Kinetic Characterization of Luminescent Fluoride Phosphate Glass

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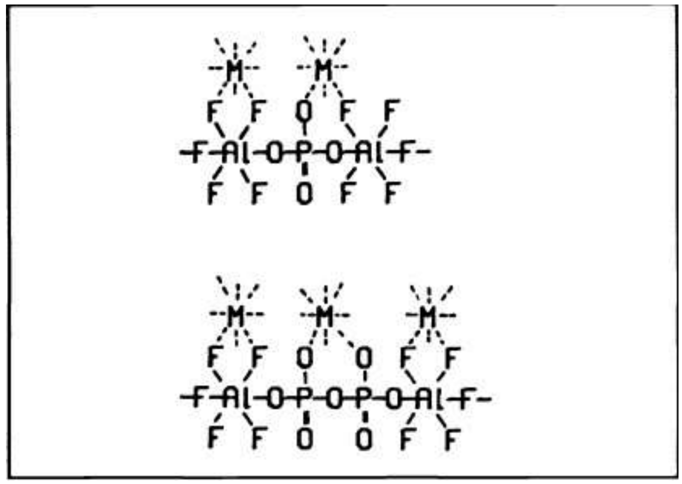
Abstract: **- The potential of fluoride phosphate glass to sense ionizing radiation can be utilized in various forms for the purpose of radiation detection. The luminescence properties have been studied using techniques such as thermoluminescence (TL) and optically stimulated luminescence (OSL) to further understand the ability of this material. In present paper the thermoluminescence study of fluoride phosphate glass has been reconsidered to evaluate order of kinetics. Along with activation energy and escape frequency factor order of kinetics is an important parameter to characterize the luminescent material under consideration. It has been found that the first two of the above said parameters are characteristic properties of the material and last one depends on the experimental conditions.**

Keywords: **Luminescence, Thermoluminescence, Activation Energy, Frequency Factor, Order of Kinetics.**

I. INTRODUCTION

For radiation dosimetry, Fluoride phosphate glass has been studied by several researchers and scientists with the help of optically stimulated luminescence technique [1, 2]. In these work material was fabricated into optical fibers to create a fiber based radiation dosimeter, where the optical fiber itself acts as the radiation sensing component. To further understand the potential of this material, the luminescence properties have been studied using techniques such as thermoluminescence (TL). The determination of TL decay parameters (namely activation energy also known as trap depth E_a, frequency factor s and order of kinetics) provides an insight into the suitability of the material for various dosimetry applications. Therefore, for detailed study of behavior of this material with respect to their luminescence properties additional investigations were performed, focusing on the properties above said parameters, and mainly how the order of kinetics are affected. This parameter along with TL decay parameters allow us to establish the capabilities of the material in a practical dosimetry application, indicating the temperatures and time-scales in which a device made from this material would be most effective. A detailed study on the application of TL to dosimetry has been done by Aitken [3] and McKeever [4].

Here we reconsider the already reported experimental and analytical data of Kalnins et. al. [5] to evaluate order of kinetics involved in TL spectrum of Fluoride phosphate glass, in accordance new method of analysis.



II. MATERIAL AND METHOD

The starting material is commercially available Schott N-FK51A fluoride phosphate glass. Kalnins et. al. [5] have performed the TL measurements on a Risø TL/OSL DA-20 Reader, which incorporates a 90Sr/90Y beta source, gas-cooled heating plate, optical stimulation using an LED module at 470 nm and an optically filtered EMI 9235QB photomultiplier tube for luminescence detection.

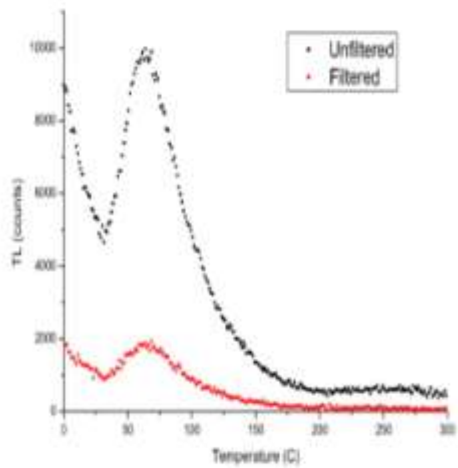


Fig.1 TL spectra of fluoride phosphate glass [5].

TL emission spectra measurements were performed on a 3D TL spectrometer [6]. Kalnins et. al. [5] have ground samples of fluoride phosphate glass into grains with diameters from 150 to 250 µm. Several samples were used, where the mass of material was approximately 12-14 mg per sample. All experiments were performed following a dose of 1 Gy delivered at ambient temperature. TL measurements were performed at a heating rate of 1 ºK/s under a nitrogen atmosphere. The experiment was also run on an un-irradiated sample to provide a background measurement to subtract the incandescence detected at higher temperatures.

III. RESULTS AND DISCUSSION

The TL spectra as reported by Kalnins et. al. [5] is shown in Fig.1. They use initial rise method [4] to determine trap depth (also known as activation energy E_a) and frequency factor (s). The activation energy and frequency factors as reported by Kalnins et. al. [5] are shown in Table 1. There are so many theories are reported in literature for the appearance of TL glow curve. In all theories condition for peak temperature is same and is given by

$$T_m^2 = \frac{bE_a\tau_m}{k}$$

where T_m is peak temperature, b is linear heating rate, E_a is activation energy, τ_m is relaxation time at peak temperature and k the Boltzmann's Constant. The relaxation time is related with frequency factor by Arrhenius relation [7]

$$\tau_m = \tau_0 \exp\left(\frac{E_a}{kT_m}\right) \qquad and\ \ \tau_0 = \frac{1}{s}$$

Table.1 Reported TL decay parameters [5] and evaluated order of kinetics.

b (K/s)	E_a (eV)	s (s^{-1})	T_m (K)	T_m^2 (K^2)	$\frac{bE_a exp(\frac{E_a}{kT_m})}{ks}$ (K^2)	ℓ
1	0.5	1.90E+06	333	110889	112820.3611	0.982881094
1	0.63	5.10E+07	353	124609	141666.4853	0.879594068
1	0.69	1.40E+08	373	139129	120403.634	1.155521602
1	0.76	2.90E+08	393	154449	169657.2268	0.910359098
1	0.89	5.10E+09	413	170569	147035.6735	1.160051816

So, the reported values of trapping parameters and peak temperature must satisfy the above condition for peak temperature. But the values shown in fifth and sixth columns of Table 1 are not same, means peak temperature relation is not satisfied. In order to remove this shortcoming here we apply a new method of analysis suggested by Prakash [8] and Prasad et.al.[9]. As per this new theory, the TL intensity is given by

$$I = (1-x)n_0 s \exp\left[\left(-\frac{E_a}{kT}\right) - \frac{s\,(1-x)}{b}\int_{T_0}^{T} \exp\left(-\frac{E_a}{kT'}\right) dT'\right]$$

and peak temperature relation is

$$T_m^2 = \frac{\ell\, b\, E_a \tau_m}{k}$$

where I is TL intensity at temperature T, $\boldsymbol{x}$ is extent of retrapping, n_0 is the initial concentration of trapped carriers per unit volume, s is frequency factor, T_o the temperature at which TL glow curve starts to appear and T' is any arbitrary temperature in the range T_o to T. Extent of retrapping $\boldsymbol{x}$ decides the order of kinetics ℓ involved in glow curve as per the relation

$$\ell = \frac{1}{1-x}$$

As per this new method of analysis order of kinetics parameter for different glow curves are calculated and shown in seventh column of Table.1.

The experimentally reported measurements shown here explain the behavior which are in agreement with new theory. It is interesting to compare fluoride phosphate glass with other dosimeter materials. The extensively-used Al_2O_3:C has a high sensitivity for TL compared with most other luminescent materials. In comparison, fluoride phosphate glass has particularly efficient bleaching characteristics: a short pulse of stimulation is sufficient to revert the material back to its pre-irradiated state. From these results, we can establish this glass is suitable for a certain range of applications, and unsuitable for others. Due to its shallow traps and short lifetime at ambient temperature, this material is suitable for applications where interrogation of the material occurs on a rapid duty cycle, or where the material does not need to sit in a passive environment for time periods longer than several minutes. This also makes the material ideal for applications where fast and efficient bleaching is required, and/or where repeatability from one measurement to the next is necessary. Applications for which this material would not be suitable include environments where there is a significant delay between radiation exposure and interrogation.

IV. CONCLUSION

Fluoride phosphate glass, N-FK51A purchased from Schott Glass Company, was studied by Kalnins et. al. for its luminescence characteristics, and its response to various TL measurements. From the reported value of characteristic parameters i.e., trap depth and fequency factor, order of kinetics parameter is evaluated. It is observed order of kinetics depends on experimental conditions. This decides by the amount of retrapping in TL process. The suitability of material for dosimetry may be more ascertained by knowing order of kinetics.

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