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Response of Makrofol polycarbonate plastic track detector to 1.1 MeV/N $^{132}_{54}$Xe-ion

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Abstract. Makrofol polycarbonate plastic track detectors have been exposed to $^{132}_{54}$Xe -ions of energy 1·1 MeV/N from the cyclotron beam. The bulk etch rate and track etch rate are measured for different temperatures and the activation energies are calculated. The maximum etched track length is compared with the theoretically computed range. The critical energy loss is $(dE/dx)_c = 5$ MeV cm^2 mg^{-1} for this detector material.

Keywords. Solid state nuclear track detector; activation energy; track registration sensitivity; response curve; critical energy loss.

1. Introduction

In recent years solid state nuclear track detectors (SSNTDS) have found widespread applications (Fleischer *et al* 1975). In these detectors paths of individual heavily ionizing charged particles are revealed by selective chemical etching of the radiation damaged material along the particle's trajectory. The maximum etched track length provides the particle range and its energy. The length is also a measure of the mass A and charge Z of the incident particles (Price and Fleischer 1971; Fleischer *et al* 1965). In the present work we have tried to measure the range of $^{132}_{54}$Xe-ion by determining the maximum etched track length. Theoretical relations are used to compute the range of $^{132}_{54}$Xe-ion in Makrofol and the range is compared with maximum etched track length. The response curve is plotted and the critical energy loss $(dE/dx)_c$ is determined. The bulk and track etch rate are measured for different temperatures and the activation energy is calculated.

2. Experimental details

In the present study the bulk etch rate has been measured by the track diameter method (Enge *et al* 1975). In this method small areas of detectors are irradiated vertically in vacuum with fission fragments from ^{252}Cf source and then etched in NaOH solution at a constant temperature. The bulk etch rate V_b is calculated by

$$D = 2V_b\, t, \tag{1}$$

where D is the diameter of fission fragment tracks and t is the etching time.

Samples of Makrofol-E (200 μm thick) have been irradiated with $^{132}_{54}$Xe-ions of energy 1·1 MeV/N at an angle of 30° with respect to the detector surface from the cyclotron beam at the Joint Institute for Nuclear Research, Dubna, USSR. Conical tracks are observed after etching for a short time in the NaOH solution. The major and minor axis diameters are measured. The projected track length is measured from the centre of track ellipse at the etched surface to the end of the track tip. At least 50 tracks are measured each time. The corrected projection length l_p is determined by taking the geometry of tracks (Benton 1968). The true track length L (the length from the original surface to the terminal end of the track) is calculated by the relation (Dwivedi 1977; Dwivedi and Mukherji 1979).

$$L = \frac{l_p}{\cos \delta} + \frac{V_b\, t}{\sin \delta} - V_b\,(t - t_c), \tag{2}$$

where δ is the dip angle and t_c is the etching time required to etch the tracks upto the point where they stop. The track etch rate V_t is calculated using the relation (Dwivedi 1977; Dwivedi and Mukherji 1979)

$$V_t = \Delta L/\Delta t, \tag{3}$$

where ΔL is the track length increase in etching time Δt.

After exposure the plastic samples are developed for convenient times in a NaOH (6 ± 0·05) N stirred solution at a constant temperature of ± 0·5°C. All measurements are made with an Olympus microscope having an eyepiece micrometer (least count = 0·215 μm) at a total magnification of 900×.

3. Results and discussion

3.1 *Effect of temperature on bulk etch rate*

The bulk etch rate V_b is determined at 50, 60, 70, 80 and 90°C for NaOH solution. New solutions are used so that the etchant concentration remains constant throughout the experiment. The results are shown in figure 1a. It is obvious that in the temperature range applied in our experiments, the data can be well described by the Arrhenius correlation of the form

$$V_b = A \exp(-E_b/kT), \tag{4}$$

where A is a constant, k is the Boltzmann constant, E_b is the activation energy for the bulk etching and T is the temperature of etchant in °K. The activation energy is found to be $E_b = (0{\cdot}72 \pm 0{\cdot}06)$ eV which agrees with that reported by Enge *et al* (1975).

3.2 *Effect of temperature on track etch rate*

The variation of l_p with etching time when etched in 6N NaOH at 70°C is shown in

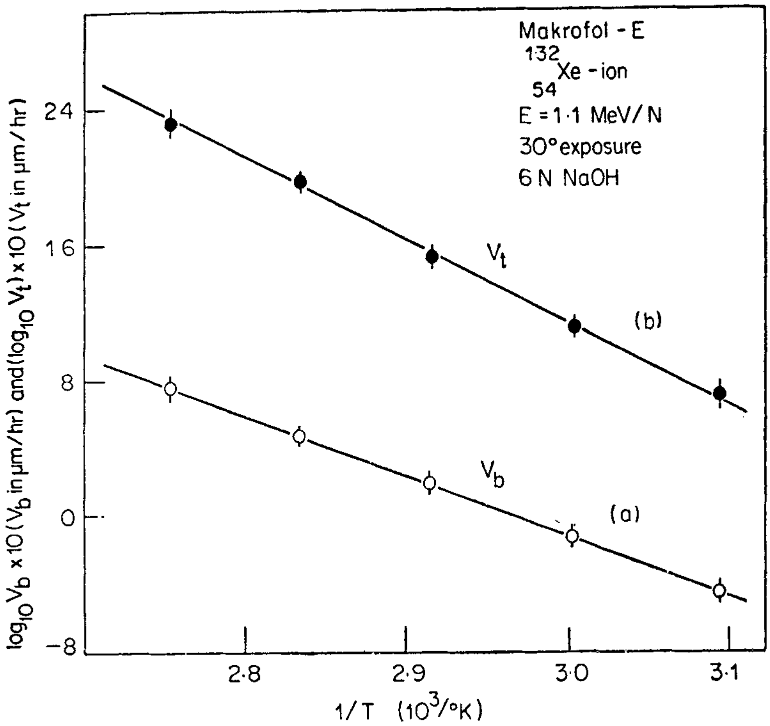

Figure 1. Variation of (a) bulk etch rate and (b) track etch rate with etching temperature for Makrofol-E exposed to 1·1 MeV/N $^{132}_{54}$Xe-ions.

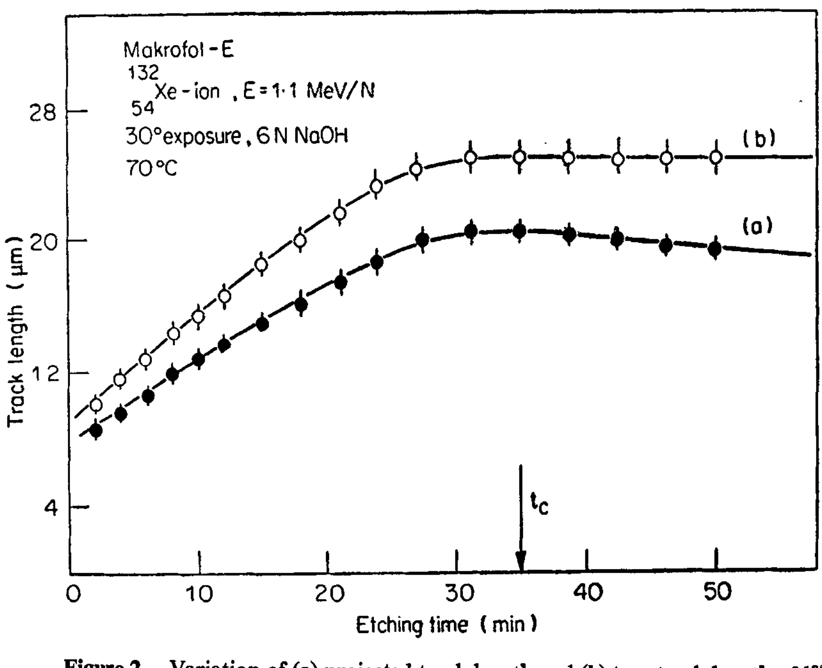

Figure 2. Variation of (a) projected track length and (b) true track length of $^{132}_{54}$Xe-ion in Makrofol-E with etching time.

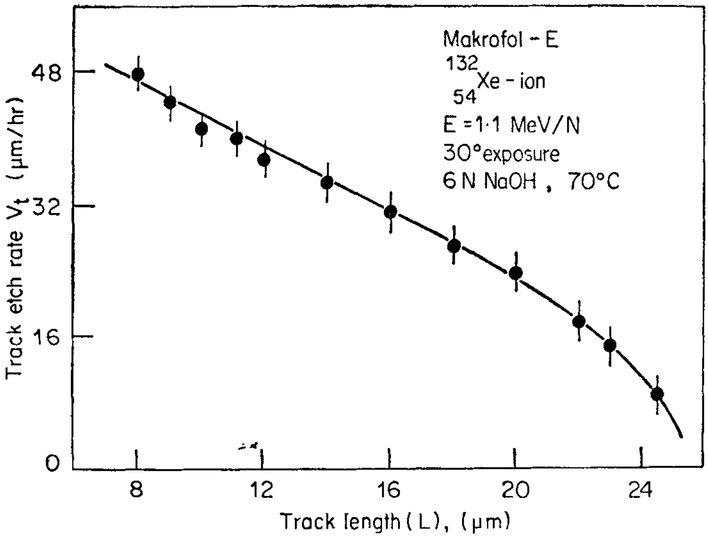

Figure 3. Variation of track etch rate with track length of $^{132}_{54}$Xe-ions in Makrofol-E.

figure 2a for 30° exposure of Makrofol sample with $^{132}_{54}$Xe-ion of energy 1·1 MeV/N. The variation of true track length with etching time is shown in figure 2b. The projected track length starts decreasing after the etching time t_c because the bulk etching shortens the completely developed track after t_c. When the bulk etching and over etching corrections are made (see equation (2)), the true track length remains constant beyond t_c (figure 2b). Figure 3 shows the variation of V_t with L for 6N NaOH at 70°C. Clearly V_t decreases with penetration depth and this can be explained if we consider the energy loss *vs* energy curve for $^{132}_{54}$Xe-ion. The beam energy is 1·1 MeV/N in the present case. When the beam penetrates the detector with this energy the energy loss decreases with penetration depth. Since V_t is a function of energy loss, the track etch rate also decreases with penetration depth.

Plots of V_t *vs* L (not shown) for etching at 50, 60, 80 and 90°C are similar to that shown in figure 3. From these plots the V_t value corresponding to a particular track length (14 μm in this case) is determined for different temperatures. The effect of etching temperatures on V_t is shown in figure 1b. It is evident that the increase in the value of V_t with etching temperature is exponential and can be expressed by the relation

$$V_t = B \exp(-E_t/kT). \tag{5}$$

The value of E_t for track etching calculated from figure 1b is found to be $E_t = (0{\cdot}70 \pm 0{\cdot}04)$ eV.

Using the relation $V = V_t/V_b$ the values of V have been calculated for different temperatures from the experimentally determined V_b and V_t values.

3.3 *Range of $^{132}_{54}$Xe-ion in Makrofol-E*

Recently, Mukherji and Nayak (1979) have given a set of equations to calculate the

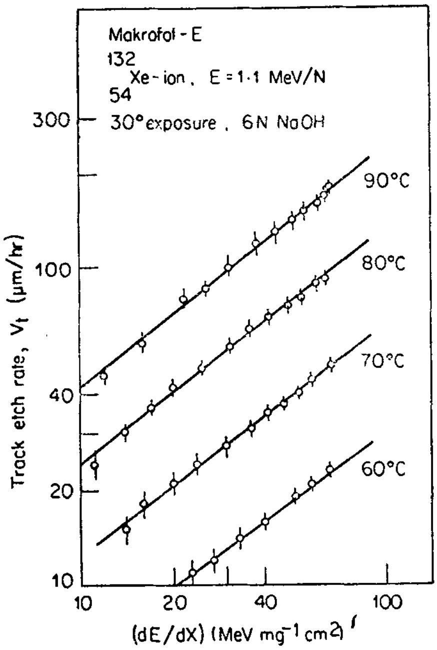

Figure 4. Variation of track etch rate with energy loss for $^{132}_{54}$Xe-ion tracks in Makrofol-E.

energy loss rate and range of heavy ions in complex media. The same procedure is followed by us to compute the range and energy loss of $^{132}_{54}$Xe-ion in Makrofol-E ($C_{16}H_{14}O_3$ and $\rho = 1{\cdot}2$ g/cm^3). The theoretical range of 1·1 MeV/N $^{132}_{54}$Xe-ion in Makrofol-E is found to be R=27·27 μm. The average length of etched tracks is calculated using (2). About 300 tracks are measured to calculate the average value. The average value of maximum etched track length with its standard deviation is L=(25·75 $\pm$ 1·02) μm.

3.4 *The response curve*

Using computer output, the plot of energy loss dE/dx *vs* penetration depth *i.e.* track length has been drawn (not shown). The variation of V_t with track length is shown in figure 3. Combining these two figures, the response curve [(dE/dx) *vs* V_t] for etching at 70°C is plotted on a double-logarithmic paper as shown in figure 4. The response curves for different etch bath temperatures are also presented in figure 4 and it is clear that V_t depends on dE/dx as well as on etch bath temperature.

The experimental data are transformed into the normalized track etch rate (V_t/V_b) and in figure 5 these are plotted against (dE/dx) on a linear diagram for four different temperatures. It can be seen that all our data normalized in this way belong to the same curve within the accuracy of the measurements. Thus the normalized track etch rate depends only on energy loss dE/dx and not on the etching temperatures. The solid curve is the best fit to the experimental points. This is done with the use of computer program which fits the curve of nth degree based on the principle of least-square polynomial approximation. The curve is extrapolated for the predicted values

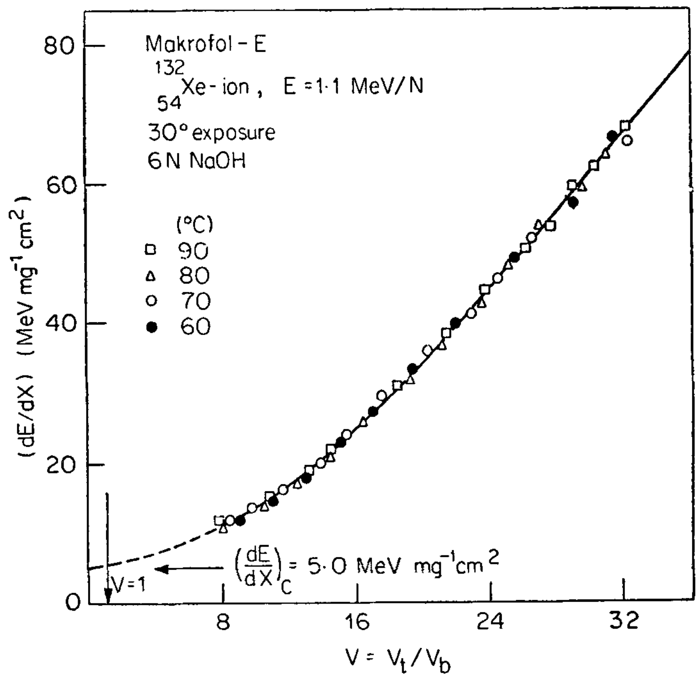

Figure 5. Variation of normalized track etch rate with energy loss for $^{132}_{54}$Xe-ion tracks in Makrofol-E.

of $(\mathrm{d}E/\mathrm{d}x)$ against V. The $\mathrm{d}E/\mathrm{d}x$ at which the V_t equals V_b (*i.e* $V_t/V_b=1$) is taken as the critical energy loss $(\mathrm{d}E/\mathrm{d}x)_c$ for track etching below whichno etchable track can be produced (Tanti-Wipawin 1975). The present value of $(\mathrm{d}E/\mathrm{d}x)_c=5$ MeV cm^2 mg^{-1} agrees with that reported in literature (Debeauvais *et al* 1967; Fleischer *et al* 1965).

The relation between V and $(\mathrm{d}E/\mathrm{d}x)$ can be expressed by the relation (Somogyi *et al* 1976; Enge *et al* 1975).

$$V = 1 + A(\mathrm{d}E/\mathrm{d}x)^B, \tag{6}$$

where A and B are fitting parameters. Using the computer program the A and B values are found to be $A = 0{\cdot}016$ and $B = 2{\cdot}78$. These values agree with those reported earlier (Somogyi *et al* 1976; Enge *et al* 1975).

4. Concluding remarks

The dependence of both V_b and V_t on etching temperature is exponential. The maximum etched track length can be regarded as the range of $^{132}_{54}$Xe-ion in Makrofol. The normalized track etch rate is independent of etching temperature. The critical energy loss for this detector material is relatively high as compared to other plastic detectors like CN and CR-39.

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