MATERIAL SCIENCE (MEE102A)

Learning Objectives

- Give basic knowledge of science behind materials.
- Introduce the structure property relations.
- Lay the groundwork for studies in filed such as heat treatment, mechanical behavior of materials, failure of materials & their protection,
- Understanding the behavior of materials, particularly structure-property correlation, will help selecting suitable materials for a particular application.
- How the material science used in engineering practices.

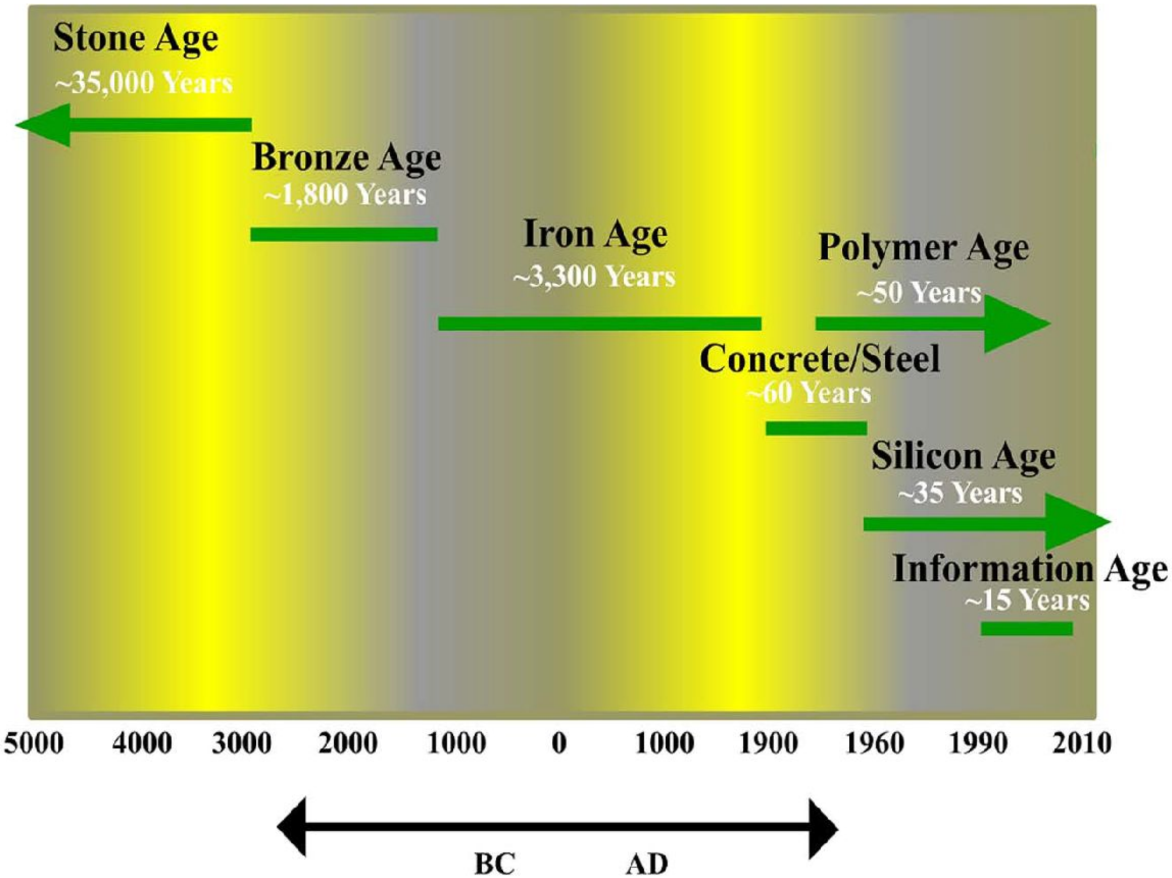
Material Science ?

- Materials science, also commonly termed materials science and engineering, involves the discovery and design of new materials.
- Material Science is the investigation of the relationship among processing ,structure , properties & performance of materials

Materials in day to day life

Historical Development of Material

- Development and advancement of Human societies-closely related with materials
- Civilizations have been named based on the level of their materials development – Stone age, Bronze age etc.



History of Materials Science

- Materials closely connected our culture.
- The development and advancement of societies are dependent on the available materials and their use.
- Early civilizations designated by level of materials development.

Classification of Materials

Metals

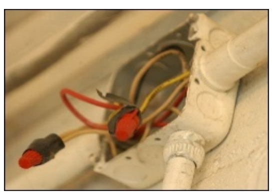
- good conductors of electricity and heat
- lustrous appearance
- susceptible to corrosion
- strong, but deformable

Ceramics & Glasses

- thermally and electrically insulating
- resistant to high temperatures and harsh environments
- hard, but brittle

Polymers

- very large molecules
- low density, low weight
- maybe extremely flexible

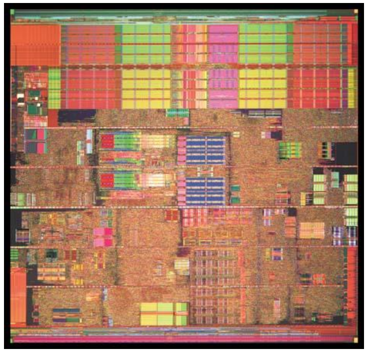




A Few Additional Categories

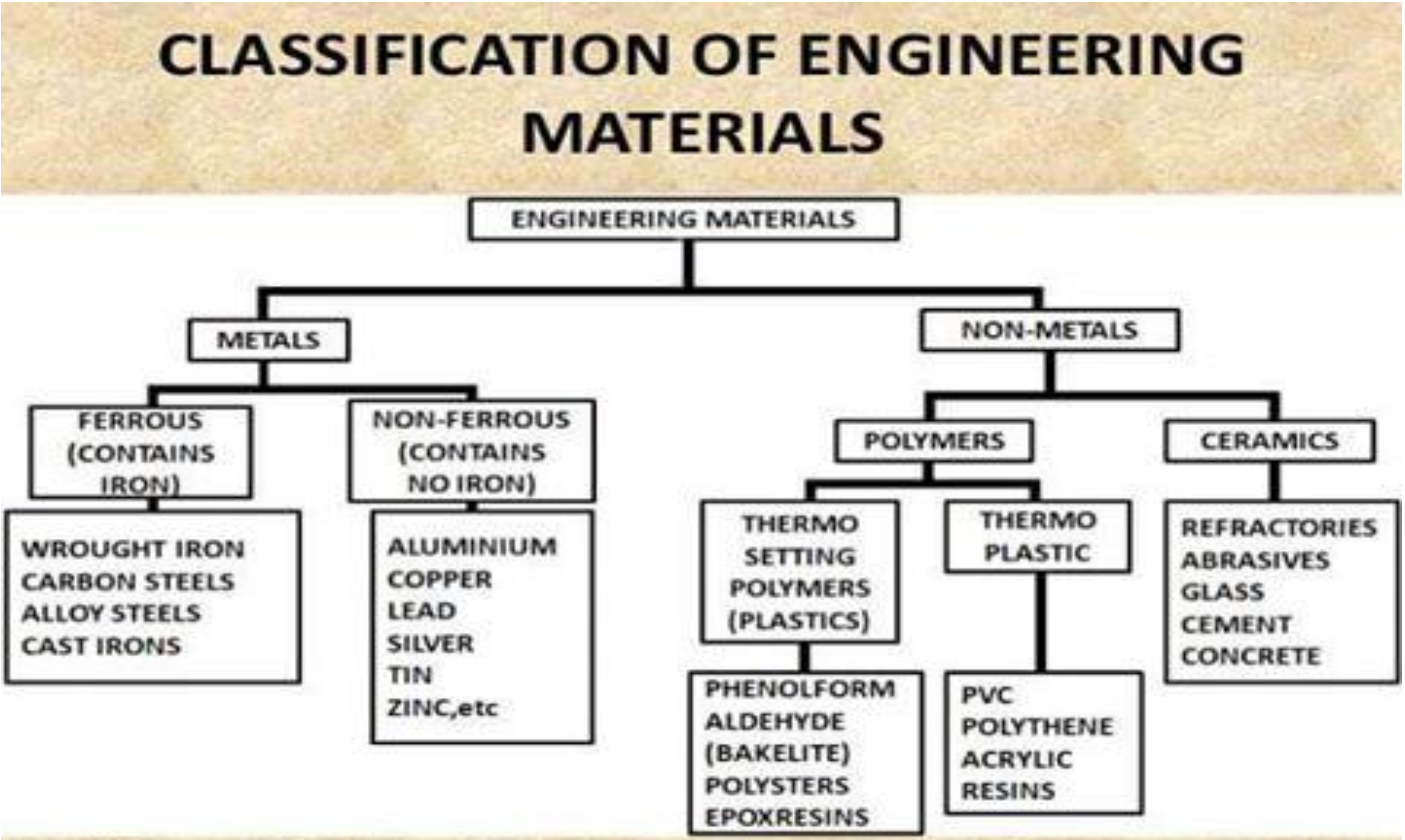
Biomaterials
- implanted in human body
- compatible with body tissues

Semiconductors
- electrical properties between conductors and insulators
- electrical properties can be precisely controlled



Composites
- consist of more than one material type
- designed to display a combination of properties of each

Classification of Materials



Why study materials?

- Applied scientists or engineers must make material choices
- Materials selection
  - In-service performance
  - Deterioration
  - Economics

aluminum

glass

plastic

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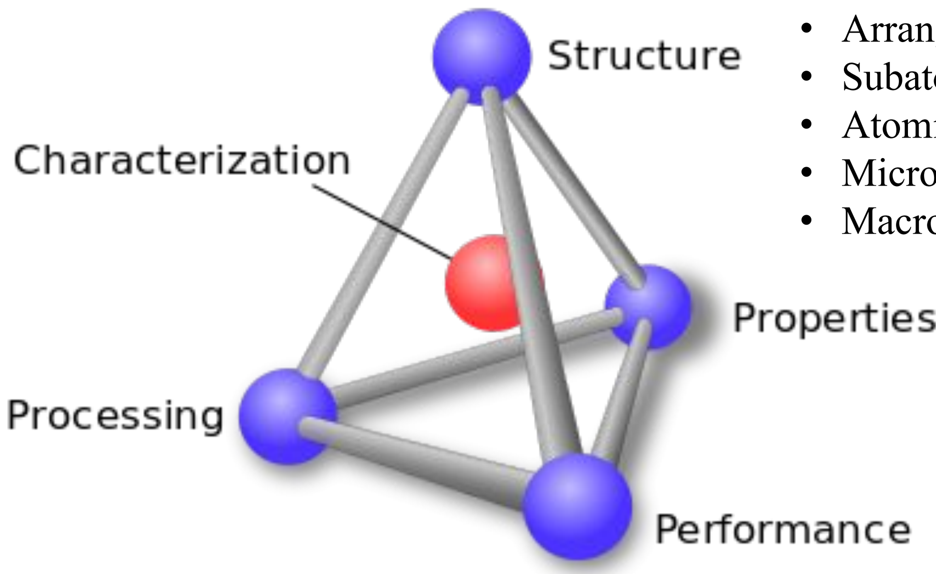
Why study materials?

Airless tyre

The Materials Tetrahedron



- Arrangement of internal components
- Subatomic
- Atomic
- Microscopic
- Macroscopic (bulk)

- Material characteristic
- Response to external stimulus
- Mechanical, electrical, thermal, magnetic, optical, deteriorative

- Behavior in a particular application

The Materials Tetrahedron

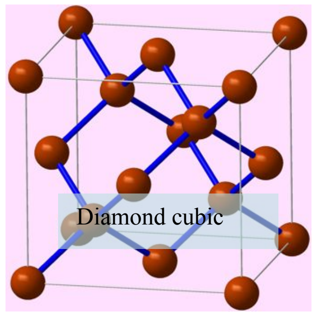
- A materials scientist has to consider four 'intertwined' concepts, which are schematically shown as the 'Materials Tetrahedron'.
- When a certain performance is expected from a component (and hence the material constituting the same), the 'expectation' is put forth as a set of properties.
- The material is synthesized and further made into a component by a set of processing methods (casting, forming, welding, powder metallurgy etc.).

The Materials Tetrahedron

- The structure (at various length scales) is determined by this processing.
- The structure in turn determines the properties, which will dictate the performance of the component. Hence each of these aspects is dependent on the others.

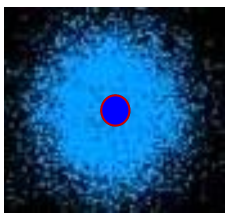
Material Science

- Casting
- Metal Forming
- Welding
- Powder Processing
- Machining

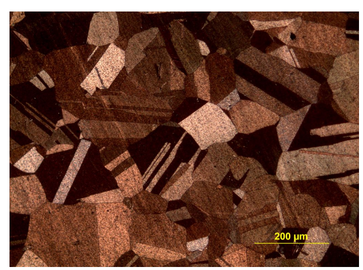


Crystal

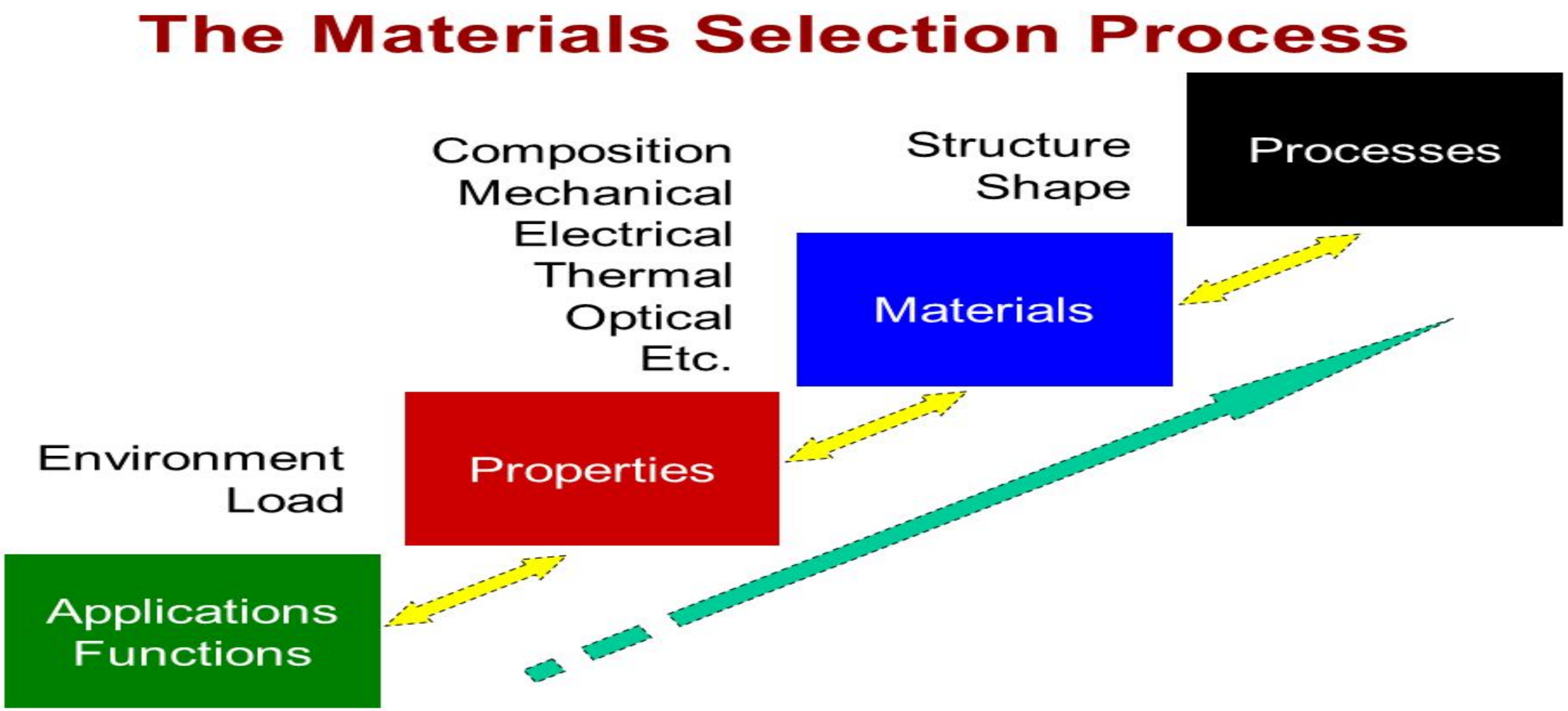
Thermo-mechanical Treatments



Atom → Structure → Microstructure → Component



Selection Process of Engineering Materials



Recent Development……

- Nano Technology
- Biomaterials
- Smart Materials

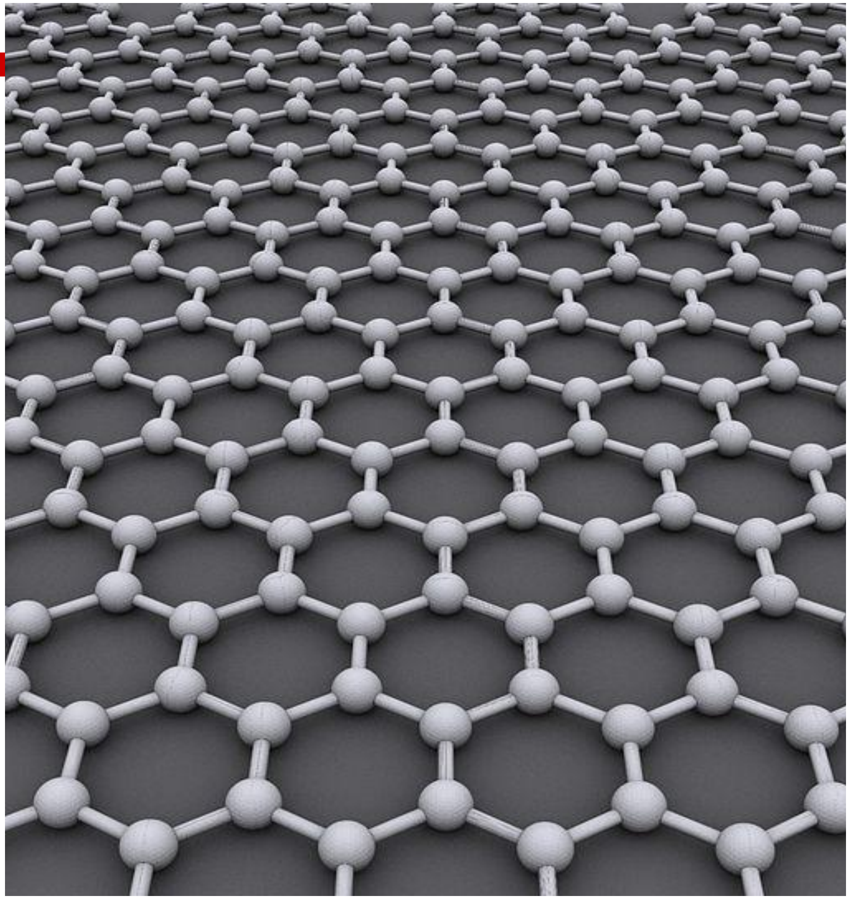
Graphene

Atom Thick

- You can write with it, or make squash rackets.
- In 2004, researchers used Scotch tape to pull up layer after layer until there was only a single-atom layer left.
- Since then, others have come up with more efficient—and more advanced—methods for making atom-thick sheets, called graphene.
- The honeycomb lattice of carbon-to-carbon bonds has some pretty remarkable properties. It's flawless, light, and strong. It's flexible, can be bent into any shape, can carry a charge, and it won't oxidize.

Graphene

- 2-dimensional, crystalline allotrope of carbon
- Allotrope: property of chemical elements to exist in two or more forms
- Single layer of graphite
- Honeycomb (hexagonal) lattice



Graphene

Mechanical Properties

- Due to the strength of its 0.142 Nm-long carbon bonds, graphene is the strongest material ever discovered, with an ultimate tensile strength of 130,000,000,000 Pascals (or 130 gigapascals), compared to 400,000,000 (400 Mpa) for A36 structural steel, or 375,700,000 for Aramid (Kevlar).

Electronic Properties

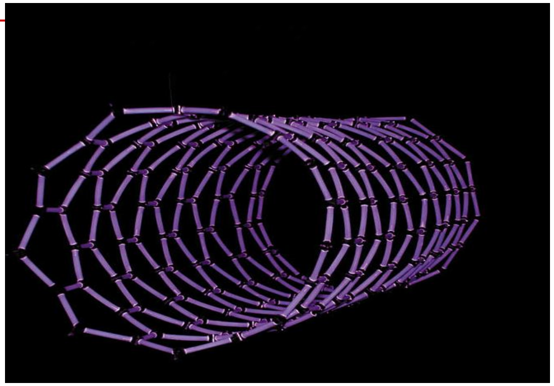
Carbon atoms have a total of 6 electrons; 2 in the inner shell and 4 in the outer shell. The 4 outer shell electrons in an individual carbon atom are available for chemical bonding, but in graphene, each atom is connected to 3 other carbon atoms on the two dimensional plane, leaving 1 electron freely available in the third dimension for electronic conduction.

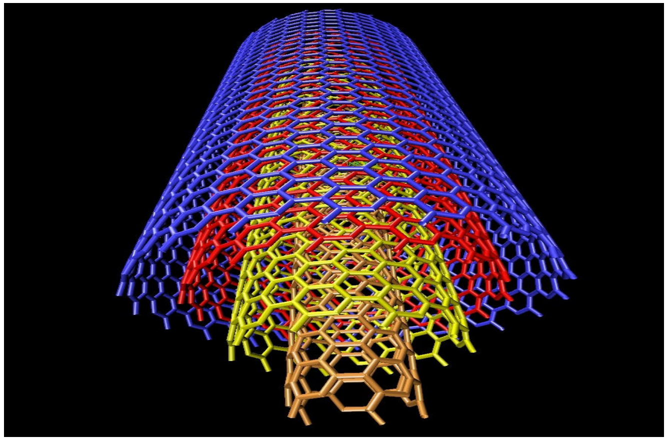
Graphene

- The market price of graphene was about **$100 per gram**
- Everyone agrees that graphene is an amazing material. Graphene has better electron mobility than any metal, is one atom thin, is flexible, and all that while being stronger than steel.
- Graphene has been shown to enhance batteries, solar cells, electronic transistors, flexible displays, sensors, and material strength.
- Thousands of patents are being filed every year for inventions ranging from graphene tires to flexible cellphones.

Carbon nanotubes

- **Carbon nanotubes** (**CNTs**) are allotropes of carbon.
- These cylindrical carbon molecules have interesting properties that make them potentially useful in many applications in nanotechnology, electronics, optics and other fields of materials science, as well as potential uses in architectural fields.
- They exhibit extraordinary strength and unique electrical properties, and are efficient conductors of heat.
- Their final usage, however, may be limited by their potential toxicity.

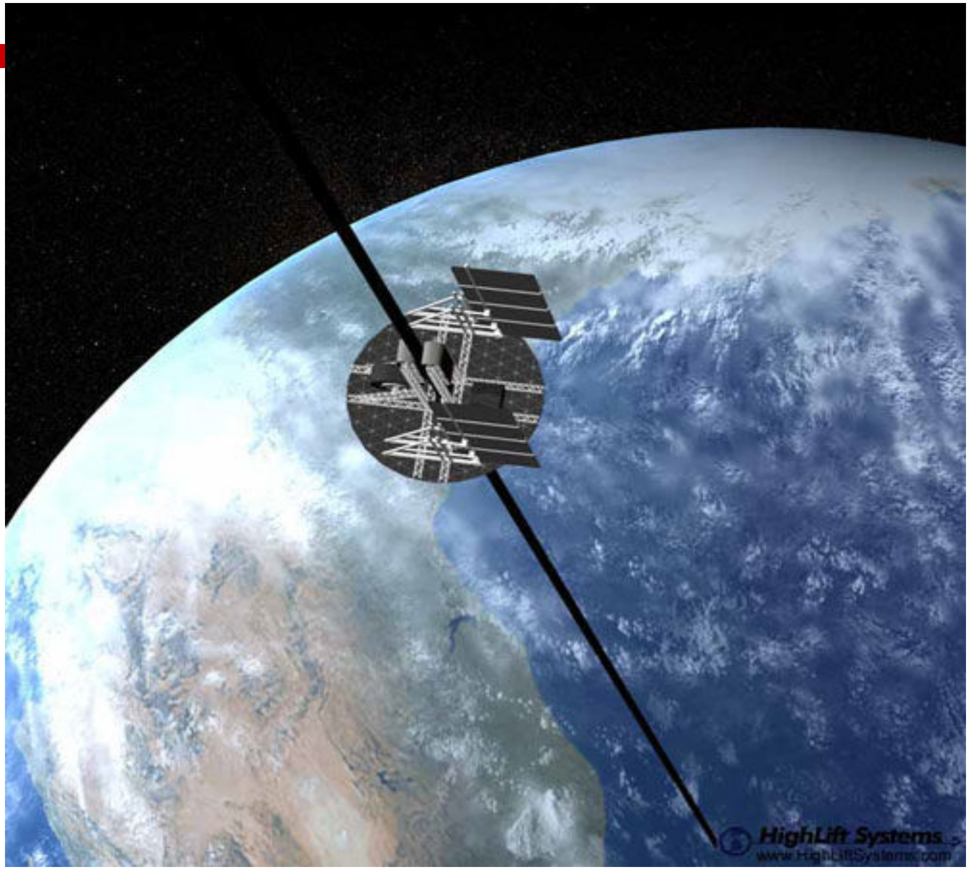




Carbon nanotubes

- Owing to the material's exceptional strength and stiffness, nanotubes have been constructed with length-to-diameter ratio of up to 132,000,000:1, significantly larger than for any other material.

- Nanotubes' excellent strength to weight ratio creates the potential to build an elevator to space.



Carbon nanotubes

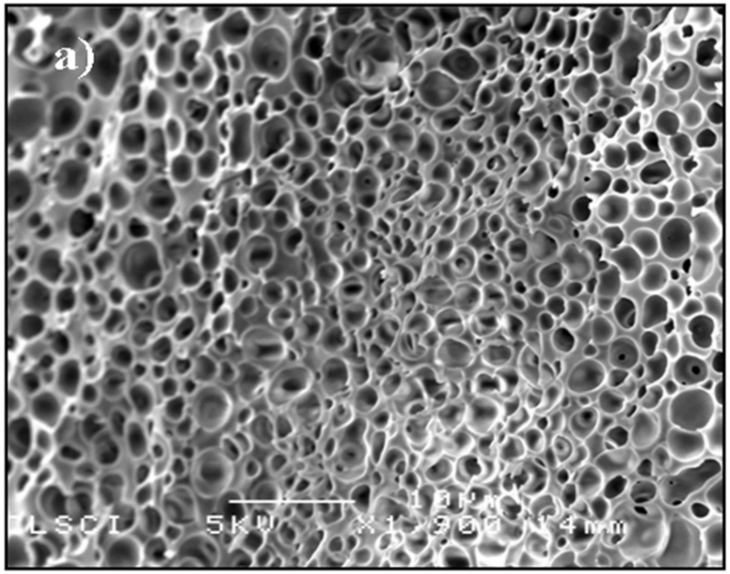
Health Hazards

- According to scientists at the National Institute of Standards and Technology, carbon nanotubes shorter than about 200 nanometers readily enter into human lung cells similar to the way asbestos does, and may pose an increased risk to health.
- Carbon nanotubes along with the majority of nanotechnology, are an unexplored matter, and many of the possible health hazards are still unknown.

Aerogel

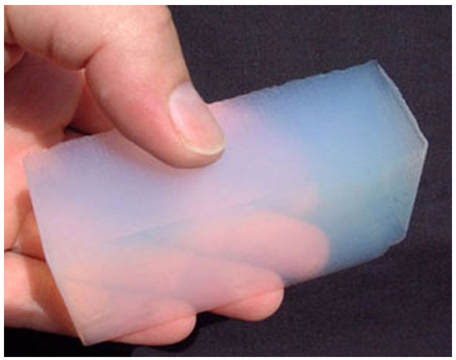
Aerogel is nanotechnology

- A nanometer is 1 billionth of a meter.
- A hair is 80,000 nm wide.
- Aerogel is a glass foam with bubbles 10 nm wide.



Scanning electron microscope picture of aerogel

Aerogel

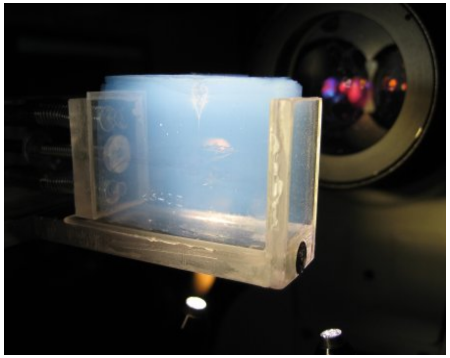


Aerogel - Universal solution

- aerogel is often called a "frozen smoke“;
- it consists of lightweight silica solids derived from a gel;
- liquid phase is completely replaced by gas;
- conduction through the solid is therefore very low;
- the world’s lowest density solid (0.020 g cm-3) ;
- aerogel consists of 99.8% of air;
- Aarogel can be used at temperatures ranging from - 200° C to + 650°C;

Aerogel

Properties of Aerogel



- low thermal conductivity ;
- heat resistance;
- transparency;
- elasticity;
- insulation;
- durability;
- flexibility ;

Aerogel

Fields of Applications:

- sub-ambient piping and equipment;
- cryogenic storage ;
- sea transport;
- liquefied natural gas (LNG) import/export pipelines;
- Gloves, jackets, sleeping bags, boots;

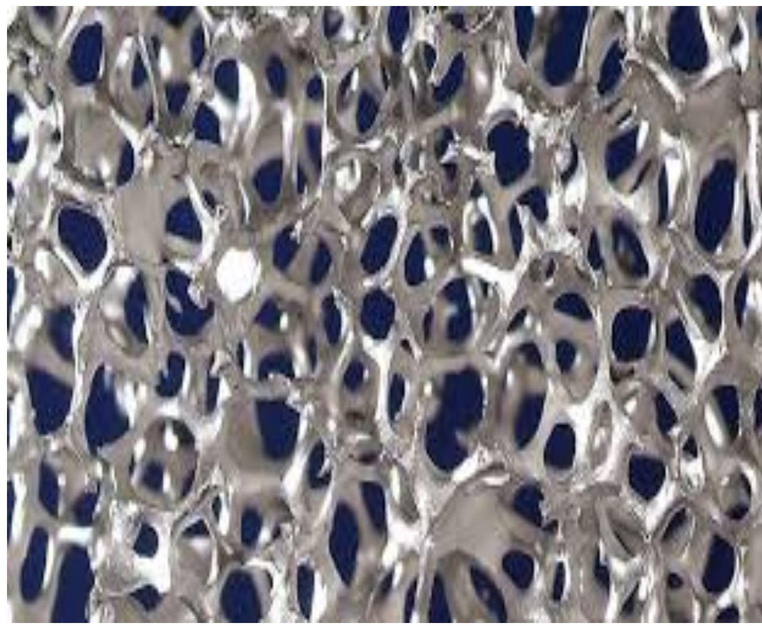
Titanium foam

Titanium foam could make your bones as strong as Wolverine's

- New titanium foam could revolutionize bone implants.
- The material can integrate with the patient's natural bone, reducing the stress on both the original bone and the implant and making the overall skeleton stronger.
- Currently, bone implants use solid metal, most often titanium.
- These integrate well with the body's immune system, but they're a lot stiffer than natural bone, and this means the implant can end up carrying a lot more weight than the adjacent bone.
- This can cause the bone to deteriorate and the implant to get damaged and need a replacement.

Titanium foam

- That's why titanium foam is such an attractive alternative. It's spongy like real bones, and it's porous, meaning the bone can actually grow into it and intermingle, effectively merging bone and titanium into a single structure.



D3O

- **D3O** (formally "D3o") is a polyurethane energy-absorbing material containing several additives a dilatant non-Newtonian fluid.
- It is liquid substance, that in its raw state flows freely when moved slowly, but on shock, locks together to absorb and disperse energy, before returning to its flexible state.
- The commercial material known as D3O is in essence polyurethane foam with traces of polyborodimethylsiloxane which makes the product rate sensitive thus dissipating more energy than plain polyurethane at specific energy levels.
- D3O's technology is sometimes used in skiing/snowboarding and motorcycle suits.

D3O

D3O has been applied in the following areas:

- Military
- Workwear
- Sports, including ski and snowboard, baseball, volleyball, tennis, squash, shooting, mountain biking and cycling, Footwear.
- Cases for electronic devices
- Ice Skating and Figure Skating

Reference Books

1. Callister William D. “Material Science and Engineering an Introduction”, 9th Ed, John Wiley & Sons Inc., 2013.

2. Askeland Donald R, Phule Pradeep, “The Science and Engineering of materials”, 5th Ed, Thomson Brooks/cole, 2005.

3. Avner Sidney H., “Introduction to Physical Metallurgy”, 2nd Ed, McGraw-Hill, 1997.

THANK YOU