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Track Etching Characteristics of Glass Track Detectors

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Samples of barium phosphate (BP-1), soda and quartz glasses have been irradiated by the ^{238}U (11.4 MeV/u) ion beam available from the heavy ion UNILAC accelerator at GSI, Darmstadt, Germany. After chemical etching of these specimen samples in appropriate etchants at different temperatures, the values of etched track parameters, viz. bulk etch rate, track etch rate, sensitivity, etching efficiency and the critical angle of etching, have been determined. The activation energies for bulk and track etch rates have also been determined. Finally, a comparison of the track etch parameters for these glass detectors has been made.

Introduction

Due to diverse applications (Fleischer *et al.*, 1975) of solid state nuclear track detectors in the fields of nuclear physics, astrophysics, health physics, environmental science and nuclear geophysics for example, many types of plastic and glass detectors have been developed. For heavy ion studies, glass detectors play an important role due to particular advantages over other detectors such as the discrimination of light, charged particles, freedom from mechanical ruggedness, less prone to environmental changes and aging effects (Portwood *et al.*, 1986) etc. The outcome of the efforts made by different trackologists leads to the development of many new glass track detectors. Among them Price *et al.* (1987a, b) have found a very sensitive phosphate glass detector VG-13. However VG-13 has a number of disadvantages due to its uranium content. It is mildly hazardous to handle and it corrodes quickly in air. Wang *et al.* (1989) made a systematic search of phosphate glasses of various compositions which were free from uranium. This work resulted in the development of barium phosphate (BP-1) glass, a glass with highest charge resolution and sensitivity among glasses. Moreover, like other glasses the sensitivity of BP-1 is unaffected by the presence, or absence, of oxygen, so it can be used in space for identification of ultraheavy nuclei and isotopes of heavy nuclei in cosmic rays. In the present investigation, a quantitative analysis of different track etching parameters of the three glass track detectors, viz. BP-1, soda and quartz glasses have been made. Finally, an attempt has been made to check the suitability of BP-1 for the single sheet particle identification method and to select the optimum etching conditions for this new phosphate glass.

Experimental Details

Samples of soda, quartz and BP-1 phosphate glass track detectors were irradiated (using the UNILAC accelerator at GSI, Darmstadt, Germany) by ^{238}U ions having an energy 11.4 MeV/u. All these irradiations were carried out with ion fluences of 10^4 ions/cm^2 at angles of 45 and 90° with respect to the surface of the detector. These irradiated samples were etched at a series of constant temperatures of 40, 50, 60 and 70°C in a 48 vol% HF solution. After etching, the samples were washed in running water and then dried in the folds of a tissue paper. The etched and dried samples were scanned under the Carl Zeiss binocular microscope. The bulk etch rate V_b is determined by using two different techniques (Durrani and Bull, 1987): (1) the thickness measurement technique; and (2) weight loss method.

The track etch rate V_t is determined by taking the slope from the linear portion of the plot between track length and etching time. The track etching parameters viz. the sensitivity, the etching efficiency and critical angle of etching have been determined by using the following relations (Fleischer *et al.*, 1975), respectively:

sensitivity:

$$S = V_t/V_b,$$

track etching efficiency:

$$\eta = (1 - V_b/V_t)$$

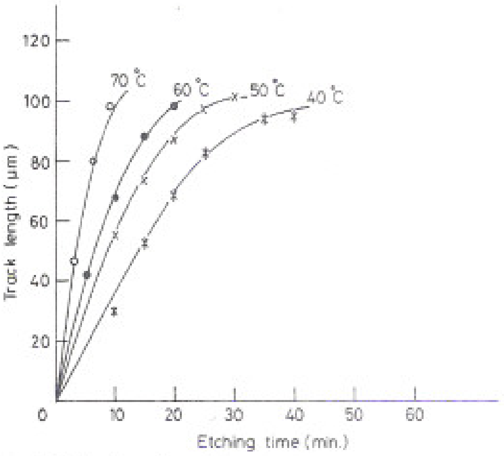

Fig. 1. Variation of track length with the etching time for ^{238}U (11.4 MeV/u) ion in BP-1 phosphate glass.

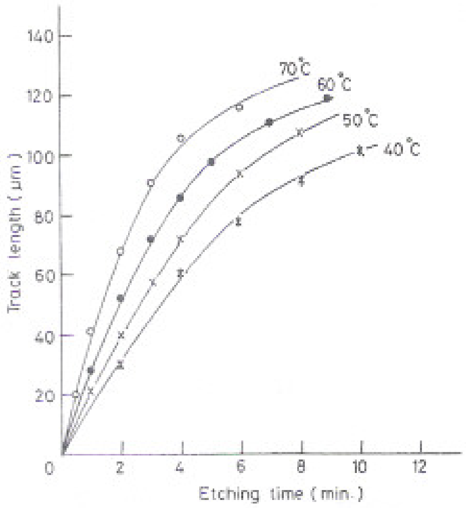

Fig. 3. Variation of track length with the etching time for ^{238}U (11.4 MeV/u) ion in quartz glass.

Critical angle of etching:

$$\theta_c = \sin^{-1}(V_b/V_t).$$

In order to choose the optimum etching conditions for BP-1 phosphate glass the etching has also been done in 6.25 N NaOH solution at different temperatures.

Results and Discussion

The variations of track length with etching time for ^{238}U (11.4 MeV/u) ion in BP-1 phosphate, soda and quartz glass detectors at different temperatures of the etching solution are plotted in Figs 1–3, respectively. The values of average track etch rates have been determined by taking the slope from the linear portion of these plots. The values of bulk etch rate (V_b), track etch rate (V_t), sensitivity (S), track etching efficiency (η) and critical angle of etching (θ_c) are summarized in Table 1. In the field of SSNTDs, the sensitivity S, given by the ratio of rate of etching along the path of the damaged trail to the rate of etching of the undamaged material is the most important parameter. From Table 1, it is evident that sensitivity S for BP-1 phosphate glass is many times more than that of the soda and quartz glasses. Hence, BP-1 is the most sensitive glass track detector. The sensitivity S of each detector decreases with an increase in temperature of the etching solution (Fig. 4). BP-1 phosphate glass has also been etched in 6.25 N NaOH solution. The values of different etching parameters for this glass are also given in Table 1. It is clear that the value of S is more in the case of 48 vol% HF than the 6.25 N NaOH solution. Hence, the 48 vol% HF is the most suitable etchant for the development of tracks in BP-1 phosphate glass. The track etching efficiency is one of the important criteria in the choice of a detector. BP-1 phosphate glass has the highest value of track etching efficiency among these glass track detectors. As the

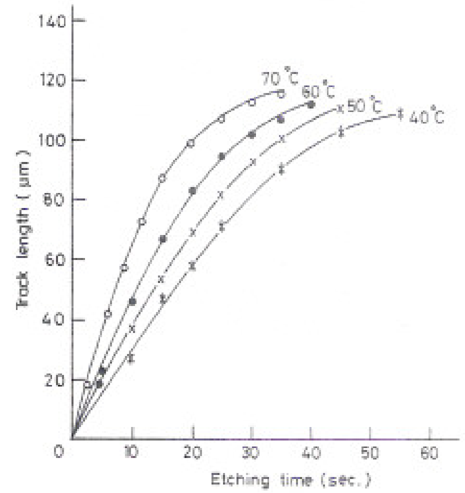

Fig. 2. Variation of track length with the etching time for ^{238}U (11.4 MeV/u) ion in soda glass.

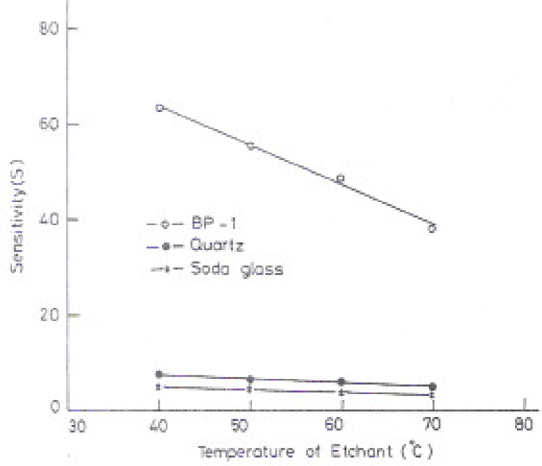

Fig. 4. Variation of sensitivity with the temperature of etching solution for ^{238}U (11.4 MeV/u) ion in BP-1 phosphate, quartz and soda glass.

Table 1. Track etching characteristics of BP-1, soda and quartz glass track detectors

Glass detector type	Etching solution	Temperature of etching solution (°C)	Sensitivity, $S = V_t/V_b$	Etching efficiency η (%)	Critical angle of etching, θ_c
BP-1 phosphate	48 vol% HF	40	63.46	98.42	0.90
		50	55.55	98.20	1.03
		60	49.03	97.96	1.16
		70	38.33	97.39	1.49
Soda glass	48 vol% HF	40	4.94	79.75	11.68
		50	4.81	79.21	11.99
		60	3.54	71.74	16.41
		70	3.34	70.10	17.39
Quartz glass	48 vol% HF	40	7.69	87.00	7.47
		50	6.64	84.96	8.65
		60	6.11	83.64	9.41
		70	4.92	79.66	11.73
BP-1 Phosphate	6.25 N NaOH	40	48.73	97.94	1.18
		50	33.56	97.02	1.70
		60	43.05	97.67	1.33
		70	33.36	97.01	1.71

tracks are inclined at less than cone angle θ_c (critical angle of etching) to a surface are not etched out, in order to make the tracks visible by etching in a suitable etchants, the angle of incidence of the particle to the detector surface should be greater than θ_c. The minimum calculated values of the critical angle are 0.90, 11.68 and 7.47° for ^{238}U (11.4 MeV/u) in BP-1 phosphate, soda and quartz glasses, respectively. Thus, it can be concluded that BP-1 phosphate glass can record the track of a particle even when it is incident at low azimuth angles. From the above results and discussion, it is concluded that the BP-1 phosphate glass is one of the most sensitive glass track detectors among all the commercially available glass track detectors. The bulk etch rate V_b and track etch rate V_t have exponential dependence on the temperature of the etching solution as given by the relation (Enge *et al.*, 1975):

$$V_b = A_b\, e^{-E_b/KT} \text{ and } V_t = A_t\, e^{-E_t/KT}$$

Where A_b and A_t are the constants, E_b and E_t are the activation energies for bulk and track etching respectively, and K is the Boltzmann constant. The values of E_b and E_t are calculated by plotting ln V_b and ln V_t vs (1000/T) for each detector. Such plots for BP-1 phosphate glass are given in Figs 5 and 6. The values of activation energies for bulk and track etching are given in Table 2.

Due to the higher sensitivity of BP-1 glass, it can be used for charge and isotopic resolution in cosmic ray studies. Among particle identification methods, single sheet identification (Price *et al.*, 1967; Randhawa and Virk, 1995) is the popular method. In

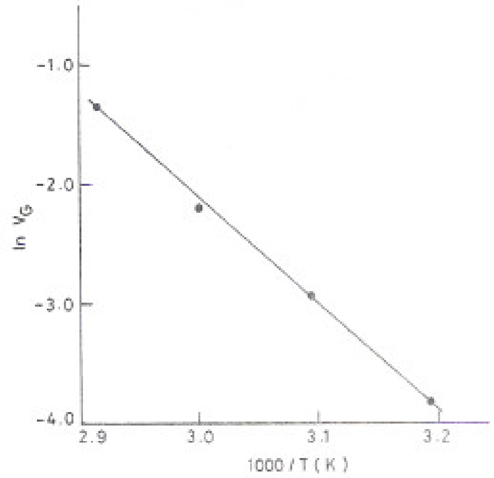

Fig. 5. Plot of ln V_b and 1000/T (K) for the determination of activation energy E_b in the case of the BP-1 phosphate glass.

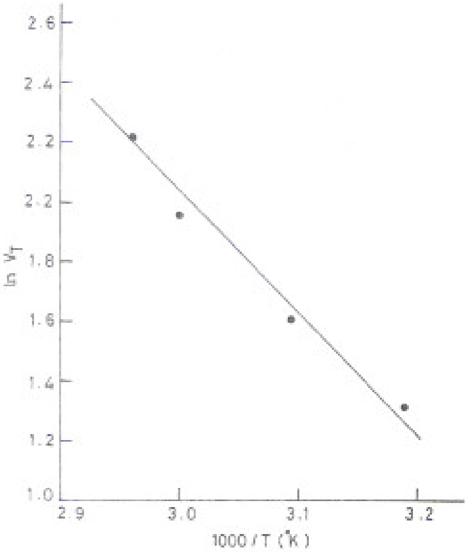

Fig. 6. Plot of ln V_t and 1000/T (K) for the determination of activation energy E_t in the case of the BP-1 phosphate glass.

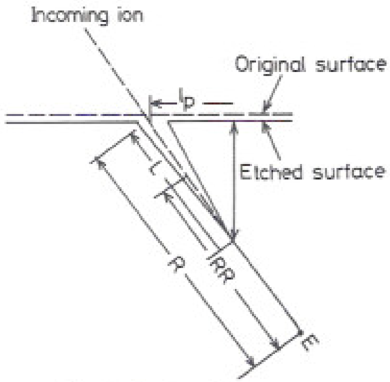

Fig. 7. Track etch geometry.

Table 2. Activation energies for bulk etching E_b and track etching E_t for different glass track detectors

Glass detector	Activation energy for bulk etching E_b (eV)	Activation energy for track etching E_t (eV)
BP-1 phosphate	0.76	0.35
Soda glass	0.36	0.23
Quartz glass	0.24	0.17

this method the residual range in plotted against track cone length. From Fig. 7, the residual range is defined as:

$$\text{residual range} = \text{total etchable range} - 1/2 \text{ track cone length},$$

$$\text{i.e. } RR = R - L/2.$$

A plot of RR vs L (Fig. 8) is drawn for the ^{238}U (11.4 MeV/u) ion in a BP-1 phosphate glass track detector. An interesting point to be noted here is that the variation of the residual range with the track cone length is independent of the temperature of etching solution. Since all the points corresponding to different pairs of (RR, L) lie on a single line (Fig. 8), hence, it is concluded that BP-1 phosphate is quite suitable for the single sheet particle identification technique.

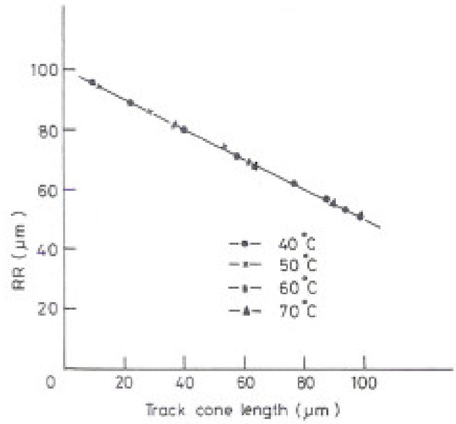

Fig. 8. Variation of residual range (RR) with track cone length (L) for ^{238}U (11.4 MeV/u) ions in BP-1 phosphate glass.

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