

# Sonochemical driven ultrafast synthesis of Praseodymium doped $Y_2O_3$ nanostructures for display applications

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**Abstract.** For the first time  $Pr^{3+}$  (1-11 mol %) doped  $Y_2O_3$  nanophosphors were synthesized by ultrasound supported sonochemical method using *mimosa pudica* (MP) leaves extract as bio-surfactant. The obtained product was heat treated at 700°C for 3 h and used for characterization. The powder X-ray diffraction (PXRD) profiles of nanophosphors showed cubic phase structure. The sonication time and concentration of bio-surfactant play a vital role in tuning the morphologies of  $Y_2O_3$ . The particle size was further confirmed by transmission electron microscope (TEM) and it was found to be in the range of 20-30 nm. The band gap energy of the phosphors were estimated by making use of diffuse reflectance spectrum (DRS) and the values were found to be in the range of 5.67 – 5.80 eV. Under 447 nm excitation wavelength, the photoluminescence (PL) emission spectrum was recorded. The PL emission spectra consist of sharp peaks centred at 554, 612 and 738 nm and were attributed to  $^3P_0 \rightarrow ^3H_5$ ,  $^3P_0 \rightarrow ^3H_6$ , and  $^3P_0 \rightarrow ^3F_4$  transitions respectively. The 5 mol%  $Pr^{3+}$  doped  $Y_2O_3$  nanophosphors showed maximum intensity. Further CIE and CCT were estimated and found that the color coordinates lies in between (0.593, 0.412) and (0.358, 0.544) respectively. Results obtained evident that the phosphor was highly useful in display device applications.

**Keywords:** Ultrasound, diffuse reflectance spectra, Photoluminescence, display devices.

## 1. Introduction

In the recent years nanomaterials with unusual morphology has driven the science community especially material scientists and chemists due to their unique properties. These unusual shaped structures have great impact over the structural, optical and luminescence properties [1]. Yttrium oxide ( $Y_2O_3$ ) is an important semiconducting material with wide band gap energy (5.67 eV), high dielectric constant and optically isotropic in nature. Apart from these  $Y_2O_3$  has got high thermal stability with small phonon energy ( $380\text{ cm}^{-1}$ ), which is desirable for radiative transitions among electronic energy levels of rare earth elements [2]. In ultrasound assisted sonochemical method, a series of chemical reactions arises from acoustic cavitation which results for the formation, growth and sudden collapse of bubbles in the solution. As per the hot-spot theory, a very high temperature ( $> 5000\text{ K}$ ) was accomplished upon the collapse of a bubble. Subsequently this collapse happens within  $10^{-9}$  sec. These exciting alterations can tune the size distribution, shape and size of the powders more effectively. In order to obtain nano/micro structured materials at sensibly low temperature was extremely indispensable for industrial applications via ultrasound route [3-8].



In this paper we are the first to report the synthesis of various nanostructures of  $Y_2O_3$  doped with Pr by using bio-surfactant (mimosa pudica). Further, in detail study on photoluminescence (PL) was carried out for the obtained phosphors for their potential applications in the field of solid state lighting devices.

## 2. Materials and methods

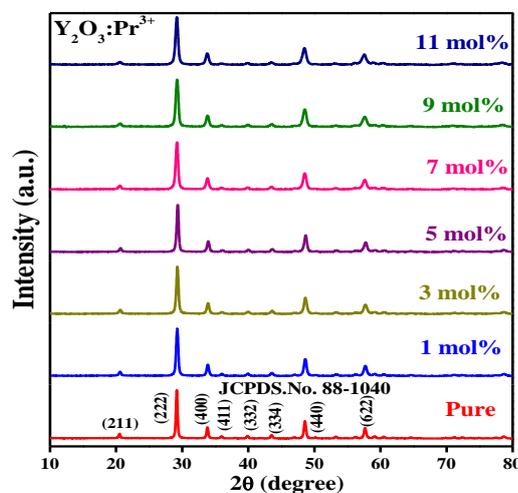
Undoped and (1-11 mol %)  $Pr^{3+}$  doped  $Y_2O_3$  nanostructures were prepared via ultrasound method using MP as bio-surfactant. To prepare  $Y_2O_3:Pr^{3+}$  (1 mol %), the precursor solutions of Yttrium nitrate [ $(Y(NO_3)_3 \cdot H_2O)$ : 3.83 g] and Praseodymium nitrate [ $(Pr(NO_3)_3 \cdot 5H_2O)$ : 0.0428 g] were mixed homogeneously in 50 ml of double distilled water and then they were mixed homogeneously using magnetic stirrer. 20 ml of MP gel was diluted by adding ~ 80 ml of double distilled water and kept on a magnetic stirrer for ~ 30 min to get uniform mixture. Further the resulting mixture was divided into 5, 10, 15, 20, 25 & -30 ml and added slowly to the beaker containing the mixture of Yttrium and Praseodymium nitrates and subjected to sonochemical treatment using ultrasonic frequency 20 kHz, power ~ 300 W at constant temperature of ~ 80 °C with different ultrasound time (1 - 6 h). The mixture was undisturbed till a milky white precipitate was achieved. The unreacted materials if any in the precipitate was then washed several times using alcohol and distilled water. Similarly the procedure was repeated for varying remaining concentrations of  $Pr^{3+}$  (3-11 mol %) by maintaining the same experimental conditions. The filtrate was dried at 80 °C for 3 h in a hot air oven and calcined at ~ 700 °C for 3 h and used for structural, morphological and photoluminescence studies.

## 3. Results and discussion

PXRD profiles of the undoped and  $Pr^{3+}$  doped  $Y_2O_3$  nanostructures were shown in Fig.1. The PXRD result confirms the cubic phase with reference to JCPDS. No.88-1040 of the standard compound. The crystallite size was estimated by using the Scherrer formula

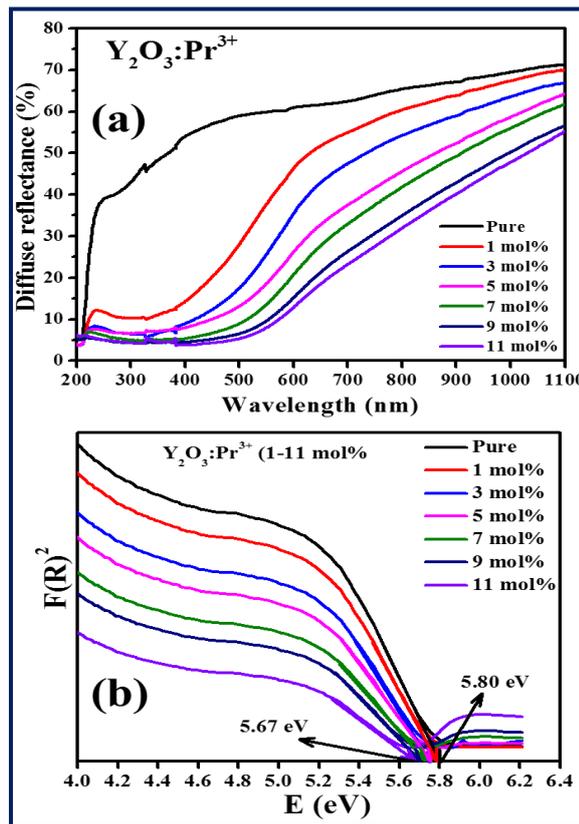
$$D = \frac{0.89\lambda}{\beta \cos \theta}$$

Where D; the average crystallite size,  $\lambda$ ; the wavelength of the X-rays (0.154 nm), and  $\theta$ ; the diffraction angle and  $\beta$ ; full-width at half maximum (FWHM) of the peaks in the XRD patterns.

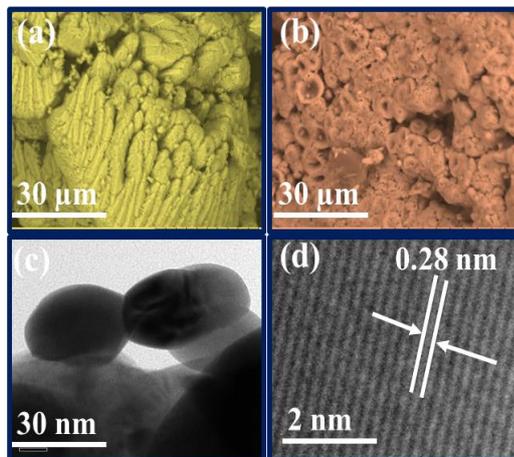


**Figure 1.** PXRD patterns of Pure and  $Pr^{3+}$  doped  $Y_2O_3$  nanostructures.

The DR Spectra of undoped and  $Y_2O_3:Pr^{3+}$  (1-11 mol %) nanostructures (NSs) was depicted in Fig. 2a. The Kubelka-Munk relation was utilized to estimate the energy band gap of the phosphors and it was found to be in the range of 5.67 – 5.80 eV (Fig. 2b) [9].

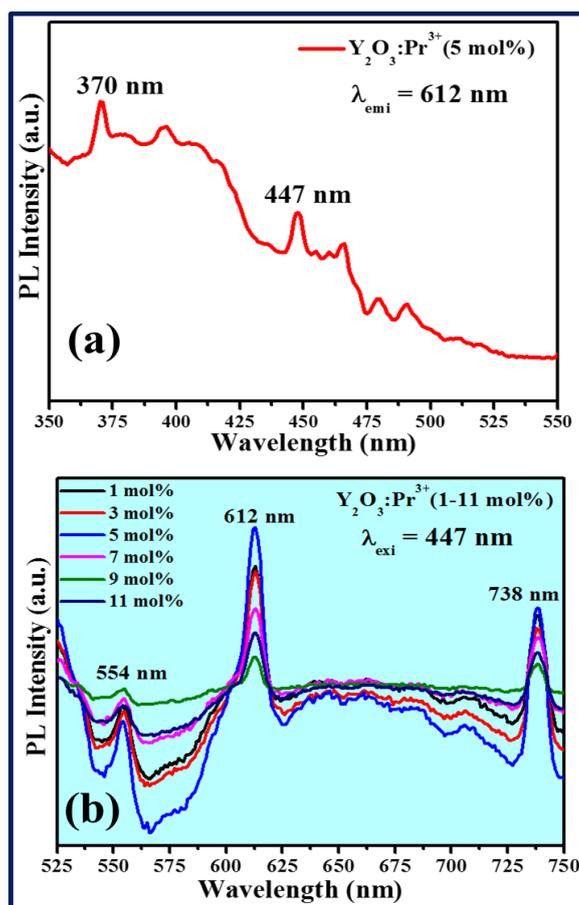


**Figure 2.** (a) Diffuse reflectance spectra, (b) energy band gap of  $Y_2O_3:Pr^{3+}$  NSs.



**Figure 3.** SEM (a, b), TEM (c) & HRTEM (d) image of  $Y_2O_3:Pr^{3+}$  (5 mol %) nanophosphors.

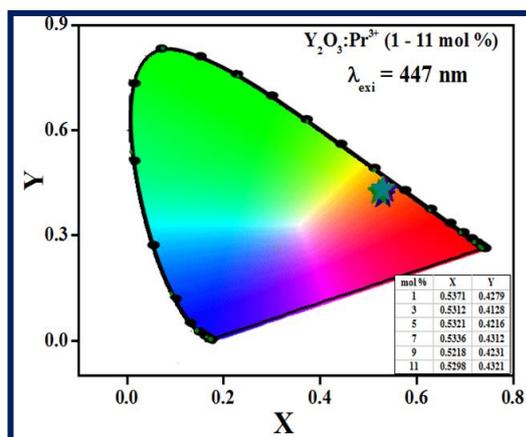
Fig. 3(a & b) shows the SEM micrographs of  $\text{Y}_2\text{O}_3:\text{Pr}^{3+}$  (5 mol %) nanophosphors. It can be observed from the figure that at lower concentration (5 ml) of the surfactant a spike like projected structures were formed (Fig.3a). Further, when the concentration of the surfactant was increased (30 ml), flower like morphology was observed (Fig. 3b). It can be evident that the surfactant concentration greatly influence on the morphology of the product. Fig.3 (c, d) shows the TEM and HRTEM image respectively. From TEM image it was confirmed that the particle size was in nano range (~20 – 30 nm) with an inter-planar spacing (d) was found to be 0.28 nm.



**Figure 4(a).** Excitation spectrum and (b) PL Emission spectra of  $\text{Y}_2\text{O}_3:\text{Pr}^{3+}$  nanophosphors.

Fig.4 (a) shows the excitation spectrum recorded by monitoring 612 nm emission ( $^3\text{P}_0 \rightarrow ^3\text{H}_6$ ). From the figure it was evident that a sharp peak is centered at 447 nm. The emission spectrum was recorded at room temperature in the range of 525 – 750 nm by monitoring 612 nm wavelength. It was noticed that the emission spectra comprises of several peaks centered at 554, 612 and 738 nm and were attributed to  $\text{Pr}^{3+}$  ion transitions  $^3\text{P}_0 \rightarrow ^3\text{H}_5$ ,  $^3\text{P}_0 \rightarrow ^3\text{H}_6$ , and  $^3\text{P}_0 \rightarrow ^3\text{F}_4$  respectively [10].

CIE 1931 x-y chromaticity diagram of  $\text{Y}_2\text{O}_3:\text{Pr}^{3+}$  (1-11 mol %) nanophosphors was presented in Fig. 5, excited under 447 nm and the corresponding CIE coordinates were given in the inset of Fig. 5.



**Figure 5.** CIE diagram of  $\text{Y}_2\text{O}_3:\text{Pr}^{3+}$  (1-11 mol %) nano structures.

## CONCLUSIONS

This paper reports the ultrasound synthesis of  $\text{Y}_2\text{O}_3:\text{Pr}^{3+}$  (1-11 mol %) nanostructures. The PXRD patterns confirmed the cubic phase of the material. The diffuse reflectance spectral studies revealed that the band gap of the obtained product lies between 5.67 – 5.80 eV. The effect of sonication time and bio-surfactant concentration plays a chemical role in tuning the superstructures of  $\text{Y}_2\text{O}_3$ . The particle size was estimated from TEM results. The PL emission spectra show three intense peaks and CIE diagram indicates the orange-red emission which is useful for display applications.

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