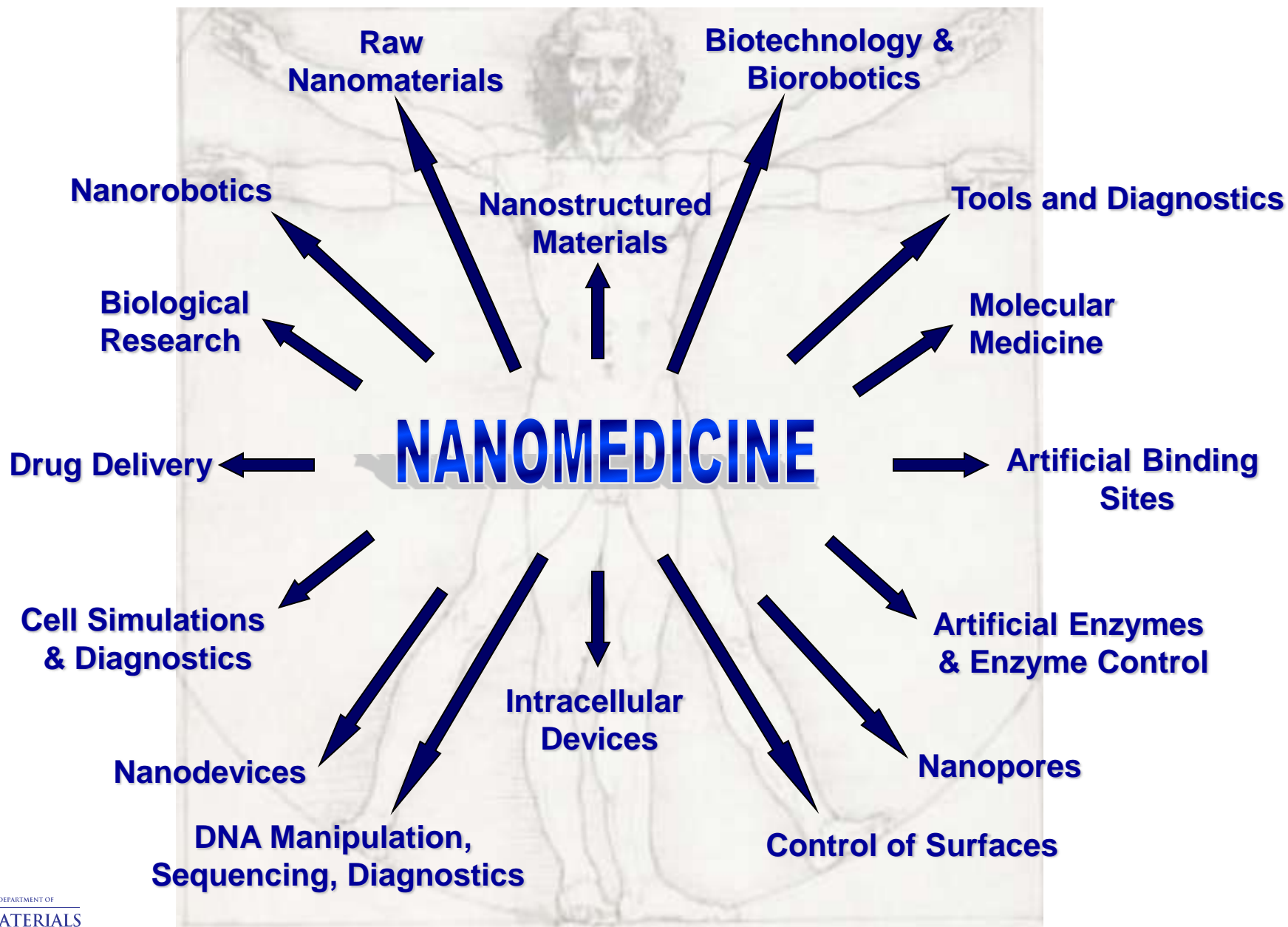
James Adair –

Professor of Materials Science and
Engineering and Bioengineering at Penn
State University

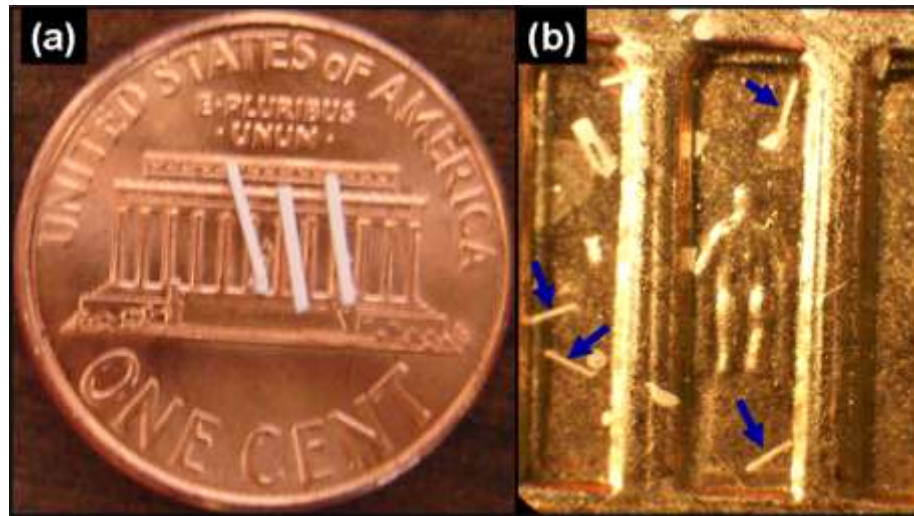
[http://www.youtube.com/watch?v=P6XrpH
nyaqk&feature=player_embedded#](http://www.youtube.com/watch?v=P6XrpHnyaqk&feature=player_embedded#)

Questions?

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Chat Box

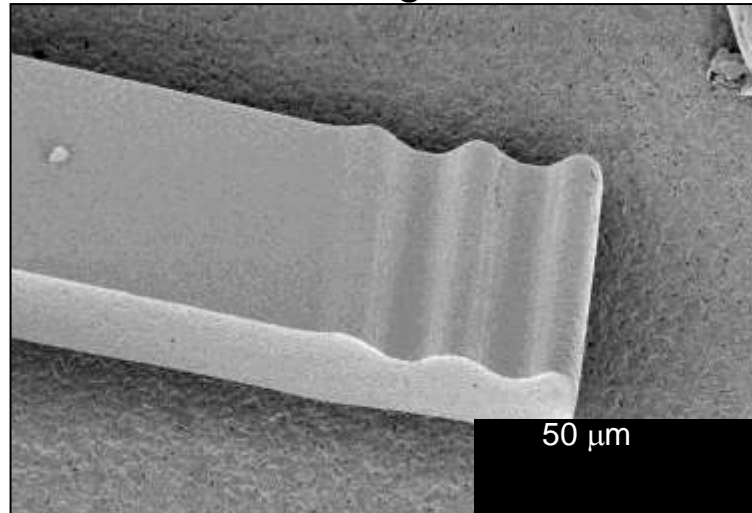


Surgical Tools



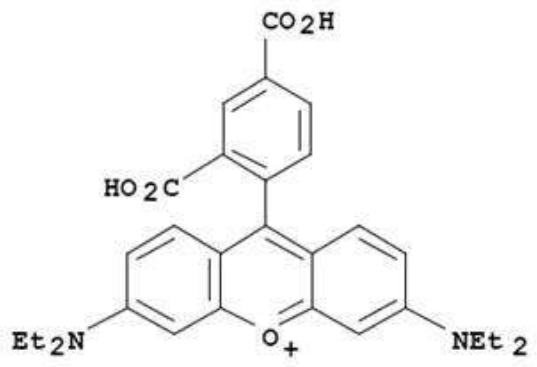
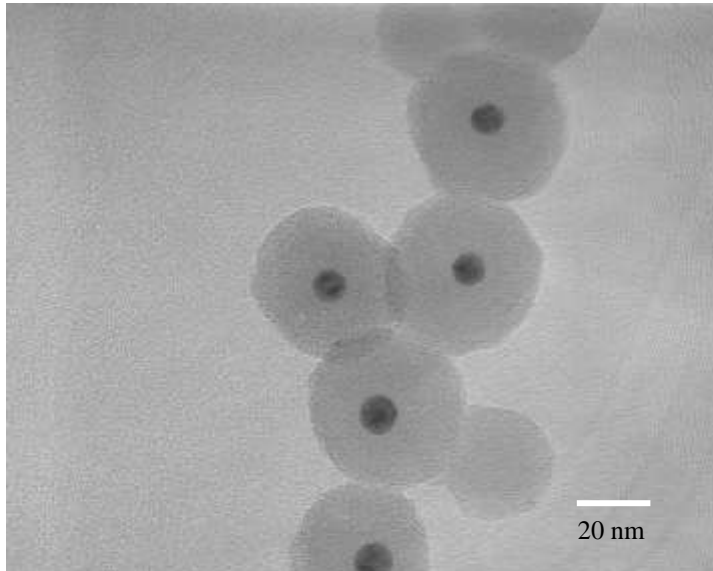
A) Bend bars made using 400 micron thick molds

B) Bend bars made using 25 micron thick molds



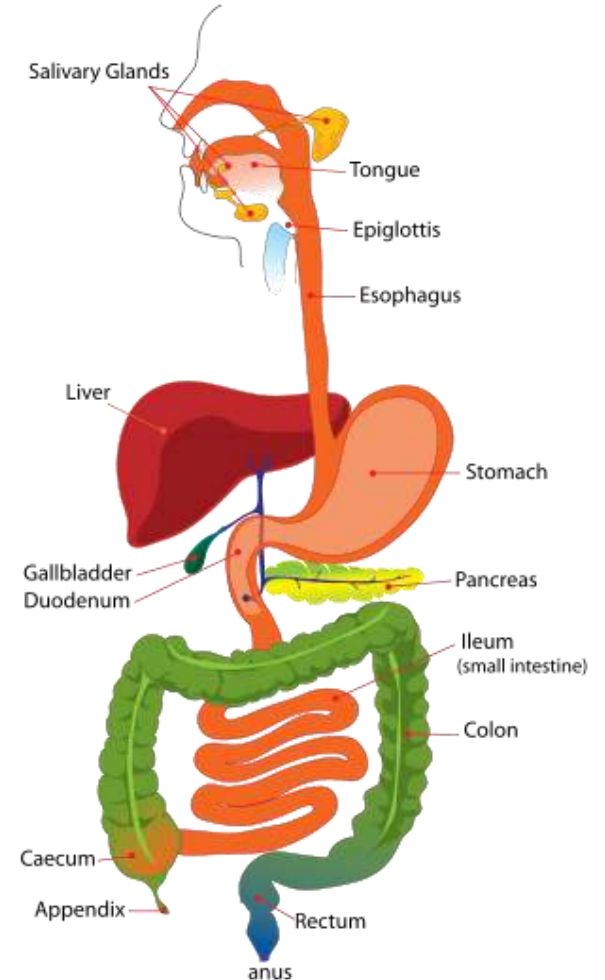
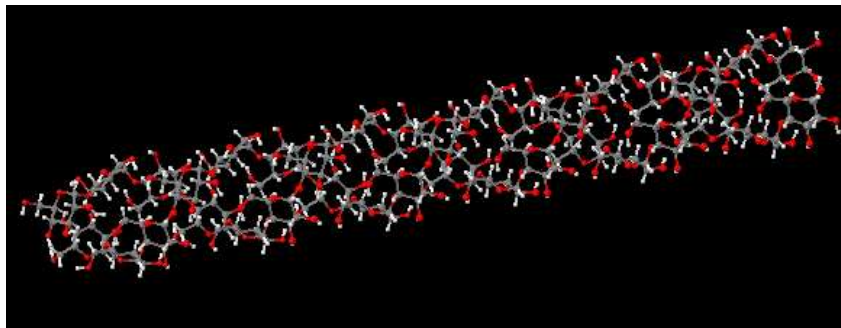
Nanocomposite Particles

Silica shell with rhodamine WT core



- Particles on the order of 1 – 100 nm in diameter
- Shell and core of particle are two different materials
- Can be tailored to absorb specific radiation frequencies – military application
- Can be designed to emit specific wavelengths of light – flat panel displays
- Can be designed with any desired surface – biomedical imaging and drug delivery

Drug Delivery Systems



The Many Uses of Gold Nanoparticles

- First Response home pregnancy test



- Gold nanoparticles with complementary DNA base pair sequence for HcG
- The gold nanoparticles allow for more base pair detectors to be present on the applicator – thus heighten sensitivity to elevated levels of HcG

Research Motivation

Nanotechnology has the potential to transform the medical field –

Development of novel diagnostic, therapeutic and preventative medical treatments

Enhancement of current medical technologies:¹

- *Enhanced product performance*
- *Drug delivery alternatives*
- *Lifespan of therapeutic agents*
- *Decrease cost of expensive materials*
- *Reduction in side effects*
- *Increased patient compliance*

1. Cancer Nanotechnology, Going Small for Big Advances- Using Nanotechnology to Advance Cancer Diagnosis, Prevention & Treatment, NIH Publication No. 04-5489 (2004).
2. S.K. Sahoo and V. Labhasetwar, *Drug Discovery Today*, **8**[24] (2003).
3. G.A. Hughes, *Nanomedicine* **1**[1] (2005).

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➤ Demand for drug delivery systems in the US expected to grow 9% annually to more than \$82 billion by 2007.²

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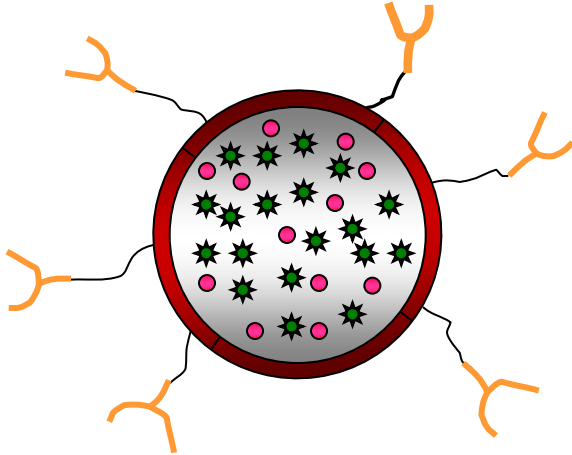
➤ *Over 300 US-based companies involved with the development of drug delivery systems.³*

1. Cancer Nanotechnology, Going Small for Big Advances- Using Nanotechnology to Advance Cancer Diagnosis, Prevention & Treatment, NIH Publication No. 04-5489 (2004).

2. S.K. Sahoo and V. Labhasetwar, *Drug Discovery Today*, **8**[24] (2003).

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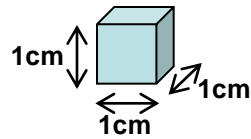
Imaging and Medical Therapeutic Delivery in NanoComposite Particles



Encapsulating material protects the imaging and therapeutic agents and provides unique features:

- Small size (5 – 50 nm) compatible for biological and medical applications
- Shell material can be modified and functionalized for specific applications
- Targeting is surface of the matrix material specific, not imaging or therapeutic agent specific- cheaper and chemically more straightforward
- Multiple active-medical agents can be simultaneously loaded

Can be used for a variety of nanomedical applications including Bioimaging, Drug Delivery and Gene Therapy



**A one centimeter cube full of this 8nm particle size powder
would have an equivalent surface area of ~1400 sq ft.!**
1cm = 0.40inches

NANOTECHNOLOGY ADOPTION IN INDUSTRY

Sales of products that incorporate nanotechnology

Year	Sales of Nano-incorporated products (in billions)
2004	\$12.98
2005	\$30.73*
2006	\$51.63*
2007	\$88.46*
2008	\$150.14*
2009	\$291.65*
2010	\$507.74*

- About 1200 start-up companies based on a nanotechnology have formed since year 2000 (half of them in the U.S).
- 19 of the 30 companies listed on the Dow Jones Industrial Index have started nano initiatives.
- Venture capitalists have invested \$500,000,000 over the last two years in nanotechnology companies
- Government funding of nanotechnologies around the world is \$4.7 billion annually

Source: Business Week Online, as of Feb. 2005

* Estimated

Source: Lux Research, as of Jan. 27, 2005

DEPARTMENT OF
MATERIALS
SCIENCE

Department of Materials Science and Engineering

COLLEGE OF EARTH AND
MINERAL SCIENCES

PENNSTATE



Large Effects of Smallness

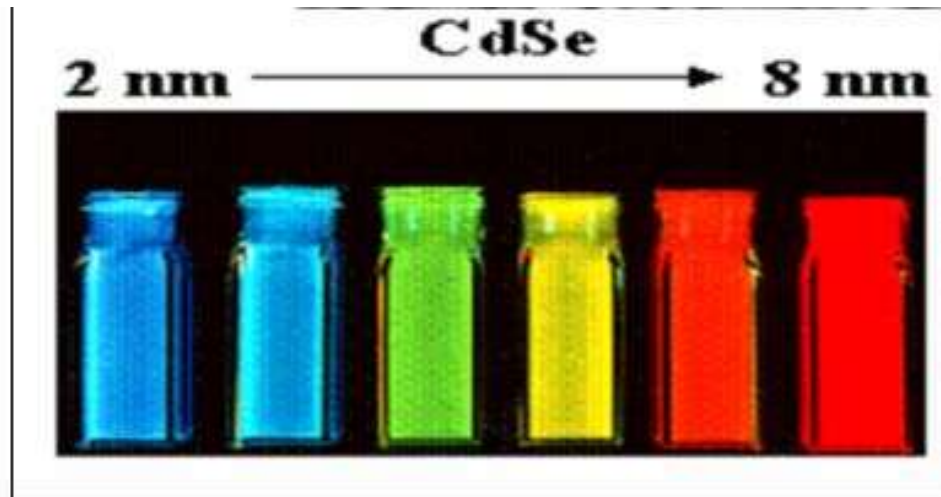
- Nanoparticles: as you **DECREASE the diameter** of the particles you **INCREASE the surface area**. (you can get a lot more particles into the same fixed volume of space)



- Left jar contains 3000 marbles 5/8" in diameter
- Right jar contains 5000 marbles 1/2" in diameter
- A reduction of 20% created a gain of 2000 marbles

Large Effects of Smallness

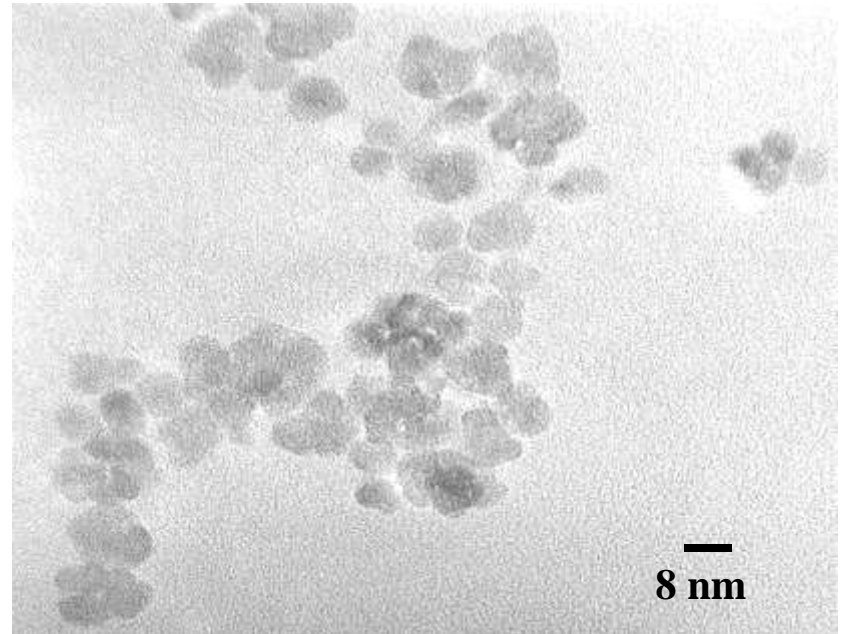
- Sometimes we are just interested in making really small particles



- Here quantum dots of cadmium selenide (CdSe) are used to create an array of colors

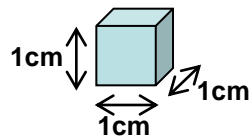
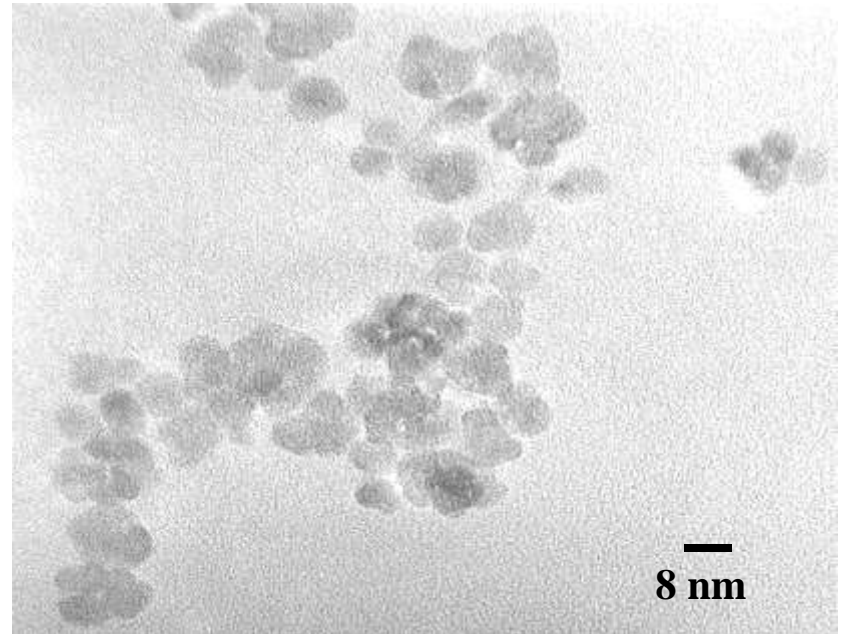
Large Effects of Smallness

- Surface area: amount of surface available for chemical reaction
- “traditional” ceramic powders are typically around 1 to 10 micrometers in size
- Surface area of $<1 \text{ m}^2/\text{g}$
- These ceramic particles are around 8 nanometers in size
- A reduction of ~ 1000 times in size
- Surface area of $\sim 130 \text{ m}^2/\text{g}$
- What does that mean physically?



Large Effects of Smallness

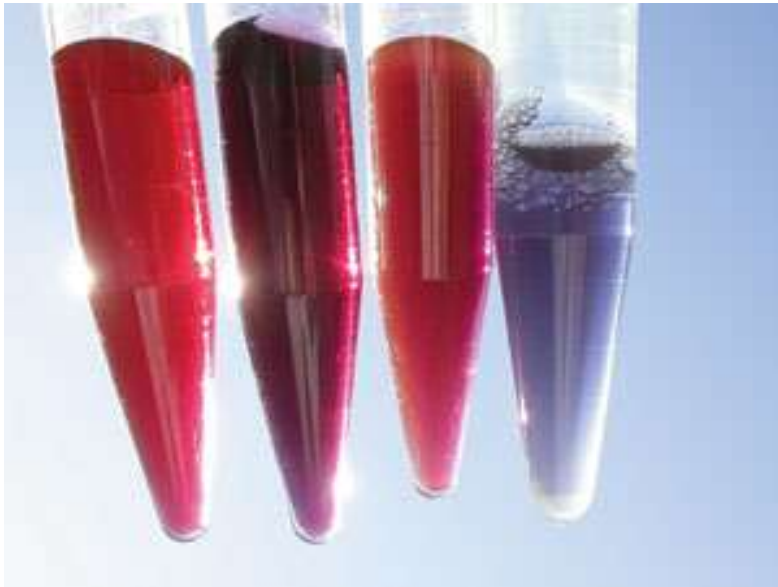
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- **These ceramic particles are around 8 nanometers in size**
- **A reduction of ~ 1000 times in size**
- **Surface area of $\sim 130 \text{ m}^2/\text{g}$**



A one centimeter cube full of this 8nm particle size powder would have an equivalent surface area of $\sim 1400 \text{ sq ft.}$!
1 cm = 0.40 inches

A Little History

- Nanotechnology has been around for a long time – 2000 years ago nano-gold particles were used in the coloring of glass
- The left picture shows the array of colors possible with gold nanoparticles

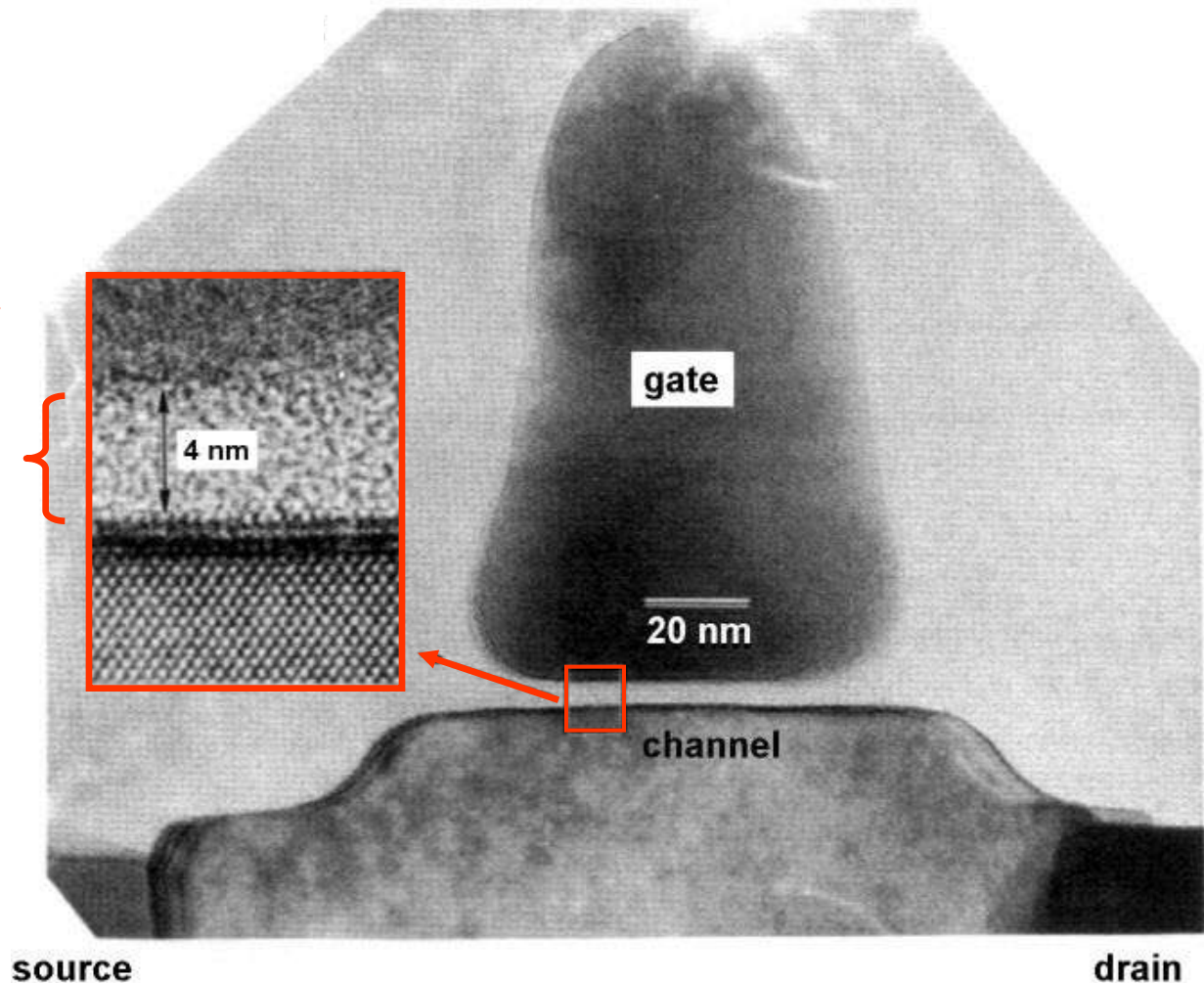


Power consumption by a leaky gate oxide: A show-stopper for Moore's Law ?

Gate oxide has
shrunk to $< 2\text{nm}$,
 < 10 atom layers.

Electrons can
tunnel through
when applying
a gate voltage.

Uses up to $\frac{1}{3}$
of the power.



Questions?

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<http://questionpro.com/t/ABkVkZLoh1>

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Workshop

Hands-on Introduction to
Nanotechnology for Educators

May 7-9:
Conference

Micro Nano Tech Conference 2012
Penn Stater Conference Hotel

May 24:
Webinar

How Safe is Nanotechnology In Our
Lives?

July 23-26:
Conference

HI-TEC 2012
Denver Marriott Tech Center

Aug. 13-16:
Workshop

Course Resource Workshop II:
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Nanotechnology and Materials: Nanotechnology Impact on Materials Properties and Performance