Thermoluminescence of synthetic quartz

Z Mthwesi & M L Chithambo

Department of Physics and Electronics,
Rhodes University.
PO BOX 94 Grahamastown, 6140

mthwesiz@gmail.com

Abstract

Thermoluminescence of synthetic quartz annealed at 1000°C for 10 minutes has been studied. The sample was beta irradiated to 10 Gy and then heated at 1°C/s. The glow curve obtained has three glow peaks; one high intensity component and two weaker-intensity ones. This study was on the main peak found at 76°C. Kinetic analysis was carried out to determine the activation energy, frequency factor and the order of kinetics of this main peak using the initial rise, peak shape and variable heating rate methods. The mean activation energy obtained from these methods was 0.96 ± 0.01 eV. The geometric factor 0.47 ± 0.05 found using the peak shape method indicates first order kinetics. The dose response of the peak position further confirmed this order of kinetics. The rate at which electrons escape the traps was found to be $\sim 10^11$ s^{-1}.

Introduction

Thermoluminescence (TL) is the thermally stimulated emission of light from the insulator or semiconductor, following previous absorption of energy from radiation. TL can be emitted from natural or synthetic quartz when the irradiated material is heated at a controlled rate. TL appears as a series of peaks called a glow curve with each peak associated with an electron trap. We report the kinetic analysis as well as the irradiation induced features of the main TL peak in synthetic quartz.

Experimental Details

Synthetic quartz of grain size 90-500 μm (Sawyer Research Products, Ohio, USA) was used. A few milligrams of sample was placed on stainless steel discs of 1 mm thickness and 10 mm diameter. Luminescence was measured using a RISØTL/OSL-DA-20 Luminescence Reader. An inbuilt ^{90}Sr/^{90}Y beta source was used to irradiate the samples at a dose rate of 0.1028 Gy/s. Luminescence was detected by an EMI9235QB photomultiplier tube through a 7.5 mm thick Hoya U-340 filter (transmission band 280-390 nm). All TL measurements were made in a nitrogen atmosphere to avoid spurious luminescence from air and to improve thermal contact between the sample disc and the heater plate. Samples were annealed at 1000°C for 10 minutes before use in order to remove any residual signal. The quartz is subject to the pre-dose effect and the heating also improved its sensitivity by way of thermal activation.

Method: Kinetic Analysis

Kinetic parameters such as frequency factor s, order of kinetics b and activation energy E, are associated with the TL process and as such need be evaluated. These parameters were evaluated using the following methods:

- The Initial Rise Method (IR)
- The Variable Heating Rates Method (VHR)
- The Peak Shape Method (PS).

Methods	Procedure of evaluating
PS	$E_\alpha = C_\alpha(kT^2{}_m/\alpha) - b_\alpha(2kT_m)$ where $\alpha = \delta, \tau, \omega$ and $\mu = \delta/\omega$
IR	$\ln I = \left(\frac{-E}{kT}\right) + \ln C$ slope of the graph yields E,
VHR	$\ln\left(\frac{T_m^2}{\beta}\right) = \frac{E}{kT_m} + \ln\left(\frac{E}{sk}\right)$ slope and intercept of the graph are used to evaluate both E and s

Table 1: Equations of the methods Kinetic Analysis

Here E is the trap depth (eV), s frequency factor (s-1), Tm peak position (K), I intensity (a.u.), k Boltzmann's constant, β = heating rate (°C/s) and C constant.

Results

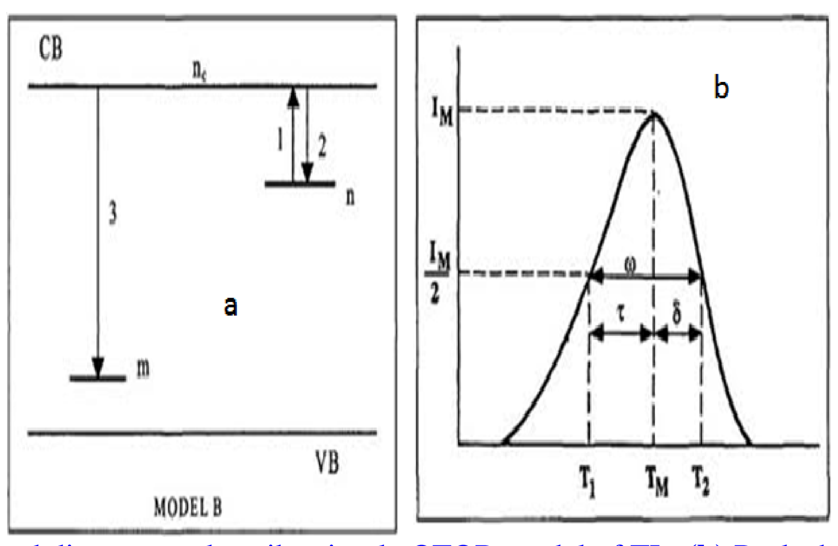

Figure 1: **(a)** Energy band diagram to describe simple OTOR model of TL. **(b)** Peak shape method parameters.

Evaluation of kinetic parameters of the main peak (Figure 2 (a))

Peak-shape method

- The activation energy was find to be E_α = 0.81±0.01 eV, E_δ = 0.83±0.01 eV and E_ω= 0.82±0.01 eV.
- The value of $\mu = \delta/\omega$ = 0.47±0.05, indicates first order kinetics. The means retrapping of electrons is negligible.

Initial rise method

- This method focuses on the low temperature tail of the main TL glow peak. It is assumed that the amount of trapped charge in this temperature range is constant, thus the TL emission can be described by $I(T) \propto \exp(-E/kT)$
- As shown in Figure 2(b), plotting $\ln(I)$ against $1/kT$ yields a straight line with slope E, which in this case is equal to 1.17±0.01 eV.

Variable heating rate method

- Figure 3(a) gives a more accurate value of E = 0.89± 0.01 eV, because it does not need clean peaks. All the data points are included for T_m and β.
- Figure 3 (b) shows the relationship between T_m and β for heating rates between 0.5 to 5 °C/s.

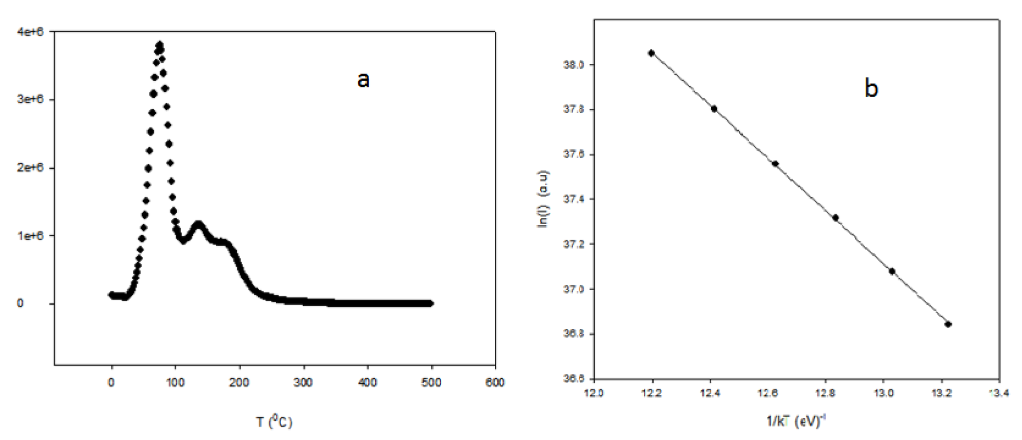

Figure 2: **(a)** A glow curve measured at 1 °C/s following irradiation. **(b)** The graph of $\ln(I)$ against $1/kT$.

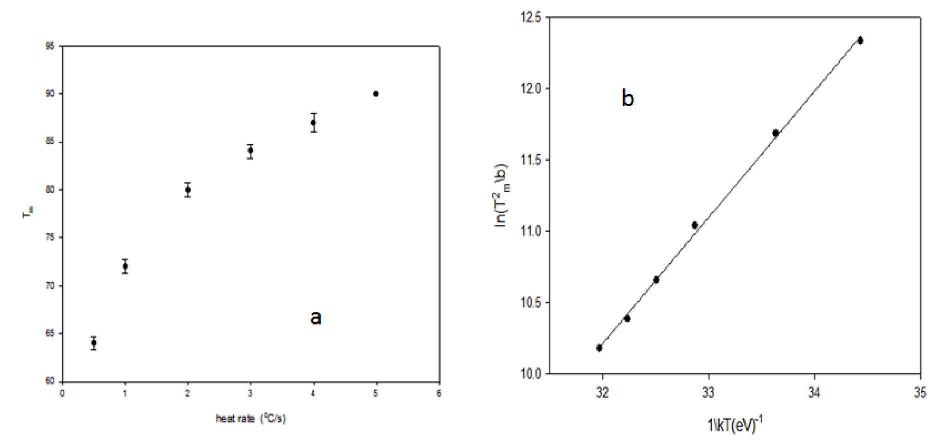

Figure 3: **(a)** Effect of heating rate,β on peak position T_m **(b)** Graph of $\ln T_m^2/\beta$ against $1/kT_m$.

Test for order of kinetics

T$_m$-T$_{stop}$ method

- This method is used to find the number, and position of overlapping peaks associated to the main peak; as well as to determine the order kinetics.
- The sample was irradiated to 10 Gy and then preheated up to 54°C. This temperature corresponds to the position of the low temperature tail of the first glow peak (main peak). The sample was then cooled to room temperature and then heated at the same rate to record the remaining glow curve.
- The maximum temperature was noted after each preheat. T_{stop} was chosen from 54°C to 74°C with 2°C intervals.
- Figure 4(a) shows T_m vs T_{stop}. T_m increases with increasing T_{stop}. The flat zones on Figure 4(a) indicate the positions of a peak.

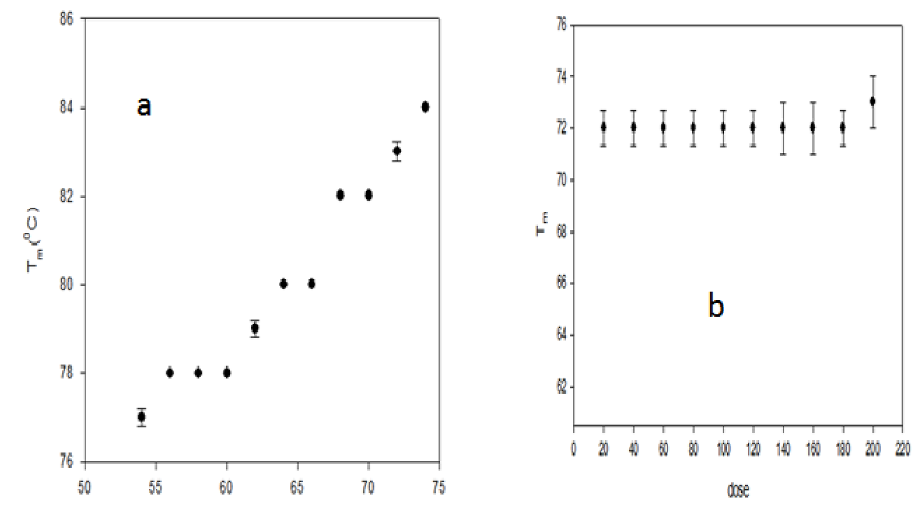

Figure 4: **(a)** The relationship between T_m and T_{stop}. **(b)** The plot of T_m against dose, D [20-200 Gy].

Dose dependence

- The dependence of TL intensity on dose was studied for doses between 20 and 200 Gy.
- The results show that the maximum temperature is independent of irradiation dose.
- The peak position was independent of dose. This behaviour is consistent with first order kinetics.

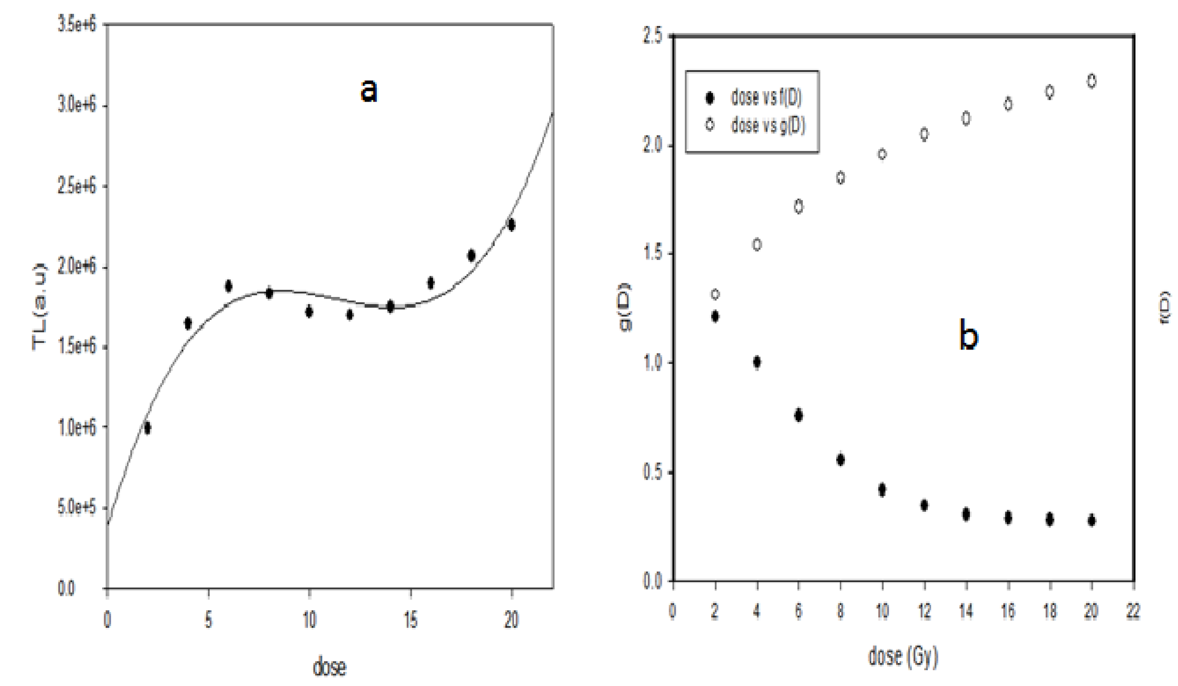

Figure 5: **(a)** TL growth curve for 2-20 Gy. **(b)** A plot of $g(D)$ and $f(D)$ against dose [2-20 Gy].

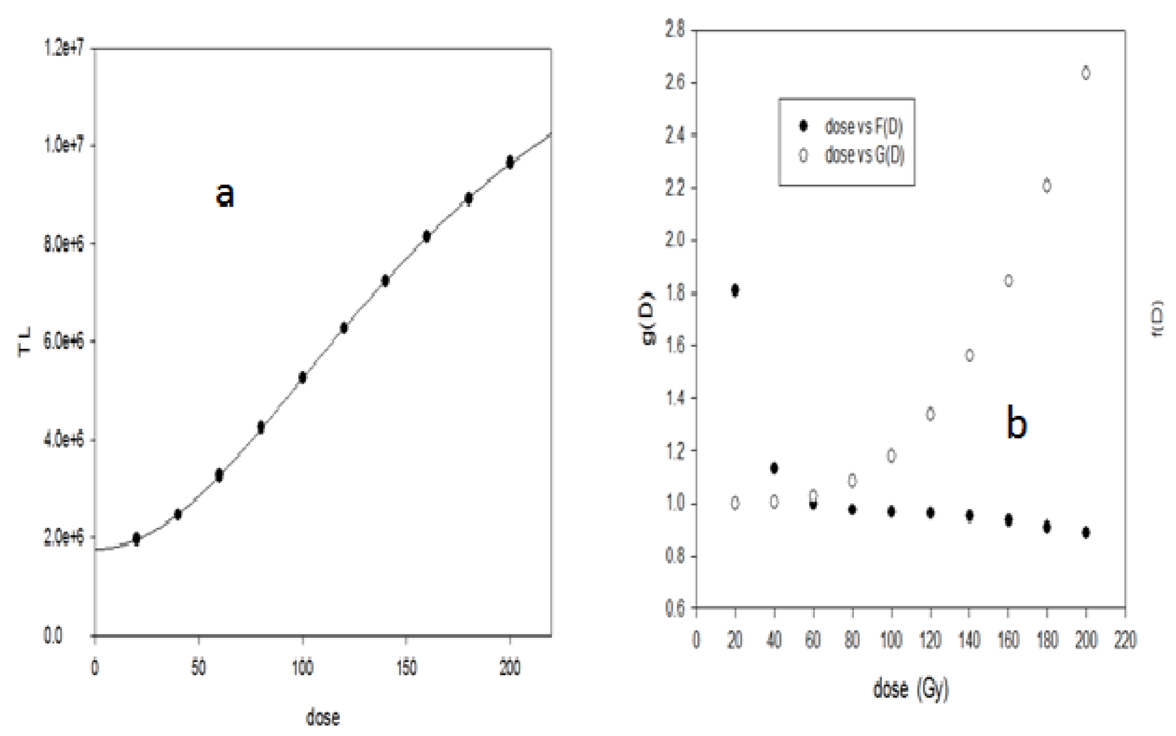

Figure 6: **(a)** TL growth curve for 20-200 Gy. **(b)** A plot of both indices against dose [20-200 Gy].

Conclusion

Thermoluminescence of synthetic quartz annealed at 1000°C for 10 minutes has been studied. Samples were beta irradiated to 10 Gy then heated to 500°C at 1°C/s. The glow curve for this sample has three peaks. Kinetic analysis of the main peak shows that it is of first order and its mean activation energy is about 1 eV. The position of this peak is independent of dose but increases with heating rate.

References

[1] Furetta C., Handbook of Thermoluminescence (2003).

[2] McKeever S.W.S., Thermoluminescence of solids (1985).

[3] Mckeever S.W.S., Moscovitch M., and Townsend P.D., Thermoluminescence dosimetry materials: properties and uses (1995).

[4] Yukihara E.G., and Mckeever S.W.S., Optically stimulated luminescence :fundamentals and applications (2011).

[5] Hayes W., and Stoneham A.M., Defects and defects processes in non-metallic solids (1984).

Acknowledgements

We would like to acknowledge the financial support from National Research Foundation and Rhodes University.