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Etching Studies of Radiation Damage in CR-39

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The influence of the etchant; its concentration and temperature on CR-39 is studied using normal as well as oblique (45°) incident ^{93}Nb ions (18 MeV/n). The results obtained are used to calculate the efficiency and critical angle for track etching in CR-39. It is found that as temperature or concentration of the etchant increases, the efficiency decreases, hence indicating that low concentration at low etching temperatures is favourable for higher detection efficiency.

Energetic heavy ions on passing through insulating materials[1] create a region of radiation damage—a region of high free-energy as compared to the virgin portion of the matrix. To optically reveal the path adopted by the penetrating ion, it is sufficient to treat it with a suitable reagent, which would erode off the damaged path faster than the untouched matrix[2-4]. During the process of chemical etching, the factors influencing the track geometry are the angle of incidence of the penetrating beam and the etch rates – V_b (bulk etch rate) and V_t (track etch rate).

A simple exponential dependence of V_b and V_t on temperature T, is given by the relations[5]:

$$V_b = A_b\, e^{-E_b/kT} \text{ and } V_t = A_t\, e^{-E_t/kT} \qquad \ldots (1)$$

where A_b and A_t are constants, E_b and E_t are activation energies for bulk and track etching respectively, and k is the Boltzmann's constant. It is observed that the above equation does not convey any message regarding the dependence of V_b and V_t on concentration of the etchant. These relations [Eq. (1)] should hence be replaced by the formulae of Somogyi and Hunyadi[6] taking concentration of etchant into account:

$$V_b = \alpha_b\, C^{n_b}\, e^{-E_b/kT} \text{ and } V_t = \alpha_t\, C^{n_t}\, e^{-E_t/kT} \qquad \ldots (2)$$

where $n_b = n_t$ are exponents of concentration and α_b, α_t are proportionality constants. There relations have been found to hold good for CR-39 (Ref. 6).

In the following, we present data on the etching carried out in ^{93}Nb ion-irradiated CR-39. Using the observed data, we have studied the influence of various parameters on etch rates, V_b and V_t. We find Eq. (2) to be the best fit to our approach. The work is extended to determine the critical angle and efficiency of track etching at different concentrations and temperatures in CR-39.

Irradiation and etching conditions—Samples of CR-39 were irradiated with 18 MeV/n ^{93}Nb ion beam, using GSI Darmstadt, at azimuth angles of 45° and 90°, respectively. Etching was carried out with different concentrations, i.e. 5, 6, and 7N of NaOH solution at temperatures of 55, 60, 65 and 70°C. Under the same temperature conditions, KOH of 5N was also used to etch the samples, so as to observe the effect of different etchants on the radiation damage created by the ions.

Etch rate measurements—It has been observed that in cases, as in ours, where the ratio V_t/V_b is large, the diameter method, i.e.

$$D = 2\, V_b t \qquad \ldots (3)$$

can be used to find the value of bulk etching rate V_b.

The value of V_t is obtained from the equation:

$$V_t = L/T \qquad \ldots (4)$$

where L is the length obtained after applying corrections for bulk etchig and over etching[7].

The values of V_b and V_t are obtained graphically after applying standard deviation correction to both D and L.

Effect of etchant parameters—An extensive effort to study the effect of the following parameters on bulk and track etching is taken up:

(i) Etchants	NaOH	KOH
(ii) Normalities	5N-7N	5N
(iii) Temperatures	55,60,65,70°C	

The bulk etching rate (V_b) and track etching rate (V_t) are obtained for both the etchants under all possible combinations of the above parameters.

To study the effect of normality on V_b and V_t, graphs between $\log V_b$ and $\log V_t$ versus $\log C$ (Figs 1 and 2) at different temperatures are plotted using Eq. (2), it is observed that n_b and n_t values are 1.64 and 0.564, respectively. Comparing them with those of Somogyi and Hunyadi[6] it is seen that whereas the values of n_b is nearly the same, that for n_t is quite different (Table 1).

Graphs are also plotted between log V_b and

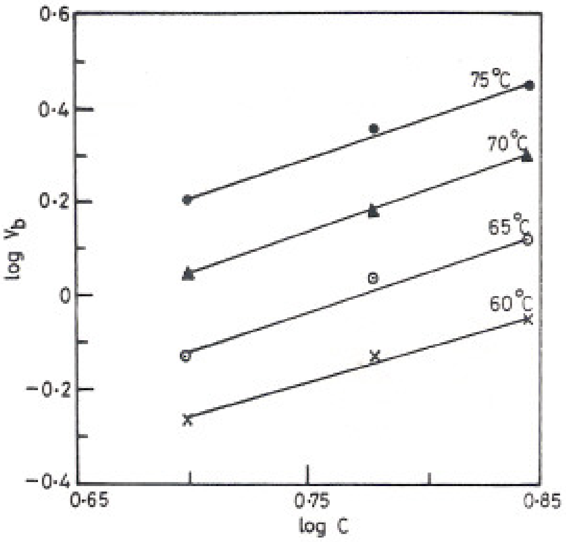

Fig. 1—Plot of log V_b versus log C at different etching temperatures

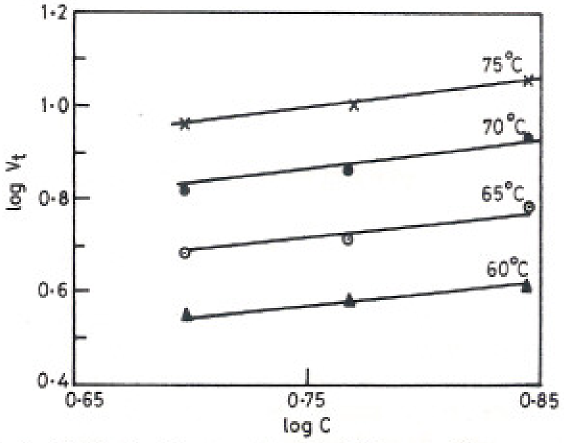

Fig. 2—Plot for log V_t versus log C at different etching temperatures

Table 1—Values of n_b, n_t, E_b and E_t for Different Etchants on CR-39	NaOH				KOH	
	n_b	n_t	E_b(eV)	E_t(eV)	E_b(eV)	E_t(eV)
Present study	1.64	0.564	0.77	0.70	0.74	0.73
Somogyi and Hunyadi[6]	1.33	1.75	0.88	0.88	—	—
Al-Najjar *et al.*[9]	1.80	—	0.73	—	—	—
Modgil and Virk[11]	1.53	—	0.74	—	0.73	—

log V_T versus $1/T$ at different concentrations (Fig. 3 and 4). The constant values obtained for the slopes at different concentrations indicate that the activation energies for bulk and track etching, i.e. E_b and E_t are constants, independent of concen-

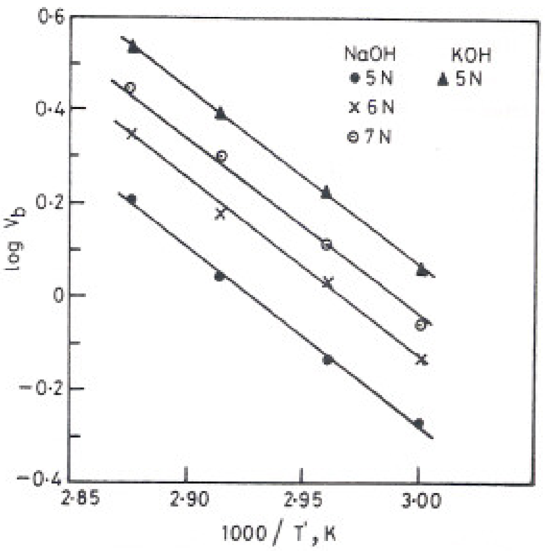

Fig. 3—Plot for the determination of E_b for two different etchants

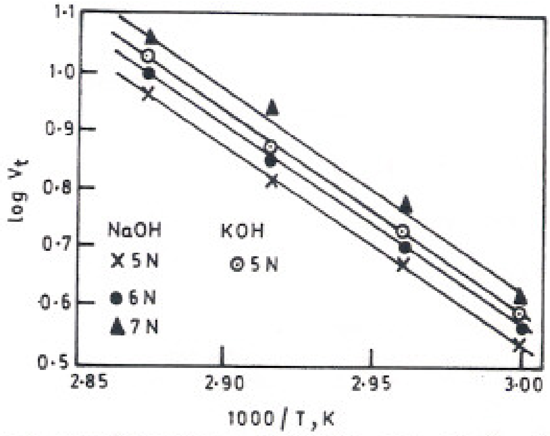

Fig. 4—Plot of log V_t versus $1000/T$ for determination of E_t for two different etchants

tration, a result in contradiction with that of Singh and Sharma[8]. Also incorporated into Figs 3 and 4 is the graph for 5N KOH etchant. It is evident from the parallelism of the different graphs that E_b and E_T are independent of the etchant used (Table 1). The results are compared with those of other authors as shown in Table 1 (Ref. 9).

Critical angle and efficiency determination—The etching efficiency for track detection was calculated from the relation:

$$\eta = 1 - V_b / V_t \qquad \ldots (5)$$

Replacing V_b and V_t in terms of concentration and temperatures we have:

$$\eta = 1 - \frac{a_b C^{n_b} e^{-E_b/kT}}{a_t C^{n_t} e^{-E_t/kT}}$$

Table 2—Values of θ_c, η, α_b/α_t Under Different Etchant Concentration and Temperature

Concentration	Temp. (K)	α_b/α_t	θ_c	η%
5N	328	0.0027	0.107	99.80
	333	0.0024	0.110	99.80
	338	0.0028	0.120	99.79
	343	0.0029	0.129	99.77
6N	328	0.0033	0.160	99.72
	333	0.0033	0.163	99.71
	338	0.0035	0.180	99.68
	343	0.0037	0.200	99.65
7N	328	0.0036	0.205	99.64
	333	0.0025	0.145	99.74
	338	0.0038	0.232	99.59
	343	0.0035	0.218	99.57

or

$$\eta = 1 - \frac{\alpha_b}{\alpha_t} C^{n_b - n_t} e^{(E_t - E_b)/kT} \qquad \ldots (6)$$

Similarly, the critical angle

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

can be rewritten and is given by

$$\theta_c = \sin^{-1} \alpha_b/\alpha_t \, x_C^{n_b - n_t} e^{(E_t - E_b)/kT} \qquad \ldots (7)$$

From Eqs (6) and (7), it is clear sthat as n_b, n_t, E_b, E_t and k are constants, η and θ_c should depend on the ratio α_b/α_t, C and T.

The values of θ_c, η and α_b/α_t under different etching conditions using Eqs (6) and (7) are given in Table 2. It is felt that α_b/α_t tend to increase with the increase of temperature and concentration of the etchant; provided one of the parameters is kept constant.

The variation of θ_c and η with temperature and concentration is also studied. Value of θ_c is found to increase with the rise of the etchant concentration for a particular temperature and with the increase of temperature for a particular concentration as evident from Eq. (7). The efficiency of the detector is found to vary inversely with temperature and concentration under the condition that one of the parameters is kept constant while the other is varied. It has been observed that θ_c and η calculated above vary appreciably from values given using the data obtained by other authors [Ref. 10]. For CR-39, Eqs (6) and (7) can be expressed as:

$$\eta = 1 - \frac{\alpha_b}{\alpha_t} C^{1.076} e^{-\frac{812.06}{T}} \qquad \ldots (8)$$

where as

$$\theta_c = \sin^{-1} \alpha_b/\alpha_t \, C^{1.076} e^{-\frac{812.06}{T}} \qquad \ldots (9)$$

It may hence be concluded from our discussion that low concentration of etchant at low etching temperatures is favourable for higher detection efficiency in CR-39; as already observed in glass detectors by Modgil and Virk[11].

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