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ORIGINAL ARTICLE

Thermal plasma synthesis of nanotitania and its characterization

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Abstract Titanium dioxide (TiO_2) nanoparticles were prepared by the thermal plasma synthesis; which give a highly crystalline product. Their morphological studies are carried out by using techniques like SEM, EDAX, TEM and SEAD. Crystal size was calculated by XRD using Scherrer equation; which is observed at two current amperes; at 80 A size ranges between 25 and 30 nm and at 120 A size ranges between 30 and 42 nm. Composition analysis was done by TEM–EDAX, FTIR and Fast Fourier Transform techniques. The FTIR peaks clearly show that synthesized TiO_2 nanoparticles are in anatase phase; this phase is generally preferred because of its high photocatalytic activity, since it has a more negative conduction band edge potential (higher potential energy of photogenerated electrons), high specific area, nontoxic, photochemically stable and relatively in expensive.

1. Introduction

Nanotechnology is the study of the control of matter on an atomic and molecular scale. Generally nanotechnology deals with structures of the size 1–100 nm or smaller, and involves developing materials or devices within that size. It deals with various structures of matter having dimensions of the order of a billionth of a meter. While the word nanotechnology is relatively new, the existence of functional devices and structures of nanometer dimensions is not new, and in fact such structures have existed on the Earth as long as life itself (Charles et al., 2004).

Nanomaterials have gained importance due to an overall enhancement of properties like mechanical, electrical, optical, magnetic, etc., as compared to its bulk counterpart. Materials reduced to the nanoscale can suddenly show very different properties compared to what they exhibit on a macroscale (Prasad, 2008). Many properties of solids depend on the size range over which they are measured: The very high surface area to volume ratio of nanoparticles. So, we can say that as particle size reduces, there are more surface area and less volume as compared to large size (Prasad, 2008).

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$\text{Surface area/Volume} = (4\Pi r^2)/(4/3\Pi r^3) = 3/r$

Surface effects:

1. More percent of atoms on surface compared to those present in the bulk.
2. The increased surface area and surface atoms result in the increase of surface energy associated with the particles.
3. Increasing the surface area of a substance generally increases the rate of a chemical reaction.

Volume effects:

1. Lower wavelength (higher frequency, higher energy).
2. Magnetization increases when the particle is smaller than the magnetic domain in a magnetic material.
3. In a free electron model average energy spacing increases as the number of atoms reduce. This enhances the optical properties of nanoparticles.

For example, sintering is possible for smaller particles at lower temperatures and over shorter durations than for larger particles. The surface effects of nanoparticles also reduce the melting temperature; insulator becomes semiconductor or conductor as the particle size is reduced; opaque substances become transparent; inert materials attain catalytic properties; high mechanical strength $(\sigma): \sigma = 1/(d^{1/2})$; stable materials turn combustible; etc. (Prasad, 2008).

The element titanium was discovered in 1971 by William Gregor, in England while studying mineralogy. He found a black sandy substance and after he was assured that it was a mineral, he called it Menachanite. Four years later a man named Martin H. Klaproth recognized that there was a new chemical element in this mineral, he later named it titanium after the titans, which were humongous monsters that ruled the world as per Greek mythology. Titania (titanium dioxide, TiO_2) is an abundant and commercially available n-type semi conducting transition metal oxide and may be sourced as an ore or by extraction from iron sands. Martin H. Klaproth was not able to make the pure element of titanium, however, he was only able to produce titanium dioxide (Linsebigler et al., 1995).

Titanium dioxide (TiO_2) is a semi-conductor, photocatalyst, anti-microbial metal oxide. When exposed to UV light in the sub 400 nm range, TiO_2 becomes a photo catalyst oxidizer (PCO) as well which creates hydroxyl radicals and super oxide ions which are two times stronger disinfectants than chlorine and 1.5 times stronger disinfectant than ozone. TiO_2 is safe and widely used in many household products such as toothpaste, food and teeth whitening solutions. TiO_2 nanoparticles are successfully synthesized via Thermal Plasma Process. Nano TiO_2 liquid can be applied on fabrics, curtains, carpets, woods, tiles, ceramics and glasses, even on metal and painted surfaces. If the surface is exposed to direct sunlight, do not apply to black or very dark colored surfaces as the oxidation process can remove some pigments from the surfaces.

For TiO_2 nanoparticles, catalytic activity is dramatically increased at particles sizes below 20 nm. TiO_2 have three phases they are as: anatase (tetragonal, band gap 3.3 eV), Rutile (tetragonal, band gap 3.1 eV) and brookite (orthorhombic) (Table 1). Generally TiO_2 is preferred in anatase form because of its high photocatalytic activity, since it has a more negative conduction band edge potential (higher potential energy of photogenerated electrons), high specific area, nontoxic, photochemically stable and relatively in expensive. Thermal conductivity of $TiO_2 = 22\ \mathrm{W\,m^{-1}\,k^{-1}}$, melting point of $TiO_2 = 1941\ \mathrm{K}$, boiling point of $TiO_2 = 3546\ \mathrm{K}$. TiO_2 applications: for wastewater remediation, as a photocatalyst, pigment, etc.

Table 1 Physical properties of the titania polymorphs.

Crystalline phase	Anatase	Rutile	Brookite
Band gap energy (eV)	3.2	3.0	3.2–3.8
Refractive index	2.49	2.61	2.58
Unit cell	Tetragonal	Tetragonal	Orthorhombic
No. of TiO_2/unit cell	4	2	8
Density (g/cm^3)	4.26	3.84	4.11

Plasma consists of a collection of free moving electrons and ions, neutrals. It is obvious that energy is needed to strip electrons from atoms to make plasma. The energy can be generating from various origins for example, thermal, electrical, or light. With insufficient sustaining power, plasma recombines into neutral gas. Some, or all, of the electrons in the outer orbital have been stripped away. The result is a collection of ions and electrons, which are no longer bound together. Because the particles are not neutral plasma behaves differently than regular gases (Noordermeer et al., 2011). The 'fourth state of matter' because it differs from them in several ways. Unlike gases, solids, or liquids, plasma does not contain molecules. Instead, it is a gas that is composed of ions and electrons. So plasma basically contains charged particles. (So collection of only electrons or ions can be known as plasma, if have no. of electrons = no. of ions for plasma it is called neutral plasma otherwise non-neutral plasma.) Plasma is highly electrically conductive. Plasma shows collective behavior (Linsebigler et al., 1995).

2. Synthesis of nanomaterials

There are two ways in which nanomaterials can be synthesized.

(i) *Top–down approach or breaking down process*

Bulk material is broken down by mechanical processes like ball milling to obtain ultrafine particles. However, there are large limitations of this method and nanomaterials of effectively small size are difficult to obtain. This process is not commonly employed.

In electrochemical process, electrochemical etching is effectively used to obtain nanomaterial. For e.g. porous silicon is made from silicon wafer by etching it in a solution of HF and ethyl alcohol and passing a few mA current in the solution. This method is employed in a few specific cases

(ii) *Bottom–up approach or building up process*

This is a widely used method for nanomaterial synthesis. Under this approach there are various techniques available like inert gas phase condensation (high vacuum process), plasma synthesis (high temperature process), laser ablation, sol–gel synthesis (wet chemical process), Chemical Vapor Deposition (CVD) (Prasad, 2008).

Titanium dioxide is commercially very important as a white pigment because of its maximum light scattering with virtually no absorption and because it is nontoxic, chemically inert, and