Research Journal of Chemical Sciences _____ E-ISSN 2231-606X
Vol. **6(6),** 1-5, June **(2016)** *Res. J. Chem. Sci.*

Synthesis and Luminescence Properties of $NaCaPO_4$: Eu Phosphor for Radiation Dosimetry and Solid State Lighting

C.B. Palan*, A.O. Chauhan, N.S. Sawala and S.K. Omanwar
Department of Physics, Sant Gadge Baba Amravati University, Amravati-444602, India
chetanpalan27@gmail.com

Available online at: www.isca.in, www.isca.me
Received 22nd March 2016, revised 11th May 2016, accepted 4th June 2016

Abstract

The polycrystalline $NaCaPO_4$: Eu phosphor was developed by using solid state diffusion method (SSD). The structure of $NaCaPO_4$: Eu phosphor confirmed by using X-ray diffraction pattern and crystal structure of $NaCaPO_4$:Eu phosphor was orthorhombic with space group Pnam (62). The prepared $NaCaPO_4$: Eu phosphor showed excellent luminescence (TL/OSL) responses under β irradiation. The TL glow curves were consists over lapping peaks in temperature range 200-450°C and peak fit software was used for deconvolution of this peak. The peak shape method was employ for calculation of kinetics parameters. The photoluminescence spectra of $NaCaPO_4$: Eu phosphor show emission in red-orange regions under near-UV excitation. This excitation is useful for solid state lighting. The prepared phosphor showed outstanding TL/OSL properties hence this phosphor is suitable candidate for radiation dosimetry.

Keywords: Solid state lighting, TL/OSL, β irradiation, Kinetics parameter.

Introduction

OSL technique is a now well-developed for its application in radiation dosimetry. Antonov Romanovskii *et al.* firstly suggested use of OSL for personal dosimetry[1]. The OSL technique most popular for personnel dosimetry only after the development of crystalline Al_2O_3: C[2,3]. The OSL technique is applicable for personnel dosimetry, environmental dosimetry, medical dosimetry, space dosimetry[4-6].

Now day various phosphates, borate, sulphate based OSL materials available for personal, environmental and medical dosimetry applications[7-11]. The phosphate base $ABPO_4$ compound (A=Li^+, Na^+, K^+ -monovalant cations, B= Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+} -divalent cat ions) show excellent luminescence (TL/OSL) properties. These compounds show excellent thermal, hydrolytic stability and magneto electric properties. However $NaCaPO_4$:RE compound is including in $ABPO_4$ phosphate family and effective atomic number (Z_{eff}=14.63) is nearly same as effective atomic number of human tissue (Z_{eff}=7.4)[12]. Grandhe *et al.* reported $NaCaPO_4$:RE (RE= Eu^{3+}, Eu^{2+}) phosphor for white light application and display device[13]. Qin *et al.* developed $NaCaPO_4$:Eu^{2+} phosphor via high temperature solid state method and this phosphor applicable for green emitting for W-LED[14]. Li *et al.* developed Mn doped $NaCaPO_4$ phosphor via sol-gel process and reported this phosphor for field emission displays[15]. From above literature survey we observed that $NaCaPO_4$: M (M= Eu, Mn and rare earth (RE)) phosphor is applicable for solid state lighting (SSL).

In the present paper, $NaCaPO_4$:Eu phosphor was developed by using SSD method and its TL/OSL properties under β irradiation studied.

Methodology

The polycrystalline $NaCaPO_4$: Eu phosphor was developed by using SSD method[16]. Phase purity of $NaCaPO_4$:Eu phosphor was checked by using X-ray diffraction (XRD) using a Rigaku miniflex II diffractometer with Cu Kα (λ= 1.5405 Å) operated at 5 kV. Irradiations of all the samples were performed at room temperature using a calibrated $^{90}Sr/^{90}Y$ β source in-housed in RISO TL/OSL Reader (DA-15 Model).

The TL/OSL measurement was carried out using an automatic RISO TL/OSL-DA-15 reader at RPAD, BARC (Mumbai). The PL and PL excitation (PLE) spectra were measured on (Hitachi F-7000) fluorescence spectrophotometer[17].

Results and Discussion

X-ray Diffraction pattern: The XRD pattern of the $NaCaPO_4$:Eu phosphor was shown in Figure-1. The patterns matched with the International Center for Diffraction Data (ICDD) having card no.-00-029-1193.

They were in good agreement with the ICDD file in terms of peak position as well as intensity.

CW-OSL response (continuous wave optically stimulated luminescence): The sample was studied for its OSL response using blue LED stimulation (470 nm)[8]. Figure-2 shows the CW-OSL response of $NaCaPO_4$:Eu phosphor for 100mGy of β-irradiation. Also CW-OSL curve fitted with 3rd order exponentially decay and found three components such as fast, medium and slow.

Thermoluminescence (TL): Figure-3 represent TL glow curve of $NaCaPO_4$:Eu phosphor under β-irradiation. The peak fit software was used for deconvolution of TL glow curve[18,19]. The peak shape method was employ for calculation of kinetics parameters[20-22]. The calculated kinetics parameters such as activation energy, frequency factor and order of kinetics were given in Table-1.

Photoluminescence (PL): The combined excitation and emission spectra of $NaCaPO_4$:Eu phosphor was shown in Figure-4. The excitation and emission spectra were observed under 613 and 393 nm respectively. From Figure-4 excitation spectra consists sharp peaks at 393 nm corresponds to the $^7F_0$-$^5L_6$ transition. The emission spectra consist of also sharp peaks at 595nm and 613 nm correspond to $^5D_0$ -$^7F_0$ and $^5D_0$ -$^7F_2$ transitions[23].

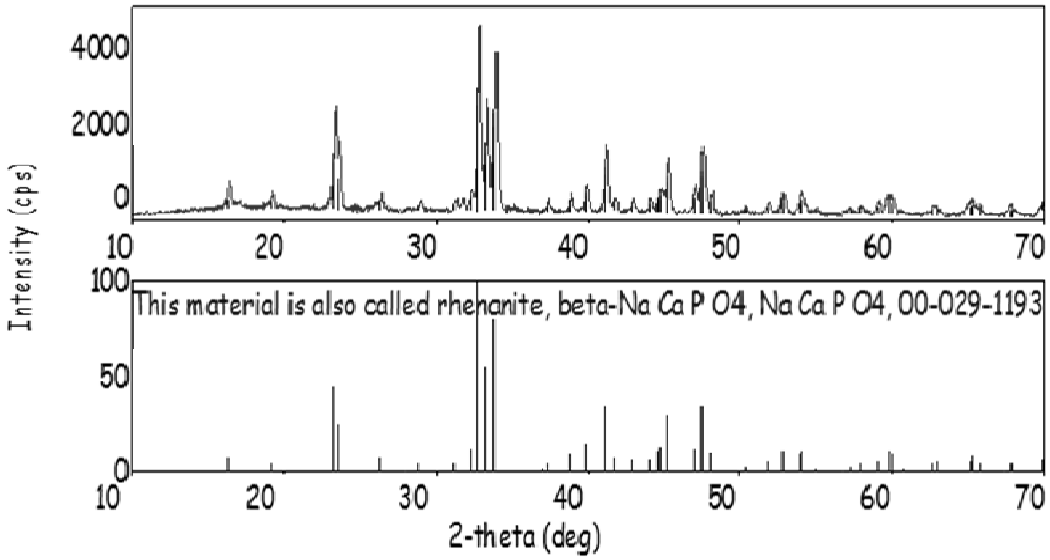

Figure-1
XRD pattern of $NaCaPO_4$:Eu phosphor with ICDD file No. 00-029-1193

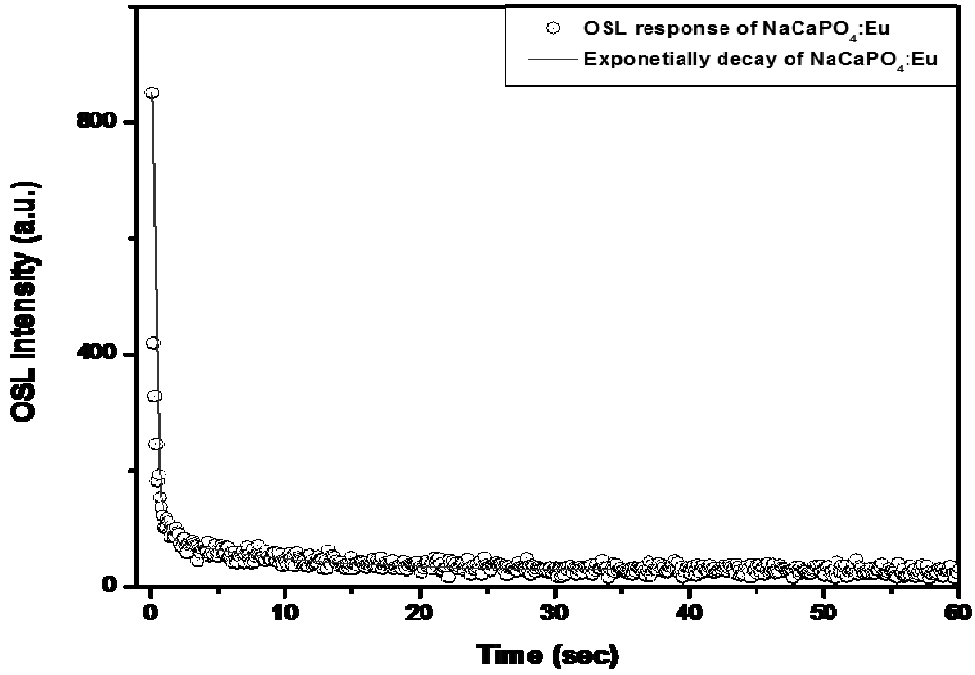

Figure-2
CW-OSL responses of $NaCaPO_4$:Eu phosphor under beta irradiation

Table-1
Kinetics parameter of $NaCaPO_4$:Eu phosphor

Phosphor	Peaks	Activation energy	Frequency factor	Geometric factor (μg)
$NaCaPO_4$:Eu	Peak-1	1.308	1.38×10^{11}	0.5
	Peak-2	2.052	1.01×10^{14}	0.5

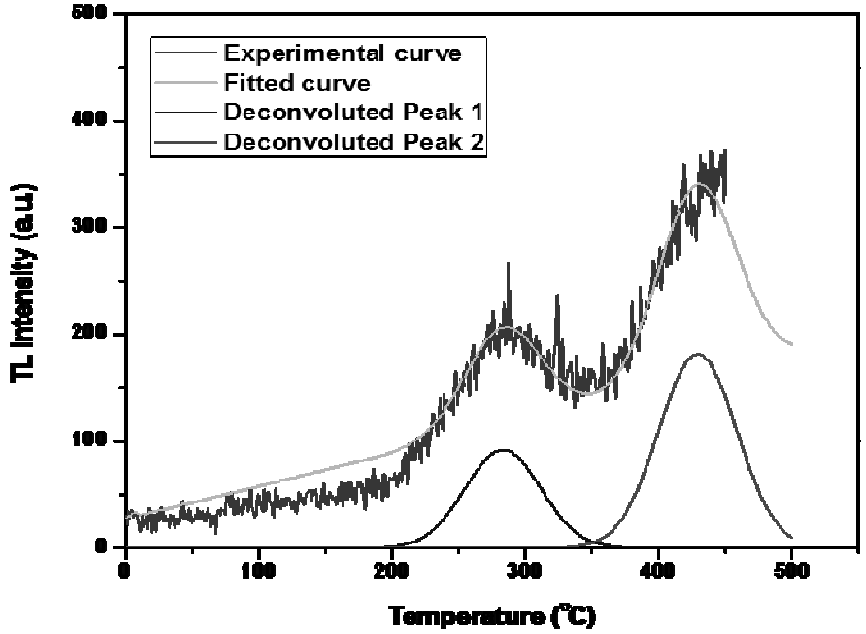

Figure-3
Deconvoluted TL glow curve of $NaCaPO_4$: Eu phosphor

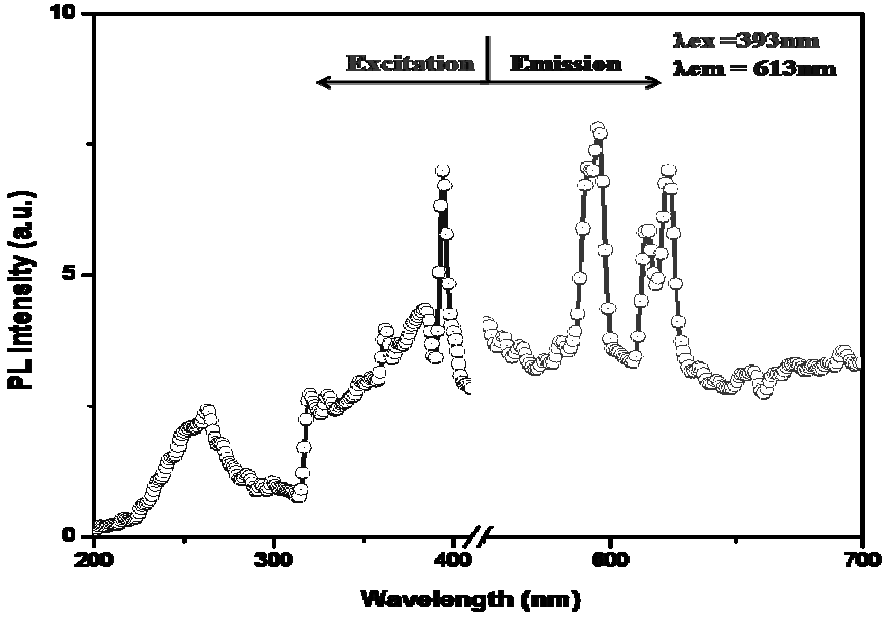

Figure-4
Excitation and emission spectra of $NaCaPO_4$:Eu phosphor under UV excitation

Conclusion

Polycrystalline sample of $NaCaPO_4$:Eu phosphor was successfully developed by using SSD method. The XRD pattern of prepared phosphor was well match with ICDD files with card No. 00-029-1193 and phosphor shows excellent luminescence (TL/OSL) properties. The TL glow curve of prepared phosphor was observed in temperature range 50-500°C. The peak shape method was utilized to calculate the kinetic parameters, i.e., activation energy and frequency factor from the TL glow curve. The CW-OSL response of prepared phosphor was show fast decay curve and fitted with 3rd exponentially decay. The photoluminescence spectra of prepared phosphor were show emission in red-orange regions under Near-UV excitation.

Acknowledgement

One of the authors CBP is thankful to Head RPAD- BARC Mumbai-400085, India for providing the necessary facilities for the analysis of OSL and TL results.

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