A REVIEW OF NANOTECHNOLOGY AND ITS APPLICATIONS

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ABSTRACT

Nanotechnology deals with materials and structures having at least one dimension in the range of 1 to 100 nm. At this scale materials show properties different from bulk due to quantum effects and high surface area. This review presents work done in nanotechnology till 2010. It covers classification of nanomaterials, synthesis methods, characterization and applications in electronics, medicine, energy and environment. Main materials discussed are nanoparticles, carbon nanotubes, quantum dots and nanocomposites. Problems related to production, dispersion and safety are also discussed. Future research was directed toward low cost synthesis and integration with conventional technologies [1-3].

Keywords: Nanotechnology; Nanoparticles; Carbon nanotubes; Synthesis; Applications

1. INTRODUCTION

The idea of manipulating matter at atomic level was given in 1959. Later with invention of scanning tunneling microscope and atomic force microscope it became possible to see and move atoms. Materials when reduced to nanometer size show change in melting point, strength, electrical and optical properties. This is because of large surface to volume ratio and quantum confinement. Till 2010 most work was on zero dimensional particles, one dimensional tubes and wires, and composites with nano fillers. Industries started using nanomaterials in coatings, catalysts and electronics. This paper reviews the materials, methods and applications reported till that time [1-4].

. CLASSIFICATION OF NANOMATERIALS

Nanomaterials are classified by dimensions. Zero dimensional materials have all dimensions in nano range. Examples are metal nanoparticles of Au, Ag, Cu and oxide nanoparticles of TiO_2, ZnO, Al_2O_3. These were made by chemical and physical methods and used in catalysis and coatings [3, 5]. One dimensional materials have one dimension outside nano range. Carbon nanotubes and nanowires come in this group. CNTs were found to have very high strength and electrical conductivity. Both single walled and multiwalled tubes were studied. Semiconductor nanowires of Si and ZnO were also made for sensors [5-6]. Two dimensional materials are thin films and coatings with thickness in nanometers. These were made by PVD, CVD and sol-gel for optical and protective coatings [10-11]. Three dimensional materials are bulk materials made of nano grains or containing nano dispersions. Nanocomposites belong to this group where nanoparticles are added to polymer, metal or ceramic matrix to improve properties [17-18]. Quantum dots are another important class. CdSe, CdS and ZnS quantum dots show size dependent color due to quantum confinement. These were studied for optical devices [8-9].

3. SYNTHESIS METHODS

Two routes were followed for making nanomaterials. Top-down and bottom-up [2, 10]. In top-down method bulk material is broken to nano size. Ball milling was used to make nanocrystalline metals and ceramics. Limitation was contamination from balls and wide size distribution. Lithography was used in microelectronics to make patterns but resolution was limited to 100 nm [10-11]. In bottom-up method atoms are assembled to form nanostructures. Sol-gel process was common for oxides. Metal alkoxides were hydrolyzed to get gels and then heated to get nanoparticles. Chemical vapor deposition was used to grow carbon nanotubes and thin films. Hydrocarbons were decomposed at high temperature on catalyst to get CNTs. Arc discharge and laser ablation were also used for CNT production but yield was low. Hydrothermal method was used for oxides and nitrides at high pressure. Template synthesis using porous alumina was used to make nanowires and nanotubes of metals and polymers [10-12]. For nanocomposites, polymer nanocomposites were made by solution mixing, melt mixing and in-situ polymerization. Clay and CNT were added to epoxy and nylon. For metal matrix, powder metallurgy and stir casting were used to add SiC and Al_2O_3 nanoparticles [17].

4. CHARACTERIZATION

Study of nanomaterials needed special tools. Scanning electron microscope gave surface morphology. Transmission electron microscope was used to see lattice and tube structure. Atomic force microscope gave 3D surface profile. X-ray diffraction was used to find crystal structure and grain size by Scherrer formula. BET method gave surface area. Raman spectroscopy was used to confirm CNT structure. For colloidal particles, dynamic light scattering was used to measure size in liquid [1, 5, 13].

5. PROPERTIES

Properties change at nanoscale. Mechanical strength increases due to grain refinement. Nanocrystalline Ni and Cu showed higher hardness than coarse grain. CNTs showed tensile strength near 50 GPa and modulus near 1 TPa [5-6]. Optical properties of quantum dots changed with size. Smaller CdSe dots gave blue emission and larger gave red. This was used in displays [8]. Electrical conductivity of CNT was ballistic. Metal nanoparticles showed surface plasmon resonance. Au colloid gave red color [5]. Magnetic nanoparticles below critical size showed superparamagnetism. This was used in recording media.Thermal conductivity of fluids increased with addition of CuO and Al_2O_3 nanoparticles. This led to study of nanofluids for cooling [14].

Table 1: Properties of Selected Nanomaterials

Material	Type	Size Range	Key Property
Single Walled CNT	1D	Dia 1-2 nm	Tensile strength ~50 GPa
Au Nanoparticle	0D	5-20 nm	Surface plasmon resonance
TiO2 Nanoparticle	0D	10-30 nm	Photocatalytic activity
CdSe Quantum Dot	0D	2-10 nm	Size dependent fluorescence
Al2O3 Nanoparticle	0D	20-50 nm	High hardness

6. APPLICATIONS

Application areas were expanding. In electronics, CNTs were studied for field emission displays and as interconnects. Quantum dots were used in LEDs and solar cells. Nanostructured thin films were used in sensors for gas and humidity [14-18]. In medicine, drug delivery was a major area. Liposomes and polymeric nanoparticles were used to carry drugs. Iron oxide nanoparticles were used as MRI contrast agent. Gold nanoparticles were used for detection due to color change [15]. In energy, TiO2 nanoparticles were used in dye sensitized solar cells. Nanostructured electrodes improved performance of Li-ion batteries. CNTs were studied for hydrogen storage. Fuel cells used Pt nanoparticles as catalyst [16]. In environment, TiO_2 was used for photocatalytic degradation of pollutants in water and air. Nanofilters with pore size in nm were used for water purification [14]. In composites, addition of 2-5% nanoclay in polymer increased modulus and reduced gas permeability. CNT in epoxy increased strength and conductivity. Metal matrix with nano Al_2O_3 showed better wear resistance [17-18].

Table 2: Application Areas of Nanomaterials

Area	Material	Use
Electronics	CNT, Quantum Dots	Displays, Sensors, Solar cells
Medicine	Liposomes, Fe3O4, Au	Drug delivery, Imaging, Diagnosis
Energy	TiO2, CNT, Pt nano	Solar cells, Batteries, Catalyst
Environment	TiO2, Nanofilters	Water treatment, Air cleaning
Structural	Nanoclay, CNT	Polymer composites

7. PROBLEMS AND LIMITATIONS

There were many problems till 2010. Bulk production with narrow size distribution was difficult. CNT synthesis gave mixture of metallic and semiconducting tubes. Dispersion of nanoparticles in matrix was a problem due to agglomeration. Cost of CNT and quantum dots was high. Health effects were not fully known. Some studies showed that inhaled nanoparticles can cause lung problems. So safe handling guidelines were needed. Measurement standards were also not fully developed [19-20].

8. CONCLUSION

Nanotechnology grew fast before 2010. New materials like CNT, quantum dots and nanoparticles were made and studied. Synthesis methods like CVD, sol-gel and ball milling became common. Applications started in electronics, medicine and energy. But commercial use was still limited due to cost and safety issues. Further work was needed on scalable production and understanding of toxicity [1-3, 20].

9. FUTURE DIRECTION

Based on literature, future work was expected in three areas. First, development of cheaper methods for bulk production. Second, study of interaction of nanomaterials with biological systems. Third, use of self-assembly to make devices. Integration of nanomaterials with existing materials was also seen as important path [10, 19-20]

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