CHEE6320 Introduction Nanomaterials Engineering
MTLS6320 Nanomaterials Engineering
CHEE5320 Intro Nanomaterials Engineering
ECE5320 Intro Nanomaterials Engineering
MECE5320 Intro Nanomaterials Engineering
ECE 6307 Nanomaterials and Solar Energy

Lectures: Tuesday and Thursday 11:30 AM – 1:00 PM; E312 D3

Course Instructor:
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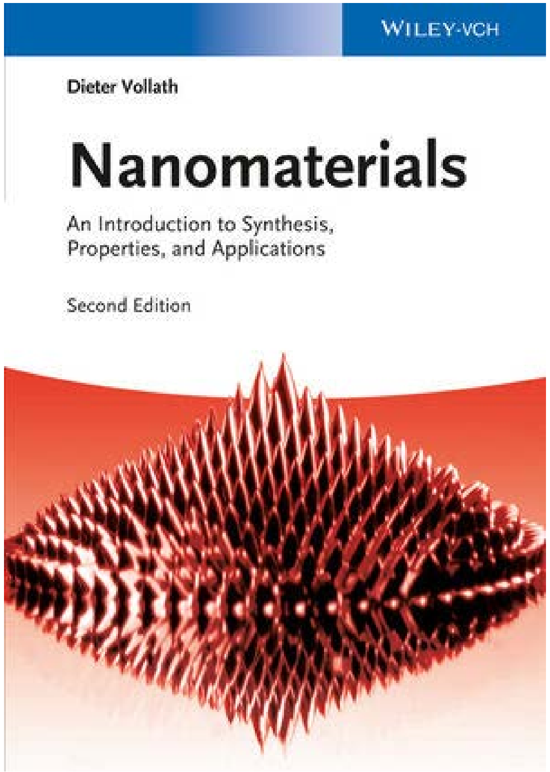
Office Hours:
Tu@Th 2-3 PM.

Course Material

Dieter Vollath, Nanomaterials: “An Introduction to Synthesis, Properties and Applications”, Wiley, 2004, ISBN: 3527315314.



Book should be available at UH Bookstore, alternatively, Internet price range from 40-80$.

Additional Course Material will be distributed in class or e-mailed as pdf.

Course Grading

GRADING:
Course grades will be calculated with the following approximately weights:

Homework: 30% Midterm: 30% Final Exam: 40%

The letter grade indicated below is the minimum grade that you will receive for a given numerical average.

90 - 100: A 75 - 89: B 60 - 74: C 45 - 59: D < 44 F

Syllabus

COURSE TOPICS:

- Motivation: nanomaterials for high efficiency photovoltaics
- Introduction to modern physics and quantum mechanics
- Basic understandings of atoms, molecules, solids, metals, semiconductors and insulators
- Review of semiconductor physics: band theory, concept of electrons and holes, effective masses.
- Introduction to nanostructured materials (Chapter 1, Dieter Vollath)
- Surface in nanomaterials (Chapter 2, Dieter Vollath)
- Phase transformation of nanoparticles (Chapter 3, Dieter Vollath)
- Gas phase synthesis of nanoparticles (Chapter 4, Dieter Vollath)
- Optical properties of nanoparticles (Chapter 6, Dieter Vollath)
- Solar cells and sunlight: the photovoltaic vision, characterizations of solar radiation
- Doping and Fermi level, P-N junction
- I-V curves in dark and under illumination.
- Optical absorption in semiconductors, generation and recombination of electrons and holes.
- Efficiency limits and losses in solar cells, ideal conversion efficiency,
- Basic structure of crystalline silicon solar cells, polycrystalline silicon solar cells, amorphous silicon thin film solar cells
- Other types of second-generation thin film solar cells: gallium arsenide solar cells,
- polycrystalline thin-film CdTe and CuInSe2 cells,
- Third generation solar cells: multi-junction solar cells,
- Nanostructured solar cells, organic solar cells, concentrator cells, dye sensitized solar cells.
- New concept toward high efficiency solar cells beyond Shockley-Queisser limit
- Solar water splitting and artificial photosynthesis
- Thermoelectric power generations

Definition of Nano….

"Nano…… is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale."

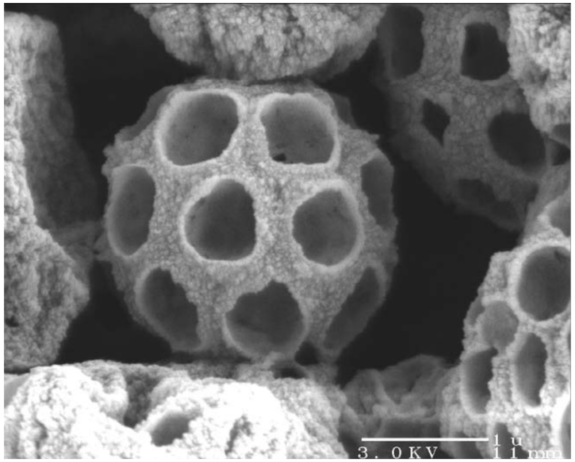
-National Nanotechnology Initiative

Why Nanotechnology?

At the nanoscale, the physical, chemical, and biological properties of materials differ in fundamental and valuable ways from the properties of individual atoms and molecules or bulk matter.

Nanotechnology R&D is directed toward understanding and creating improved materials, devices, and systems that exploit these new properties.

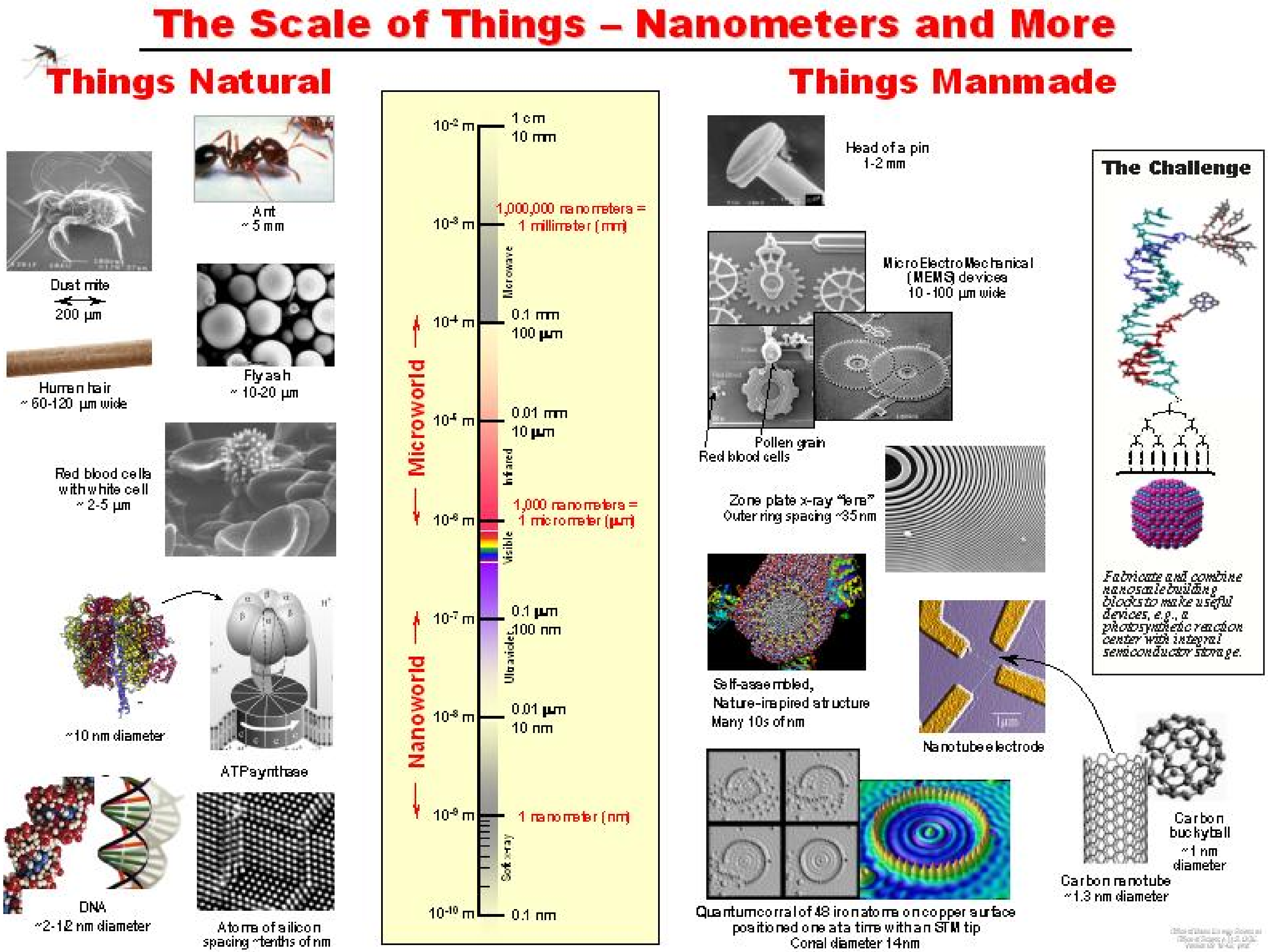
In Other Words….



Small photonic crystals: titanium dioxide micro-sphere 1-50 μm in diameter

Working at the atomic, molecular and supra-molecular levels, in the length scale of approximately 1 – 100 nm range, through the control and manipulation of matter at the atomic and molecular level in order to design, create and use materials, devices and systems with fundamentally new properties and functions because of their small structure.

Courtesy: National Science Foundation
Credit: *S. Klein, F. Lange and D. Pine, UC Santa Barbara*



For Pam Norris- July 2009

Why Now?

Richard Feynman's famous presentation "There's Plenty of Room at the Bottom" was in the 1959 at the American Physical Society.

Here he asked:

•Why can't we manipulate materials atom by atom?

• Why can't we control the synthesis of individual molecules?

•Why can't we write all of human knowledge on the head of a pin?

•Why can't we build machines to accomplish these things?

Why Now?

- New tools for atomic-scale characterization
- New capabilities for single atom/molecule manipulation
- Computational access to large systems of atoms and long time scales
- Convergence of scientific-disciplines at the nanoscale

What's the BIG deal about something so SMALL?

Materials behave differently at this size scale.
It's not just about miniaturization.
At this scale---it's all about INTERFACES

Size Matters!

Color depends on particle size
Quantum dots 3.2 nm in diameter have blue emission
Quantum dots 5 nm in diameter have red emission

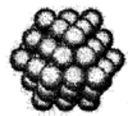
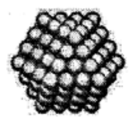
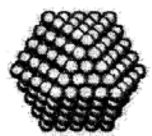
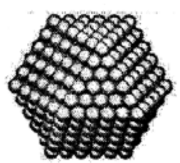
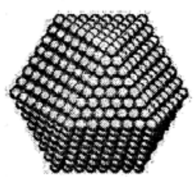
Evident Technologies
evidot Quantum Dots

Color is Size Dependent

- For semiconductors such as ZnO, CdS, and Si, the bandgap changes with size
  - Bandgap is the energy needed to promote an electron from the valence band to the conduction band
  - When the bandgaps lie in the visible spectrum, changing bandgap with size means a change in color

- For magnetic materials such as Fe, Co, Ni, Fe_3O_4, etc., magnetic properties are size dependent
  - The 'coercive force' (or magnetic memory) needed to reverse an internal magnetic field within the particle is size dependent
  - The strength of a particle's internal magnetic field can be size dependent

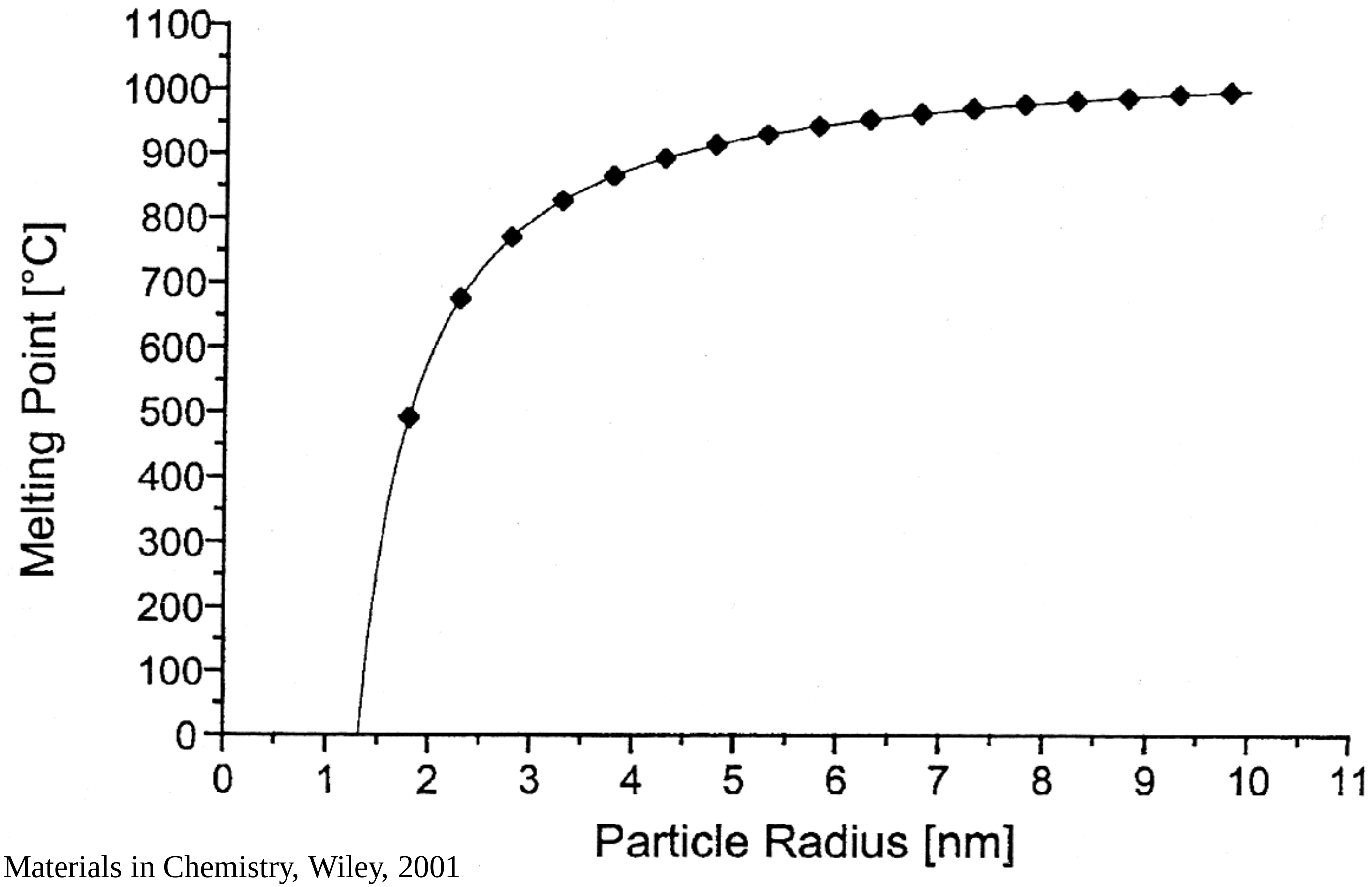
Contribution of the Surface to Observed Properties and Percentage of Surface Atoms is Size Dependent

Full-shell Clusters		Total Number of Atoms	Surface Atoms (%)
1 Shell		13	92
2 Shells		55	76
3 Shells		147	63
4 Shells		309	52
5 Shells		561	45
7 Shells		1415	35

Source: Nanoscale Materials in Chemistry, Wiley, 2001

Melting Temperature is Size Dependent

The melting point decreases dramatically as the particle size gets below 5 nm



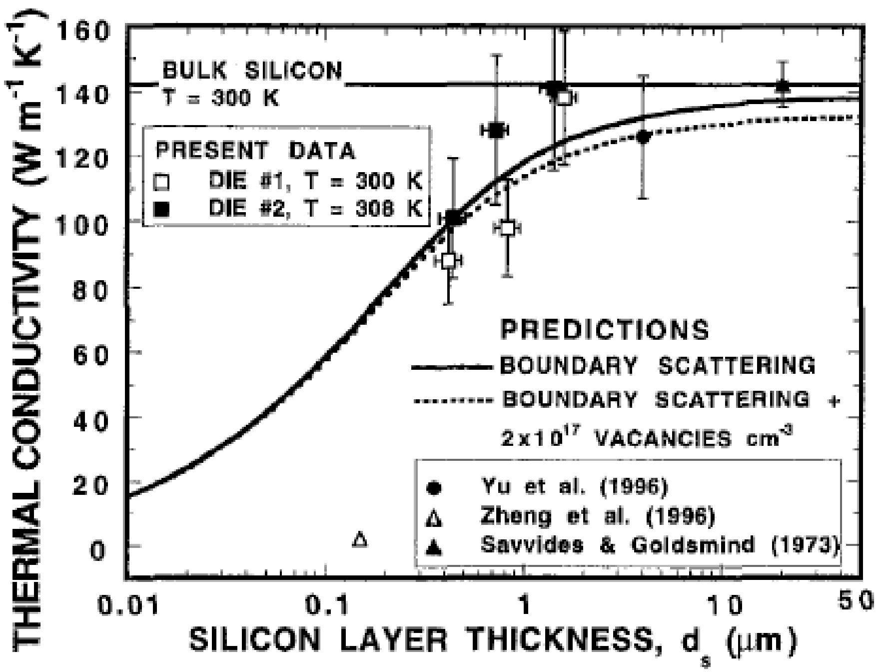
Source: Nanoscale Materials in Chemistry, Wiley, 2001

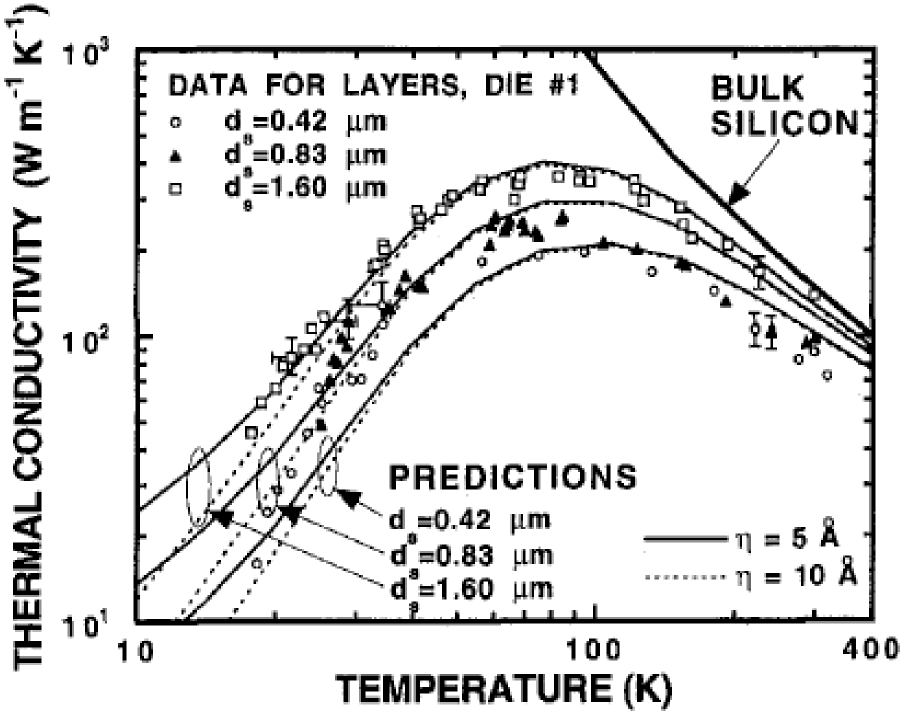
Nanoporous Materials – A lot of Surface to Work with

- Zeolite is an old example which has been around a long time and used by petroleum industry as catalysts
- The surface area of a solid increases when it becomes nanoporous; this improves catalyst effects, adsorption properties
- ‘Adsorption’ is like ‘absorption’ except the absorbed material is held near the surface rather than inside
- How to make nanopores?
  - lithography followed by etching
  - ion beam etching/milling
  - electrochemical techniques
  - sol-gel techniques

Thermal Conductivity

Si phonon thermal conductivity: Bulk vs. Microscale





Room-temperature thermal conductivity data for silicon layers as a function of their thickness.

Thermal conductivities of the silicon device layers with thicknesses 0.42, 0.83, and 1.6 μm.

Asheghi, A., Touzelbaev, M.N., Goodson, K.E., Leung, Y.K., and Wong, S.S., 1998, "Temperature-Dependent Thermal Conductivity of Single-Crystal Silicon Layers in SOI Substrates," ASME *Journal of Heat Transfer*, **120**, 30-36.

Benefits of Nanotechnology

"The power of nanotechnology is rooted in its potential to transform and revolutionize multiple technology and industry sectors, including aerospace, agriculture, biotechnology, homeland security and national defense, energy, environmental improvement, information technology, medicine, and transportation. Discovery in some of these areas has advanced to the point where it is now possible to identify applications that will impact the world we live in."

-National Nanotechnology Initiative

Understanding the Challenges of the Nanoscale

There are many length and time scales that are important in nanotechnology.

- Length scale goes from 10 Å to 10^4 Å ---- this corresponds to 10^2 to 10^{11} particles
- Time scales ranging from 10^{-15} s to several seconds

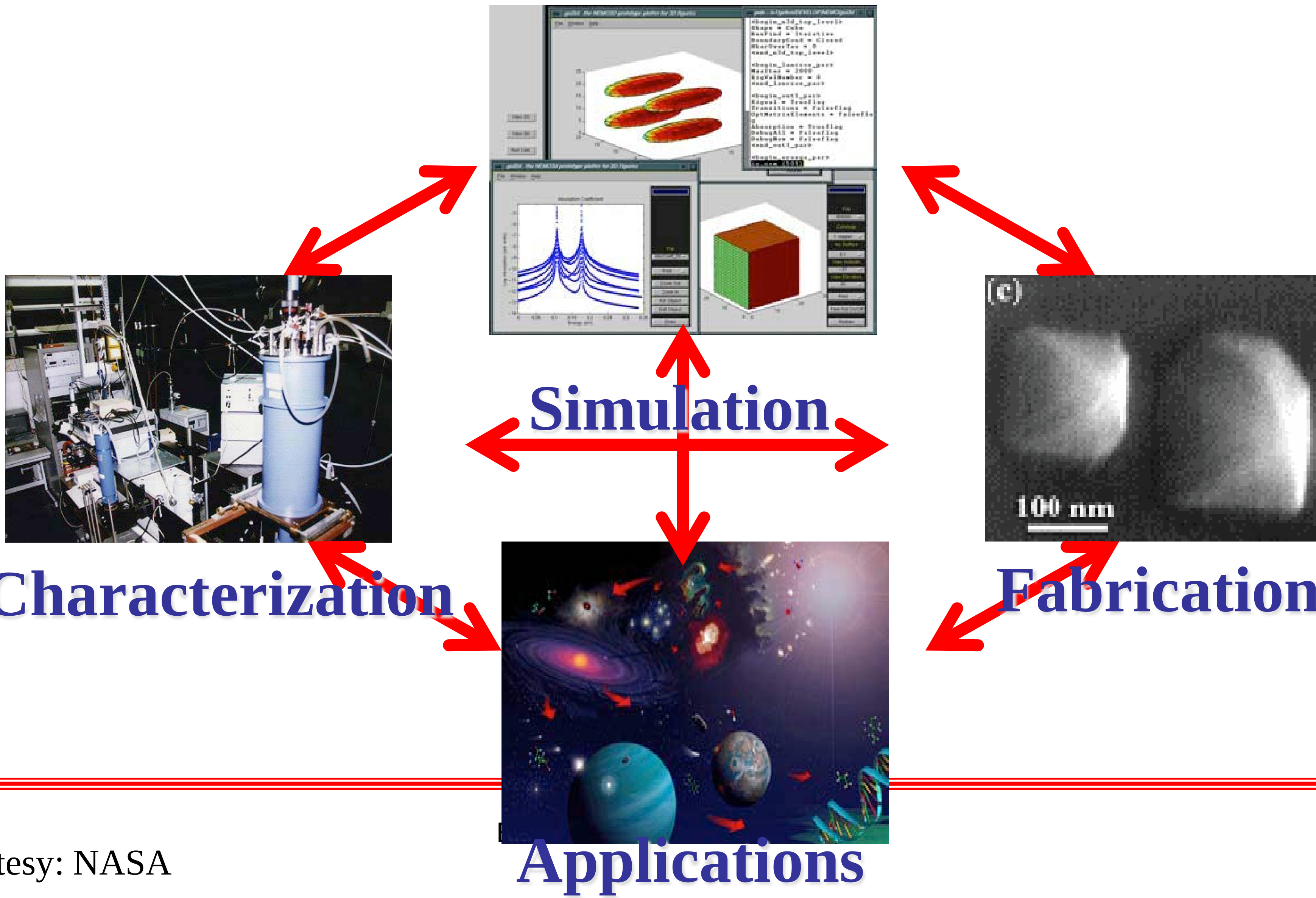
The temporal scale goes linearly in the number of particles N, the spatial scale goes as (NlogN), yet the accuracy scale can go as high as N^7 to N! with a significant pre-factor.

Challenges of this Size Scale

A critical issue for nanotechnology is that components, structures, and systems are in a size regime about whose fundamental behavior we have little understanding. They are:

- too small for direct measurements
- too large to be described by current rigorous first principle theoretical and computational methods
- exhibit too many fluctuations to be treated monolithically in time and space
- too few to be described by a statistical ensemble.

Modeling, Characterization and Fabrication are Inseparable for Nanoscale Devices



Courtesy: NASA

Nanoscience will change the nature of almost every human-made object in the next century.

National Science and Technology Council, 2000

Economic Impact of Nanotechnology

Market Size *Predictions* (within a decade)*

$340B/yr	**Materials**
$300B/yr	**Electronics**
$180B/yr	**Pharmaceuticals**
$100B/yr	**Chemical manufacture**
$ 70B/yr	**Aerospace**
$ 20B/yr	**Tools**
$ 30B/yr	**Improved healthcare**
$ 45B/yr	**Sustainability**

$1 Trillion per year by 2015

2007 Estimates by industry groups, source: NSF

Economic Impact of Nanotechnology

According to "The Nanotechnology Opportunity Report (NOR)," 3rd Edition Cientifica Ltd., published in June 2008

"The market for products enabled by nano-technologies will reach US$ 263 billion by 2012."

"The highest growth rates will be in the convergence between bio- and nanotechnologies in the healthcare and pharmaceutical sectors."

National Investment

Fiscal Year	NNI
2000	$270M
2001	$464M
2002	$697M
2003	$862M
2004	$989M
2005	$1,200M
2006	$1,303M
2007	$1,425M
2008	$1,491M
2009	$1,527M

The US investment in nano-technology represents about ¼ of the world R&D investment.

The 2010 Budget provides $1.6 billion, reflecting steady growth in the NNI investment.

Forbes Top 10 Nanotech Products--2003

1. High Performance Ski Wax
2. Breathable Waterproof Ski Jacket
3. Wrinkle-Resistant, Stain Repellent Threads
4. Deep Penetrating Skin Cream
5. World’s First OLED Digital Camera
6. Nanotech DVD and Book Collection
7. Performance Sunglasses
8. Nanocrystalline Sunscreen
9. High Tech Tennis Rackets
10. High-Tech Tennis Balls

Forbes Top 10 Nanotech Products--2004

1. Footwarmers
2. Washable Bed Mattress
3. Golf Balls and the “Nano” Driver
4. Nano Skin Care
5. Nanosilver Wound Dressing for Burn victims
6. Military-Grade Disinfectants
7. BASF Superhydrophobic Spray
8. Clarity Defender Automotive-Glass Treatment
9. Flex Power Joint and Muscle Pain Cream
10. 3M Dental Adhesive

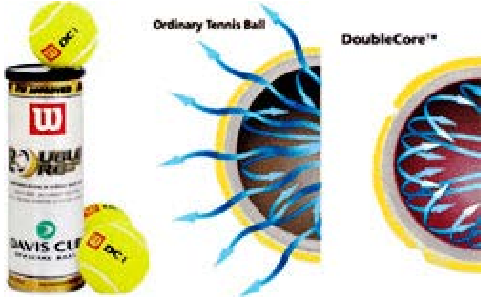
Forbes Top 10 Nanotech Products--2005

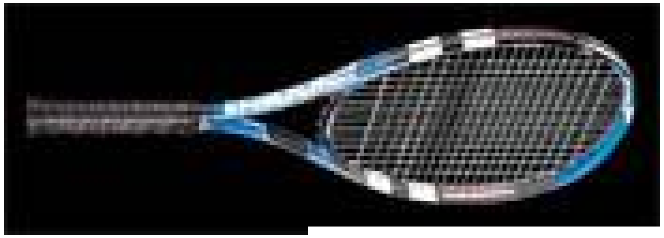
1. iPod Nano
2. Canola Active
3. O'Lala Foods Choco'la Chewing Gum
4. Zelens Fullerene C-60 Face Cream
5. Easton Sports Stealth CNT Bat
6. Casual Apparel-Nanotex
7. ArcticShield Socks- odor and fungus resistant
8. Behr NanoGuard Paint
9. Pilkington Active Glass
10. NanoBreeze Air Purifier

About $80B in products incorporate nanotechnology in the US in 2009 with the leading category being:

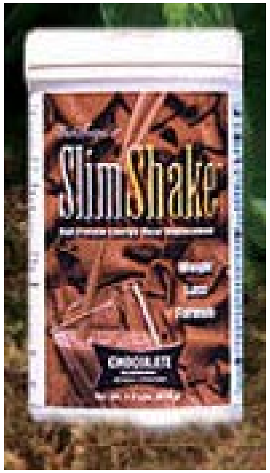
Consumer Products

Sporting Goods

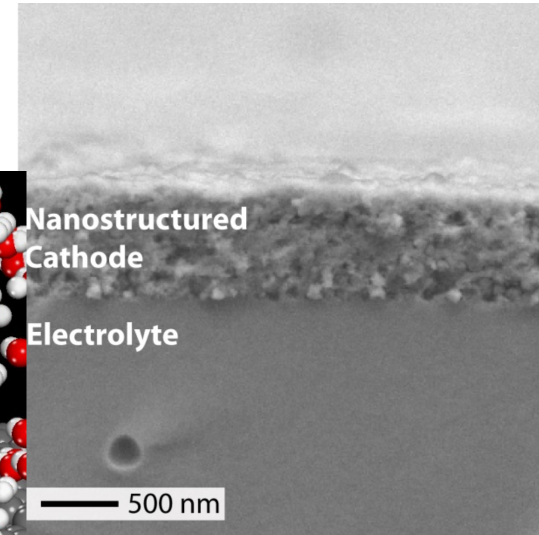




Cosmetics, Clothes and Food

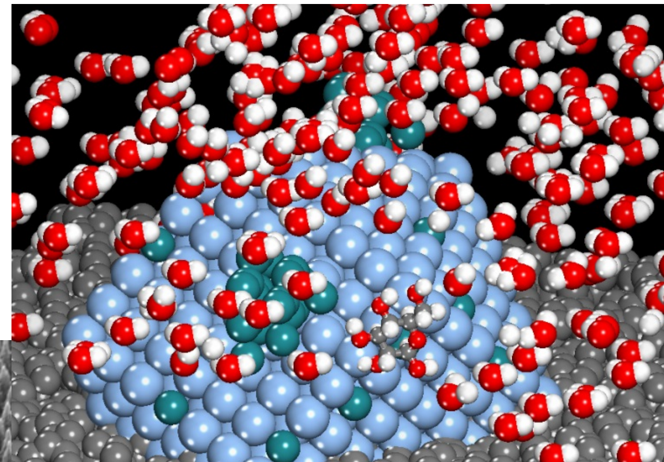


Clean and Cheap Energy



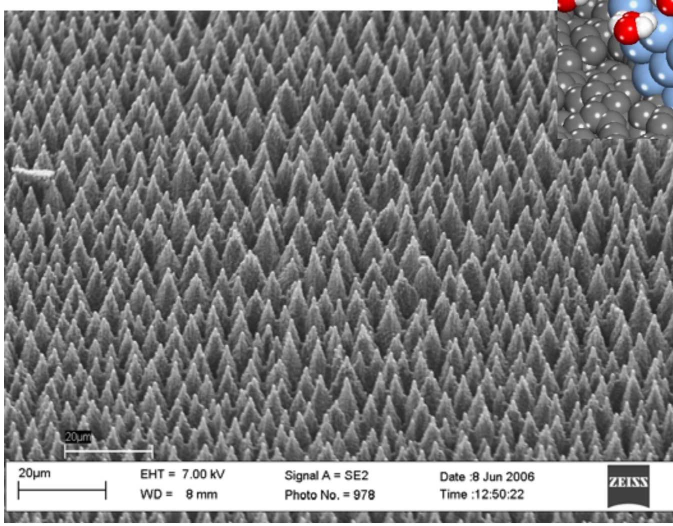
Solid oxide fuel cell

Courtesy: Steve McIntosh, UVA



Computational catalysis

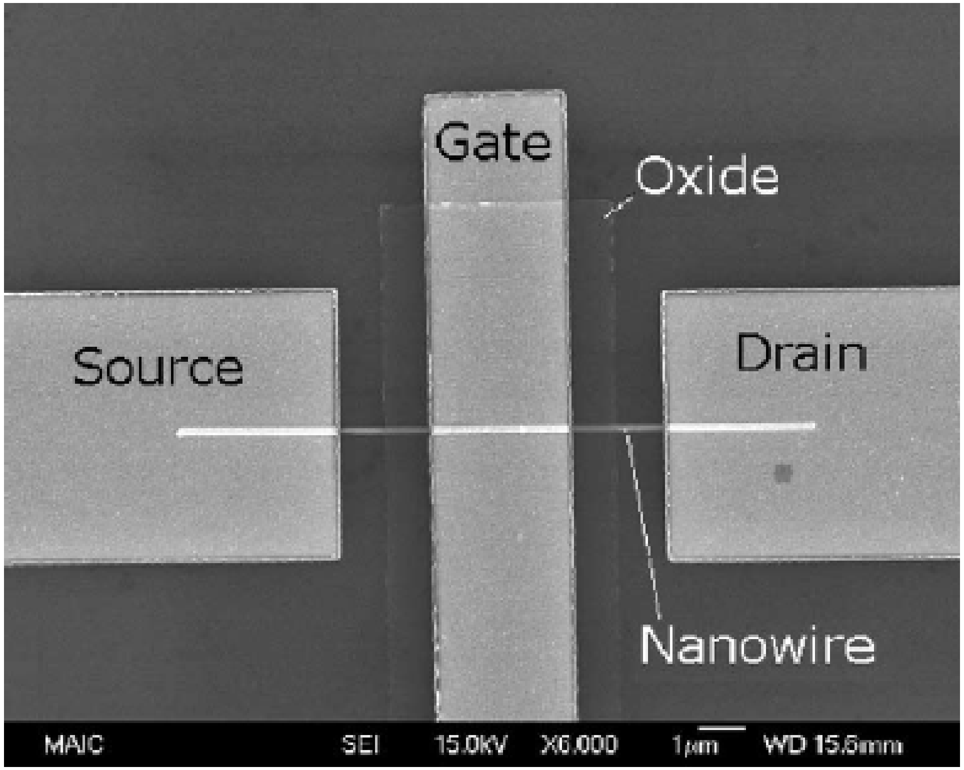
Courtesy: Matthew Neurock, UVA



Laser-textured silicon for solar cells

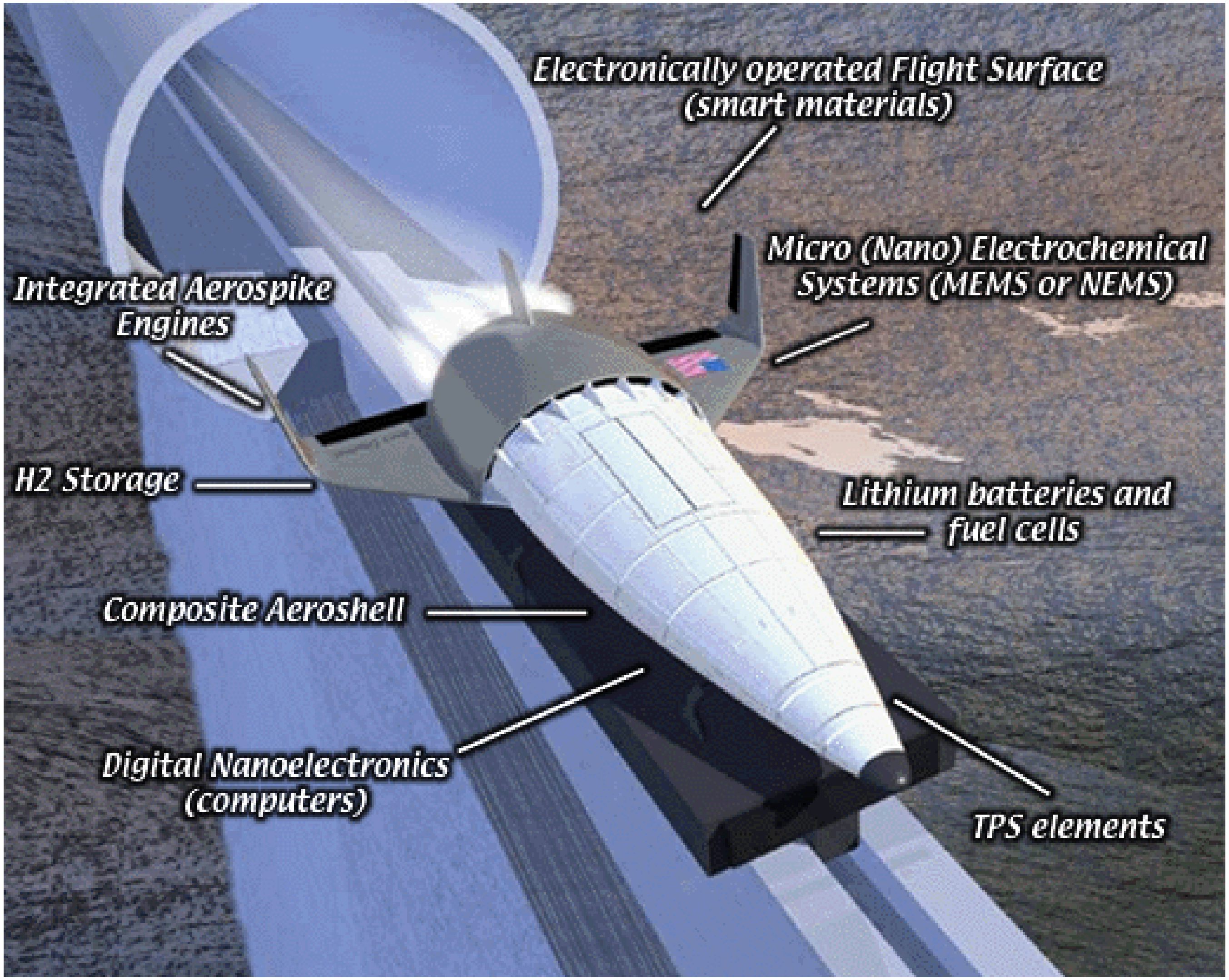
Courtesy: Mool Gupta, UVA

Crossed Nanowire devices



SEM micrograph of fabricated FET.

Faster, Better, Cheaper Space Transportation with Nanotubes



Courtesy of NASA

References

http://www.nanotechproject.org/inventories/consumer/ An inventory of nanotechnology-based consumer products currently on the market.

Productive **Nanosystems A Technology Roadmap,** 2007, Battelle Memorial Institute and Foresight Nanotech Institute.

IWGN Workshop Report: Nanotechnology Research Directions: Vision for Nanotechnology in the Next Decade, 2000, Edited by M.C. Roco, R.S. Williams, and P. Alivisatos, Springer.

www.nano.gov

www.science.doe.gov/nano

www.nnin.org