NANOTECHNOLOGY, NANOSCIENCE & NANOMATERIALS

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Introduction

Nanotechnology & Nanomaterials

Synthesis of nanomaterials: Top-down and Bottom-up approach

Sol-Gel method

Ball Milling method

Properties of Nanomaterials

Applications of Nanomaterials
What is Nanotechnology

• the study of the controlling of matter on an atomic and molecular scale. Generally nanotechnology deals with structures sized between 1 to 100 nanometer in at least one dimension, and involves developing or modifying materials or devices within that size.
Nanotechnology

• is already making today’s products:
  – Lighter
  – Stronger
  – Faster
  – Smaller
  – More Durable
How small is Nano - small?

Units in nanometers (µm)
Compared to Human Hair

A Human Hair is about 100,000µm wide
Nanomaterials are the materials of size between 1 nm to 100 nm.

- If a bulk metal is made thinner and thinner, until the electrons can move only in two dimensions (instead of 3), then it is “2D quantum confinement.”
- Next level is ‘quantum wire’
- Ultimately ‘quantum dot’
• **Nanotechnology** is science, engineering, and technology conducted at the nanoscale (about 1 to 100 nanometers)

• **Nano** can refer to technologies, materials, particles, objects – we are focusing on **nanomaterials** as these are already being used in workplaces more widely

• A sheet of paper is about 100,000 nanometers thick, a human hair is around 80,000-100,000 nanometers wide

References:
- [http://www.nano.gov/nanotech-101](http://www.nano.gov/nanotech-101)

**The Scale of the Universe video**
Nanomaterials can...
- occur naturally
- be produced by human activity either as a product of another activity
- on purpose (engineered)

Our focus: *engineered* nanomaterials as these are designed and integrated into products because of the specific characteristics of the nanomaterial

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<table>
<thead>
<tr>
<th>Naturally Occurring</th>
<th>Human Origin (Incidental)</th>
<th>Human Origin (Engineered)</th>
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<tbody>
<tr>
<td>Forest fires</td>
<td>Cooking smoke</td>
<td>Metals</td>
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<tr>
<td>Sea spray</td>
<td>Diesel exhaust</td>
<td>Quantum dots</td>
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<td>Mineral composites</td>
<td>Welding fumes</td>
<td>Buckyballs/Nanotubes</td>
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<td>Volcanic ash</td>
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<td>Viruses</td>
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<td>Nanocapsules</td>
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</tbody>
</table>

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References:
https://nanohub.org/groups/gng/training_materials
(Introduction to Nanomaterials and Occupational Health)

Images:
http://www.everychina.com/m-rubber-nano-zinc-oxide
http://img.docstoccdn.com/thumb/orig/76747818.png
http://www.nanodic.com/carbon/Fullerene/1_resize.jpg
http://www.icbpharma.pl/techno_slow.html

Date, location
Nanotechnologies can be:

• Top-down
  – Etching a block of material down to the desired shape
  – Chips and processors

• Bottom-up
  – Building materials atom by atom - like lego
  – Nanoparticles such as C\textsubscript{60}, carbon nanotubes, quantum dots

Images:
Classes of nanomaterials

References:

Date, location
NanoZnO – One Chemistry, Many Shapes

Courtesy of Prof. Z.L. Wang, Georgia Tech
• At nano-scale,
  • the material **properties change** - melting point, fluorescence, electrical conductivity, and chemical reactivity
  • **Surface size is larger** so a greater amount of the material comes into contact with surrounding materials and increases reactivity
  • Nanomaterial properties can be ‘tuned’ by varying the size of the particle (e.g. changing the fluorescence colour so a particle can be identified)
  • Their **complexity** offers a variety of functions to products

References:
http://www.nano.gov/nanotech-101
http://www.phys.sinica.edu.tw/TIGP-NANO/Course/2012_Fall/classnotes/NanoB_PART_I_20121101.pdf
• Examples:
  • Amorphous silica fume (nano-silica) in **Ultra High Performance Concrete** – this silica is normally thought to have the same human risk factors as non-nano non-toxic silica dust
  • Nano platinum or palladium in **vehicle catalytic converters** - higher surface area to volume of particle gives increased reactivity and therefore increased efficiency
  • Crystalline silica fume is used as **an additive in paints or coatings**, giving e.g. self-cleaning characteristics – it has a needle-like structure and sharp edges so is very toxic and is known to cause silicosis upon occupational exposure

References:
http://www.efbww.org/pdfs/Nano.pdf
http://www.nano.gov/nanotech-101/special
http://old.vscht.cz/monolith/
http://www.efbww.org/pdfs/Nano.pdf

Date, location
In 2004, a scientist working in the US proposed 4 generations of nanotechnologies, with the 1st generation already existing: nanomaterials.

1\textsuperscript{st} generation generally combines a nanomaterial with another material to introduce a new functionality or enhance performance/behaviour.

Increasing complexity and ethical issues.

Generational timeline was optimistic.

References:

Synthesis of nanomaterials: Top-down and Bottom-up approach

- **Macro mm**: Equiangle extrusion, Rapid solidification
- **Micron mm**: Mechanical alloying, Micromachining
- **Nanometer**: Inert gas condensation, Sol-gel and self-assembly

Scale:
- **Top down**: Bulk nanostructured solid
- **Intermediate**
- **Bottom up**
Sol-Gel method

The method is used for the fabrication of metal oxides, especially the oxides of silicon and titanium. The process involves conversion of monomers into a colloidal solution (sol) that acts as the precursor for an integrated network (or gel) of either discrete particles or network polymers.
Ball Milling method

**Ball Milling:**
Ball milling is an old and relatively simple method for grinding large lumps of materials into smaller pieces and powder form.

**Principle of the process:**
The principle is simple and is based on the *impact and shear forces*. Hard balls are used for mechanical comminution of brittle materials and producing powders.

**Milling Unit:**
The basic apparatus consists of the following:
- A ball mill or jar mill which mainly consists of a rotating drum lined from inside with a hard material.
- Hard balls, as a grinding medium, which continue to impact the material inside the drum as it rotates/rolls.
Physical Properties of Nanomaterials

1. **Reduced Melting Point** -- Nanomaterials may have a significantly lower melting point or phase transition temperature and appreciably reduced lattice constants (spacing between atoms is reduced), due to a huge fraction of surface atoms in the total amount of atoms.

2. **Ultra Hard** -- Mechanical properties of nanomaterials may reach the theoretical strength, which are one or two orders of magnitude higher than that of single crystals in the bulk form. The enhancement in mechanical strength is simply due to the reduced probability of defects.

3. **Optical properties** of nanomaterials can be significantly different from bulk crystals.
   --- **Semiconductor Blue Shift** in adsorption and emission due to an increased band gap.
   --- **Quantum Size Effects**. **Particle in a box.**
   --- **Metallic Nanoparticles Color Changes** in spectra due to **Surface Plasmons Resonances**
   Lorentz Oscillator Model.

4. **Electrical conductivity decreases** with a reduced dimension due to increased surface scattering. **Electrical conductivity increases** due to the better ordering and ballistic transport.

5. **Magnetic properties** of nanostructured materials are distinctly different from that of bulk materials. Ferromagnetism disappears and transfers to superparamagnetism in the nanometer scale due to the huge surface energy.

6. **Self-purification** is an intrinsic thermodynamic property of nanostructures and nanomaterials due to enhanced diffusion of impurities/defects/dislocations to the nearby surface.

7. **Increased perfection enhances** chemical stability.

Most are tunable with size!
Applications of Nanotechnology

MEDICINE
Diagnostics
Drug Delivery
Tissue Engineering
Current Applications

- burn and wound dressings, water filtration devices, paints, cosmetics, coatings, lubricants, textiles, memory/storage devices
- medical diagnostics, displays, sensors, drug delivery, composite materials, solid state lighting, bio-materials, nano arrays, more powerful computers, protective armor, chem-bio suits, and chem-bio sensors
Applications of Nanomaterials

1. TEXTILES
2. RENEWABLE ENERGY
3. ENVIRONMENT
4. ELECTRONICS
5. INDUSTRIAL
6. FOOD AGRICULTURE
7. HEALTH CARE
8. BIOMEDICAL
THANKS