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Application Of Semiconductor Nanomaterials: An Overview

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Abstract

Semiconductor nanomaterials have interesting physical and chemical properties and useful functionalities when compared with conventional bulk counterparts and molecular materials. Narrow and intensive emission spectra, continuous absorption bands, high chemical and photobleaching stability, processability, and surface functionality are among the most attractive properties of these materials.

Introduction

The development of "nanochemistry" is reflected in an immense number of publications on the synthesis of semiconductor nanoparticles [1-2]. For instance, spatial quantum confinement effect results in significant change in optical properties of semiconductor nanomaterials. The very high dispersity (high surface-to-volume ratio), with both physical and chemical properties of the semiconductor has major influence on their optical and surface properties. As a result, semiconductor nanomaterials have been the focus of research for about 20 years and have attracted significant interest in research and applications in diverse disciplines such as solid-state physics, inorganic chemistry, physical chemistry, colloid chemistry, materials science, and recently biological sciences, medical sciences, engineering, and interdisciplinary fields. Among the unique properties of nanomaterials, the movement of electrons and holes in semiconductor nanomaterials is primarily governed by the well-known quantum confinement, and the transport properties related to phonons and photons are largely affected by the size and geometry of the materials [3-6]. The specific surface area and surface-to-volume ratio increase dramatically as the size of material decreases [3, 7].

Parameters such as size, shape, and surface characteristics can be varied to control their properties for different applications of interest [8].

These novel properties of semiconductor nanomaterials have attracted significant attention in research and applications in emerging technologies such as nanoelectronics, nanophotonics, energy conversion, non-linear optics, miniaturized sensors and imaging devices, solar cells, catalysis, detectors, photography and biomedicine etc., In this section we discuss about the application of semiconductor nanomaterials in catalysis and medical sciences.

Semiconductor Nanomaterials in Catalysis

The modification of the rate of a chemical reaction, usually acceleration, by addition of a substance not consumed during the reaction is known as catalyst. In a catalyzed reaction, the catalyst generally enters into chemical combination with the reactants but is ultimately regenerated, so the amount of catalyst remains unchanged. Since the catalyst is not consumed, each catalyst molecule may induce the transformation of many molecules of reactant. The great Swedish chemist Jöns Jacob Berzelius was first coined the term catalysis (from the Greek kata-, "down," and lyein, "loosen") to describe reactions that are accelerated by substances that remain unchanged after the reaction. Catalysts may be gases, liquids, or solids. Catalysts reduce the activation energy barrier between reactants and products than the reaction route not mediated by the catalyst. When more than one reaction is possible, a catalyst that accelerates only one reaction pathway selectively enhances the creation of its product. Catalysis can be classified into two types namely homogeneous and heterogeneous catalysis, depending upon their physical state, chemical nature or the nature of the reaction that they catalyze. The study of catalysis is very important because many industrial processes depend upon catalysts for their success. The most important peculiar phenomenon of life would hardly be accelerated by without the biological catalysts termed enzymes. This is process known as biocatalysis. Catalysis is an interdisciplinary area that applied to many areas of chemistry such as inorganic chemistry, organic chemistry, bio-chemistry, chemical engineering, bio-engineering, material science, surface science organometallic chemistry, environmental science, kinetics, theoretical chemistry comprising quantum chemistry and molecular modeling. Catalytic reactions are environmentally benign green chemistry reaction due to the reduced amount of waste generated, as compared to stoichiometric reactions in which all reactants are consumed and more side products are formed. Many catalysts such as zeolite, silica, alumina, transition metal oxides (n –type semiconductor), alkaline oxides (p –

type semiconductor), rare earth oxides (p –type semiconductor), mixed metal oxides, and noble metals can be effectively used as a recyclable catalyst for the production of various fine chemicals in environmentally benign way. Among these catalysts, semiconductor nanomaterials have been used as an emerging catalyst for environmental remediation, medicinal application in the filed of cancer therapy as a fluorescent probe and some other disease diagnostics, energy application in production and storage of hydrogen, adsorption and separation of harmful gases, sensors, photography, solar cells, and quantum dot devices and electronic applications like NLO properties and optoelectronic. In this section we can see the application of semiconductor nanomaterials in environmental purification, hydrogen production, and green organic transformation.

Semiconductor nanomaterials for Environmental Purification

The global industries and agricultures release large quantities of toxic organic compounds, hazardous inorganic constituents into wastewater. The presence of organic, inorganic pollutant and microorganism cause pollution to surroundings and pose severe ecological problems. All over the world facing major issue of wastewater treatment. The different types of traditional technologies have been used for the treatment of waste water such as, adsorption on activated carbon, ultrafiltration, reverse osmosis, coagulation by chemical agents, ion exchange on synthetic adsorbent of resins, biological treatment etc., However, those are non-destructive and transfer the organic compounds from one phase to another phase, thus creating secondary pollution. Consequently, it requires regeneration of the adsorbent materials and post-treatment of solid- wastes, which are expensive operations. The new oxidation technology knows as Advanced Oxidation Processes (AOPs), appear as an emerging technology for destructing complete mineralization of the organic and inorganic pollutants. Among AOPs, heterogeneous photocatalysis using semiconductor nanomaterials for the wastewater purification appears to be the most promising technology, because the photoactivated semiconductors can completely decompose (mineralize) various kinds of pollutants that are refractory, toxic, and non-biodegradable, to CO_2, water and mineral acids under mild conditions (room temperature and atmospheric pressure)[9-11]. The heterogeneous photocatalysis of organic and inorganic compounds by semiconductors is the generation of electron-hole pairs in the semiconductor particle. When a photon of energy $h\upsilon$, equal or greater than the bandgap energy (Eg = 3.2 eV) of semiconductor photocatalyst like TiO_2 produces a electron, e^-_{cb}, in the conduction band (CB) and leaving a hole, h^+_{vb} in the valence band (VB). The photogenerated valence bond hole react with a surface hydroxyl group ($^{-}$OH) or an adsorbed water molecule and produces a hydroxyl ($^{\bullet}$OH), a strong oxidizing agent. The photogenerated conduction band electron reacts with electron acceptors such as O_2 adsorbed on the surface of the catalyst or dissolved in water, reducing it to superoxide radical anion $O_2^{\bullet-}$. These two high potent radicals ($^{\bullet}$OH and $O_2^{\bullet-}$) can be used to degrade a wide range of organic and inorganic pollutants. The schematic representation of complete photocatalytic process was given in the figure 1.

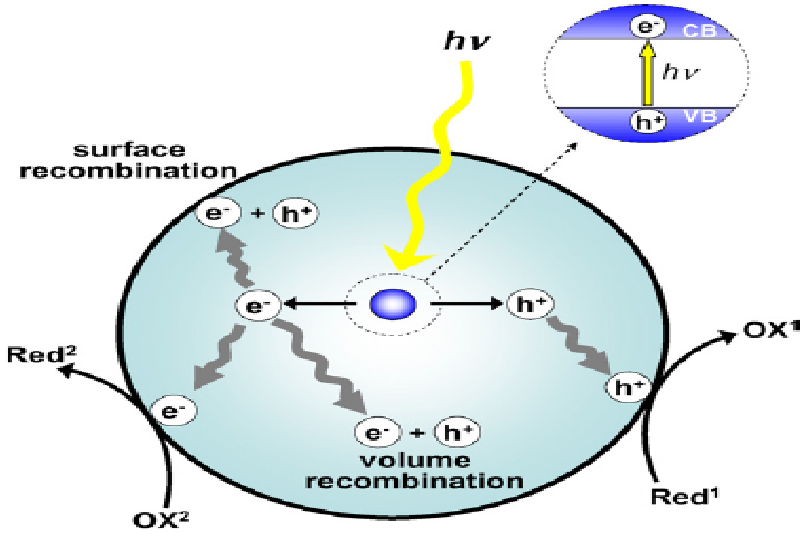

Figure 1: mechanism of semiconductor photocatalysis [12].

Many semiconductors, such as TiO_2, SnO_2, ZnO, ZrO_2, $SrTiO_3$, CdS, MoS_2, Fe_2O_3 and WO_3, have been examined as dynamic photocatalysts for the degradation of organic contaminants. Among these semiconductors, titanium dioxide (TiO_2) is one of the most important and widely used photocatalyst because of its suitable flat band potential, high chemical stability, nontoxicity, and high photocatalytic activity. In 1972, the photoinduced water cleavage on TiO_2 semiconductor electrode discovered by Fujishima and Honda [13]. After this discovery the same phenomenon has been applied to a variety of problems of environmental interest in addition to water and air purification. However, most of these semiconductor photocatalysts have bandgap in the ultraviolet (UV) region, i.e., >3.2 eV (λ = 387 nm) and require UV radiation for excitation. In addition, surface and volumetric charge recombination is another obstacle that hinders heterogeneous photocatalysis to becoming an efficient purification method. In order to suppress the electron–hole recombination and to enhance the activity of photocatalysts for applications in wastewater treatment using visible light. The semiconductor nanomaterials were doped with different metal and non-metals ions [14-17] to reduce the effective bandgap or introduce bandgap states in the semiconductor, leading to enhanced visible light absorption and interfacial charge transfer. The different types of organic and inorganic compounds effectively degraded with the use of semiconductor nanomaterials. The number of publication in semiconductor photocatalysis is increasing day by day. The figure 2 explains the number of publication in semiconductor photocatalysis.

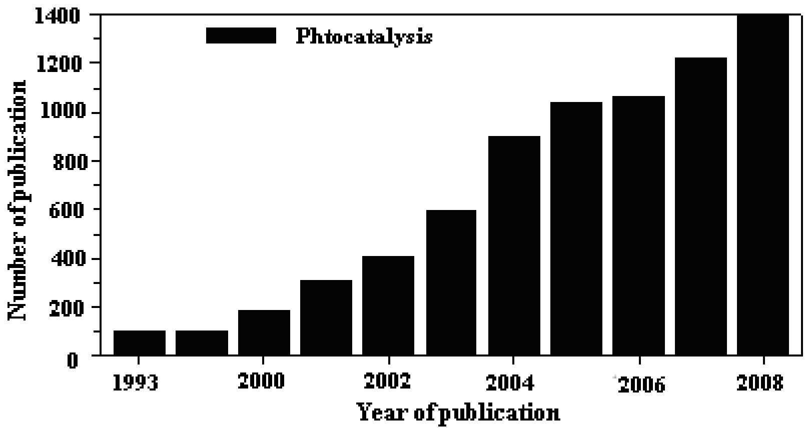

Figure 2: the number of publication in semiconductor photocatalysis.

The UV radiation required for the photoexcitation of TiO_2 particle (λ = 390nm, Eg = 3.2 eV), obtained from the artificial UV sources or sun. In the case of artificial UV radiation, the efficiency of conversion of electricity to the UV radiation and its subsequent use in photocatalytic degradation is very low. Photocatalytic reaction can also be powered by solar light as 4-5 % of the wavelengths of the solar spectrum can excite TiO_2. Solar energy, which is renewable energy sources and abundantly available in the tropical and equatorial countries such as Australia, African countries, and Indian Subcontinent etc., can be used as a economically alternative to artificial UV radiation for the photoexcitation of semiconductor photocatalyst like TiO_2 in the daytime[18].

SUMMARY

The use of solar energy as the source for heterogeneous semiconductor photocatalysis is an emerging technology for the treatment of industrial wastewater in present and future. The variety of organic compounds, dyes and other inorganic pollutants can be effectively mineralized with use of semiconductor nanomaterials and renewable solar energy as an irradiation source.

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