Study of etching and annealing characteristics of 100 MeV ^{28}Si ions in Makrofol-DE polycarbonate plastic detectors

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Introduction

When a heavily ionizing charged particle passes through polycarbonate plastic, it leaves a narrow trail of damage along the path. This is called ‘Latent Track’. These latent tracks can be developed so that they can be viewed under an optical microscope by etching with chemicals.
Various etching parameters, namely bulk etch rate, track etch rate, critical angle, sensitivity of Makrofol-DE plastic for registration of 100 MeV ^{28}Si ions, etching efficiency and activation energies for bulk and track etching are reported. For the study of annealing characteristics, Price et al. [4] and Bhatia and Virk [5] empirical formulation were used. The experimental range of ^{28}Si ions in Makrofol-DE has been compared with the calculated values obtained from **TRIM 2008** [1] computer programme.

Experimental Details

Single foils of Makrofol-DE polycarbonate plastic detectors (thickness ~ 250 µm) were irradiated with 100 MeV ^{28}Si ions from 15 UD Pelletron at IUAC, New Delhi, India. The angle of incidence of beam with respect to detector surface was 45^0. For this irradiation general scattering chamber was used. An optimum flux of ~ 10^4 ions / cm^2 was used. Some Makrofol-DE plastics irradiated with 100 MeV ^{28}Si ions were annealed in a temperature controlled oven with an accuracy of ± 1^oC in a temperature range from 50^oC to 150^oC for fixed intervals of 30 minutes as discussed in our previous publications [2, 3]. All the annealed samples were annealed at 60^oC.

Annealing Mechanism

Price et al.1987 [4] modified the equation of Modgil and Virk 1985 [5] by replacing thermal annealing rate with fractional thermal rate

$$\{[(S-1)_i-(S-1)_f/(S-1)_i\}=At_a^{1-n}\exp(-E_a/kT_a) \quad (1)$$

Where S= (V_T/ V_G) and subscripts i and f refers to the initial and final values, A is proportionality constant, t_a (h) is annealing time, k (eV/K) the Boltzmann constant, T_a (K) is the annealing temperature and E_a (eV) the activation energy for the annealing of latent tracks. Bhatia and Virk 1989 [6] further improved the previous formulation as follow

$$[d(V_T/V_G)/dt_a]=At_a^{-n}\exp(-E_a/kT_a) \quad (2)$$

Where d (V_T/ V_G) is the track etch to bulk etch rate ratio for a particular annealing time and temperature. Track etching and annealing parameters are discussed in detail in our previous publications [2, 3].

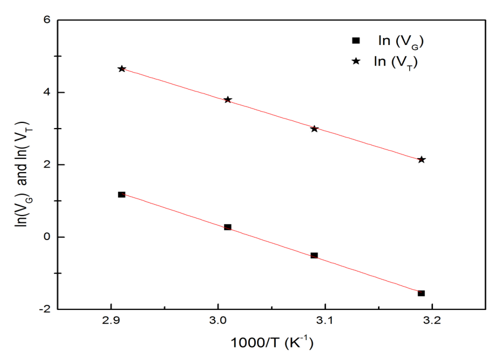

Fig.1 Plot of ln V_G and V_T versus 1000/T (K^{-1}) for un-annealed Makrofol-DE plastic.

Results

The values of various parameters for unannealed sample i.e. V_G, V_T, S, θ_c and η at 100 MeV in table 1. From the table it is calculated that for 100 MeV, V_G increases with increasing temperature of etchant. The value of V_T also increases with the increase of etchant temperature. This value depends upon the incident particle energy. The values of S at different temperature have been determined and found more at 40^0C for a given energy of the ion.

Figure1 shows the variation of track etch rate and temperature (at 100 MeV) ^{28}Si ions.

The various etching parameters for annealed polycarbonates for 100 MeV ^{28}Si ions are also given in table1. In case of 100 MeV annealing polycarbonates, all the etching parameters slightly change after annealing at temperatures viz, 50^{o}C, 70^{o}C, 90^{o}C, 110^{o}C, 130^{o}C & 150^{o}C. For annealed polycarbonates, bulk etch rate slightly decreases with the increase of annealing temperature. The sensitivity S and etching efficiency η decreases with the annealing of latent tracks.

Table1: Values of etching and annealing parameters V_G (µm/h), V_T (µm/h), $S(V_T/\ V_G)$, $\eta\%=[(1-(V_G/\ V_T)]$ and $\theta_c = \text{Sin}^{-1}\ (V_G/\ V_T)$ for un annealed and annealed Makrofol-DE plastic.

Etching Temp (°C)	V_G	V_T	S	η%	θ_c
40	0.21	8.49	40.47	97.58	1.41
50	0.60	20.01	33.33	97.00	1.71
60	1.31	45.01	34.36	97.68	1.68
70	3.21	105.12	32.71	96.94	1.75
Annealing Temp (°C)	V_G	V_T	S	η%	θ_c
50	1.53	44.91	29.30	96.59	1.95
70	1.50	42.64	28.40	96.47	2.01
90	1.47	39.82	27.07	96.30	2.11
110	1.42	37.63	26.47	96.18	2.16
130	1.39	35.02	25.53	96.08	2.24
150	1.36	33.85	24.91	95.98	2.30

The activation energy of bulk and track etching has been determined [4] from the slopes of Fig. 1 and comes out to be 0.83 eV ± 0.24 and 0.77eV±0.12resp.

The activation energy Ea of annealing has been determined from the slope of graphs of Fig. 2 and found to be same (0.07 eV) from [4,5].

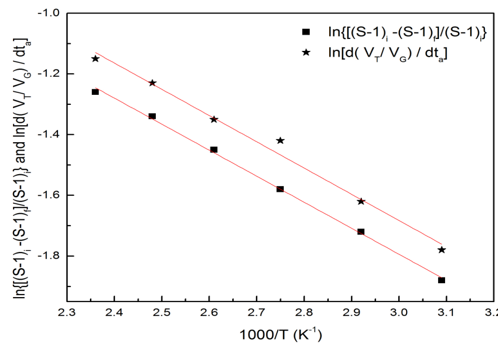

Fig. 2 Variation of $\{[(S\text{-}1)_i\text{-}(S\text{-}1)_f] / (S\text{-}1)_i\}$ and ln $[d(V_T/V_G)/dt_a]$ versus $1000/T_a$ (K^{-1}) for annealing of tracks in Makrofol-DE plastic.

Conclusion

The sensitivity of Makrofol-DE for ^{28}Si slightly decreases with temperatures 50^0C, 60^0C & 70^0C but is more at 40^0C. Price et.al. 1987 [4] and Bhatia & Virk 1989 [6] formulations (both) can be used to explain the kinetics of radiation damaged Makrofol-DE plastics. The range of 100 MeV ^{28}Si ions in Makrofol-DE is estimated experimentally 46 ± 4 µm. The theoretical calculations (46.6 µm) using TRIM 2008 shows a reasonable agreement with the experimental value.

References

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