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# Upconversion emission in $Sm^{3+}$ doped $Y_2O_3$ phosphor

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**ABSTRACT**

The $Sm^{3+}$doped $Y_2O_3$ phosphor has been prepared by using combustion technique. The visible frequency upconversion emission has been observed from the developed phosphor under excitation with a 980 nm diode laser excitation. The upconversion mechanism involved in the $Sm^{3+}$ doped $Y_2O_3$ phosphor has been explained on the basis of excited state absorption (ESA) process.



## Introduction

The rare earth doped solid hosts are crucial for improving the existing devices like, solar cells, solid state lasers, light emitting diodes, temperature and radiation sensors, display devices, etc. along with its biological applications [1-5]. The optical emissions and excitations are observed among 4f electronic states present in the trivalent rare earth (RE) ions. Inner f-f electronic transitions of trivalent RE ions give emissions covering the spectral region from the ultraviolet to the infrared (IR) of the electromagnetic spectrum [6].

In a system of trivalent rare earth ions doped into an inorganic matrix, luminescence efficiency depends upon the energy transfer from host-to-rare earth ions. An increase in the quantum efficiency from $RE^{3+}$ ions doped in nanocrystals with its reduced crystal size has been reported [7].

Yttrium oxide ($Y_2O_3$) exhibits polymorphic forms, classified as hexagonal, monoclinic and cubic forms, respectively [8]. In the excitation and emission for rare earth ions in yttrium oxide, only magnetic transitions can be recorded due to centro-symmetric character in $S_6$ symmetry [9]. On the other side, its non-centrosymmetric character, such as $C_2$ group, partially allows the forced electric dipole f-f transitions because of odd parity terms in the crystal field Hamiltonian. The characteristics like high band gap, low phonon frequency, wide transmission, high melting point, range etc. [10] attract researchers to use as host.

The analysis of fluorescence properties of $Sm^{3+}$ ion is one of the most fascinating among rare earth ions because of its use in high density optical data storage, under sea communication, color displays, etc. The presence of $^4G_{5/2}$ level in $Sm^{3+}$ ion presents relatively high quantum efficiency and also shows various emission channels.

The photoluminescence properties of $Y_2O_3$: $Sm^{3+}$ phosphor materials have been studied [11-13]. Synthesis of phosphors is customarily done via two major processes, physical and chemical methods. Solution combustion method brings the direct crystallization to smaller-sized particles utilizing low processing temperature in a short time. The reaction which leads to the formation of product is an exothermic one between oxidizer (e.g., metal nitrates) and fuel (e.g., urea, glycine).

In the present paper we have synthesised the $Sm^{3+}$ doped $Y_2O_3$ phosphor by low temperature combustion method. The visible upconversion emission in the synthesised material has been investigated on 980 nm diode laser excitation and process involved is discussed in detail.

## Experimental

### Material preparation

In the combustion process, combustion takes place between the metal nitrate and urea ($NH_2$–CO–$NH_2$) serving the purpose of oxidizing agent and organic fuel respectively. The composition of the raw materials were set as,

99.8 $Y_2O_3$ + *0.2* $Sm_2O_3$

The nitrates namely $Y(NO_3)_3{\cdot}6H_2O$ and $Sm(NO_3)_3{\cdot}6H_2O$ were formed by dissolving yttrium oxide and samarium- oxide in concentrated $HNO_3$ and then diluted with deionized water to make the transparent solution. The urea was then added to the nitrate solutions and stirred with a magnetic stirrer at some desired temperature. After some time the solution was converted into transparent gel. The formed gel is taken into an alumina crucible and placed inside an electrical furnace preheated at 600$^o$C temperature. Within few minutes, the gel became foamed with producing flame and a fluffy mass like product was obtained. The obtained product was taken out and grinded into fine powder with the help of pestle and mortar. In this way, the $Y_2O_3$ phosphor powders doped with $Sm^{3+}$ was made and given for heat treatment at desired temperature for 3 hours. The heat treated sample was used for further characterization purposes.

### Characterization

A system comprising of Princeton triple grating monochromator (Acton SP-2300) attached with a photomultiplier tube (PMT) and personal computer (PC) has been used for recording the upconversion (UC) emission spectra. A continuous wave (CW) diode laser operating at 980 nm at room temperature was used to pump the phosphor sample.

## Results and discussion

### Upconversion emission study

The visible frequency upconversion (UC) emission spectra of 0.2mol% $Sm^{3+}$ doped $Y_2O_3$ phosphor annealed at desired temperature is shown in Fig. 1. The observed peaks in UC emission spectra were assigned as $^4G_{7/2} \rightarrow {}^6H_{5/2}$ (~489 nm), $^4F_{3/2}$

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$\rightarrow {}^6H_{5/2}$ (~535 nm) and ${}^4G_{5/2} \rightarrow {}^6H_{5/2}$ (~551 nm) transitions of $Sm^{3+}$ ions.

The mechanism involved in the UC emission is shown in Figure 2. A 980 nm radiation excites the $Sm^{3+}$ ions to the ${}^6F_{11/2}$ state through ground state absorption (GSA) process. The $Sm^{3+}$ ions in the ${}^6F_{11/2}$ level are lifted to the ${}^4G_{7/2}$ level by absorbing a second photon via excited state (ESA-1) process. A small part of population stored in the ${}^6F_{11/2}$ state decay nonradiatively to the ${}^6F_{9/2}$ state and again lifted to the ${}^4F_{3/2}$ state through the ESA-2 process. A fraction of population of ${}^4G_{7/2}$ level relaxes radiatively to the ground state (${}^6H_{5/2}$) giving blue emission while rest part decay nonradiatively to the ${}^4F_{3/2}$ and ${}^4G_{5/2}$ state. The population of ${}^4G_{5/2}$ state is enhanced further via nonradiative relaxation from ${}^4F_{3/2}$ state. Thus the intensity of ${}^4G_{5/2} \rightarrow {}^6H_{5/2}$ transition is large compared to other bands.

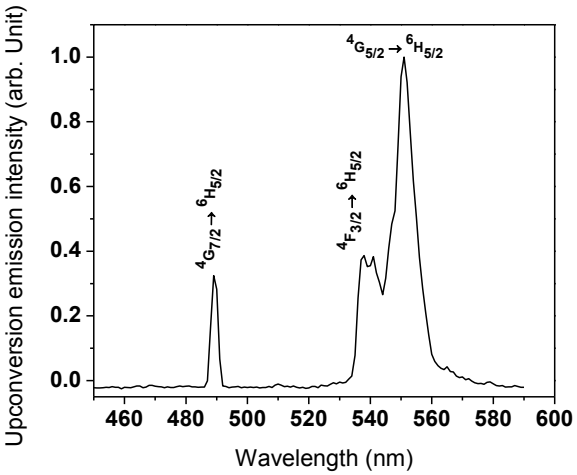


**Fig 1: Upconversion emission spectra of $Sm^{3+}$ doped $Y_2O_3$ phosphor.**

The UC emission intensity ($I_{UC}$) and pump excitation power (P) follows a relation, asgiven by [14],

$$I_{UC} \sim P^k \quad \text{..... (1)}$$

where k stands for number of photons required to excite the levels responsible for emission. To estimate the number of pump photons involved in the UC process, a log-log plot between upconversion intensity versus pump power is done. The slope was found to be approximately ~ 2, showing the contribution of two near infrared (NIR) photons in the frequency UC process.

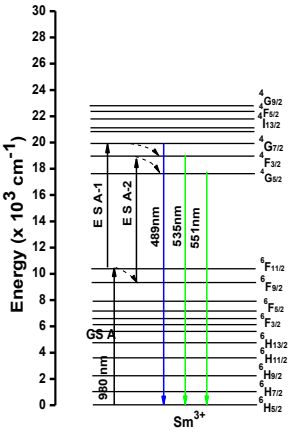


**Fig 2. Schematic energy level diagram of $Sm^{3+}$**

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