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Photocatalytic, optical and magnetic properties of Fe-doped ZnO nanoparticles prepared by chemical route

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ABSTRACT

Polyvinyl pyrrolidone (PVP) capped $Zn_{1-x}Fe_xO$ ($0.000001 \leqslant x \leqslant 0.1$) nanocrystalline powders were prepared by chemical co-precipitation technique. Structural, optical and magnetic characterizations of the annealed samples were performed using X-ray powder diffraction (XRD), transmission electron microscope (TEM), energy dispersive X-ray fluorescence (EDXRF), Fourier-transform infrared (FTIR) spectroscopy, UV–visible spectrophotometry, photoluminescence (PL) and vibrating sample magnetometer (VSM) measurements. XRD and TEM studies reveal that the synthesized ZnO nanocrystals have hexagonal wurtzite structure with average crystalline size ~8–15 nm. EDXRF and FTIR measurements confirmed the doping and incorporation of Fe impurities in ZnO nanostructures. Photocatalytic efficiency of the synthesized samples was determined by degradation of methylene blue (MB) dye in aqueous solution under UV/sunlight exposure. The dependence of photocatalytic behavior and luminescence efficiency on the dopant concentration was studied in detail. Magnetic measurements performed at room temperature show that pure ZnO exhibits diamagnetic behavior, ferromagnetic order was clearly observed at minute concentration of Fe impurity (at 0.000010%) and large concentration of dopant (at 10%) leads to strong paramagnetic component in all the Fe-doped ZnO samples.

1. Introduction

Synthesis and characterizations of wide-band gap semiconductor nanomaterials with unique photocatalytic, optical and magnetic properties have been the main research area over the last decade. Most preferred wide-band gap II-VI semiconductors are TiO_2, CdS, ZnS, ZnSe and ZnO. ZnO is an *n*-type semiconductor with band gap (3.37 eV) and a large exciton binding energy of 60 meV at room temperature. Furthermore, ZnO nanocrystals have shown wide applications in ultra-violet absorbent [1], photocatalyst [2,3], gas sensor [4,5], photo-detector [6,7] and anti-virus agent [8,9]. The photocatalytic activities of various photocatalysts have been tested using aqueous solutions of several dyes [10–15] and other environmental pollutants [16–19]. In many cases, ZnO has been reported to be more efficient than other photocatalysts [10,15,17]. High photosensitivity, excellent mechanical characteristics and environmentally safe nature together make ZnO as suitable photocatalyst to treat water from a number of organic pollutants and solving environmental pollution problems. It has been noticed that the photocatalytic activity of ZnO is mainly dependent on the electrons and holes which are produced by light absorption. Additionally, the valence band position of a semiconductor and the incident photon energy also plays an important role in deciding the photocatalytic activity of the semiconductor. The wide band gap semiconductor materials assisted processes, for their activation, demand higher photon energy, which could be near-UV or in UV range [20–21]. However, since UV occupies merely ca. 4% of whole solar energy, the technology becomes difficult, if not impossible, to widen the application. Activity of a photocatalyst nanoparticle can be elevated and extended in the visible region using a number of strategies such as doping, sensitization, nanostructuration and phase mixing [22]. The electronic and optical properties of semiconductor nanomaterials are tuned by quasi-stable energy states within the band gap [23,24]. Therefore, it is indispensable and urgent to develop a particular photocatalyst sensitive to sunlight for waste water treatment.

Diluted magnetic semiconductors (DMSs) have also attracted considerable attention due to their potential applications in the new emerging fields of optoelectronics, spin-polarised light emitting diodes (LEDs) and photovoltics [25,26]. Numerous contradictory results on the magnetic properties of transition metal (TM)-doped ZnO nanomaterials have been reported in literature [27–36]. From all the experimental investigation on the ferromagnetism of TM-doped ZnO; some measurements confirmed the presence of ferromagnetism while other measurements report

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