Introduction to Nanotechnology

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ABSTRACT

Nanotechnology deals with creation of materials, devices and systems in the nanometer scale (1-100 nm) through manipulating matter at that scale and exploiting novel properties arising because of the nanoscale. This lecture will first define nanotechnology, particularly describing what it is and what it is not, followed by detailed examples of change in various properties seen by going from bulk to nanoscale. The effect of nanoscale on physical properties, bandgap, etc. will be illustrated. Examples of novel nanomaterials such as nanotubes, nanowires, nanoparticles, etc. will be introduced. Also, the tools used in nanotechnology research such as the scanning probe microscopes, scanning tunneling microscopes etc. will be mentioned and a summary of top-down and bottom-up processes needed in manufacturing will be presented as an introduction to the more detailed coverage later. Finally, a broad overview of the potential of nanotechnology on a sector-by-sector basis will be given to set the stage for the subsequent lectures in this NATO series.

Nanotechnology deals with creation of materials, devices and systems through manipulation of matter at the nanometer length scale. The object created itself does not have to be nanoscale, but can be micro or macro size. What is critical is the ability to exploit the novel properties that arise because of nanometer length scale. Indeed when we go down from bulk to nanoscale, physical, chemical, mechanical, electrical, optical, magnetic and other properties change. The field is about making use of such changes and developing novel products and processes which have not been possible until now.

The advent of scanning tunneling microscope and atomic force microscope in the 1980s has essentially ushered in the nano era. With these powerful tools, scientists were able to see nature at the atomic level. Simultaneously, with increased computing power available, modeling and simulation enabled an understanding of properties at the nanoscale. This powerful combination of atomic scale characterization and detailed modeling has led to the explosion we see today in nanoscale science and technology research.

Nanoscale materials have a large surface area for a given volume. The surface properties dominate compared to bulk properties. Quantum phenomena becomes critical at reduced length scales. In most cases, the change in behavior is not a simple extrapolation of bulk behavior as we know. In materials where strong chemical bonding is present, delocation of valence electrons can be extensive. The extent of delocalization can vary with the size of the system. Structure also changes with the size. These two changes can lead to different physical and chemical properties depending on size, for example, magnetic, optical properties, melting point, specific heat, surface reactivity, bandgap, etc.

Meyyappan, M. (2005) Introduction to Nanotechnology. In *Nanotechnology Aerospace Applications* (pp. I-1 – I-2). Educational Notes RTO-EN-AVT-129, Introduction. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int/abstracts.asp.

Nanomaterials currently under investigation include nanoparticles, nanotubes, nanowires, powders, quantum dots, nanoporous materials, dendrimers, nanofibers, fullerenes, etc. Examples of each of these will be discussed in the presentation. The application range for these materials is very broad from electronics, sensors, electromechanical systems to composites, coatings and lubricants.