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Synthesis and Applications of Nanoparticle

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Abstract

Nano is an abbreviation of the nanometer (nm), which is a unit of length. It is one-billionth of a meter. The diameter of a human's hair is about sixty thousand to eighty thousand nanometers. If we could put hydrogen atoms together, one nanometer would approximately equal the length of ten hydrogen atoms arranged together in a line. A material is called the nanomaterial if the size of the material is below 100 nm. Nowadays, the synthesis and characterization of nanomaterials like carbon nanotube, noble metal nanoparticles, metal oxide nanomaterials, etc., are a great challenge for researchers. Nanomaterials can be stabilized by stabilizers like micelle, reverse micelle, polymer, etc., due to aggregation property formed by bulk materials. The variety of Applications of Nanoscience and engineering could improve our lives and describe some potential risks of nanotechnology. Possible applications are in materials science, Health Care, Technology, Environment, etc.

Keywords: Nanoparticle, Technology, Environment

1. Introduction

Nanoscience and nanotechnology are a recent, revolutionary development in Science and Engineering that are evolving quickly. It is driven by the interest to fabricate new materials with novel and improved properties that are likely to impact virtually all areas of physical and chemical sciences, biological sciences, and health sciences. The word 'nano' comes from the Greek word 'Nanos,' which means dwarf or extremely small, and mathematically, a nanometer is one-billionth of a meter or 10^{-9} m. The term nanoparticle is generally used to represent particles having a diameter in the range of 1 to 100 nm, whether dispersed in gaseous, liquid, or solid medium. The particles in this particular size regime are generally larger in dimension than that of individual atoms or molecules and smaller than the bulk solid. Therefore these species follow neither absolute quantum mechanics nor the laws of classical physics. More specifically, they display characteristic physical, chemical [1], and optoelectronic properties[2], which are strikingly different from those of the corresponding bulk materials. The current research interest of physicists and chemists has been directed mainly towards the electronic structure of metal and semiconductor nanoparticles because of the quantum size effect, which has been shown to appear in that size range.

We know that the smaller the nanoparticles, the larger the total surface area to volume ratio. Therefore if we have a gram of gold grains whose size is below 100 nm, the surface of the grain will become very important. We know that the atoms on the material surface are highly unstable and very active in the chemical reaction. As a result, the increasing of the surface area will significantly enhance the chemical reaction, the ability of surface absorption, and the catalytic ability of the material. In addition, the ability of heat conduction, mechanical strength, as well as optical property of the nanomaterials are also very different from that of the bulk system. For example, the melting point of metal gold is about 1000 ºC whereas for the nano sized gold grains with a typical size of 2 nm, the melting point is down to 330 ºC. The absorption of ultraviolet of some nanomaterials can be enhanced significantly. Furthermore, new effects start to manifest when the size is below 100 nm. Hence a class of new materials emerges at nanoscale.

2. Nanoparticle synthesis strategy

Dispersions of metallic nanoparticles can be obtained through two main approaches: 'top-down' and 'bottom-up'(Figure 1): 'Top-down' approach involves mechanical subdivision of metallic aggregates by physical method whereas 'bottom-up' technique substantiates formation of nanoparticles through nucleation and growth of metallic atoms in chemical process. To achieve nanoclusters having (i) specific size (ii) well-defined surface composition, and (iii) isolable and dissolvable properties. These two approaches are mainly used in wide extent. Nowadays, the research interest has been focused towards the development of a reproducible synthetic strategy for the transition metal colloids. In this framework, physical method yield nanoparticle having wide size distribution with comparatively larger size with inconsistent catalytic activity. On the other hand, chemical methods such as the reduction of transition metal salts are the most convenient ways to control the size of the particles.

2.1 Chemical methods

The simplest and the most commonly used bulk-solution synthetic method is the chemical reduction of metal salts [3]. This

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has now been classified into two major classes, photochemical and wet chemical reduction. In wet chemical technique, an aqueous solution of metal salt is reduced to its corresponding atom by suitable reducing agents like sodium borohydride, aldehydes, alcohols, di-ketones, sugars etc.

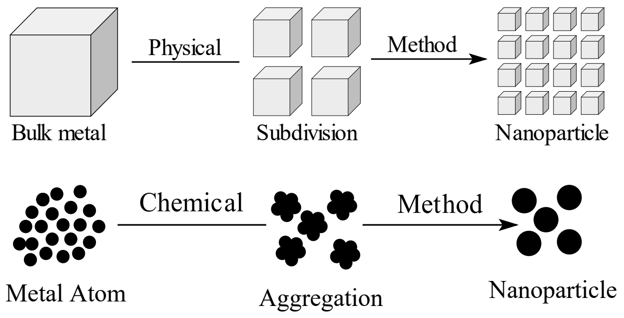

Figure1. Schematic representation of 'top-down' (above) and 'bottom-up' (below) approach.

On the other hand, the photochemical process generally involves the formation of metal nanoparticles from specific precursor by means of photo-irradiation technique. The photo-generated radicals become effective reducing agent for the conversion of metal ions to the corresponding atoms. Hydrated electrons and radicals generated in-situ, by photolysis, radiolysis or electrolytic methods can also reduce solute ionic moieties to form nanoparticles.

2.2 Physical methods

Several physical methods such as near-IR laser irradiation[4], greensynthesis[5], sonolysis[6], radiolysis have been adopted for the fruitful generation of metal nanoparticles in a variety of environments. Recently, lithographic techniques, such as laser-beam lithography, electron-beam lithography are being used for the preparation of well-defined sizes and non-spherical nanoparticles. Nanosphere lithography (NSL) is the second generation innovation of the technique originally known as 'natural lithography' and is an inexpensive nanofabrication technique that is now being employed in laboratories around the world.

2.3 Stabilization of nanoparticles

One of the main characteristics of colloidal particles is their small size. Unfortunately, these metallic nanoparticles are unstable due to their high surface to volume ratio. In most cases, this aggregation leads to the loss of the properties associated with the colloidal state of these metallic particles. For example, during catalysis, the coagulation of colloidal particles used as catalyst leads to a significant loss of activity. The stabilization of metallic colloids and thus the means to preserve their finely dispersed state is a crucial aspect to consider during their synthesis. At short interparticle distance, the van der Waals forces attract two metallic particles to each other. In the absence of repulsive forces opposed to the van der Waals forces, the colloidal metal particles aggregate. Consequently, the use of a stabilizing agent able to induce a repulsive force opposed to the van der Waals forces is necessary to provide stable nanoparticles in solution.

There are four kinds of stabilization procedures: (i) the electrostatic stabilization, (ii) steric stabilization, (iii) the combination of these two kinds of stabilization with the electrostatic stabilization, and finally (iv) the stabilization by a ligand.

3. Characterization techniques

A variety of techniques are employed for the characterization of nanoparticles in dispersed state. The most widely used one is transmission electron microscopy (TEM), which gives a photograph of the nanoparticle. High resolution transmission electron microscopy (HRTEM) gives a better and clear image of the crystal structure of the nanoparticles. The dimension of the particles can also be determined using scanning tunneling microscopy (STM), atomic force microscopy (AFM), small-angle X-ray scattering (SAXS), laser desorption ionization mass spectrometry (LDI-MS). The coinage metal nanoparticles, such as Cu, Ag, and Au, possess strong absorption in the visible region and can be characterized by UV-visible spectra. The UV-visible and IR spectra provide an identification of the ligand, and that can be confirmed by NMR spectroscopy, except that the ligand atoms close to the core give broad signals. Surface-enhanced Raman scattering (SERS) helps in analyzing the chemisorptive properties of the ligands and give information about the surface passivation. Extended X-ray absorption fine structure (EXAFS) allows the investigation of the size-dependent distance contraction in ligand-stabilized metal particles and the short metal-ligand bond suggests a strong surface interaction. Scanning electron microscopy (SEM), X-ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS) have also a wide range of applicability for particle size and surface characterization.

4. Applications

The particles in the nanometer size regime exhibit potential applications in display devices, microelectronics (light-emitting diodes and photovoltaic cells), nanofabrication, nanopatterning, self-assembly, drug delivery etc. Other useful applications of nanoparticles include ultra-fine wiring, efficient solar cell[7], doping for metal, ceramic, epoxy-material, fiber and coating for surfaces of glass, lens, film, electrode etc. Besides these applications, nanoparticles are being currently used in catalysis for several reactions.

The current research interest has been devoted to study the optical properties of noble metal nanoparticles. This is due to their use as functional materials in optical devices, optical energy transport, near-field scanning optical microscopy (NSOM), the most important chemical application of metal nanoparticles. Moreover size of nanoparticles provide control over other physical properties like luminescence, conductivity etc. Very recently, the applications of metallic nanoparticles have been realized in magnetic resonance imaging (MRI) and cancer therapy.

It offers one of the most exciting prospects for new phenomena, new materials, and new science. Some people believe that it will lead to a new industrial revolution. Roughly speaking, the nanotechnology has been applied to the four disciplines: (1). nanoelectronics: new electronic devices with novel functions and the advantage of high speed and at the same time consuming less energy power. (2). nanomaterial science: new materials with novel properties, which grow perfectly without any impurities and defects, ideal for nanodevices. (3). nanobiology including mapping the genetic information in DNA and RNA molecules. (4). nanomedicine: discover, design, and deliver new drugs on the nano level. In addition to the use of nanomaterials as cell and tissue scaffolds, which in essence, places nanomaterial outside of the cell, nanomaterials can be placed inside of the cells, resulting in nanomaterial–cell hybrids, which have a variety of possible applications in medicine. One application uses immune cells as carriers for nanomaterial delivery in the body. For example, macrophages and microglia, as well as other mononuclear phagocytes can endocytose colloidal nanomaterials, for example, liposomes or nanosuspensions, and subsequently carry and release the drug to the site of tissue injury, infection, or disease.

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