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THERMAL EFFECTS OF HEAVY ION RADIATION DAMAGE IN GLASS TRACK DETECTORS

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The radiation damage after bombardment with high energy particles is believed to be caused by the displacement of atoms from their normal sites. These displaced atoms tend to return to their original positions particularly during annealing. The thermal effects caused by ^{238}U having ion beam energies 15.0 and 5.9 MeV/n were studied in sodalime, phosphate and silicate glass detectors. The annealing kinetics of these radiation damaged tracks is discussed using both isochronal and isothermal processes. A modified formulation developed earlier is employed to calculate the activation energy of annealing.

Key words: radiation damage, heavy ions, glass track detectors, thermal effects.

1 INTRODUCTION

It is believed that fast moving charged particles in passing through solids are mainly responsible for losing their energy due to excitation and ionisation processes[1]. The stability of latent track is best understood by annealing which has been applied to gain an insight into healing, ageing or fading processes[2] and to discuss changes that may have occurred during thermal history for samples found in nature. The annealing behaviour of heavy ion radiation damage in glasses and minerals has been studied by various authors[3–8] to understand the complete theory of track formation.

2 ANNEALING FORMULA

The track retention rate and the track etch rate has been found to be important parameters in determining the annealing kinetics. A number of models have been proposed[9–14] based on these parameters.

The phenomenon of annealing mainly responsible for the healing of radiation damage in solids has been isolated into a single activated process. The isothermal and isochronal annealing data has been used to develop annealing formula within the framework of a single activated process.

Incorporating the errors in Modgil and Virk model[14] a modified formulation has been developed[15] for calculating the activation energy of annealing. The modified annealing formula relating track retention rate with activation energy is

$$1 - r = At\exp(-E_a/kT),$$

where $r = D/D_0$, the track diameter reduction for high cone angle etch pits and l/l_0, the track length reduction for low cone angle etch pits. A is proportionality constant, k the Boltzmann's constant, T the annealing temperature and t is the annealing time.

The activation energy can be calculated from the plot of $\ln(1-r)$ against inverse temperature for a constant time interval t. This relation is used for determining the activation energy of annealing, E_a in sodalime, phosphate and silicate glass detectors irradiated with ^{238}U having ion beam energies of 15.0 and 5.9 MeV/n.

3 EXPERIMENTAL PROCEDURE

Samples of sodalime (microscopic), phosphate (LG-700, LG-750 and LG-760) and silicate (KF_3 and BK_7) glass detectors were exposed vertically to ^{238}U ions of energies 15.0 and 5.9 MeV/n at the GSI heavy ion accelerator, UNILAC at Darmstadt. Phosphate and silicate glass samples are commercially available and obtained from Schott Glass Technologies, USA.

Isothermal and isochronal annealing of sodalime samples was carried out in a muffle furnace at temperatures of 100, 150, 200 and 250°C and for time intervals of 10, 20, 40 and 80 minutes. All these samples for two ion beam energies were etched alongwith the parent unannealed sample under the optimum etching conditions of 2.5% HF at room temperature (30°C) for 35 min.

Isochronal annealing of phosphate and silicate glass detectors was carried out from 400 to 650°C and 500 to 750°C respectively for time intervals of 30 min after each 50°C. The optimum conditions were applied for etching these samples. Phosphate glass samples were etched in 40% HF for 30 min and silicate glass samples were etched in 40% HF for 15 min at room temperature (30°C). These samples were, then, washed thoroughly in running water.

The mean track lengths and diameters were measured using Carl Zeiss microscope with a resolution of 1 μm. The measurements for each set were obtained after applying statistical errors. The track reduction ratios were calculated from the data obtained and used to calculate the activation energy of annealing in these glass detectors.

4 RESULTS AND DISCUSSION

The track reduction ratio, r for all the glass detectors has been used to determine the activation energy of annealing. The annealing formula [Eq. (1)] has been employed in fitting the data points for r. The method of least squares has been used in plotting the graphs in order to best fit the data obtained. The track reduction ratio was found to decrease with increase of temperature (Figure 1).

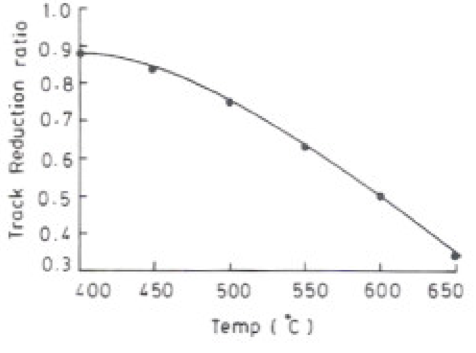

FIGURE 1 The variation of track reduction rate with annealing temperature.

The results for isothermal as well as isochronal annealing in sodalime glass for the two ion beam energies are shown in Figure 2 and Figure 3. The activation energy is calculated from the slopes of the plot of $\ln(1-r)$ against inverse temperature and found to be 0.16 eV in both cases. The next plots (Figure 4–7) show the results for isochronal annealing of phosphate (LG-750) and silicate (KF_3) glass detectors for both ion beam energies. The activation energies are obtained

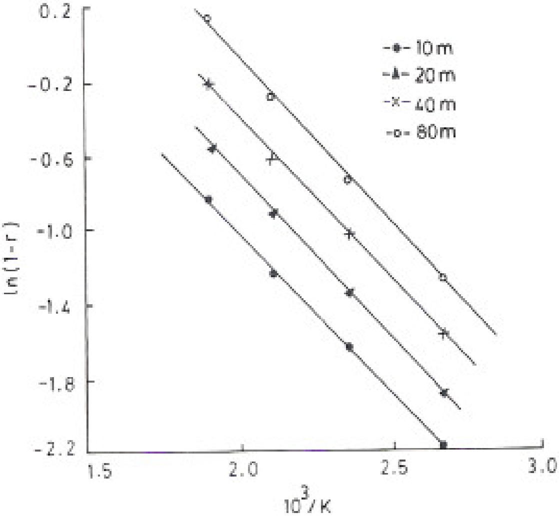

FIGURE 2 The plot of $\ln(1-r)$ against inverse temperature for sodalime glass irradiated with ^{238}U (15.0 MeV/n).

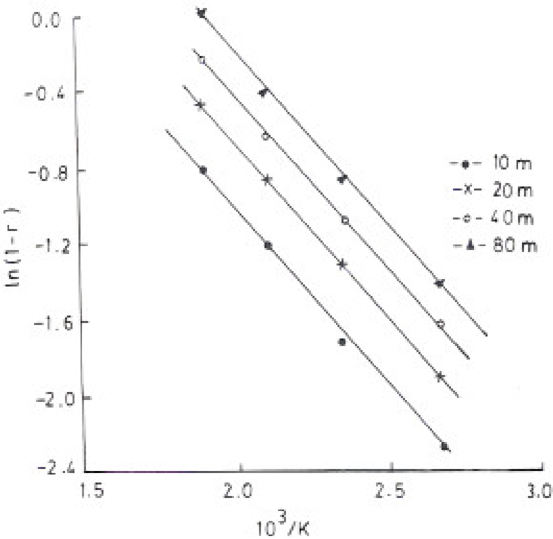

FIGURE 3 The plot of $\ln(1-r)$ against inverse temperature for sodalime glass irradiated with ^{238}U (5.9 MeV/n).

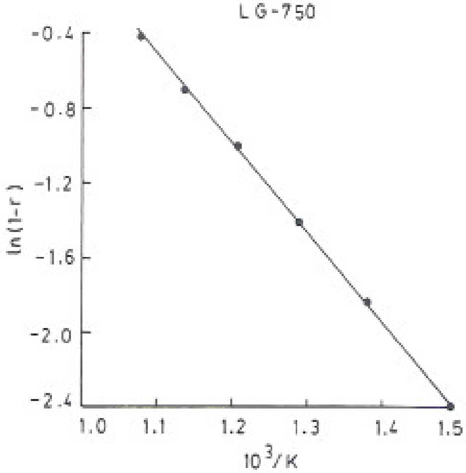

FIGURE 4 The plot of $\ln(1-r)$ against inverse temperature for phosphate (LG-750) glass irradiated with ^{238}U (15.0 MeV/n).

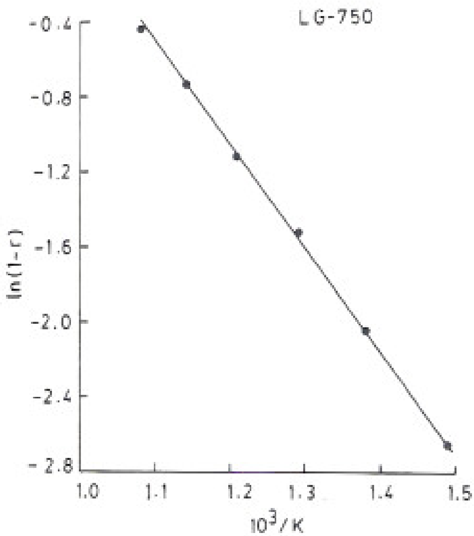

FIGURE 5 The plot of $\ln(1-r)$ against inverse temperature for phosphate (LG-750) glass irradiated with ^{238}U (5.9 MeV/n).

from the slopes of the plot of $\ln(1-r)$ against inverse temperature. The results for other glass detectors are summarized in Table I as they show correspondence for each glass detector.

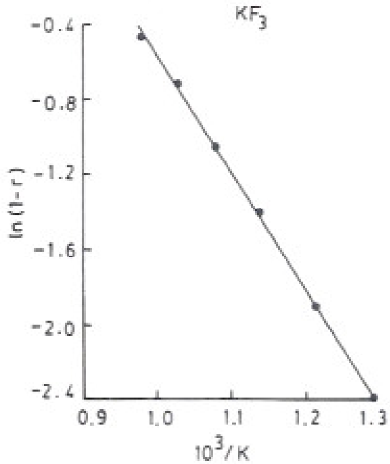

FIGURE 6 The plot of $\ln(1-r)$ against inverse temperature for sodium silicate (KF_3) glass irradiated with ^{238}U (15.0 MeV/n).

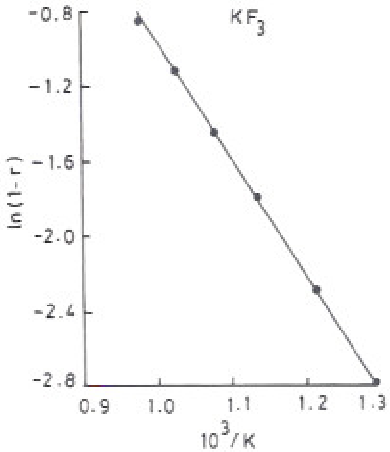

FIGURE 7 The plot of $\ln(1-r)$ against inverse temperature for sodium silicate (KF_3) glass irradiated with ^{238}U (5.9 MeV/n).

TABLE I
The values of activation energy in different glass detectors irradiated with ^{238}U

S.No.	Glass Detectors	Activation energy (eV)	
		^{238}U (15.5 MeV/n)	^{238}U (5.9 MeV/n)
1.	Sodalime	0.16	0.16
2.	Phosphate, LG-760	0.45	0.45
3.	Phosphate, LG-750	0.48	0.48
4.	Phosphate, LG-700	0.54	0.54
5.	Sodium Silicate, KF_3	0.57	0.57
6.	Borosilicate, BK_7	0.61	0.61

5 CONCLUSIONS

1) Annealing of heavy ion radiation damage follows a single activated process and, therefore, predict single activation energy for a given detector.

2) Activation energy is found to be independent of the energy and nature of ion beam used and hence a detector property.

3) Simple models with less fitted parameters are generally preferable.

4) The modified formula overcomes the shortcomings of previous model and gives better fitting.

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