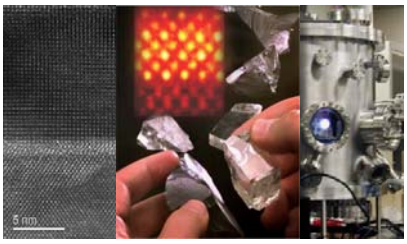
Materials Science and Engineering

Interdisciplinary with HUGE potential



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Yale University • Southern CT State University

Materials and Manufacturing Teacher Institute 2016

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Introduction

What is materials science*?

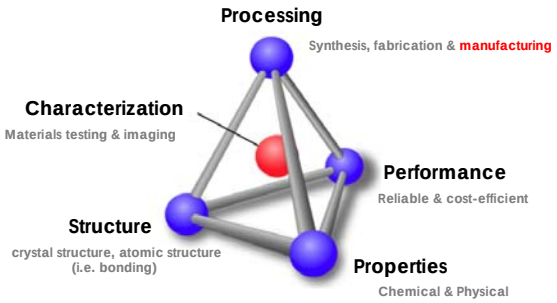
- A branch of science that focuses on materials; interdisciplinary field impacting the physical, life & engineering sciences.
- Relationship of material properties to its structure, performance and processing.

What is a materials scientist?

- A person who uses his/her knowledge of science and engineering to exploit structure - property relationships for practical use.
  - Goal: Take raw materials & make finished products

*Materials Science and Engineering [MSE]

Materials Science and Engineering



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What are Materials?

Classification of materials:

- **Metals** (Al, Ni, Cu, etc. // good conductors)

- **Ceramics/Glasses** (Al_2O_3, glass //good insulators)

- **Polymers** (plastic, rubber, proteins // synthetic, natural)

- **Composites** (combination of 1-3; i.e. carbon fiber)

Advanced materials, i.e. semiconductors, biomaterials, smart materials, and nano-engineered materials

Materials engineering – fabrication and application of new materials

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The impact of Materials Science

- Materials have defined the progression of humankind: Stone Age, Bronze Age, Iron Age
- Today's age: Silicon Age, Information Age

metals • ceramics • semiconductors • polymers
composites • smart materials

New generation of materials created by pushing the boundaries of science/innovation

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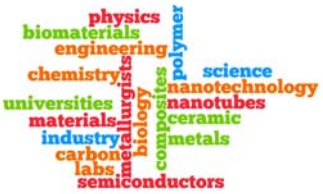
What do Materials Scientists do?

- Investigate how materials are made, figure out how they can be changed and improved, and engineer entirely new materials.



Materials science is an interdisciplinary field with many applications

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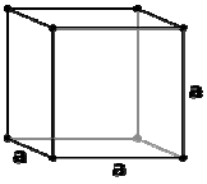
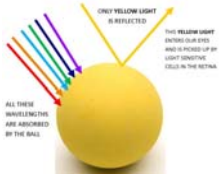
What is structure?
Atomic Structure – 10^{-10} m

- Pertains to electron structure and atomic arrangement
- Atom length scale
  - Includes electron structure – atomic bonding
    - ionic
    - covalent
    - metallic
    - secondary bonding (Van der Waals)
  - Atomic ordering – crystal structure
    - Crystalline
    - Polycrystalline
    - Amorphous
  - Long range (metals), short range (glass)



What is a property?

- **A material's response to an external stimuli – physical and chemical**
  - Electrical
  - Mechanical
  - Chemical
  - Optical
  - Magnetic



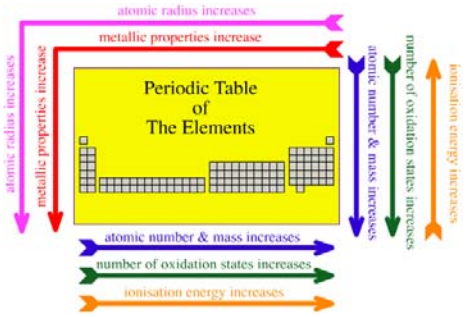
Optical: Stimuli = light [EM radiation]

https:// colour-yourlife.co.uk

Structure/Property Relationships

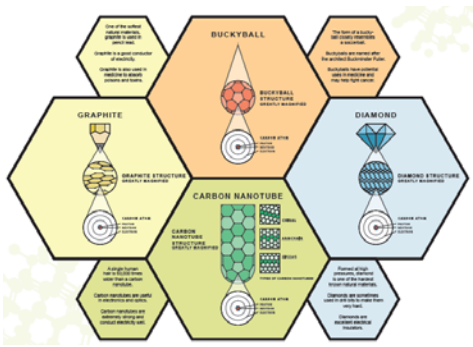
Atomic Structure

- Periodic Table – general trends



Structure/Property Relationships

Crystal structure and bonding



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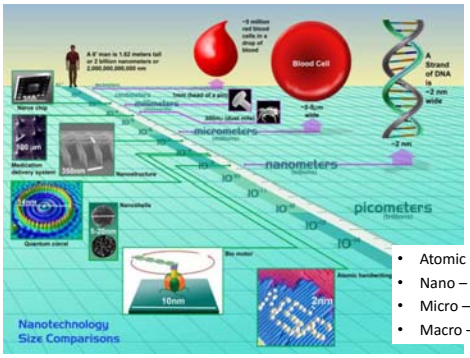
Length Scales of Materials Science



- Atomic – < 10^{-10} m
- Nano – 10^{-9} m
- Micro – 10^{-6} m
- Macro – > 10^{-3} m

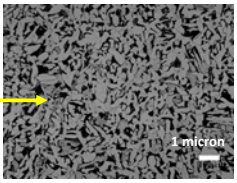
Nano Structure – 10^{-9} m

- Length scale that pertains to clusters of atoms that make up small particles or material features
- Show interesting properties because of large surface area to volume ratio
  - More atoms on surface compared to bulk atoms
  - Optical, magnetic, mechanical and electrical properties change
- How to visualize nano?

  Your finger nail grows ~1nm every second

Microstructure – 10^{-6}

- Larger features composed of either nanostructured materials or periodic arrangements of atoms known as crystals
- Features are visible with high magnification in light microscope.
  - Grains, inclusions other or micro-features that make up material
  - These features are traditionally altered to improve material performance
  - Human hair is ~100 microns in diameter



Macrostructure – 10^{-3} m

- Macrostructure pertains to collective features on microstructure level
- Grain flow, cracks, porosity are all examples of macrostructure features
- Some features can be observed with the naked eye

Classes of Materials

- metals
- polymers
- ceramics/glasses
- composites

Ceramic/glass Applications

- Window glass: Al_2O_3 – SiO_2 – MgO – CaO
- Aerospace, energy and automotive industry
  - heat shield tiles
  - engine components
  - reactor vessel and furnace linings
- Consumer products:
  - pottery
  - dishes (fine china, plates, bowls)
  - glassware (cups, mugs, etc.)
  - eye glass lenses
  - Ceramic braces

Other advanced materials

- **Semiconductors – ceramics**
  - computer chips
  - memory storage devices
  - solar cells
  - image screens
- **Nanomaterials – ceramics, metals, polymers**
  - gold nanoshells
  - quantum dots
  - ferrofluids
  - medical devices

How do we test materials?
Materials Characterization

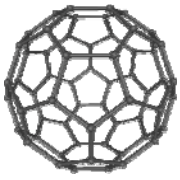
We use mechanical, chemical and imaging methods

- Mechanical testing gives strength, ductility and toughness material information
  - tensile tests
  - bend tests
  - compressive tests
  - fracture testing
- Chemical testing tells us about composition and chemical stability
  - x-ray diffraction and fluorescence – composition testing
  - corrosion testing
- Microscopy is more of a way to view atomic, nano and microstructures, and gives us insight to structure property relationships
  - light optical microscope – microstructure
  - scanning electron microscope – microstructure and nano structure
  - transmission electron microscope – nanostucture and atomic structure
  - scanning probe microscope – atomic structures

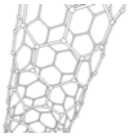
Nanotechnology

Control & manipulation of matter [1-100nm]

Unique phenomenon enable novel applications



C_{60} buckyball
fullerene



C nanotube
cylindrical fullerene
[photovoltaic, solar cell]

Quantum dots
Nanosize semiconductors
[DVD, video games]

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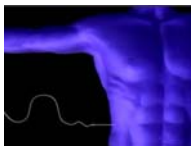
Innovations In Development or Under Investigation

- **Health Care**
  - Chemical and biological sensors, drugs and delivery devices, prosthetics and biosensors
- **Technology**
  - Better data storage and computation
- **Environment**
  - Clean energy, clean air

Thin layers of gold are used in tiny medical devices

Carbon nanotubes can be used for H fuel storage



Possible entry point for nanomedical device

Examples of current commercial products

- Cosmetics (skin care products)
- Tennis balls which last longer
- Wrinkle free fabrics, "nano-fabrics"
- Sunscreen with transparent zinc-oxide

The possibilities are limitless…

Potential Impacts

How might Materials Science, Engineering and Manufacturing enhance K-12 education?

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For Discussion -- M&M Connections to the NAE Frameworks

SCIENCE AND ENGINEERING PRACTICES FOR K-12 SCIENCE CLASSROOMS

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

CORE AND COMPONENT IDEAS IN THE PHYSICAL SCIENCES

Core Idea PS1: Matter and Its Interactions
PS1.A: Structure and Properties of Matter
PS1.B: Chemical Reactions
PS1.C: Nuclear Processes

Core Idea PS2: Motion and Stability: Forces and Interactions
PS2.A: Forces and Motion
PS2.B: Types of Interactions
PS2.C: Stability and Instability in Physical Systems

Core Idea PS3: Energy
PS3.A: Definitions of Energy
PS3.B: Conservation of Energy and Energy Transfer
PS3.C: Relationship Between Energy and Forces
PS3.D: Energy in Chemical Processes and Everyday Life

Core Idea PS4: Waves and Their Applications in Technologies for Information Transfer
PS4.A: Wave Properties
PS4.B: Electromagnetic Radiation
PS4.C: Information Technologies and Instrumentation

Summary

Materials Science & Engineering

- A branch of science that focuses on materials; interdisciplinary field composed of physical, life and engineering sciences.
- Relationship of material properties to its structure, performance and processing.
- Interdisciplinary field with huge potential for synergies with the National Academies Next Works, Next Generation Science Standards & Common Core.

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The Hammer Project

Materials, Manufacturing and the K-12 Curriculum

David Tuttle

- David is the Dept. head for the Precision Manufacturing Program at Platt Technical High School which is part of the Connecticut Technical High School System in which he oversees two instructors, teaches grades 11 & 12 in advanced technologies. He also manages program budgets, purchasing, inventory, shop floor requirements, industrial relations and job placements for Platt Tech. David has many years for relevant industry experience that he will share during his sessions

Gregory AmEnde

- Greg is currently entering his 4th year as a manufacturing instructor at Platt Technical High School. He previously worked for 2 years as a manufacturing instructor at Housatonic's Advanced Manufacturing program. Before teaching Greg worked for EDAC Technologies in the Aero Rotating Components division. At EDAC he worked in multiple departments including VTL operations, Tool Room, Special Processes, Inspection, and Assembly. EDAC specializes in aerospace engine components for the military, commercial airlines, energy companies, and NASA.

Curriculum facilitator -- Yvonne Klancko

- Yvonne is a partner of the consulting firm of Klancko & Klancko, LLC, specializing in the areas of education consulting, new program development, creative teaching techniques, testing and community relations.