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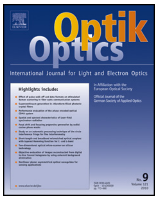

Near-infrared downconversion in $Y_{(1-x)}Yb_xVO_4$ for sensitization of c-Si solar cells

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ABSTRACT

The material YVO_4 provide suitable environment as host lattice for Yb^{3+} ion. The materials $Y_{(1-x)}Yb_xVO_4$were successfully synthesized by co-precipitation method varying the concentration of Yb^{3+} ions from 0 mol% to 2.0 mol% and annealed at high temperature. It was characterize by powder X-ray powder diffraction (XRD) and surface morphology was studied by scanning electronic microscope (SEM). The photoluminescence (PL) properties were studied by spectrophotometers in near infra red (NIR) and ultra violet visible (UV–vis) region. The Yb^{3+} ion doped YVO_4 phosphors that can convert a photon of UV region (318 nm) into two photons of NIR region (992 nm). Hence this phosphor could be used as a downconversion (DC) luminescent convertor in front of crystalline silicon solar cell (c-Si) panels to reduce thermalization loss of the solar cell. The theoretical value of quantum efficiency (QE) was calculated from steady time decay measurement and the maximum efficiency approached up to 162.53%. The $Y_{(1-x)}Yb_xVO_4$ can be potentiality used for betterment of photovoltaic (PV) technology. This result further indicates its potential application as a luminescence converter layer for enhancing solar cells performance.

1. Introduction

Quantum-cutting (QC) through downconversion (DC) is able to split one incident high-energy photon into two (or more) lower energy photons with conversion efficiency higher than 100%. The QC process could generate two or more low-energy photons from an absorbed incident high energy photon. This idea was first predicted by Dexter in 1957 and was demonstrated in YF_3:Pr^{3+} phosphor under the excitation of 185 nm with a quantum efficiency of around 140% in 1974 [1–3]. As we know that most widely used solar cells are based on crystalline silicon having efficiency is about to 29% only. In recent years, DC materials have attracted considerable attention because of their strong potential to enhance conversion efficiency of solar cells. The process of DC involved conversion of one UV or VIS photons into two photons of NIR region where solar response and conversion efficiency of crystalline silicon (c-Si) is maximum as their emission energy is just above the band gap of silicon (Si) ($E_g = 1.12$ eV, $\lambda = 1100$ nm) [4]. However, a maximum conversion efficiency of 39.63% can be achieved using this DC system [5]. The process of DC could minimize the energy loss caused by thermalization of hot charge carriers after the absorption of high-energy photons, if the down converted photons can be absorbed by solar cells. Due to potential application in solar cells, the investigation of near-infrared NIR QC/DC phosphors has attracted huge amount of attention in the recent years. Generally, the research work of NIR QC materials focused on Re^{3+}-Yb^{3+} doped phosphor because the transition from excited state $^2F_{5/2}$ to $^2F_{7/2}$ of Yb^{3+} [6,7] ion give an emission corresponding to wavelength around 1000 nm, the energy just more than band gap of silicon, which can be easily absorbed by crystalline silicon solar cells. So far, the infrared emission of Yb^{3+} in these Re^{3+}–Yb^{3+} co doped systems is still very weak, due to the inefficient excitation of the donors for their parity forbidden intra configuration 4f transitions [8]. An effective solution is the direct energy transfer from host to Yb^{3+}, because its excitation originated from the allowed electric-dipole transition and its excitation band is usually broad, which would result in more efficient excitation [9].

YVO_4 (wakefieldite) provide favourable conditions as host material. Because of efficient resonant energy transfer from host to lanthanide ions, YVO_4 has been widely used as host lattice. It has been confirmed that there exists efficient cooperative energy transfer (CET) from YVO_4 host to Yb^{3+} Comparing with the Re^{3+}–Yb^{3+} system, the intensity of Yb^{3+} emission was significantly improved in yttrium orthovanadate [10].

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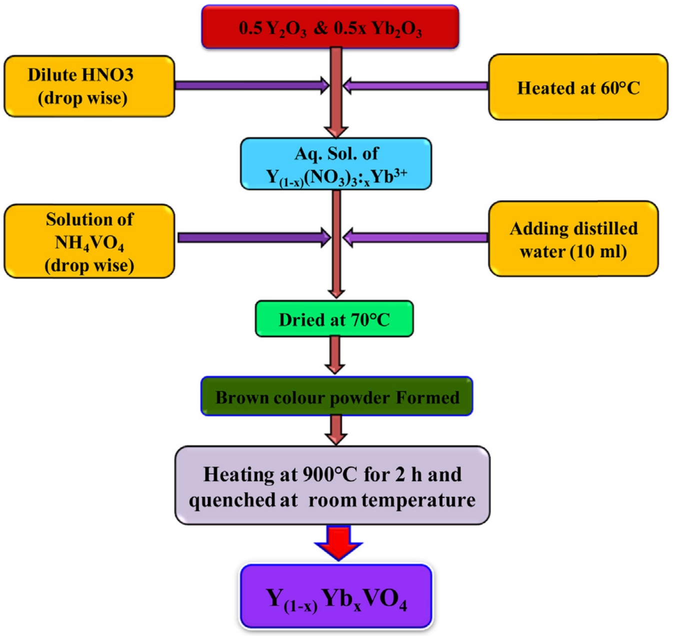

Fig. 1. Flow chart of synthesis of $Y_{(1-x)}Yb_xVO_4$ via co-precipitation method.

In this work the method of co-precipitation had been first time employed for synthesis of $Y_{(1-x)}Yb_xVO_4$ by varying molar concentration of Yb^{3+} ions at low temperature and taking less duration of time. Co-precipitation has also been used to fabricate fluoride-based and oxide-based QC phosphors [11–13]. Co-precipitation synthesis may be regarded as an attractive method for the preparation of materials because it results in smaller grains and more homogeneous distribution of dopant ion. Wei et al. [10] reported the YVO_4 host matrix with Yb^{3+} as dopant by using solid state reaction method involving very high temperature(1200 °C) that too for longer period of time (6 h).

2. Experimental

2.1. Synthesis of phosphors

The phosphors $Y_{(1-x)}Yb_xVO_4$ ($x = 0\%$, 0.5%, 1.0% and 2.0%) were synthesized by slow evaporated precipitation method often called co-precipitation method [14]. The precursors Y_2O_3 (99.9% AR), Yb_2O_3 (99.9% AR) and NH_4VO_4 (99.9% AR) used for synthesis of $Y_{(1-x)}Yb_xVO_4$ phosphor. The composition of each chemical weighed in proper stoichiometric ratio. The starting chemicals Y_2O_3 (99.9%, AR) and Yb_2O_3 (99.9%, AR) were mixed together in a china clay basin and boiled in HNO_3 so as to convert them into respective nitrates. HNO_3 was added drop by drop and under observation, mixture was heated slowly at 70 °C, till the paste dissolved completely in distilled water. The solution was further heated to evaporate excess of water. Little quantity of double distilled water was again added to make aqueous solution of nitrates of precursors. The resulting solution was considered as $Y_{(1-x)}Yb_x\,(NO_3)_3$, to this soluble solution, NH_4VO_4 (99.9% AR) dissolved in double distilled water was added drop by drop with help of burette. The entire homogenous soluble solution was then placed on hot plate maintaining the temperature of 60 °C for slow evaporation of water. The dried precursor was finally crushed and heated at 900 °C for 2 h to get white crystalline powder of $Y_{(1-x)}Yb_xVO_4$ ($x = 0\%$, 0.5%, 1.0% and 2.0%). The same process was utilized in synthesis of all the samples, only the Y/Yb ratio was changed as per the formula $Y_{(1-x)}Yb_x\,VO_4$. The complete process involved in the reaction was summarized in a flow chart as Fig. 1.

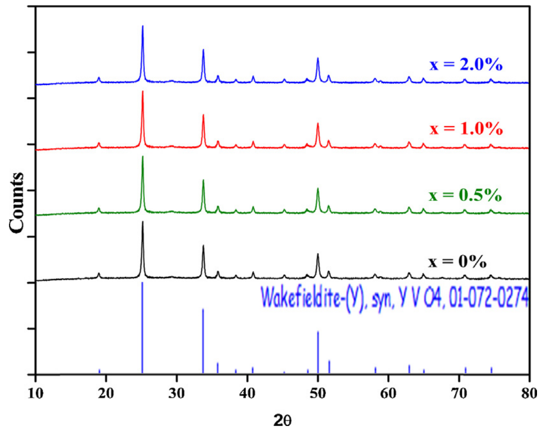

Fig. 2. XRD pattern of $Y_{(1-x)}Yb_xVO_4$ ($x = 0\%$, 0.5%, 1.0% and 2.0%).

2.2. Characterizations of materials

The confirmation of as prepared materials was done by XRD method by using Rigaku miniflex II X-ray diffractometer with scan speed of 2.000°/min and Cu K_α ($\lambda = 1.5406$ Å) radiation in the range 10° to 80°. The structural and morphological characteristics i.e., particle size and shape of particle sample was studied using a SEM analysis. The measurement was performed using a ZEISS EVO/18 Research. In this study, sample in powder form (100–150 µm) was placed directly on sample holder of SEM for imaging. The PL emission and PL excitation spectra were recorded at room temperature on (Hitachi F-7000) fluorescence spectrometer associated with 450 W Xenon discharge lamp in wavelength range 200–600 nm. The measuring parameter such as width of monochromatic slit (1.0 nm), photomultiplier tube (PMT) detector voltage, scan speed (240 nm/min), spectral resolution were kept constant throughout the analysis of materials. The NIR emission spectra were recorded with (Edinburgh photonics FLS 980) NIR spectrophotometer at room temperature keeping the other parameter same.

3. Results and discussion

3.1. Structural confirmation

The formation of the $Y_{(1-x)}Yb_xVO_4$ ($x = 0\%$,0.5%, 1.0% and 2.0%) sample in the crystalline phase synthesized by co-precipitation method was confirmed by XRD pattern as shown in Fig. 2. The XRD pattern for $Y_{(1-x)}Yb_xVO_4$ agreed well with the standard data from ICDD file (01-072-0274) of YVO_4. Also the XRD pattern show that the formed material was completely crystalline and in single phase, where $a = b = 7.1000$ Å and $c = 6.270$ Å. The prepared materials crystallizes in tetragonal phase and high intensity peaks observed at 25.06, 33.68, 35.74, 49.94, 51.44 and 62.90, corresponding to plane (2 0 0), (1 1 2), (2 2 0), (3 1 2), (4 0 0) and (3 3 2), respectively. The space group for YVO_4 is I41/amd.

From analysis of the XRD pattern, it is understood that the introduction of activator Yb^{3+} ions does not influence the crystal structure of the YVO_4 sample, because both Yb^{3+} and Y^{3+} ions have similar ionic radius at appropriate approximation (Yb^{3+}: 0.86 Å, Y^{3+}: 0.89 Å) and hence the ytterbium ions enters the lattice substitution ally in yttrium sites. The average crystalline size of YVO_4 phosphor was found to be 45.32 nm as estimated by Scherrer's formula

$$D = \frac{K\lambda}{\beta \cos\theta}$$

where, θ is Bragg angle of diffraction lines, K is a shape factor taken as 0.90, λ is wavelength of incident X-rays ($\lambda = 0.154$ nm) and β is full-width at half maximum (FWHM in radians).