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Spectral characterization and white light generation by yttrium silicate nanopowders undoped and doped with Ytterbium(III) at different concentrations when excited by a laser diode at 975 nm

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ABSTRACT

We have studied nanophosphors of yttrium silicate (YSO) undoped and doped with different concentration of ytterbium (Yb^{3+}) synthesized by using the sol-gel method. Structural and luminescence properties of the nanophosphors were studied experimentally by using different analytical techniques. For the structural analysis, we performed X-ray diffraction (XRD), Transmission Electron Microscopy (TEM) and Energy Dispersive X-ray Spectrometry (EDS) measurements. Upconversion (UC) and the white light (WL) emission properties were investigated by using the near infrared cw laser excitation of 975 nm. The spectral properties have been found to depend on several physical parameters.

1. Introduction

Rare earth (RE) ions embedded in host crystals have been investigated for optical applications such as optical sensing photovoltaics, data storage, nonlinear imaging and biomedicine [1–3]. In some circumstances, they show upconversion properties and multiphoton absorption luminescence characteristics. Due to the crystal field of the host materials, the energy levels of the rare earth ions split into several Stark levels and selection of host material changes the luminescence effects of the emission. Yttrium silicates (YSO) are suitable host materials for the RE ions because of their high thermal and chemical stability [4,5].

The NIR photons of the diode used to excite the system can't bridge the energy gap of the host material. Therefore, the light emitted by the excited nanopowder is of frequency higher than that of the diode excitation, the process of excitation should be considered nonlinear since it requires the absorption of several photons of the emitted light by the diode [4].

In cooperative emission, that is a kind of upconversion, two interacting ions in the excited state return to the ground state simultaneously, and emit one photon with the sum of the energies of the single ion transitions. This upconversion has been observed for Yb^{3+} pairs in many investigations [6,7]. Yb^{3+}sensitized phosphors are of interest to researchers for their intense emission in the shorter visible wavelength region [8,9].

The synthesis techniques of nanostructured yttrium silicates affect the optical and structural properties of the materials. The sol-gel method is the preferable technique used to form Y_2O_3: SiO_2 nanocomposite since it has a lot of advantages; such as needed low temperature, minimal thermal decomposition and easy to control process [10,11].

In the present study, we used the sol gel method to prepare a series of YSO samples with concentrations of 1%, 2%, 5% and 10%, 20% per mole Yb^{3+} doped and undoped yttrium silicate nanopowders and studied the details of emission for the different pumping powers in each sample investigated under continuous wave near infrared laser excitation (975 nm).

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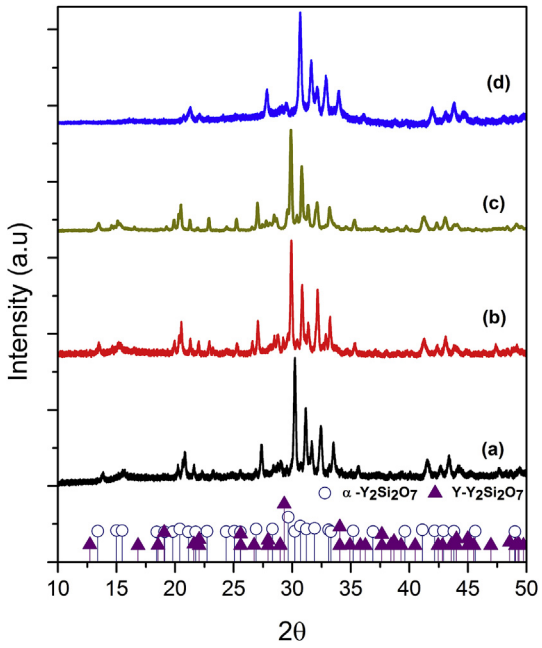

Fig. 1. XRD patterns of the (a) 1% per mole (b) 2% per mole and (c) 5% per mole Yb^{3+} doped and d) undoped $Y_2Si_2O_7$ nanophosphors annealed at 1250 °C for 12 h.

2. Experimental part

2.1. Synthesis of the undoped and Yb^{3+} doped Y_2O_3-SiO_2 (YSO)

The nanopowders of Y_2O_3-SiO_2 (YSO) undoped and doped with different concentrations of Yb^{3+} from 1% to 20% nanopowders were synthesized by the sol-gel method [10,11]. The ratio of Y_2O_3-SiO_2 was kept at 1.127.

Yttrium(III) nitrate hexahydrate ($Y(NO_3)_3{\cdot}6H_2O$ – 99.9%), Ytterbium(III) nitrate pentahydrate ($Yb(NO_3)_3{\cdot}5H_2O$ – 99.9%) salts and tetraethyl orthosilicate (TEOS, 99.9%) were purchased from Sigma–Aldrich company. Ethanol and distillate water were used for solving $Y(NO_3)_3{\cdot}6H_2O$ and $Yb(NO_3)_3{\cdot}5H_2O$ with 1 N 1 cc HNO_3 as catalyst, separately. TEOS, distillate water and ethanol solution prepared to initiate sol-gel reaction with 1 N 1 cc HCl as catalyzer at room temperature. $Y(NO_3)_3.6H_2O$ and $Yb(NO_3)_3{\cdot}5H_2O$ solutions were mixed at 70 °C for 40 min. Then, $Y(NO_3)_3{\cdot}6H_2O$, $Yb(NO_3)_3{\cdot}5H_2O$ and TEOS solutions were mixed for 2.5 h continuously at room temperature. Finally, the samples were poured into petri dishes and left in the desiccator at least 3–4 weeks to obtain glassy form. The samples were annealed at 1250 °C for 12 h and were grinded in agate mortar to produce nanocrystalline YSO powders.

2.2. Structural analyses of the undoped and Yb^{3+} doped Y_2O_3-SiO_2 (YSO)

For the structural characterization the X-Ray Diffraction (XRD), Transmission Electron Microscopy (TEM) and Energy-dispersive X-ray spectroscopy (EDS) techniques were used. The X-ray diffraction (XRD) images of the samples were taken by the Bruker D2 Phaser Model (Cu-Kα radiation) diffractometer setting in the 2θ range from 10° to 50° with scanning steps of 0.002. The average particle size of the powders was estimated by using the Scherer Equation [12].

$$D = \frac{0.9\lambda}{\delta 2\theta \cos\theta}$$

where grain size (D) and FWHM (δ2θ) in radians, λ is the wavelength, and θ is the diffraction angle. Transmission electron microscopy (TEM) measurements were carried out in JEOL 2010F model transmission electron microscope equipped with energy dispersive X-ray spectroscope (EDS). The specimen was prepared by dispersing powder in ethanol, followed by ultrasonic agitation, and then deposition on a lacey carbon film on a 400 mesh copper grid.

2.3. Optical characterization of the undoped and Yb^{3+} doped Y_2O_3-SiO_2 (YSO)

The UC and WL emission spectra in different concentrations of the Yb^{3+} doped and undoped yttrium silicate nanopowders were measured between 450 nm and 900 nm by using a diode laser LDI-820 with 975 nm excitation wavelength and a McPherson Inc. Model 2051 monochromator under 0.01 mbar pressure and different pumping power values. The slit of the 1 m McPherson monochromator was set at 500 μm for all samples except for the 20% Yb^{3+} doped sample (it had to be changed to 20 μm because of its very bright white light) and the optical signal was detected by a Hamamatsu R1387 photomultiplier tube and the electrical signal was sent to an EG&G Model 5210 lock-in amplifier. An Allied Scientific Pro ASP-MK350 Model illuminator was used to determine the colour quality parameters. A short pass 900 nm cut off filter was placed between the excited sample and the monochromator's

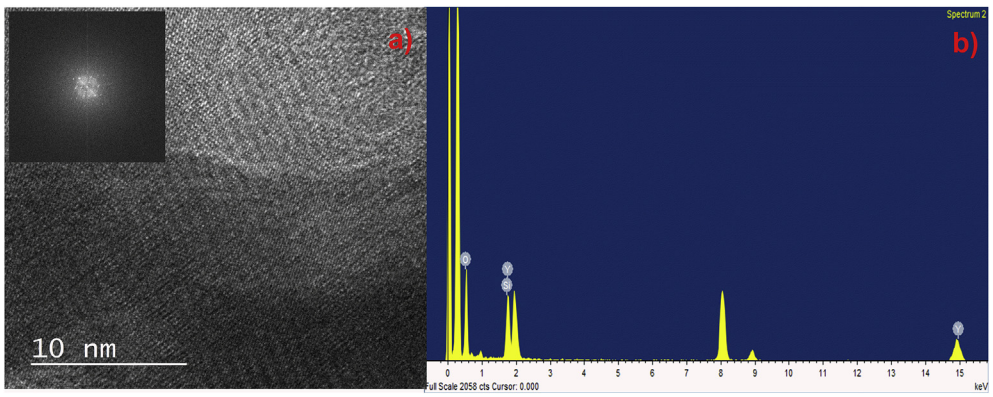

Fig. 2. a) Transmission Electron Microscopy (TEM) b) Energy-dispersive X-ray spectroscopy (EDS) images of undoped yttrium silicate powder.

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