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Physical basis of persistent luminescence in $Sr_4Al_{14}O_{25}$: Eu^{2+}, Nb^{3+}

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Abstract

The physical basis of persistent luminescence in $Sr_4Al_{14}O_{25}$: Eu^{2+}, Nb^{3+} has been provided by estimating the lifetimes (τs) of the trapped charges. The analysis shows that the charge created by the optical excitation to a great extent i.e., more than 90% are trapped in metastable state having τ ≈ min to hr that form the physical basis of persistent luminescent in $Sr_4Al_{14}O_{25}$: Eu^{2+}, Nb^{3+}.

Keywords: Luminescence, Thermoluminescence, Lifetime, trapping parameters.

1 INTRODUCTION

The lifetime (τ) of the charge at room temperature (RT) is the heart of persistent luminescence, which can last for minutes to hours and is governed by the simple equation

$$\tau = s^{-1} exp\left(\frac{E}{kT}\right) \qquad \dots 1$$

where τ is the lifetime of the charge in the trap, *E* the trap-depth, *s* the frequency factor, *T* is the storage temperature (≈300) and *k* is Boltzmann constant. However for non first order case (b≠1), Singh and Gartia [1] have shown that the relevant equation for lifetime is

$$\tau = \frac{exp\left(\frac{E}{kT}\right)}{s(2-b)} \qquad \dots 2$$

This has profound influence in the value of τ for non-first order TL since it increases by order of magnitude depending upon the value of b.

Therefore the physical basis of any persistent luminescent material essentially is based on the values of E, s and b. Keeping this in mind, in the present work the complex glow curve of $Sr_4Al_{14}O_{25}$:Eu^{2+},Nb^{3+} has been analyzed by Computerized Glow Curve Deconvolution (CGCD) and the lifetime of charge in various traps have been estimated; a formidable task already done and documented in literature [2]. It is to be noted that CGCD is the accepted technique for analysis of TL curves [3].

2 EXPERIMENTAL DETAILS

The persistent luminescence material used in the experiment is of commercial grade, obtained from Jash Marketing, Hyderabad, India. It is identified as $Sr_4Al_{14}O_{25}$: Eu^{2+}, Nb^{3+}. This is based on XRD and EDAX analysis. Its emission occurs at 500 nm. The excitation source used is an ordinary tube light. The afterglow decays and TL measurements are carried out with the help of Nucleonix TL Reader Type TL1009 (Nucleonix Systems Private Limited, Hyderabad). The heating rate (β) is set to 1°C s^{-1} to minimize thermal lag.

3 RESULTS AND DISCUSSION

TL curves of $Sr_4Al_{14}O_{25}$:Eu^{2+},Nb^{3+} excited by tubelight for 5 minutes having undergone different extents of elapsed time at RT are shown in Fig.1. The results show some interesting features. These are:

(i) The TL curves are complex with major signal occurring at region ~97-131 °C

(ii) The materials do not have any TL peak beyond 215°C. In other words, there is total absence of dosimetric peak.

(iii) There is intense afterglow just after the excitation.

A visual profile of persistent luminescence of the material is shown in Fig. 2. In order to evaluate the lifetime of the charge in the major signals that gives rise to persistence luminescence, a relative simply TL curve (i.e. 1 hour elapsed time) is deconvulated using the general order kinetics equation of Chen [4] using the software developed at Manipur University [5]. The CGCD program is user-friendly and capable of deconvoluting complex glow curves of NaCl [6], quartz [5], ice [7] and alkali halides [8]. In all these works, it has been possible to give conclusion with TL peaks where the value of frequency factor always remain in the physically realistic range of $10^8 \leq s \leq 10^{14}$ s^{-1}, a situation often not adhered in many CGCD studies [9-10]. The best fit curves are shown in Fig. 3. The relevant parameters are presented in Table 1. The goodness of fit can be judged from the value of Figure of merit (FOM). The low value of FOM (1.5%) refers the fit is good [11]. But this is only quantitative measure of deviations of the fit from the experimental curve. For qualitative analysis, standard statistical tests were also performed as mentioned in our recent paper [12]. The results are provided in the inset of Fig. 3 and the statistic, e.g., W = 0.96677 shows the fit is acceptable.

The deconvolution shows that there are as many as three trapping levels that contribute to the phenomenon of persistent luminescence of the time from ≈ 20 mins to ≈ 20 hours. As an approximate estimation of efficiency of storage of optical energy in the system relevant to persistent luminescence the ratio of relevant and irrelevant TL signals is estimated. It shows that more than 90% of stored optical energy is utilized for persistent luminescence. In short, TL data supports the practical aspect of persistent luminescence in this commercial material.

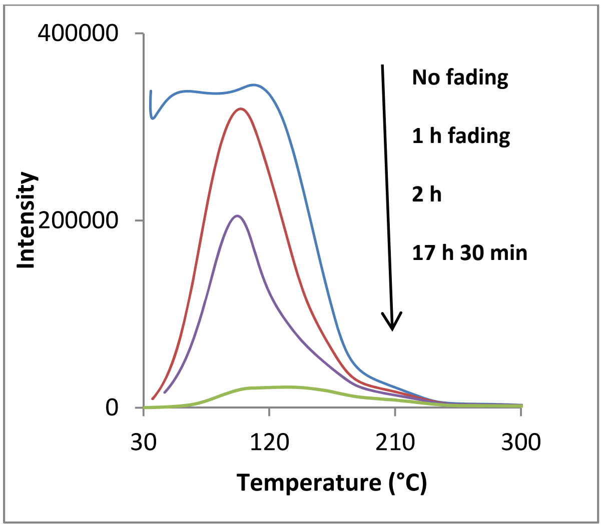

Fig.1: TL curves of the $Sr_4Al_{14}O_{25}$: Eu^{2+}, Nb^{3+}.Excitation: Tubelight for 5 min; β=1°C/s.

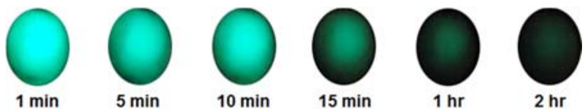

Fig.2: Visual profile of the $Sr_4Al_{14}O_{25}$: Eu^{2+}, Nb^{3+}.

Table 1: Lifetime (τ_{300}) of $Sr_4Al_{14}O_{25}$: Eu^{2+}, Nb^{3+}.

T_m(°C)	I_m(Rel)	E (eV)	b	s(s^{-1})	τ_{300}
74.5	33	0.8	1.20	3.04x10^{10}	18.871 min
97.0	100	0.8	1.63	5.12x10^{09}	4.04 h
124.0	55	0.8	1.50	8.13x10^{08}	18.81 h
160.0	16	1.0	1.40	2.63x10^{10}	46.27 dys
205.0	6	1.0	1.50	1.71x10^{09}	2.34 yrs

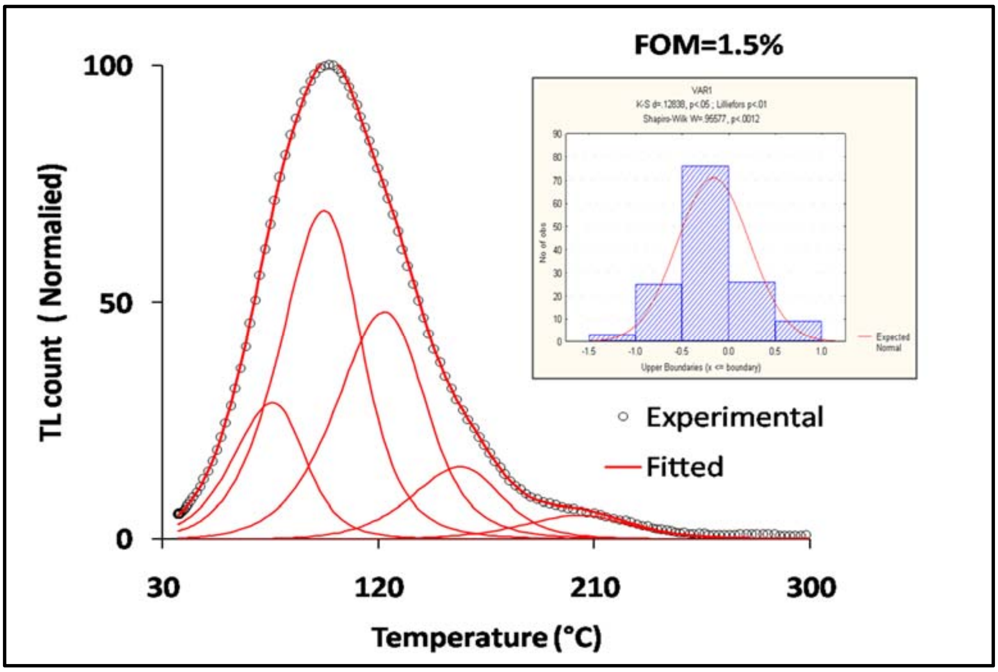

Fig.4: Deconvolution of TL curve of the system excited for 5 min and after 1 hour elapsed time

4 CONCLUSIONS

The analysis shows that out of the charges created by optical excitation, more than 90% are trapped in trapping levels having lifetime (τ) ≈ minutes to hours. Thus, the physical basis of persistent luminescence in $Sr_4Al_{14}O_{25}$:Eu^{2+}, Nb^{3+} has been established.

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