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Synthesis and characterization of VO^{2+} doped ZnO–CdS composite nanopowder

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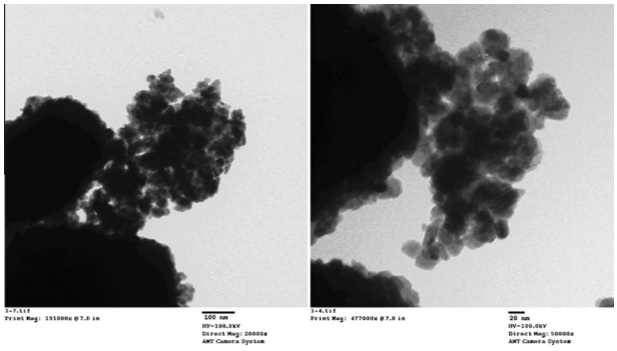
HIGHLIGHTS

- VO^{2+} doped ZnO–CdS composite synthesized by simple chemical precipitation method.
- Average particle size is found to be 17.7 nm.
- Spherical like structures were observed in SEM and TEM micrographs.
- Ionic bonding is observed between vanadyl ions and its ligands.
- Vanadyl ions entered into the host lattice as tetragonally distorted octahedral sites.

GRAPHICAL ABSTRACT

TEM images of VO^{2+} doped ZnO–CdS composite nanopowder reveal that the sample contains spherical like structures. The average particle size of VO^{2+} doped ZnO–CdS composite nanopowder is around 20 nm. These results are in good agreement with X-ray diffraction data.



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ABSTRACT

VO^{2+} doped ZnO–CdS composite nanopowder has been synthesized by chemical precipitation method. The prepared sample has been characterized by powder X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), FT-IR, photoluminescence (PL), optical absorption and EPR spectroscopy. From XRD pattern, average crystallite size is about 18 nm. SEM and TEM images showed sphere like structures. FT-IR spectrum indicates the presence of fundamental modes of ZnO, CdS and other functional groups. The PL spectrum of VO^{2+} doped ZnO–CdS composite nanopowder exhibits UV, blue and green emissions. Optical and EPR studies revealed the tetragonal compressed octahedral site symmetry for VO^{2+} ions. The bonding between VO^{2+} and its ligands is ionic.

Introduction

Various fabrications of semiconducting materials like cadmium sulfide (CdS) and zinc oxide (ZnO) have attracted much attention to researchers over the past decades because of their synthesis

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procedure and functional behavior having unusual optical, electric properties and potential applications in nanodevices [1]. ZnO based nanostructures received significant attention in the recent development of science and technology because of their potential applications in optics, catalysts and solar cells [2–4]. These semiconducting nanostructures revealed appreciable structural, optical, electronic, luminescence and photocatalytic properties. ZnO is a direct band gap semiconductor, which has great application potential for photocatalysts and photovoltaic cells, due to its wide band gap of 3.37 eV, low cost, superior carrier mobility and large excitation binding energy of 60 meV at room temperature. As well as cadmium sulfate (CdS) has received considerable attention due to a large number of technical applications like photocatalysis, sensors and solar cells. Due to its narrow band gap of 2.4 eV, CdS acts as visible-light responsive photocatalyst and a photoanode material. The combined ZnO and CdS system in nanosize, such as nanocomposites is an emerging research area [5–7]. ZnO–CdS nanocomposites have attracted a great deal of attention in recent years because of their electronic and optical properties that makes them suitable for use as light emitting devices, optoelectronics, photoconductive devices, photocatalysts, photovoltaic solar cells and fluorescence probes for biomedical applications [8–14].

Various physical and chemical synthesis techniques have been used to prepare ZnO–CdS nanocomposite, such as electrochemical deposition [15], facile chemical route [7], colloidal chemical synthesis [16], chemical bath deposition technique [17], combined sol–gel/hydrothermal/SILAR method [13], sonochemical synthesis [18] and chemical precipitation method [19]. The results show a significant improvement in their photocatalytic activity and optical properties. Among these techniques chemical precipitation method is most suitable, simple and cost effective for the fabrication of ZnO–CdS nanocomposites.

To the best of our knowledge there are no reports about the effect of transition metal (TM) ions on structural and spectroscopic properties of ZnO–CdS nanocomposites. The optical properties greatly influenced by doping of TM ions into the host lattice. However, vanadium doped systems have attracted much attention because of their interesting catalytic properties [20,21]. The results indicate that the catalytic activity of vanadium is strongly influenced by its local environment, dispersion and stability of the vanadium species present in the solid matrix. In the present investigation, V_2O_5 doped ZnO–CdS composite nanopowder was successfully prepared by the simple chemical precipitation method. Structural, morphological and optical properties were studied to identify the coordination site symmetry of doped ions in the host material and as well as its bonding nature with the ligands.

Experimental

Materials

To synthesize V_2O_5 doped ZnO–CdS composite nanopowder, the following materials were used. All the chemical reagents were analytical grade without further purification. Zinc acetate, cadmium acetate, sodium hydroxide, sodium sulfide, vanadium pentoxide and ethanol were used as precursors. Deionized water was used for all dilution and sample preparation. All the chemicals are above 99% in purity. All the glassware used in this experimental work was acid washed.

Synthesis of VO^{2+} doped ZnO–CdS composite nanopowder

In a typical procedure, 2.2 g (0.2 mol) of zinc acetate [$Zn(CH_3COO)_2{\cdot}2H_2O$] in 50 mL of deionized water–ethanol matrix (equal volumes) and an equal molar amount of sodium hydroxide [NaOH] in another deionized water–ethanol matrix were mixed drop by drop. The mixture was stirred magnetically at 80 °C until a homogeneous white solution was obtained. Then, 50 mL deionized water–ethanol matrix of cadmium acetate [$Cd(CH_3COO)_2{\cdot}4H_2O$] (0.1 mol) solution was added to the above solution. After 10 min, 50 mL of sodium sulfide [$Na_2S{\cdot}xH_2O$] (0.1 mol) solution (prepared in a deionized water–ethanol matrix) was added to the above colloidal solution drop wise with continuous stirring. Subsequently, the white solution turned light yellow, indicating the formation of ZnO–CdS nanocomposite. Later 0.01 mol% of vanadium pentoxide [V_2O_5] dissolved in 20 mL of water–ethanol matrix was added to the above solution and then stirred for 4 h. The obtained dispersions were washed with deionized water and ethanol several times to remove impurities. After washing, the solution was centrifuged at 10,000 rpm about 30 min. The settled powder was collected and dried in a hot air oven at 120 °C for 2 h. The synthesized VO^{2+} doped ZnO–CdS composite nanopowder was characterized using different techniques.

Characterization

Powder X-ray diffraction was done on PANalytical XPert Pro-diffractometer with Cu Kα radiation (1.5406 Å). Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Spectroscope (EDS) images were taken from ZEISS EVO 18. Transmission electron microscope (TEM) images are recorded on HITACHI H-7600 and CCD CAMERA system AMTV600 by dispersing the samples in ethanol. Fourier Transformed Infra Red (FT-IR) spectrum was recorded using KBr pallets on Thermo Nicolet 6700 spectrometer in the range of 4000–400 cm^{-1}. Photoluminescence (PL) spectrum was obtained from Horiba Jobin-Yvon Fluorolog-3 Spectrofluorimeter with Xe continuous (450 W) and pulsed (35 W) lamps as excitation sources. Optical absorption (UV–vis) spectrum was taken from JASCO V-670 Spectrophotometer in the wavelength region of 200–1400 nm. The EPR spectrum was obtained from JEOL JES-TE 100 EPR spectrometer operating at X-band frequencies and having a 100-kHz field modulation.

Results and discussion

Structural characterization

The phase identification, structural analysis and crystallite size evaluation of prepared sample were performed by powder X-ray diffraction study. XRD pattern of VO^{2+} doped ZnO–CdS composite nanopowder is shown in Fig. 1. All the diffraction peaks can be indexed to wurtzite hexagonal ZnO structure and hexagonal CdS structure, which is well consistence with standard JCPDS No: 36-1451 and 65-3414 respectively. Broad and strong intensity peaks corresponding to the (100), (002), (101), (110), (112) planes of CdS with lattice cell parameters $a = 0.4125$, $c = 0.6726$ nm. Sharp

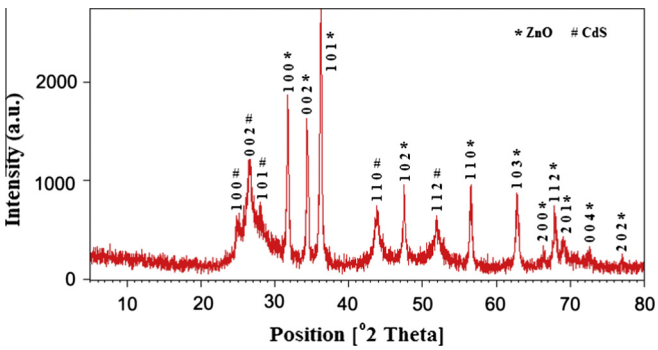

Fig. 1. XRD pattern of VO^{2+} doped ZnO–CdS composite nanopowder.