How to Keep *Introduction to Nanomaterials Science and Engineering* Current

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"Course Innovations"

New Course Spring 2002
Introduction to Nanomaterials Science and Engineering

Topics:

- Synthesis of nanomaterials, clusters, particles, fullerenes.
- Synthesis methods, vapor phase, liquid phase, aerosols, laser methods, sol-gel.
- Nanofabrication, lithography, thin film, e-beam deposition.
- Consolidation
- Characterization, scattering, diffraction, atomic force microscopy.
- Properties and Applications.

Suppose we have as a *principle* for this course
“Nanotechnology, An Enabling Technology”

- Apply our ability to understand and control the structure of matter on the nanometer scale
- Emphasize what is common
- Bridge between ideas
- Encourage interdisciplinary enrollment
- Agree with Richard Feynmann, 1959, “There’s plenty of room at the bottom.”

“Nanotechnology: An Enabling Technology”
How can Bulk Materials be Nanostructured?

- Size is the critical property-

  e.g., Quantum Dot
- Size of each crystal is critical, not the overall object-

  e.g., Polycrystalline Materials

Conventional Wisdom-

- Metals get stronger with smaller crystal size.
- But, metals get weaker below 10 nm crystals.
- Why? Dislocations?
- What about hardness and ductility?
- Incidentally, ceramics get tougher with smaller crystal size.

How are we doing so far, based on ~10 iterations of the course:

Early lessons learned:

- More quantitative problem solving is needed.
- Be both descriptive <u>and</u> rigorous
- Emphasize what is common among the disciplines
- Use plenty of “gee whiz” examples, but reinforce with fundamentals

What I learned at GNSEE Workshop in November, 2008:

- Well-developed networks, e.g., nclt and nisenet
- Vast resources for all ages, formal and informal
- “Big Ideas” agenda
- Broader social context
- Pedagogy and assessment

If nanomaterials becomes mainstream "conventional" materials science…

- Some of it already has
- Funny how some things that are old become new, and things that are new become old (examples)
- Shifted from "everything carbon nanotubes" to "everything self-assembled" (example)
- Shifted from "Moore's Law controls the fate of the world" to "nanomaterials for energy conversion and storage" (case study)

Historical Perspective on Bulk Nanostructured Materials

- Nanoscale microstructural features are not new
- Nature provides many examples of nanoscale features
- Useful nanoscale features in ENGINEERING applications:
  - Strengtheners in structural materials to impede dislocation motion
    - Grain size
    - Nanoscale dispersoids
    - Nanoscale precipitates
    - “G-PII” (Guinier-Preston) zones in aluminum-copper alloys that are 5-20 nm long and 0.5 nm thick

Bulk vs. Surface

- Think of Scotch^{TM} Tape
  - Surface Property: Adhesion. Scotch tape sticks to things
  - Bulk Property: Strength. How much force does it take to pull scotch tape apart
- Surface properties are determined by atoms less than a nanometer from the surface
- In nanotechnology, surface properties are much more important than bulk properties because the surface/volume ratio is so high.

Why is nanotechnology unique (1 of 3)?

(borrowing liberally from B. Grady, Oklahoma)

- Certain phenomena occur only when characteristic dimensions reach the nanometer scale
- e.g., quantum tunneling effects:
  - When you put a voltage across an insulator, then the current is given by V=IR. When the insulator becomes small (less than 100 nm) the current is much higher by orders of magnitude than predicted due to tunneling

Why is nanotechnology unique (2 of 3)?

- Surface effects are very important: surface to volume ratio is extremely large
- Think of water flowing through your garden hose -
  - the fluid right near the wall acts very differently than the rest of the fluid. This has a negligible effect on the water coming out of the hose end.
- When the garden hose shrinks to nanoscale dimensions -
  - all of the fluid is “near the wall”, and the laws that tell you how much fluid comes out as a function of pressure no longer apply

Why is nanotechnology unique (3 of 3)?

For materials with more than one atom, not only can the arrangement of atoms at the surface be different, but the composition can be different.

Say we have the compound AB-

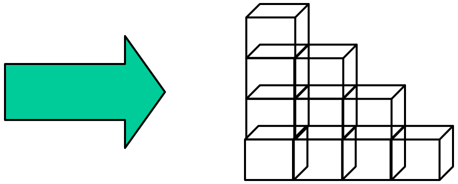
- Overall, we have equal amounts of A and B, but it is possible at the surface we have more A than B.
- In conventional materials, this surface enhancement of A does not affect the bulk properties, since the amount of material at the surface is miniscule.
- In nanomaterials, this surface enhancement not only affects the “surface” properties, but it also affects the “bulk” properties since there is much more B in the bulk, since the amount of material at the surface is significant.

Something to Consider:

- Suppose we make spherical gold nanoparticles that contain 10,000 unit cells.
- This is equivalent to a 5.5 nm diameter particle.
- Approximately 1/3 of the unit cells have one side touching the surface.
- Since gold forms into cubes, one could easily see how a nanoparticle could be cubic.
- How can it be spherical and still have a cubic unit cell?

More to consider:

- The answer is that it is not possible. Either the outside of the sphere has to look like this

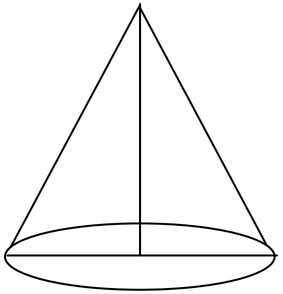


- or the atoms have to change positions at the surface.
- If atoms change positions, how deep into the nanoparticle does this go?
- It turns out that in some systems, you can make a material that is normally crystalline into an amorphous material, or even change the crystal structure entirely. Of course, the properties of the material change dramatically if this happens

What kind of micelle forms (1 of 3)?

Yoon S. Lee, Self Assembly and Nanotechnology: A Force Balance Approach, Wiley, 2008 pp. 60-62.

In a self-assembled micelle, each of the surfactant molecules occupies a volume described by the volume of a **cone**, $v = 1/3\ \pi\ r^2h$, where r is the **radius** of the base, and h is the **height** of the cone. The **area** of the base of the cone is $a = \pi\ r^2$



Suppose the surfactant molecule is a cationic surfactant:

Counter Head Hydrocarbon Tail
Ion Group

| C C C C C C C C
Cl^- N^+ / \ / \ / \ / \ / \ / \ / \ / \
| C C C C C C C C

What kind of micelle forms (2 of 3)?

The length λ of the hydrocarbon tail is estimated from:

$\lambda = 1.54 + 1.265(\mathbf{n})$ in units of 10^{-10} m, where **n** is the number of carbons in the hydrocarbon tail.

The volume of the surfactant molecule is estimated from:

$\mathbf{v} = 27.4 + 26.9(\mathbf{n})$ in units of $(10^{-10})^3$ m^3

The micelle packing factor **g** is defined as

$\mathbf{g} = \mathbf{v/(a\lambda)}$.

When **g** = 1/3, the micelle forms a sphere. When **g** = 1/2, the micelle forms a rod-like shape. When **g** = 1, the micelle forms a bilayer.

What kind of micelle forms (3 of 3)?

For the surfactant molecule with **n** = 16,

λ = _____21.78___________ x 10^{-10} m

v = ____457.8___________ x $(10^{-10})^3$ m^3

Since **v** = 1/3 π r^2h, solve for r = ___4.46_______ x10^{-10} m

Calculate the micelle packing factor **g** = ____0.33_______.

What kind of micelle does this cationic surfactant form?

sphere

What is a “Case Study”?

- Due 1 month after assignment (short time frame)
- Means to understand complexity of a problem
- Plan for formulating research program
- Way to evaluate alternative technologies
- Strategy for making decisions
- Method to incorporate continuous change
- Not a term paper
- Borrowed liberally from business school texts

The case study in 4 powerpoint slides:

Phase 1: Overview

- Define the problem
- Organize the team
- Assign tasks
- Anticipate the outcome; importance of solving the problem

Phase 2: Situation Analysis

- List the facts
- Analyze the data
- List potential concerns
    - Cost
    - Environmental
    - Competition
    - Availability
    - Regulations
- Personnel

The case study in 4 powerpoint slides:

Phase 3: Alternatives

- Identify alternatives
- Consider positive and negative aspects of each alternative
- Assess risks (pros and cons)

Phase 4: Recommendation

- Make recommendation (your strategy for solving the problem) and support it
- Clarify key assumptions
- Present action plan
  - ➢ Process (how)
  - ➢ Timetable (when)
  - ➢ Diagnostics (benchmarks)

Basis of Case Study Grade:
15 minutes, teams of 4

- Understanding the Problem - 20
- Finding a Realistic Solution - 20
- Creativity - 20
- Meeting Objectives (followed format) - 20
- Presentation (slides readable, understandable) - 20

Cases for Spring 2009: from Technology Review, March/April 2009, page 14.

NANOTUBE ELECTRONICS, Prototypes bring practical nanotube devices closer

1. Stretchy Speakers, demonstrating thermoacoustic effect
2. Printable Integrated Circuits, using semiconducting inks
3. Conductive Clothes, using coatings to turn cotton into “wires”
4. Transparent Electrodes, for flexible LCD displays to replace indium-tin oxide

What do I look for in a good case study topic

- Application that undergraduates know, preferably a consumer gadget or device
- Initial source in a scientific paper, with other sources on company websites, often start-ups
- Existing alternatives, using nanomaterial or conventional material
- Social implication, e.g., energy, climate change, scarce resource, cost
- Advantage for nanomaterial

What I have learned about “nano-education” at the undergraduate level

- My students were born after the discovery of C_{60} and nanotubes
- My students do not remember a time without the internet
- My students were required to do team projects in high school, so the case study approach works well

Critical challenges for undergraduate nano-education

- Challenge is to have the right balance of breadth and depth
- Focus is often on research, but important to point to implementation in commercial applications
- Emphasis is on workforce development, motivation for that first job