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Nucl. Tracks Radiat. Meas., Vol. 11, No. 6, pp. 323–325, 1986
Int. J. Radiat. Appl. Instrum., Part D
Printed in Great Britain

0191-278X/87 $3.00 + .00
Pergamon Journals Ltd.

SHORT COMMUNICATION

ACTIVATION ENERGY FOR THE ANNEALING OF RADIATION DAMAGE IN CR-39: AN INTRINSIC PROPERTY OF THE DETECTOR

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(*Received* 23 *July* 1986; *in revised form* 11 *November* 1986)

Abstract—An annealing model proposed originally to describe the annealing of fission fragment tracks in inorganic solids in terms of a single activation energy has been successfully employed for the plastic detector, CR-39. The activation energies E_a for annealing of tracks of heavy ions of different energies, viz. 10 MeV n^{-1} ^{238}U and 18 MeV n^{-1} ^{93}Nb are found to be the same ($\sim$0.19 eV). The concept of a single activation energy proposed in Modgil and Virk (1984) *Nucl. Tracks* **8**, 355–360, is thus reinforced.

1. INTRODUCTION

The annealing of radiation damage in different categories of solid state track detectors (SSTDs) has been studied by several researchers (Fleischer *et al.*, 1964; Naesar and Faul, 1969; Storzer and Wagner, 1969; Durrani and Khan, 1970; Wagner and Reimer, 1972; Parshad *et al.*, 1978; Koul and Virk, 1978; Singh *et al.*, 1985). A number of models (Märk *et al.*, 1973; Dartyge *et al.*, 1981; Gold *et al.*, 1981; Modgil and Virk, 1984) have been proposed to explain the annealing mechanism as a function of both annealing time and temperature. Märk *et al.* (1981) proposed that the annealing of fission tracks in apatite can be explained by a summation series of exponential decay functions. They observed different activation energies corresponding to different ranges of temperature. However, they also argue that a single activation energy is sufficient for the quantitative description of the annealing process at sufficiently high temperatures. Dartyge *et al.* (1981) suggested that radiation damage in a given SSTD consists of both point defects and extended defects and hence there are two different activation energies for annealing of the two types of defects. Gold *et al.* (1981) developed a general reaction-rate theory for the annealing process in SSTDs. The limitations of these models are discussed elsewhere (Modgil and Virk, 1985).

Modgil and Virk (1984) postulated a three-step annealing model which explains the annealing behaviour of radiation damage in bulk materials. The authors favoured the concept of a single activation energy of track annealing and proposed an empirical formula

$$V_a = At^{-n} \exp(-E_a/kT) \qquad (1)$$

where V_a is the annealing rate, i.e. the rate of change of length l, given by dl/dt; A is a proportionality constant; k is the Boltzmann constant; T and t the annealing temperature and annealing time respectively; E_a the activation energy of annealing; and n is the exponent of annealing time t. According to the proposed model it is the annealing rate V_a, and not the activation energy, which varies with temperature and time. Recently Green *et al.* (1985) have also formulated the concept of single activation energy based on the results of annealing experiments on apatite.

The present study was undertaken to test the application of our model (Modgil and Virk, 1984) to the annealing of radiation damage produced by heavy ions in CR-39 (Pershore Mouldings) plastic track detector. Though the mechanism for the annealing of tracks in organic materials (such as plastics) is quite different from that of inorganic solids (minerals and glasses) yet our model describes the results well. The mechanism will be discussed in a forthcoming publication.

2. EXPERIMENTAL PROCEDURE

Two sets of samples (2.5 cm^2) were prepared from CR-39 plastic detector manufactured by Pershore Mouldings Ltd., U.K. These sets were exposed to 10 MeV n^{-1} ^{238}U and 18 MeV n^{-1} ^{93}Nb ion beams obtained from the UNILAC accelerator at GSI, Darmstadt, West Germany. The incidence angle of beams with respect to the detector surfaces was fixed at 45°.

The specimen samples irradiated with ^{238}U and ^{93}Nb ions were heated in a muffle furnace in which the temperature was controlled to ± 1°C. The set exposed to the ^{238}U beam was heated at three different temperatures 150, 200 and 225°C for time intervals of 10, 20, 40, 60 and 80 min. The second set exposed to

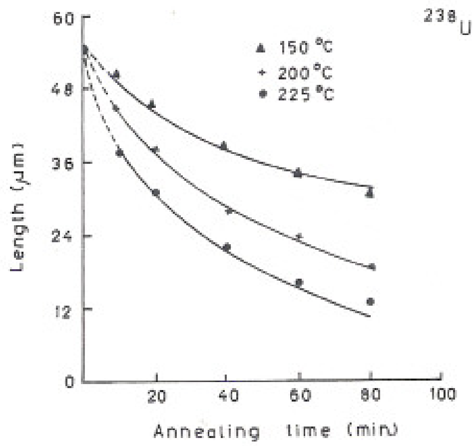

FIG. 1. The variation in length of 10 MeV n^{-1} ^{238}U ion tracks with annealing time at annealing temperatures 150°C, 200°C and 225°C in CR-39 detector.

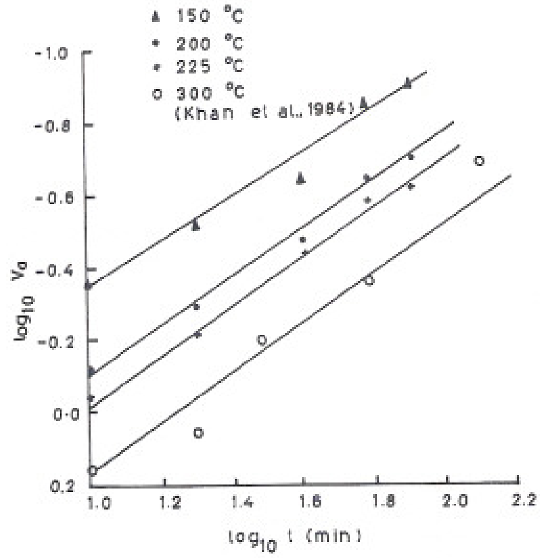

FIG. 3. Plot of $\log_{10} V_a$ vs $\log_{10} t$ (min) at annealing temperatures 150, 200 and 225°C for 10 MeV n^{-1} ^{238}U ion tracks.

the ^{93}Nb beam was annealed at temperatures of 150, 175, 200 and 225°C for time intervals ranging from 10 to 250 min. Both sets of annealed samples of CR-39 along with unannealed reference standards were then etched with 6 M NaOH for 80 min at 70°C. Track lengths were measured with a Carl Zeiss binocular microscope at a total magnification of 400×.

Figures 1 and 2 show a plot of track length as a function of annealing time. The annealing rate, V_a, was calculated from the slopes for different durations of annealing from these plots. Plots of $\log_{10} V_a$ versus $\log_{10} t$ (Figs 3 and 4) show that the annealing rate follows a power law exactly in the same manner as in the case of inorganic solids (Modgil and Virk, 1985). The value of the exponent n is given in Table 1.

Further annealing experiments were performed to study the effect of temperature on the track annealing rate. Annealing of heavy ion beam tracks was carried out by heating the irradiated samples in a muffle furnace at temperatures of 150, 175, 200 and 225°C for an interval of 10 min at each temperature. These samples, along with unannealed ones, were etched simultaneously under the above-mentioned standard conditions. The track annealing rate V_a was calculated from the measured track lengths. A plot of $\log_{10} V_a$

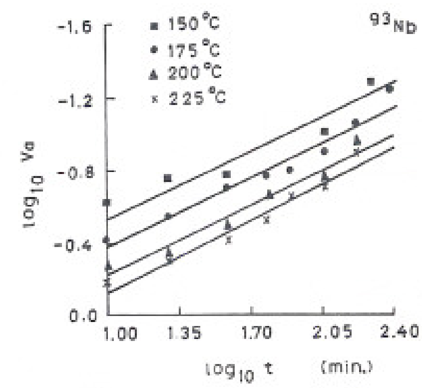

FIG. 4. Plot of $\log_{10} V_a$ vs $\log_{10} t$ (min) at annealing temperatures 150, 175, 200 and 225°C for 18 MeV n^{-1} ^{93}Nb ion tracks.

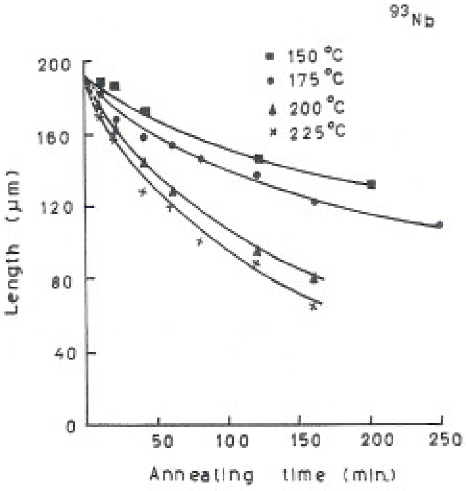

FIG. 2. The variation of length of 18 MeV n^{-1} ^{93}Nb ion tracks with annealing time at annealing temperatures 150°C, 175°C, 200°C and 225°C in CR-39 track detector.

Table 1. Activation energy of annealing of heavy-ion tracks of ^{238}U (10 and 16 MeV n^{-1}) and ^{93}Nb (18 MeV n^{-1}) in CR-39

Ion beam	Energy (MeV n^{-1})	Activation energy E_a (eV)	n value
^{238}U	16	0.185	0.65
^{93}Nb	18	0.193	0.61
^{238}U*	16	0.194	0.66

*Khan *et al.* (1984).

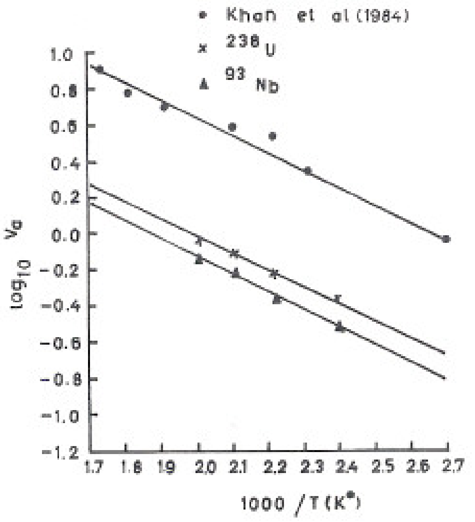

FIG. 5. Plot of $\log_{10} V_a$ vs 1/T for the 10 MeV n^{-1}, and 16 MeV n^{-1} ^{238}U ion and 18 MeV n^{-1} ^{93}Nb ion beam tracks in CR-39 detector.

vs $1/T$ (Fig. 5) shows an exponential dependence of V_a on the annealing temperature for CR-39, following equation (1).

3. DISCUSSION AND RESULTS

The experimental data on annealing of heavy ion tracks in CR-39 fully satisfies the empirical relation proposed by Modgil and Virk (1984, 1985). The activation energies as deduced from the respective plots of $\log_{10} V_a$ against $1/T$ are 0.185 eV and 0.193 eV for ^{238}U and ^{93}Nb ions, respectively. It is interesting to note that both categories of heavy ions, even of different beam energies, yield almost identical values of activation energy of annealing (Table 1). This shows that the minimum energy required to start the annealing process in CR-39 is independent of the nature and energy of the track-forming ion.

We have also calculated the activation energy from the annealing data of Khan *et al.* (1984) for 16 MeV n^{-1} ^{238}U beam tracks in CR-39, and find it to be 0.19 eV. The data are plotted in Fig. 5. This further supports the proposal that the activation energy of annealing of radiation damage is a characteristic property of the detector material.

Acknowledgement—The authors are grateful to Dr R. Spohr, GSI, Darmstadt, for providing heavy ion irradiation facilities at the UNILAC accelerator. HSV has pleasure in thanking the Director GSI for hospitality during his visit.

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