THEORETICAL STUDY OF LASER STIMULATED THERMO-LUMINESCENCE USING CO_2 LASER

Manoj Kumar Prajapati[1], Upendra Singh[2]
[1]Bhau Rao Devras Government P.G. College, Duddhi, Sonbhadra, U.P.
[2]Smt. Indira Gandhi Govt. P.G. College, Lalganj, Mirzapur, U.P.

ABSTRACT

In the phenomenon of thermoluminescence the creation of lattice defects by γ-irradiation plays important role. We have used CO_2 laser of wavelength of 10.6 μm for laser spot heating. We obtained the thermoluminescence glow curve for different types of solids by laser spot heating. The experimental glow curve match with theory. The conventional thermoluminescence measurements require small samples to be removed from a ceramic and placed in thermoluminescence machine. Laser – induced theroluminescence glow curve from different are solids are presented.

Keywords: Laser, Thermoluminescence, Glow-curve, Ceramaic, γ- irradiation.

I . INTRODUCTION

Luminescence is defined as non-equilibrium radiation that is in excess over and above the thermal radiation background and arise in the presence of intermediate process of energy transformation between absorption and emission. Thermoluminescence is a type of delayed phosphorescence, where the photon energy is released when a crystalline substance is heated from low temperature to a higher value. The substance is irradiated with ionising radiations such as α, β, γ as well as X-rays, comic rays, electron beams and other fast particles. The total light is proportational to the overall radiation dose irrespective of the dose rate. A thermoluminescence "glow curve" represents all the measured light quanta emitted by a substance when its temperature is increased. The first application of this phenomenon for domestic purpose was from Daniel et al.[1].Since then much research has been carried out for a better understanding and improvement of the material characteristics as well as to develop new TL materials. Sulphate based phosphors are good materials for irradiation dosimetry[2.3]. thermoluminescence has been studied extensively with the first model of thermoluminescence emission having appeared over fifty years ago [4,5]. Recent work on thermoluminescence has been reviewed [6-8].The thermoluminescence emission from quartz particularly its 110^0C peak has also been studied [9-14] as well as thermoluminescence emission from feldspar [15-16].. Porcelain contains quartz and has similar thermoluminescence properties[17]. Thermoluminescence emission from various materials has been reviewed[18]. Laser heated thermoluminescence dosimetry was first demonstrated on thin layers of powered ceramics [19].

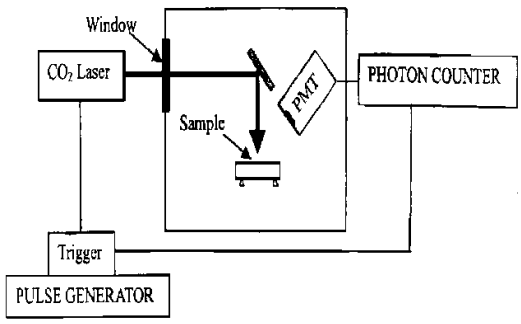

Fig. 1. Schematic of laboratory apparatus for non-destructive laser-induced thermoluminescence measurements.

. Theory

The rate of depopulation of the defect is given by (Townsend and Kelly (1973)

$$\frac{dn}{dt} = -\mathrm{n}(N_c\, Sv)\exp(-\frac{E}{KT}) + \mathrm{A}n_c(\mathrm{N\text{-}n}) \quad \ldots\ldots (1)$$

As a first simplification it is assumed that retrapping is negligible. This is a valid assumption if the concentration of traps is small compared with the concentration of recombination centers. Further, if the recombination lifetime τ is very short the electron concentration in the conduction band n_c will remain constant. Loss take place due to the recombination centers or trapping levels, so in general

$$\frac{dn_c}{dt} = -\frac{n_c}{\tau} + \frac{dn}{dt} \qquad \text{------(2)}$$

When τ is short, dnc/dt is negligible compared with other terms. We may also relate the time and temperature by $T=T_0 + \beta t$, if we raise the temperature at a constant rate $\beta=(dT/dt)$ from the initial temperature T_0. So equation ( ) becomes

$$\frac{n_c}{\tau} = \beta \frac{dn}{dT} \qquad \text{------(3)}$$

It is movement of electrons from the conduction band to the deeper levels which provides the luminescence so n_c/τ is proportional to the light intensity I. In the case of no retrapping (A=0) from equation ( ), we get

$$\frac{dn}{dt} = -n(N_c\, Sv)\exp(-\frac{E}{kT}) \qquad \text{.....(4)}$$

Or $$\frac{dn}{dt} = -n\, s \exp(-\frac{E}{kT}) \qquad \text{.....(5)}$$

Where $s=N_c$ S v is called the "frequency factor" and has unit of seconds^{-1}

Integration of equation (5) gives

$$\int \frac{dn}{n} = -\int_{T_0}^{T} \frac{s}{\beta} \exp\left(-\frac{E}{kT}\right) dT + C$$

or $$\log n = -\int_{T_o}^{T} \frac{s}{\beta}\, exp\left(-\frac{E}{kT}\right) dT + C$$

Where C is yhe integration constant.

At $T=T_0$, $n=n_0$, therefore we have

$C=\log n_0$

Now, the above equation may be written as

$$n = n_0\, exp\left[-\int_{T_0}^{T} \frac{s}{\beta}\, exp\left(-\frac{E}{kT}\right) dT\right] \qquad \text{-----(6)}$$

The light intensity may be given by

$$I = \eta \frac{dn}{dt} = \eta\, s\, n\, exp\left(-\frac{E}{kT}\right) \qquad \text{.....(7)}$$

Or $I =$

$$\eta n_0\, s\, exp\left(-\frac{E}{kT}\right)\, exp\left[-\int_{T_0}^{T} \frac{s}{\beta}\, exp\left(-\frac{E}{kT}\right) dT\right] \qquad \text{.....(8)}$$

Where η is the probability that recombination will occur radiatively.

It can be seen easily from equatin ( ) that the intensity builds up as T increases, reaches a maximum for particular value of T_m and then falls off for any further increased heating.

By setting at $T=T_m$, we obtain

$$\left[\frac{d}{dT}(logI)\right]_{T=T_m} = 0$$

Or $$\frac{d}{dT}\left[\log n_0\, s\eta - \frac{E}{kT} - \int_{T_0}^{T} \frac{s}{\beta}\, exp\left(-\frac{E}{kT}\right) dT\right]_{T=T_0} = 0$$

$$\frac{E}{kT_m^2} - \frac{s}{\beta}\, exp\left(-\frac{E}{kT_m}\right) = 0$$

Or $$\frac{\beta E}{kT_m^2} = s\, exp\left(-\frac{E}{kT}\right) \qquad \text{--(9)}$$

The fact that n_0 does not appears in equation ( ) immediately proves the first order characteristics that T_m does not depend on n_0. Equation ( ) can be written as

$$\beta = \left(\frac{sk}{E}\right) T_m^2\, exp\left(-\frac{E}{kT_m}\right) \qquad \text{--(10)}$$

Changing the heating rate β must change T_m in such a way that the equality still holds. The terms $T_m^2\, exp(-E/kT_m)$ is monotonically increasing with T_m, therefore, increasing β will immediately cause T_m to increase

Using equation (9) we get for the maximum intensity as

$$I_m = \eta s n_0\, exp(-E/kT_m)\, exp\left[-\int_0^{T_m}\left(-\frac{E}{kT_m^2}\right) dT\right]$$

Or $$I_m = \eta s n_0\, exp(-E/kT_m) \qquad \text{.....(11)}$$

Randall and Wilkins obtained the following expression for the trap depth E,

$$E = 25\ K\ T_m \qquad \text{.....(12)}$$

3. Results and Discussion

Experiments with the standard Harshaw LiF (TLD-100) was performed and a lens was placed in front of the laser beam to produce a spot size of 8mm on the target. After exposure to beta radiation, a strong thermoluminescence signal was observed. A sample of

thermoluminescence emission is shown in fig. 2. Two thermoluminescence peaks were observed. No damage was observed after eight pulse of 10 seconds duration at the maximum laser power of 38 W

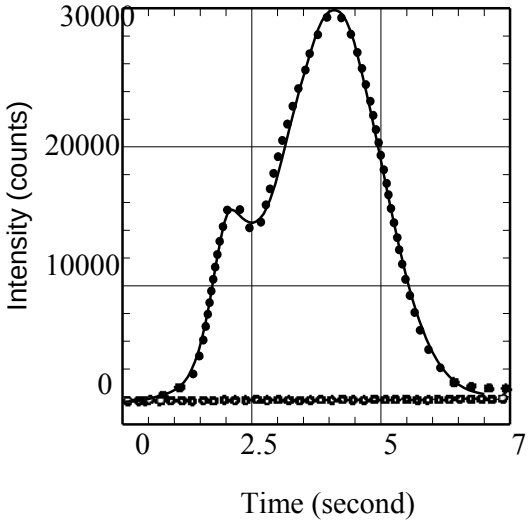

Fig.2. Laser-induced thermoluminescence emission from a LiF (TLD-100) pellet. The circles are experimental results. The solid line from theory.

At smaller spot sizes, it was possible to damage the LiF pellet. With a beam size of about 3mm damage was observed for powers as low as 15W after a few seconds of exposure. A notable feature was that even at powers for which only slight damage to the pellet was apparent to the eye, significant changes to the thermoluminescence curve were observed.

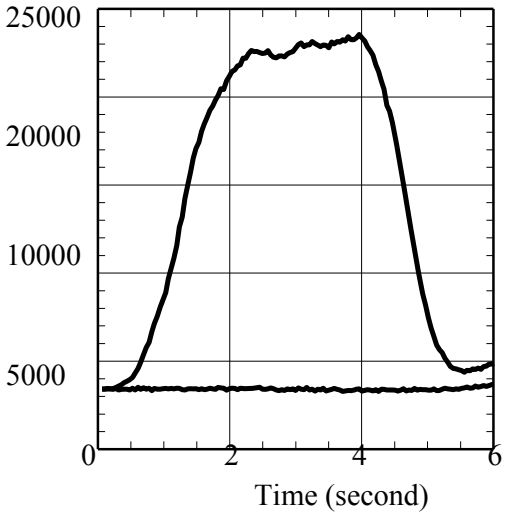

Fig. 3. Laser Induced Thermo-Luminescence emission of LiF (TLD-100) pellet exposed to 11.2W of a 3mm beam.

Fig. 3 shows thermoluminescence emission resulting from exposure to 11.2 W of CO_2 radiation. Compared to fig. 2 strong distortion of the thermoluminescence peak is observed.

We exposed a 0.5mm thick quartz slide to 172 rads and then placed it on the sample holder, because quartz exhibits weaker thermoluminescence than LiF, we exposed this sample to a higher dose of radiation and increased the laser power to obtain more signal. The slide was exposed to 38 W of CO_2 laser radiation for 10 sec. A single peak of thermoluminescence emission was observed..

A quartz slide exposed to CO_2 laser heating shows strong thermoluminescence. The laser power 38W and the beam size was 3mm.

The theoretical curves shown in the plots were derived from a numerical solution of the unsteady three-dimensional heat conduction equation with adiabatic boundary conditions combined with first order thermoluminescence kinetics. This was an extension of the unsteady 2-D numerical calculations that we described previously[20].

IV . CONCLUSION

Laser heating is capable of producing very large temperature and the resulting high intensity indicates a potential for laser- induced thermoluminescence to be not only non-destructive but also more sensitive. Non-destructive thermoluminescence testing has been demonstrared using CO_2 laser heating. The technique permits the absorbed dose to be measured in selected locations on large objects without physically removing any samples. We anticipate the application of this approach to thermoluminescence tests to antiquities.

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