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Structural and optical properties of neodymium doped lead chalcogenide (PbSe) nanoparticles

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ABSTRACT

Wet chemical precipitation technique is successfully exploited to synthesize Neodymium undoped and doped lead selenide precipitated particles at pH 5.0. Structural analysis reveals the face centered cubic structure and particle size are found to be in the range of 25–40 nm. The electron microscopic analysis clearly depicts the nanophase formation and EDAX confirmed the purity and stoichiometry ratio of the prepared samples. FT-IR analysis confirms the stretching vibration of Pb—Se and N—H bending of hydrazine hydrate are observed at 707 cm^{-1} and 1500 cm^{-1}, respectively. The strong blue shift in the UV–vis absorption region (560 nm) confirms the nano dimensional state of $Pb_{1-x}Nd_xSe$ nano particles. The varying dopant concentration influences the particle size, surface morphology and energy gap of the nanostructured lead selenide.

1. Introduction

Nowadays, there has been significant growth in the fields of structural and optical properties of nanostructured semiconductor material, in which the size dependent property has generated a long-term thrust area for innovative practical applications. Among manifold semiconductor materials like CdSe, ZnSe exhibit similar size reliant optical property; however, PbSe is distinct by its narrow band gap, high dielectric constant, large Bohr radii, fast response time, thus making it an ideal material in infrared detectors, solar energy panel, photosensors, bio sensors and photoelectric device [1–5]. Nanostuructured PbSe has greater chemical stability, match their dimension of Bohr exciton radius (46 nm) leads to stronger quantum confinement effect. Energy gap (Eg) values of PbSe could be tuned by varying the crystalline size or alloying it with appropriate transition and rare earth metals [6,7]. PbSe being a potential photovoltaic material, energy gap can be adjusted to match the ideal value of 1.5 eV, which is required for achieving a solar cell fabrication. The physical and chemical properties of lead selenide can be easily modified with the aid of doped form. Without altering the crystal structure of lead selenide, incorporating the dopant ion into the host matrices is considered as one of the leading areas in research. The transition metal (TM) and rare earth metal (RE) doped lead chalcogenides nanopowder are prepared through various synthesis methods such as thermal evaporation [8], sonochemical [9], photochemical [10], solvothermal, hydrothermal [11] and wet chemical route [12]. Among all the methods, wet chemical route is highly advisable for high yield of product and widely used because of its simplicity, high crystallized end product and cost effectiveness. In spite of many reports found in literature, enhancement of structural, optical and electrical properties of neodymium doped lead selenide has not studied in detail. In this work, synthesis of pure and doped PbSe with varying molar concentration of neodymium through wet chemical precipitation technique is reported. Further, the structural, compositional and optical analyses have also presented.

2. Experimental method

2.1. Synthesis of PbSe and PbSe:Nd nanoparticles

Neodymium doped PbSe samples ($Pb_{1-x}Nd_xSe$) with $x = 0$, 0.05, 0.10 at pH 5 were prepared by wet chemical precipitation technique, adding hydrazine hydrate as the precipitating agent at room temperature. Freshly prepared aqueous solution and analytical grade lead nitrate ($Pb(NO_3)_2$), neodymium oxide (Nd_2O_3) and selenium dioxide (SeO_2) were used as precursor materials. Initially, 2 g of lead nitrate and 0.555 g selenium dioxide were separately dissolved in 60 ml of double distilled water in three neck flask and stirred for 30 min. Conversion of neodymium oxide into nitrate by adding 2 N nitric acid in a water bath is used as dopant precursor. This freshly prepared aqueous solution was added in lead nitrate

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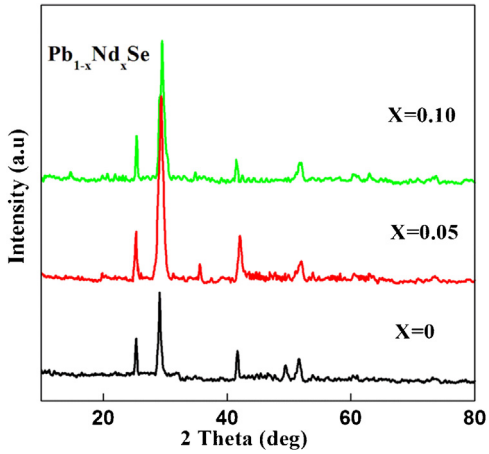

Fig. 1. XRD pattern of $Pb_{1-x}Nd_xSe$ nanoparticles.

solution with constant stirring until pale violet color turbid free solution is reached. The precipitation process was carried by drop wise addition of selenium dioxide into the lead nitrate solution under vigorous stirring, followed by addition of hydrazine hydrate to fix the pH and allowed to stir for 12 h. The resultant product was centrifuged at 4000 rpm/min and washed thoroughly with double distilled water and acetone. Finally, the samples were allowed to dry at room temperature and characterized by powder XRD, SEM, EDAX, FTIR, UV–vis and photoluminescence spectral studies.

2.2. Characterization

X-ray measurement of samples was done by XPERT-PRO diffractometer at the scanning rate of 0.02°/min for the range from 10° to 80° using Cu-K_α source. Scanning electron micrographs (SEM) was recorded on SEMJEOL JAX-840A electron micro analyzer with an operating voltage 200 kV which was also equipped with Energy Dispersive X-ray (EDAX) photometer. These samples were investigated for MIR region using Schimadzu make FTIR 8400 S series spectrophotometer with an operating range of 400–4000 cm^{-1}. The optical properties of the as prepared Nd doped PbSe nanomaterials were evaluated by UV–vis spectroscopy using JASCO V-570 Spectrophotometer ranging between 200 nm to 2000 nm at the slit width of 1 nm. The photoluminescence (PL) spectra are obtained from Perkin Elmer LS 45 Fluorescence spectrometer.

3. Result and discussion

3.1. XRD analysis

Powder X-ray diffraction spectra of neodymium doped lead selenide ($Pb_{1-x}Nd_xSe$, $x = 0$, 0.05, and 0.10) at pH 5.0 are shown in Fig. 1. The diffraction peaks obtained are characteristics of cubic structure with preferential orientation along (1 1 1), (2 0 0), (2 2 0), (3 1 1), (2 2 2) planes with *Fm*3*m* space group. The peaks are well indexed by standard JCPDS card no. (PDF# 78-1903; ICSD# 06-3097) and no other secondary phases were detected. The peak width confirms nano size particles and the intensity of peak indicates the improved crystalline nature. Using full width at half maximum of predominant peak and Debye–Scherer formula [13], the average grain size was estimated to be 37 nm, 27 nm and 25 nm for $x = 0$, 0.05, and 0.10 samples, respectively. As seen from spectra, diffraction peaks slightly shifted to higher angle and this confirms the doping of Nd ions into a host matrix. This shift may be attributed due to smaller ionic radius of Nd^{3+} (0.983 Å) compared with Pb^{2+} (1.21 Å) and this may also result as a decrease in grain size while doping [7].

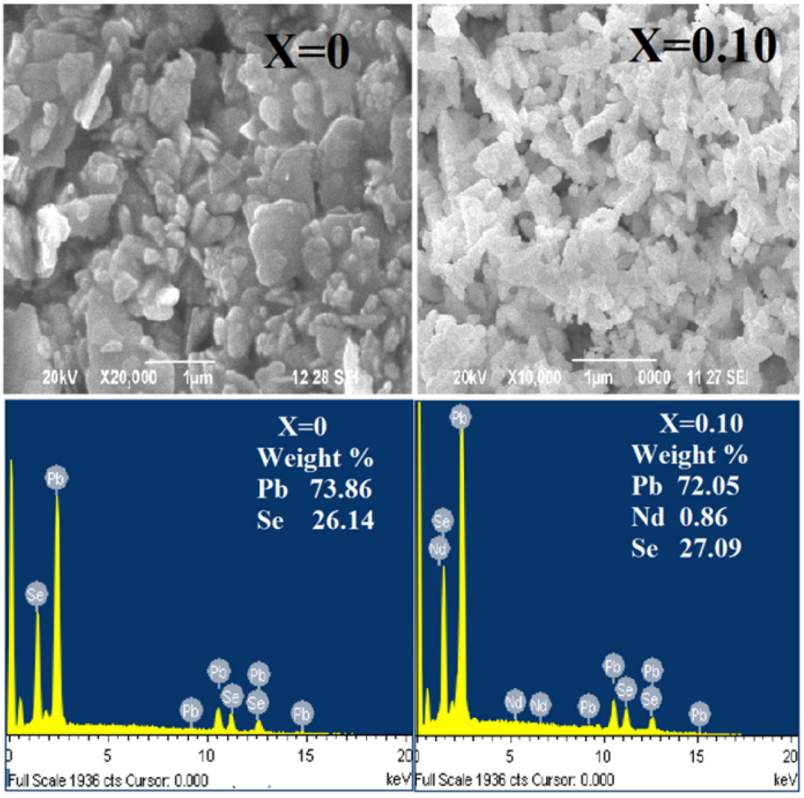

Fig. 2. SEM and EDAX spectra of PbSe and $Pb_{0.90}Nd_{0.10}Se$ nanoparticles.