ME 4875/MTE 575 - C/18

Introduction to Nanomaterials and Nanotechnology

Lecture 1 - Introduction
Course Information

Syllabus uploaded to Canvas

Schedule:

Lectures  MT-RF  10:00-10:50 pm in Olin Hall 223

Contact Information:

Prof – Pratap Rao  pmrao@wpi.edu, 508-831-4828, HL 106
TA – Cerien Vaidya  cvaidya@wpi.edu

Office Hours:

Prof.  TBD, in HL 106 and online
TA  TBD, in WB 333
Objective of the course:

- Lectures and homework: Broad introduction to nanomaterials and nanotechnology, inspire you to look into these topics further
- Project: More in-depth study of a chosen topic area

Lectures, readings, and assignments will be on Canvas

No textbook

Lectures will be recorded

Lecture recordings and lecture slides will be available on Canvas
Course Information

Coursework and Grading:

In-class

- 4 Homework Sets* 50%
  *Students in MTE 575 will have additional homework problems assigned
- Group Project (Report + Presentation) 45%
- Class Attendance 5%

Online

- 4 Homework Sets* 50%
  *Students in MTE 575 will have additional homework problems assigned
- Individual Project (Report only) 50%
Course Information

**Deadline conflicts:** Inform me during the first week of the term of any commitments (religious observances, WPI sports, etc.) or circumstances that might affect your ability to meet any of the deadlines in the course.

**Student Accommodations:** If you need course adaptations or accommodations because of a disability, or if you have medical information to share with me, please make an appointment with me as soon as possible. If you have not already done so, students with disabilities who believe that they may need accommodations in this class are encouraged to contact the Office of Disability Services (ODS) [124 Daniels Hall, disabilityservices@wpi.edu, (508)831-4908] as soon as possible to ensure that such accommodations are implemented in a timely fashion.
Waitlisted Students

- The combined enrollment of in-class sections of ME 4875 and MTE 575 has reached the physical capacity of the classroom.
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- Name
- Undergraduate/graduate, and expected graduation year
- Major
- Reasons why you need to take this class THIS term

- I will email you to let you know if you can or can’t register
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You can access the course materials at nanoenergy.wpi.edu until you get access to the Canvas site.
Immediate Assignments

HW 1 posted under ‘Assignments’
due in class Thursday January 18
Outline

- What is nanotechnology?
- Why nano?
- History of nanotechnology
The National Science Foundation defines nanotechnology as:
- research and development at the atomic/molecular/macromolecular level
- length scale of **approximately 1-100 nanometers**
- fundamental understanding of phenomena at the nanoscale
- structures, devices and systems that have novel properties and functions because of their small size.

Nanotechnology overlaps with the other sciences (physics, chemistry, biology, materials) and engineering.

1 meter = \(10^9\) nanometer

Earth = 1 m
Baseball = 1 nm

If the earth were shrunk down to 1 m diameter…. a baseball would be 1 nm in diameter.
Length Scale of Nanotechnology

- naked eye
- optical microscope
- electron microscope

- millimeter (mm) (1/1000 meter)
- micrometer (μm) (1/1000 millimeter)
- nanometer (nm) (1/1000 micrometer)

- atoms, molecules, DNA
- new physical phenomena

- individual carbon atoms!
**Things Natural**

- **Ant** ~ 5 mm
- **Dust mite** ~ 200 μm
- **Human hair** ~ 60-120 μm wide
- **Fly ash** ~ 10-20 μm
- **Red blood cells** (~7-8 μm)
- **ATP synthase** ~10 nm diameter
- **DNA** ~2-1/2 nm diameter
- **Atoms of silicon** spacing 0.078 nm

**Things Manmade**

- **Head of a pin** 1-2 mm
- **MicroElectroMechanical (MEMS) devices** 10 - 100 μm wide
- **Pollen grain**
- **Red blood cells**
- **Intel Transistor** Feature size 22 nm
- **Self-assembled, Nature-inspired structure** Many 10s of nm
- **Nanotube electrode**
- **Carbon Bucky ball** ~1.3 nm diameter
- **Carbon nanotube** ~1 nm diameter

The Scale of Things – Nanometers and More

- **Microworld**
  - 10^-2 m
  - 1 cm
  - 10 mm
  - 1,000,000 nanometers = 1 millimeter (mm)
- **Microworld**
  - 10^-3 m
  - 0.1 mm
  - 100 μm
  - 1,000 nanometers = 1 micrometer (μm)
- **Microworld**
  - 10^-4 m
  - 0.01 mm
  - 10 μm
- **Microworld**
  - 10^-5 m
  - 0.1 μm
  - 100 nm
- **Microworld**
  - 10^-6 m
  - 0.01 μm
  - 10 nm
- **Microworld**
  - 10^-7 m
  - 0.1 nm
  - 100 nm
- **Microworld**
  - 10^-8 m
  - 0.01 nm
  - 10 nm
- **Microworld**
  - 10^-9 m
  - 1 nanometer (nm)
- **Microworld**
  - 10^-10 m
  - 0.1 nm
- **Nanoworld**
  - 10^-10 m
  - 1,000 nanometers = 1 μm
- **Nanoworld**
  - 10^-9 m
  - 100 nm
- **Nanoworld**
  - 10^-8 m
  - 10 nm
- **Nanoworld**
  - 10^-7 m
  - 1 nm
- **Nanoworld**
  - 10^-6 m
  - 0.1 nm
- **Nanoworld**
  - 10^-5 m
  - 0.1 μm
- **Nanoworld**
  - 10^-4 m
  - 1 μm
- **Nanoworld**
  - 10^-3 m
  - 10 μm
- **Nanoworld**
  - 10^-2 m
  - 100 μm
- **Nanoworld**
  - 1 cm
  - 10 mm
- **Nanoworld**
  - 1,000,000 nanometers = 1 millimeter (mm)
Introduction to Nanomaterials and Nanotechnology

Physical phenomena at the nanoscale

Synthesis of materials at the nanoscale

Characterization of materials at the nanoscale

Atoms, molecules and crystals (briefly)

Weeks 3-5

Weeks 5-7

Week 2-3

Week 7

Project presentations

…more in-depth study of one application of nanotechnology per group

…with examples and applications

Project topics and resources

Course Outline
Physical properties

- The physical properties of nanoscale materials depend on their size (materials can have tunable properties at the nanoscale).
- Enhanced and/or novel phenomena unique to small structures.
- Gravitational forces become negligible while electromagnetic forces, quantum mechanical effects, and surface phenomena dominate.

Relevant ‘device’ limit. In both synthetic and natural systems, the nanometer scale represents a limit to which most functional structures might be scaled.

Unexpected science & technology. The multi-/interdisciplinary nature of nanoscience – working at interface between and bringing together different fields – could lead to revolutionary advances.
In many cases, useful region is only at the surface.

By using nano-scale size, we can make all the material useful.

Consider a cube:

Surface Area: \( S = 6a^2 \)

Volume: \( V = a^3 \)

Surface Area/Volume: \( \frac{S}{V} = \frac{6}{a} \)
High Surface Area Nanostructures in Nature - Gecko’s Foot

The extremely high surface area of a Gecko’s foot means that even the weak Van der Waals force can allow the Gecko to walk on the ceiling!

> few nanometers → no force

[Image of Gecko's foot with nanostructures]

[Image showing nanostructures: st, sp, tb]

[Image showing magnified view of nanostructures: sp, tb]

few nanometers → Van der Waals force

[Diagram showing force without and with few nanometers]
Smaller alveolar diameter leads to more efficient oxygen transfer for the same mass of lung!
Why Nano?

Quantum effects

Efficient charge and mass transport

Enhanced Strength

Surface/Interface effects

Li+


Schwierz, Nature Nanotechnology, 2010

Wu et al., Nature Materials, 2005

Natural Multiscale Hierarchical Materials

Scale of biology

Hemoglobin: 5.5 nm; DNA: 2nm

nano-micro     micro-milli     milli-centi

cell          tissue         organ

Lotus Leaf

Gecko’s Foot
Stratakis et al. *SPIE Newsroom*, 2005

Sea Sponge Skeleton

Gecko’s Foot

Karp et al. *MIT*

http://memscentral.com/famous_mems_products.htm
1959 - Richard Feynman’s seminal lecture “There’s Plenty of Room at the Bottom”

1974 - Norio Taniguchi of the Tokyo University of Science was the first to use the term "nano-technology" in a 1974 conference to describe material addition or removal processes such as thin film deposition and ion beam milling exhibiting characteristic control on the order of a nanometer.

1981 - K. Eric Drexler introduces idea of a “molecular assembler”, a hypothetical machine which would manufacture molecules and molecular devices atom-by-atom

1981 - Invention of Scanning Tunneling Microscope (1986 Nobel Prize in Physics)

1985 - Richard Smalley, Robert Curl and Harold Kroto discover C_{60} molecule (1996 Nobel Prize in Chemistry), one of the first nanometer-sized molecules, and closely related to carbon nanotubes
Feynman Prizes (1959)

Richard Feynman offered $1000 to anyone who could:

1. Build a motor that would fit inside a 1/64”x1/64”x1/64” box (400µm).
2. Write a page of text with letters that are small enough for the Encyclopedia Britannica to be printed on a pin head.

First Feynman Prize

William McLellan made a small motor almost immediately using an optical microscope, toothpick, and watchmaker’s lathe.
History of Nanotechnology

Second Feynman Prize

1985: Tom Newman, Fabian Pease (Stanford University) used e-beam lithography to write part of *A Tale of Two Cities* at the length scale requested by Feynman.

25 nm linewidth

6 μm
History of Nanotechnology

Scanning Tunneling Microscopy (STM)

- 1981: Vacuum tunneling observed by Binnig, Rohrer, Gerber, Weibel; IBM Zurich
- 1986: Nobel prize award to Binnig and Rohrer
Two Paradigms for Synthesis of Nanomaterials and Devices

**Top-down**
- Bulk
- Lithography
- Nanostructures

**Bottom-up**
- Atomic or molecular precursors
- Nanosynthesis
- Nanostructures

Domain of Engineering vs. Domain of Chemistry
Top Down MicroElectroMechanical Systems (MEMS)

- Comb drive
- Hinged mirror
- Steam engine
- Tissue shredder
These nano-components could be the building blocks of useful nanomaterials and devices.
Imaging of Nanomaterials

Optical Microscope (>100 nm)

Scanning Electron Microscope (few nm)

Transmission Electron Microscope (1/10 nm)

Scanning Tunneling Microscope (1/100 nm)

Many other types of characterization, too (chemical, crystallographic, electrical, etc.)
Next Class

- More on applications of nanotechnology
- More on project
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