



## Non-exponential time dependence of afterglow in persistent luminescent materials

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### Abstract

*Developers of new persistent luminescent materials have often fitted time dependence decay of luminescence as sum of multiple exponentials varying from two to as large as five components. However time dependence decay of luminescence for a wide variety of materials follow power law of the form  $I(t) \propto t^{-n}$ , where the exponent has values  $0.5 < n \leq 2.0$ . This paper shows that for  $\text{Ca}_x\text{Sr}_{1-x}\text{S}:\text{Eu}^{2+}, \text{RE}^{3+}$  for a wide range of dose of excitation, the exponential value is  $n \approx 1.11 \pm 0.08$ . Therefore fitting of long-period afterglow of persistent luminescent materials as a sum of multiple exponentials needs scrutiny.*

**Keywords:** Power law decay, Persistent Luminescence, Thermoluminescence.

### 1 INTRODUCTION

Afterglow decay is one of the earliest observed, measured and analyzed phenomena associated with luminescent materials that have a long history of its own spread over about four centuries. One of the early well documented and analyzed decay data is that of the luminescent KBr and LiF reported by Morrish and Dekker [1], who demonstrated the fact that decay curves plotted on log-log scale are linear for KBr at 21°C and for LiF at 21°C and 0°C with an average slope of 1.2. In a major intensive work on time dependence of luminescent in solids, Jonschers and Polignac [2] have reviewed experimental data in solids. A summary of materials relevant to the present work is presented in Table 1.

This paper shows that for  $\text{Ca}_x\text{Sr}_{1-x}\text{S}:\text{Eu}^{2+}, \text{RE}^{3+}$  for a wide range of dose of excitation, the exponential value  $n \approx 1.11 \pm 0.08$  that demonstrates power-law decay.

### 2 EXPERIMENTAL DETAILS

The persistent luminescent material used in the experiment is of commercial grade obtained from Jash Marketing, Hyderabad, India [3]. It is identified as  $\text{Ca}_x\text{Sr}_{1-x}\text{S}:\text{Eu}^{2+}, \text{RE}^{3+}$ . ( $\text{RE}^{3+}$  refers to trace levels of unidentified rare earth ions). This is based on XRD and EDAX analysis. Its emission occurs at 647 nm. The excitation source used is an ordinary white LED. The duration of excitation is controlled with the help of EXPEYE Junior [4], an instrument developed by IUAC, New Delhi. The functioning of lighting LED is controlled by python program written by our group. The afterglow decays and TL measurement are carried out with the help of Nucleonix TL Reader Type-TL 1009 (Nucleonix Systems Private Limited, Hyderabad). The heating rate used is 1°C s<sup>-1</sup>.

### 3 RESULTS AND DISCUSSION

The afterglow decay data acquired over a time span of 2s-1000s in all cases are typical ones observed in

persistent luminescent materials. The results are plotted on the log-log scale (Fig.1). The exponents of the  $I \propto t^{-n}$  plot are presented in Table 2. The results show that the exponent of the power law is  $1.11 \pm 0.08$ . This is in agreement with the values obtained in the case of ZnS based phosphors activated with different activators and co activators (Table 1).

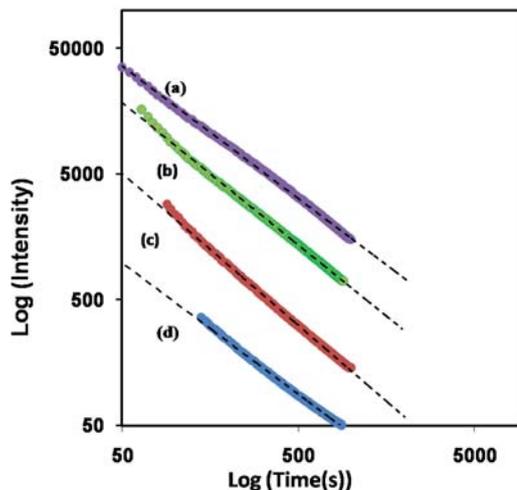
**Table 1: Exponent of the power law in materials as reported in the literature**

Material	Mode and duration of excitation	Temperature (K)	Exponent of the power law
KCl:AgCl KCl:TlCr	X-rays 1-5s	77	1.0
CdS	Optical	1.6	~1
CdS	Optical 2.3 $\mu$ s	4.2-75	1 $\frac{1}{2}$ 2
ZnS:Cu,Cl	Electron beam 0.25-100 $\mu$ s	300	1 1.2
ZnS:AgCl	Electron beam 0.25-100 $\mu$ s	300	1.1
ZnS:Cu,Al	Electron beam 5 $\mu$ s	-	1.1-1.4
ZnS:Ag	Optical 100 $\mu$ s	300	1.2 2
SrS:Ce,Sm	UV, forced by IR	300	2

[\* prepared from the data compiled in Jonscher and Polignag [2]]

Persistent luminescent materials of all kinds exhibit intense afterglow that can be easily acquired over a long time period ~ minutes to hours. This has led to the accumulation of huge data, which unfortunately is interpreted as sum of multiple exponential decay. A typical one is the case of Sakai et al. [5], where they have fitted their data to five exponentials. This work has been cited by many subsequent workers, who have fitted their data to two [6,7] or three [8–10] exponentials ignoring the fact that the classic paper of Matsuzawa et al. [11] has clearly shown that the log I– log t plots for ZnS:Cu,Co, SrAl<sub>2</sub>O<sub>4</sub>:Eu<sup>2+</sup>, SrAl<sub>2</sub>O<sub>4</sub>:Eu<sup>2+</sup>Dy<sup>3+</sup>, SrAl<sub>2</sub>O<sub>4</sub>:Eu<sup>2+</sup>,Nd<sup>3+</sup> are linear.

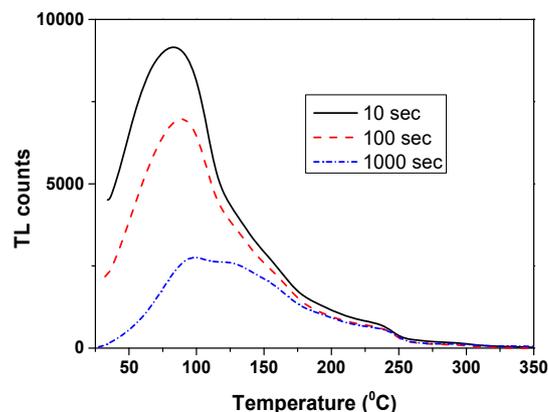
In order to substantiate the physical basis of power law decay one needs to know that the exponent of the power law essentially reflects the ratio of two fundamental trapping parameters namely the



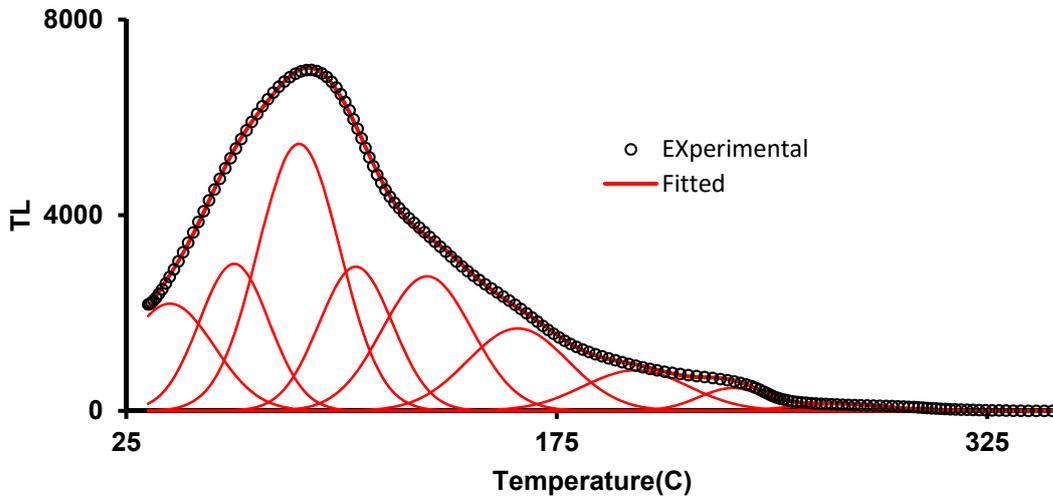
**Fig. 1: Luminescence decay of red emitting ( $\lambda=647$ nm) commercial persistent phosphor  $\text{Ca}_x\text{Sr}_{1-x}\text{S}:\text{Eu}^{2+},\text{Re}^{3+}$  at different doses of excitation; (a) 300s, (b) 30s, (c) 3s and (d) 0.3s**

**Table 2: Slopes of the log I-log t plots**

Time of Irradiation(s)	Temperature(C) RT	slope	R <sup>2</sup>
0.3	32.6	1.04	0.998
3	32.6	1.20	0.999
30	29.6	1.13	0.999
300	29.8	1.05	0.999



**Fig. 2: TL curves of the  $\text{Ca}_x\text{Sr}_{1-x}\text{S}:\text{Eu}^{2+},\text{Re}^{3+}$  at different extent of elapsed time**



**Fig.3: Deconvolution of TL curve of the system excited for 100s by LED which estimated ~9 peaks**

recombination probability ( $A_m$ ) and retrapping probability ( $A_n$ ). The tabular values of the exponent of the power-law versus ratio  $A_m/A_n$  is given in the text of Chen and Kirsh [12]. As per that data for  $\text{Ca}_x\text{Sr}_{1-x}\text{S:Eu}^{2+}, \text{Re}^{3+}$ , the ratio of  $A_m/A_n \approx 35$ . This shows that in the time span  $t_{\text{elapsed}}=10\text{s}, 100\text{s}$  and  $1000\text{s}$  (see Fig. 2) retrapping is significant. In other words, the associated TL peaks that arise due to the thermal activation of charge from traps relevant to persistent luminescence are non first order. This fact can be proved by analysis of the complex TL curve (Fig. 3). An attempt to perform Computerized Glow Curve Deconvolution (CGCD) with reasonably good precision was pretty difficult. However deconvolution of the complex signal by PeakFit software [13] shows the presence of as many as nine Gaussian signals. Therefore, fitting of decay data to sum of simple exponential is of doubtful physical significance.

#### 4 CONCLUSIONS

Time dependence of afterglow in persistent luminescent material to be more specific; sulphide based systems follow power law of the form  $I \propto t^{-n}$  with  $1.0 \leq n \leq 2.0$ .

#### 5 ACKNOWLEDGEMENT

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