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Tracks of 18·56 MeV/*u* ^{40}Ar ions in Lexan polycarbonate detector

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Abstract. Latent damage tracks of energetic ^{40}Ar ions (18·56 MeV/*u*) have been recorded in Lexan polycarbonate detector. Bulk and track-etch parameters are evaluated under successive chemical etching. Our results show a linear correlation between the measured track-etch rate along the track and the corresponding total energy-loss rate and predict a threshold value of 5·0 MeV mg^{-1} cm^2 for track registration. Maximum etchable track lengths of ^{40}Ar ions as a function of energies have also been measured and compared with three different sets of theoretical ranges.

Keywords. Activation energy; critical energy-loss rate; Lexan; track-etch rate; track length.

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1. Introduction

It is well known that the latent tracks are conveniently revealed by suitable chemical etching processes and the optimal use of any solid state nuclear track detector (SSNTD) largely depends on standardization of various etching parameters. A knowledge of bulk-etch rate (V_G) at different temperatures for any SSNTD is of considerable importance for obtaining the true track length of any heavy ion in that detector media (Fleischer *et al* 1965a; Price and Fleischer 1971; Dwivedi and Mukherji 1979a, b). Further the track-etch rate (V_T) is the best observable quantity which provides us with a measure of damage intensity. Theoretically, the range-velocity equations of Bethe (1930) and Bohr (1948) show a dependence of total energy-loss rate ($\mathrm{d}E/\mathrm{d}X$) of a moving ion in any medium on its penetration depth. Hence an attempt to correlate V_T and ($\mathrm{d}E/\mathrm{d}X$) for any ion in any media not only provides us with an understanding of track-forming mechanism but also results in a calibration curve to identify unknown track-forming particles. In this contribution, we present our results on activation energy for bulk etching, correlation between V_T and total ($\mathrm{d}E/\mathrm{d}X$), critical stopping power of Lexan for track etching and maximum etchable track length in Lexan as a function of ^{40}Ar ion energies upto 18·56 MeV/*u*. Measured track lengths are compared with the corresponding calculated values obtained from three different theoretical models.

2. Experimental

2.1 *Target preparation*

Several rectangular pieces were carefully cut from a thin foil of Lexan polycarbonate (bisphenol-A-polycarbonate). The thickness of the foils measured using an optical microscope and a 'Heidenhain' depth measuring device (Saxena 1987) was found to be $53 \pm 1\ \mu m$. Stacks of Lexan were prepared by gently pressing 10 foils together and were mounted on slide glass backing for irradiation.

2.2 *Irradiation of Lexan stacks*

Lexan stacks were irradiated with 18·56 MeV/u ^{40}Ar ions at the XO port of UNILAC, Darmstadt. Well collimated beam of ^{40}Ar ions were used to expose the stack at an incident angle of 45° with respect to the surface. An optimum dose of $\sim 10^4$ ions/cm^2 was delivered.

2.3 *Etching and measurement of nuclear tracks in Lexan*

After irradiation the foils of Lexan were removed from the stack and numbered. For obtaining maximum etchable track lengths each foil of the Lexan stack was etched in 6 N NaOH at 55°C for 200 minutes in successive time intervals of 20 minutes each. Out of ten foils of Lexan stacks, the tracks are observed only in the first seven foils. The etching of the seventh foil was continued till the track tip assumed a round shape. Lexan foils were also etched in 6 N NaOH at temperatures of 35°, 45°, 55°, 65° and 75°C for different times to determine V_G. After every etching these foils were thoroughly washed in distilled water and dried under vacuum. Track diameters and track lengths were measured at a magnification of 1500 × and 675 × respectively. From the measured data the activation energy is determined using the method of Dwivedi and Mukherji (1979a) and the true maximum etchable track lengths are obtained from the equation given by Dwivedi and Mukherji (1979b).

2.4 *Experimental errors*

The energy of heavy ions at UNILAC is very accurately known and the fluctuations vary within 0·1%. The uniformity of the Lexan foils is better than 2%. The accuracy in the measurement of track parameters is $\pm 0{\cdot}5\ \mu m$ and $\pm 0{\cdot}22\ \mu m$ at the magnification of 675 × and 1500 × respectively.

2.5 *The computer code DEDXT*

In the last few years the validity of the universal stopping-power equations of Mukherji and coworkers (Mukherji and Srivastava 1974; Srivastava and Mukherji 1976; Mukherji and Nayak 1979) has been examined for heavy ion ranges and track lengths in several solids up to 20 MeV/u and the deviations vary within ± 5% in most cases (Dwivedi and Mukherji 1979b; Farid and Sharma 1983; Subhash Chander *et al* 1983; Sexena 1987; Sexena *et al* 1987). In view of the ever increasing demand of range-energy data for heavy ions in different solids and the validity of the stopping-power equations of Mukherji and coworkers, a computer code 'DEDXT' has been developed by Dwivedi (1988). The code DEDXT is written in FORTRAN language and has a subroutine HEART. This subroutine contains all the thirteen stopping-power equations given by Mukherji and Nayak (1979) and are used for different velocity regions of stopping ions. For complex media, the stopping-powers $[(dE/dX)_E]_c$ have been obtained using Bragg's additivity rule,

$$\left[\left(\frac{dE}{dX}\right)_E\right]_c = \frac{1}{A_c}\sum_i\left[Y_i A_i\left\{\left(\frac{dE}{dX}\right)_E\right\}_i\right], \tag{1}$$

where $A_c (= \sum_i Y_i A_i)$ is the molecular mass number of the complex medium, A_i and Y_i are the mass number and the number of atoms per molecule of the ith atomic species respectively. Further, the total penetration depth or range R is calculated by

$$R(\mathrm{mg/cm^2}) = \sum_{E_i}^{E_0} \frac{\delta E}{\left[\left(\frac{dE}{dX}\right)_E\right]_c} \tag{2}$$

where δE is a small but finite energy interval (0·01 MeV/u) over which the stopping-power remains virtually constant, E_i is the initial ion energy (in MeV) and E_0 is the final energy corresponding to the ion velocity V_0 $(= e^2/\hbar)$.

The code DEDXT requires a small area (<15 kB) and can be executed on any personal computer for calculating ranges, track lengths, total energy-loss rate for both accelerating and stopping ions in any medium of known chemical composition. The output may be obtained in the form of either a plot or a printed data table.

3. Results and discussion

The bulk-etch rate at different temperatures has been determined for Lexan using the track diameter technique. The values of log V_G have been plotted against the reciprocal of etching temperatures (in °K) and the value of activation energy was 48·6 $\pm 2\,\mathrm{kJ\,mol^{-1}}$. This value is nearly 20% lower than the earlier values (Enge *et al* 1975)

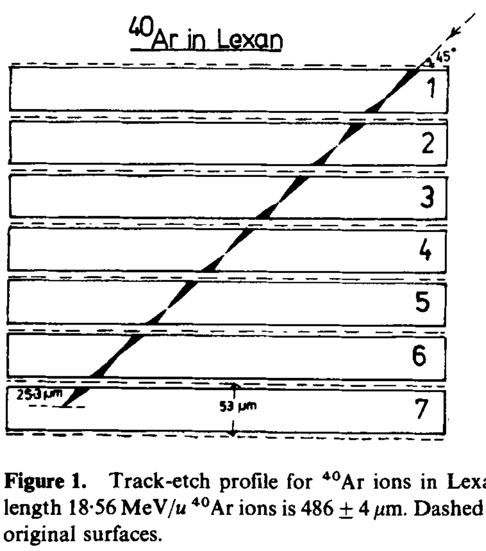

Figure 1. Track-etch profile for ^{40}Ar ions in Lexan stack. The maximum etchable track length 18·56 MeV/u ^{40}Ar ions is 486 ± 4 μm. Dashed lines between the foils indicate unetched original surfaces.

Table 1. Values of V_T at various depth of penetration (thickness) x along with the corresponding values of energies and theoretical dE/dX (Mukherji and Nayak 1979).

E (MeV/u)	Thickness x (μm)	V_T (μm/h)	dE/dX (MeV/mg/cm^2)
17·70	30	8·6	8·3
16·60	75	10·2	8·7
14·62	150	9·8	9·5
12·36	225	10·2	10·7
9·76	300	10·8	12·5
6·60	375	15·3	15·8
3·96	425	18·8	20·2
2·30	450	22·5	23·5
1·60	460	26·3	23·1
0·35	480	12·0	15·9
0·15	485	7·5	11·0
0·10	486	1·0	—

presumably due to ^{40}Ar ion is used for track formation in the present work instead of fission fragments in the other case.

The values of V_T at different points along the track have been measured after every successive etching of each Lexan foil. The tracks were found in only the first seven foils as shown in figure 1. Table 1 lists the values of V_T at various depth of penetration (thickness) X of the ^{40}Ar ion in Lexan and the corresponding values of the energies and energy-loss rate calculated from the computer code DEDXT (Dwivedi 1988) based on the stopping-power equations of Mukherji and Nayak (1979). The plot of V_T and (dE/dX) as a function of thickness is shown in figure 2. A fairly good correlation has been observed. Figure 3 represents a linear dependence of energy-loss rate on the experimental value of track-etch rate and can be expressed by the following equation,

$$V_T = 1{\cdot}165(dE/dX) - 4{\cdot}27, \tag{3}$$

where V_T is expressed in units of μm/h and (dE/dX) in units of MeV mg^{-1} cm^2.

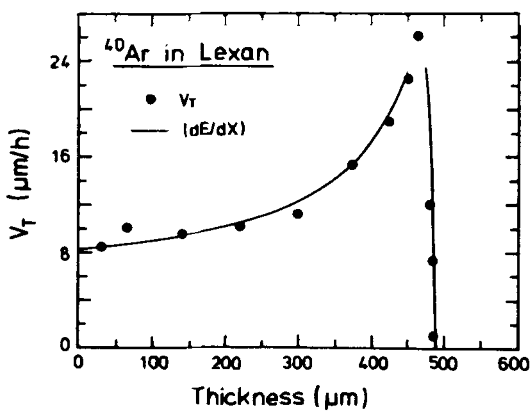

Figure 2. A plot showing measured V_T (in μm/h) and calculated dE/dX (in MeV. mg^{-1}.cm^2) for ^{40}Ar ions in Lexan as a function of penetration depth.

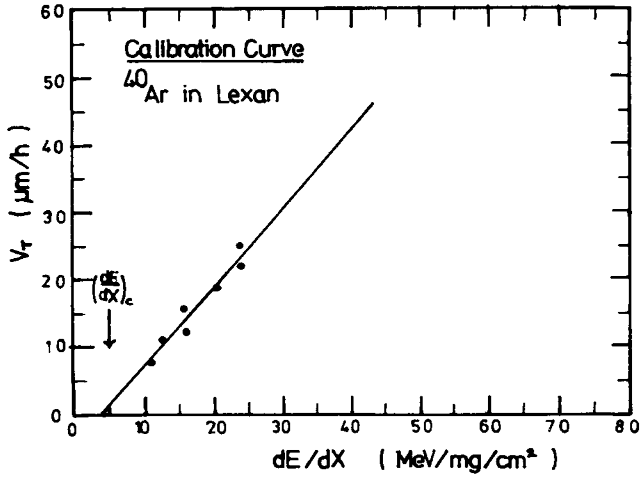

Figure 3. A plot showing calibration curve between V_T and (dE/dX) for ^{40}Ar ions in Lexan. Tracks are etched in 6 N NaOH at 55°C.

It has been observed from figure 3 that the value of $(dE/dX)_c$ for Lexan is nearly 5·0 MeV mg^{-1} cm^2 corresponding to the point at which V_T equals V_G. This value of $(dE/dX)_c$ is comparable to the values reported earlier (Fleischer *et al* 1965a; Debeauvais *et al* 1967; Remy *et al* 1970 and Dwivedi and Mukherji 1979a).

The maximum etchable track lengths as a function of ^{40}Ar ion energies and the theoretical ranges calculated from three different sources are summarized in table 2. The plots of measured track length and theoretical ranges versus ion energy are shown in figure 4. The measured range of 18·56 MeV/*u* ^{40}Ar in Lexan is $486 \pm 4\,\mu m$. Corresponding to the value of $(dE/dX)_c$ equal to 5·0 MeV mg^{-1} cm^2, it was found that nearly 2 μm of the ^{40}Ar damage trail (range) remained unetched in Lexan. As this deficit range is within the experimental errors, we can find a meaningful comparison between measured track lengths and the theoretical ranges. It has been found that our experimental data show good agreement (within 5%) with the calculated values from

Table 2. Ranges and maximum etchable track-lengths of ^{40}Ar in Lexan polycarbonate.

Ion energy E (MeV/u)	Maximum etchable track length L (μm)	Range in μm: Mukherji and Nayak (1979)	Range in μm: Northcliffe and Schilling (1970)	Range in μm: Benton (1968)
18·56	486 ± 4	488	—	465
16·66	411 ± 4	411	—	385
14·60	336 ± 4	336	—	315
12·36	261 ± 5	260	—	240
9·76	186 ± 5	186	190	172
6·60	111 ± 6	114	107	100
2·26	36 ± 6	37·4	28	28·2

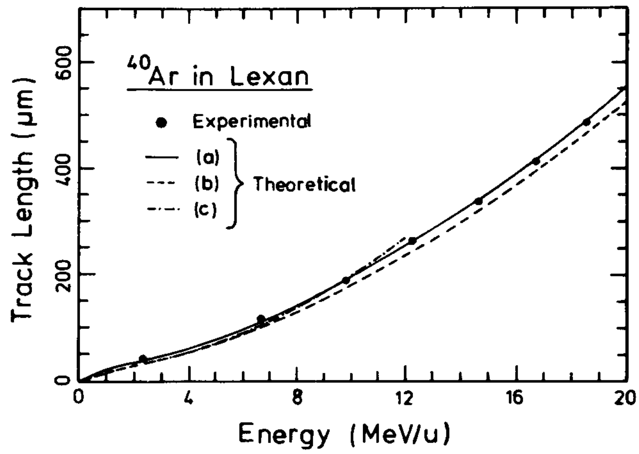

Figure 4. Measured track lengths of ^{40}Ar ions in Lexan are plotted along with calculated values from three different theories (a) Mukherji and Nayak (1979), (b) Benton (1968) and (c) Northcliffe and Schilling (1970).

Northcliffe and Schilling (1970) and Mukherji and Nayak (1979) whereas theoretical ranges of ^{40}Ar in Lexan predicted by Benton (1968) are consistently lower (5–10%) as compared to our measured values.

4. Conclusion

The comparison of our measured track lengths with the corresponding theoretical values supports earlier findings (Subhash Chander *et al* 1983; Farid and Sharma 1983; Saxena *et al* 1985; Dwivedi *et al* 1986; Saxena *et al* 1987) that the stopping power equations of Mukherji and coworkers (Mukherji and Srivastava 1974; Srivastava and Mukherji 1976; Mukherji and Nayak 1979) predict the most reliable ranges of heavy ions in the complex media. The observation of a linear correlation between track-etch rate and total energy-loss rate of ^{40}Ar in Lexan has not only provided a detector calibration curve but also supported the 'ion explosion spike model' (Fleischer *et al* 1965b) for track registration.

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