Retrapping probability of charge in traps: The parameter and its implication in luminescence

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ABSTRACT

The phenomenon of luminescence manifested by phosphors has many practical applications right from illumination, display to scintillators. However of late it has a totally new application in form of persistent luminescence wherein a phosphor emits enough photons to be visible for the whole night. These materials are known as Glow-in-the-Dark pigment. Invented in Japan, today it is a material that is used to illuminate the roads in some parts of the world. The heart of the phenomenon is the retrapping probability ($A_n$) of charge in traps, one of the intrinsic parameters that can be estimated by measuring the long period afterglow of phosphors. The parameter $A_n$ and its sister parameter recombination probability ($A_m$) and their ratio have tremendous potentialities in designing Glow-in-the-Dark phosphors. This communication will evaluate the ratio $A_m/A_n$ of some commercial phosphors to show the possible limit of optimization in development of these phosphors.

Keywords: Power law decay, Persistent Luminescence.

1 Introduction

Delayed luminescence (phosphorescence) is observed in many solids where there is a time lag between the absorptions of the exciting energy and the resulting luminescence. Becquerel [1] was one of the earliest pioneers who studied phosphorescence critically. The Becquerel type of decay is

$$I = I_0 / (t + t_0)^p$$

Where $I(t)$= Intensity at time $t$
$I_0$=Intensity at $t=0$
$t$= time
$t_0$= Initial time

Where $P$ depends upon the ratio of recombination to retrapping probability ($\gamma=A_m/A_n$).

In such situation a plot of log $I$~ log $t$ gives a straight line when $t>>t_0$. This has been serious implications in terms of providing physical significance to persistent luminescent materials where the materials exhibit enough light for visibility for unusually long time ($\approx$ 20 hours or more). The power $P$ has been evaluated by many workers where it has been reported to be in the range (in organic solid) $0.5 \leq P \leq 2.0$ [2].

Adirovitch [3] provided a meaningful co-relation between $P$ and $\gamma=A_m/A_n$, a graphical plot of which is presented in Fig.1 for ready reference and use in development of persistent luminescent materials.
In this paper we plot the log I ~ log t of some commercial glow- in-the-Dark Phosphors and discuss critically the use of Fig.1 in characterizing as well as developing new novel persistent luminescent materials. We would like to point out that while P seems to be a number A_m and A_n by themselves are intrinsic parameters that relate to the property of recombination centre and the trap that have critical role in luminescence including thermoluminescence, a technique non-exponential time dependence of afterglow in persistent luminescent materials are known for its many practical applications [4–7].

![Fig.1](image)

Plot between A_m/A_n and P. Shaded portion shows the range of A_m/A_n corresponding P.

2 Experimental Details

The persistent luminescent material used in the experiment is of commercial grade obtained from Jash Marketing, Hyderabad, India [8]. It is identified as Ca_xSr_{1-x}S:Eu. 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 [9], an instrument developed by IUAC, New Delhi. The functioning of lighting LED is controlled by python program written by our group. The afterglow decays measurements are carried out with the help of Nucleonix TL Reader Type-TL 1009 (Nucleonix Systems Private Limited, Hyderabad).

3 Results and Discussions

It is quite common in many papers on persistent luminescence where the decay data are interpreted as sum of multiple exponential components [10–15]. We believe these workers need to check the possibility of fitting their data to Becquerel type of decay and evaluate the index P.
Incidentally, practically in all such papers one finds thermoluminescence (TL) data that also can be used to check the possibility of testing the presence or absence of the role of $A_m/A_n$.

![Graphs of luminescence decay](image)

**Fig.2** Luminescence decay of a commercial available persistent luminescent materials: (a) Zinc red glow in the Dark Powder; (b) Regular green glow paint; (c) Pure blue glow paint; (d) Zinc orange glow paint.

**Table 1** Slopes of log $I$–log $t$ plot corresponding Fig. 2.

| Glow in dark materials | Slope | $R^2$ |
|------------------------|-------|-------|
| (a) Zinc red glow in the Dark Powder | 1.08 | 0.996 |
| (b) Regular green glow paint | 1.12 | 0.988 |
| (c) Pure blue glow paint | 0.98 | 0.988 |
| (d) Zinc orange glow paint | 1.07 | 0.986 |
| (e) High Purple Glow paint | 0.97 | 0.989 |

Some log $I$–log $t$ plots for data available for a commercial glow- in- the- Dark phosphors [16] are shown in Fig.2. In these the value of $P$ is $0.98 \leq P \leq 1.12$ (Table 1).

Similar plots for $Ca_{x}Sr_{1-x}S$:Eu as measured in our laboratory are shown in Fig. 3. The parameters are presented in Table 2.
Fig. 3: Luminescence decay of red emitting ($\lambda=647\text{nm}$) commercial persistent phosphor $\text{Ca}_x\text{Sr}_{1-x}\text{S}:\text{Eu}$, at different doses of excitation; (a) 300s, (b) 30s, (c) 3s and (d) 0.3s

Table 2 Slope of log I~ log t plot of $\text{Ca}_x\text{Sr}_{1-x}\text{S}:\text{Eu}$.

| Time of Irradiation(s) | Temperature(C) | slope | $R^2$ |
|------------------------|----------------|-------|-------|
|                        | RT             |       |       |
| 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 |

4 Conclusions

Estimation of the ratio of $A_m/A_n$ done by us for commercial glow-in-the-dark phosphors lie in the range $10 \leq A_m/A_n \leq 250$. Since $A_m/A_n$ can be as low as 1 physically this investigation shows that there is scope of improving by appropriate combination of recombination and trapping centers.
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