NANOWORLD OF SCIENCE AND TECHNOLOGY

Dr. David Devraj Kumar, FAIC*

Introduction

Nanoworld of science and technology is of great interest to governments, industries and academia. The prefix "nano" denotes sizes of the order of one-billionth of a meter. "Nanostructure science and technology is a broad and interdisciplinary area of research and development activity that has been growing explosively worldwide in the past few years. It has the potential for revolutionizing the way in which materials and products are created and the range and nature of functionalities that can be accessed" (Siegel, 1999, p. xvii). "Motors, turbines that go from zero to half a million RPM's in a microsecond; clamps that can literally fit onto the back of a flea – science fiction? No" (Carraher, Jr., 1994a, p. 109).

According to the Semiconductor Industry Association (2003), in 1971 it cost 10 cents to manufacture a computer chip which contained 2,300 transistors and had a clock speed of 0.8 million cycles/second. In 2003 the cost of manufacturing a computer chip (e.g., Pentium) containing 108 million transistors and a clock speed of 3,000 million cycles/second was 1/1000 cents. Notably the size of the technology has decreased from 10,000 nm in 1971 to a mere 65 nm in 2003 and is predicted to reach 32 nm by the year 2007.

The number of articles (registered by the Institute for Scientific Information) with "nano" as a topic increased from approximately 60 in year 1995 to over 3,000 by year 2004, indicating an increase in the level of interest in this critical area. In 2004, the US spent an estimated 1.6 billion dollars on nanotechnology and registered over 800 nanotechnology patents (Loder, 2005). In the United States "nanotechnology is the largest federally funded science initiative since the country decided to put a man on the moon" (Loder, 2005, p. 4). According to Roco (1999), "nanotechnology is presently at a level of development similar to that of computer information technology in the 1950s" (p. 132).

Nanoscience and Nanotechnology

The two terms often used in the literature with reference to the world of nano materials are nanoscience and nanotechnology. Nano materials denote "divided matter." As Rao (1999) said, "if you take a piece of solid matter (say a metal) containing an Avogadro number of atoms and go on dividing it to smaller bits, you will ultimately end up with an atom of the substance. Before that, you will reach a stage of very tiny particles containing 100 to 10,000 atoms. Such particles with diameters of 1-50nm (10-500 Ao) are referred to as nanoparticles. Nanomaterials exhibit properties entirely different from bulk materials and constitute materials of the future" (p. 59).

Increased surface area and quantum effects are the two key factors that separate nanomaterials from bulk materials (The Royal Society and The Royal Academy of Engineering, 2004). A substance of size 3 nm has 50% of its atoms on the surface compared to a substance of size 30 nm with 5% of its atoms on its surface. As size decreases more quantum effects begin to manifest in the form of electrical, magnetic and optical properties.

Nanoscience refers to the scientific study of materials of nanometer size, i.e., one billionth of a meter (The Royal Society, 1994). It is a combination of developments in solid state chemistry, synthetic chemistry, molecular biology, solid state physics and engineering, and scanning tunneling microscopy. According to Alfred Nordmann (cited in Schummer, 2003), it is a "site-oriented technoscience approach that differs both from classical theory-driven and problem-driven research" (p. 2). For example, nanosized indium melts at much lower temperature than respective bulk metal (Allen, 2002). Copper in extremely thin layers, in the presence of magnetic field, becomes a poor conductor of electricity (Loder, 2005).

Nanotechnology refers to various technologies to produce materials of extra high precision and dimensions on the scale of one-billionth of a meter. (Norio Taniguchi of Tokyo Science University is credited with coining the term "nanotechnology" in 1974.). Nanotechnology "implies the ability to generate and utilize structures, components, and devices with a size range from about 0.1nm (atomic and molecular scale) to about 100nm (or larger in some situations) by control at atomic, molecular, and macromolecular levels" (Roco, 1999, p. 131). One of the most interesting aspects of nanotechnology is building molecule-by-molecule materials similar to those produced by biological self-assembly, self-organization and self-regulation (Carraher, Jr., 1994b). As Stoddart (cited in The Royal Society, 1994) described, "think of atoms as the equivalent to letters, molecules as words, assemblages of molecules as sentences, and supramolecular arrays as paragraphs" (p. 2). Nanotechnology examples and applications include the following (*Institute of Nanotechnology*, n.d.).

Nanotechnology Examples

Cell Pharmacology: Use of nanomachines for site-specific delivery of drugs, and useful in chemotherapy of targeted cancer cells.

Cell Surgery: Use of medical nanomachines to manipulate cellular structures in genetic engineering.

Molecular Electronics: Use of atomically precise molecular parts for molecular switches, circuits and nanocells for creating miniaturized nanocomputers.

Scanning Tunneling Microscopy (Carraher, Jr., 1995): Useful for imaging conducting surfaces.

Nanotechnology Applications

Nanocrystals: Formed by combining two or more molecules of inorganic substances, i.e., silica and aluminum to form commercial grade heat and rust resistant coatings.

Nanotubes: Carbon atom aggregates in various forms at nanoscale, for example in the shape of cylinders which are electrical conductors, can be mixed with special polymers to make nanofibres and painted on rooftops as part of solar cells.

Quantum Dots: Size and arrangement of nanocrystals impact physical properties such as color (Carraher, Jr., 1994c). For example, nanogold appears orange (<1nm) or red (3- 30nm) depending on the size and arrangement of gold aggregates. Clear Sunscreen containing nanosized Zinc Oxide particles allows visible light to pass through and absorbs UV rays, hence appears colorless whereas bulk Zinc Oxide in regular sunscreens scatters visible light resulting in white color.

Organization

The National Science and Technology Council (NSTC) Committee on Technology, The Interagency Working Group on NanoScience, Engineering and Technology (IWGN) (1999) broadly organized nanoscience and nanotechnology into four groups as follows:

- Dispersions and coatings (e.g., functional nanocoatings, optical and thermal insulators, ink-jet, recording devices)
- High surface area materials (e.g., bacterial filters, molecular sieves, adsorption surfaces, energy storage devices)
- Functional nanodevices (e.g., biomedical sensors, nanotubes in color displays, DNA sizing and sequencing). The functional nanodevices have a large biological component compared to the other three categories.
- Consolidated materials (nanocomposite cement, ultra-high strength materials, soft magnets, magnetic refrigerants).

Nanoscale Dimensions

Nanoworld is a highly integrated and extensively broad area of research and development. The Royal Society and The Royal Academy of Engineering (2004) have categorized nanoscience into nanoscale in one dimension; nanoscale in two dimensions; and nanoscale in three dimensions.

Nanoscale in one dimension includes thin films, layers and engineered surfaces.

They provide large surface area support in catalysts useful for “on-site” manufacturing of pharmaceuticals in smaller quantities.

Nanoscale in two dimensions consists of materials such as carbon nanotubes, inorganic nanotubes, nanowires and biopolymers. Carbon nanotubes in the form of wires and tubes exhibit a wide range of electrical and mechanical properties. Inorganic nanotubes are potentially useful as catalysts and lubricants.

Nanoscale in three dimensions includes nanoparticles, fullerenes, dendrimers and quantumdots. Nanoparticles show optical properties, high chemical reactivity and are useful for targeted drug delivery while fullerenes resemble miniature ball bearings.

Potential Uses

The joint Center for Bioethics in Canada ranked potential uses of nanosciences and nanotechnologies with respect to development. The top ten uses follow (BBC News, 2005).

- Energy production, conservation and storage
- Enhancement of Agricultural productivity
- Treatment and remediation of water
- Screening and diagnosing diseases
- Systems for drug delivery
- Processing and storing food
- Controlling air pollution
- Construction
- Monitoring health
- Detecting and controlling pests

Issues

The nanoworld is not without issues. The National Science and Technology Council (NSTC) Committee on Technology in the United States raised concerns over the short term and long term health issues originating from nanotechnology products. Certain types of single walled carbon nanotubes are water soluble and shown to enter T cells (King, 2005). Carbon nanotubes are pulmonary toxicants. The British Government (2005) in a regulatory effort required all new nano materials be treated with caution as new chemicals in terms of registration, evaluation, authorization, and restriction.

End Note

The nanoworld is perhaps the fastest growing world in the twenty-first century. Global competition among nations in nanotechnology research, development and marketing is on the rise. Advantages of nanotechnology towards improving the quality of life are many. [Whether the nanoworld holds any solutions for problems faced by science education is a critical question which must be addressed in its entirety.] However, disadvantages of nanotechnology especially related to human health and the environment are only beginning to surface raising serious concerns. Systematic exploration, characterization, organization, and regulation of the nanoworld are warranted to make the best use of nanoscience and nanotechnology. The nanoworld will continue influence science and technology.

References

Allen, L. H. (2002). Nanocalorimetry studies of materials: melting point depressions and magic nanostructures. NNUN Abstracts, 40.

BBC News. (2005). *Nanotech promise for global poor.* Available at: http://news.bbc/co.uk/1/hi/sci/tech/4421867.htm.

Carraher, Jr., C. E. (1994a). Nano- technologies. Part 1, Nano-materials. *Polymer News, 19*(4), 109-110.

Carraher, Jr., C. E. (1994b). Nano- technologies. Part 3 – Molecular self-assembly. *Polymer News, 19*(8), 247-248.

Carraher, Jr., C. E. (1994c). Nano- technologies. Part 4: Quantum dots. *Polymer News, 19*(11), 344-346.

Carraher, Jr., C. E. (1995). Nano-technologies. Part 5. Nano-technology and the Scanning Tunneling Microscope. *Polymer News, 20*(3), 85-87.

Institute of Nanotechnology.(n.d.). *Nanotechnology systems.* Available at: Http://www.nano.org.uk/vocab_terms.htm

King, A. G. (2005). Research advances. *Journal of Chemical Education, 82*(5), 666-670.

Loder, N. (2005). Small wonders. A survey of nanotechnology. *The Economist, January 1, 2005*, pp. 1-12.

National Science and Technology Council (NSTC) Committee on Technology, The Interagency Working Group on NanoScience, Engineering and Technology (IWGN). (1999). *Nanostructure science and technology. A worldwide study.* Available at: http://itri.loyola.edu/nano/final/

Rao, C. N. R. (1999). *Understanding chemistry.* Hyderabad: Universities Press (India) Limited.

Roco, M. C. (1999). Research programs on nanotechnology in the world. In

National Science and Technology Council (NSTC) Committee on Technology, The Interagency Working Group on NanoScience, Engineering and Technology (IWGN). (1999). *Nanostructure science and technology. A worldwide study.* Available at: http://itri.loyola.edu/nano/final/

Schummer, J. (2003). *Conference report "discussing the nanoscale,"* University of South Carolina, Columbia, SC. Available at: http://nsts.nano.sc.edu/events.conf03/report/

Semiconductor Industry Association. (2003). *International technology roadmap for semiconductors*. Available at: http://public.itrs.net/Files/2003ITRS/Home2003.h tm.

Siegel, R. W. (1999). Executive summary. In National Science and Technology Council (NSTC) Committee on Technology, The Interagency Working Group on NanoScience, Engineering and Technology (IWGN). (1999). *Nanostructure science and technology. A worldwide study.* Available at: http://itri.loyola.edu/nano/final/

The Royal Society & The Royal Academy of Engineering. (2004). *Nanosciecne and nanotechnologies: Opportunitiesand uncertainties.* London: The Royal Society & The Royal Academy of Engineering.

The Royal Society. (1994). *Nanoscience: The forerunner to nanotechnology,* Reference PR67(94). London: The Royal Society.

*** Corresponding author name and address**

Dr. David Devraj Kumar, Florida Atlantic University, College of Education, Education and Science Building, 2912 College Avenue, Davie, Florida 33314.