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Etching properties of a Homalite polycarbonate nuclear track detector

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Experiments have been performed to study the chemical etching properties of a Homalite CR-39 nuclear track detector under different etching conditions of temperature T (50–80 °C) and concentration of NaOH solution C (5–10 N). The bulk etch rate (V_B) was determined by the weight method and found to be strongly dependent on both T and C. An average value of etching activation energy of 0.83 ± 0.04 eV was found. This was independent of the absorbed gamma dose in the studied detectors.

1. Introduction

In recent years the use of solid state detectors [1–3] in radiation dosimetry has grown rapidly. Etched solid state nuclear track detectors, where nuclear radiations produce latent trails (tracks) in such recorders, have found many technological applications [4, 5]. Development and measurement of these tracks cannot be performed without etching such detectors.

In general, etching is a diffusion process and the bulk etch rate is essentially dependent on the type, temperature and concentration of etchant solution, as well as on the duration period of the etching process. Several authors [6–9] have studied the etching properties of various plastic materials.

In the present work, various experiments have been performed in order to study the V_B characterization of a Homalite CR-39 nuclear track detector under different etching conditions of concentration and temperature of NaOH solution. Such measurements are necessary and it is important that they be stored on a computer disk for any further work with such detectors, so that one can easily choose the best etching conditions for a specified experiment without any further measurements of V_B.

The effect of gamma irradiation on detector properties was also studied through V_B measurement before and after irradiation. The induced changes in V_B due to irradiation are then a measure of the gamma effectiveness on the material properties.

Also, in this investigation the etching activation energy (E_b) of the bulk material was obtained and the effect of gamma doses on E_b values is discussed.

2. Experimental procedure

2.1. Samples used in this study

Sheets of CR-39 allyl diglycol carbonate manufactured by Homalite (Wilmington, DE, USA) have been used in the current experiments. Plastic sheets were cut into pieces of about 6 cm^2 in area in order to minimize uncertainties in V_B measurements.

2.2. The bulk etch rate (V_B) measurements and irradiation facilities

The bulk etch rate was determined by the measurements of the mass decrement (Δm) of the plastic detector as a result of etching. V_B was then calculated according to the relation

$$V_B = \Delta m / 2A\rho t_e$$

where A and ρ are the surface area and the density of the detector material and t_e is the etching time. More details about the methodology and precautions in V_B measurement have been fully described elsewhere [5].

CR-39 plastic sheets were exposed in air to different gamma doses using a ^{60}Co gamma cell as a source of gamma radiation with an exposure rate of 10.35 Krad min^{-1}.

3. Results and discussion

The bulk etch rate of the CR-39 detector was determined at temperatures of 50, 60, 65, 70, 75 and 80 °C with different concentrations of an aqueous solution of NaOH, namely 4, 5, 6.25, 7, 8, 9 and 10 N. The bulk etch rate data represented against NaOH normality (C) in the temperature range 50–80 °C are given in Fig. 1, where $\ln V_B$ is plotted versus $\ln C$. It is clear from Fig. 1 that the dependence of V_B on etchant concentration follows a power law and can be described by an empirical power function given by

$$V_B = A_1 C^n \quad (1)$$

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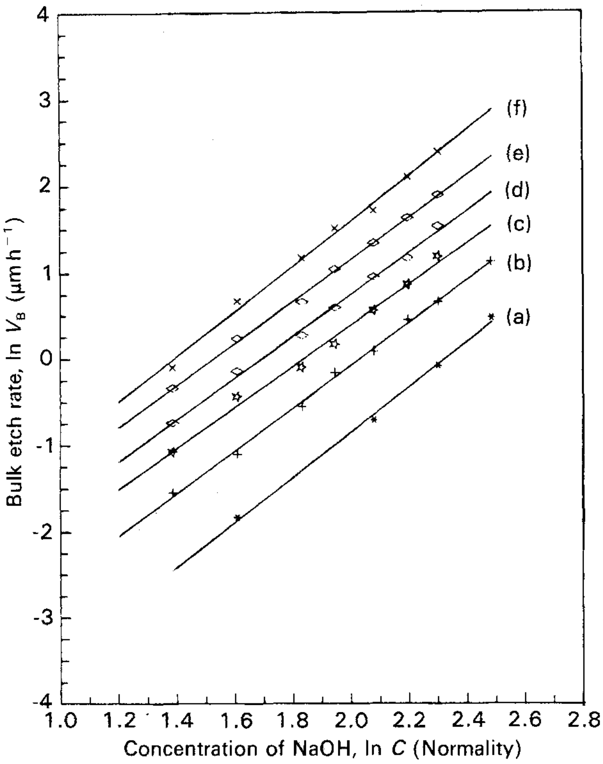

Figure 1 Relation between bulk etch rate (ln V_B) of CR-39 and etchant concentration (ln C) at different temperatures; curves a, b, c, d, e and f represent samples etched at 50, 60, 65, 70, 75 and 80 °C, respectively.

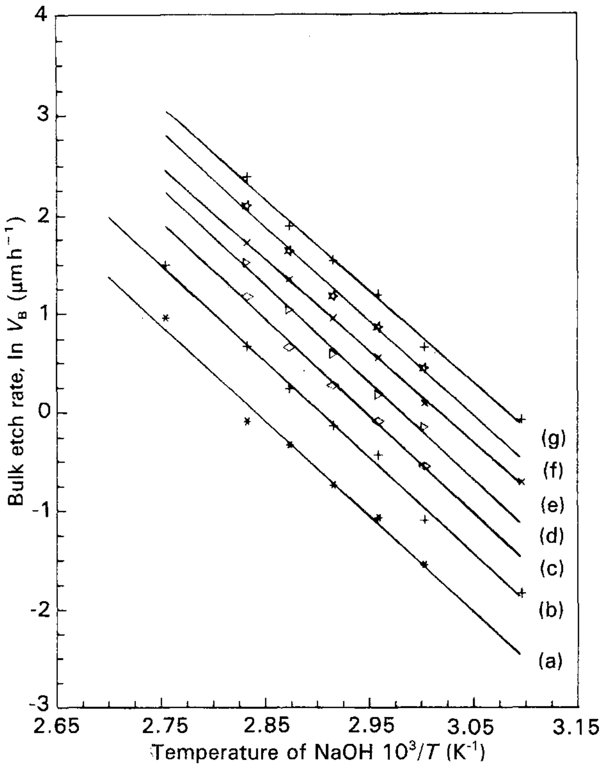

Figure 2 Relation between bulk etch rate (ln V_B) of CR-39 and etchant temperature ($1000/T$) at different concentrations; curves a, b, c, d, e, f and g represent samples etched in 4, 5, 6.25, 7, 8, 9 and 10 N NaOH, respectively.

TABLE I Values of etching constants from Equation 3

T (°C)	n	A
50	2.609	2.068×10^{10}
60	2.47	2.4×10^{10}
65	2.378	3.012×10^{10}
70	2.415	2.639×10^{10}
75	2.425	2.588×10^{10}
80	2.61	1.884×10^{10}

where A_1 is a constant, C is the etchant concentration given in normality and n is the exponent. Such power dependence is in good agreement with those given in [6, 8, 10].

The values of n (see Equation 1) were then calculated from the slopes of the straight lines given in Fig. 1. Table I contains the extracted values of n, which were found to vary slightly with the etching temperature. For an estimated value of n one can get a value of 2.46.

Fig. 2 shows the dependence of ln V_B on T (K^{-1}) and the results reflect an exponential behaviour of V_B with T which can be expressed by the relation

$$V_B = A_2 \exp - (E_b/kT) \quad (2)$$

where A_2 is a constant, E_b is the activation energy for bulk etching and k is the Boltzmann constant. Using a least square fit method, the values of E_b were calculated from the slopes of the straight lines given in Fig. 2. An average value of E_b was found to be 0.83 eV, where the maximum discrepancy in E_b was better than 5%. Previously, Cartwright *et al.* [11] reported an E_b value of 0.85 ± 0.05 eV, while values of 0.88 ± 0.04, 0.78 ± 0.03 and 0.88 eV have been given [10, 12–13]. Since E_b is essentially a property of the detector material and due to the background radiation in our

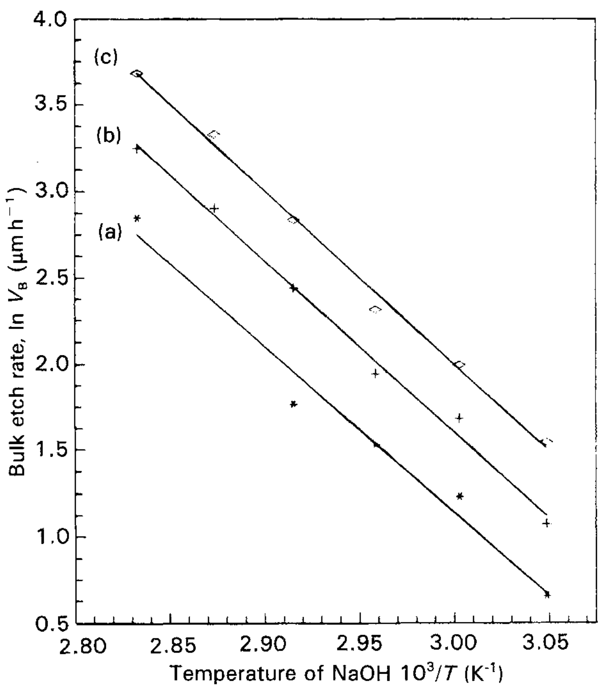

Figure 3 Relation between bulk etch rate (ln V_B) of CR-39 and etchant temperature ($1000/T$); curves a, b and c represent samples exposed to 5, 10 and 15 min Mrad γ-dose, respectively. Etched in 6.25 N NaOH

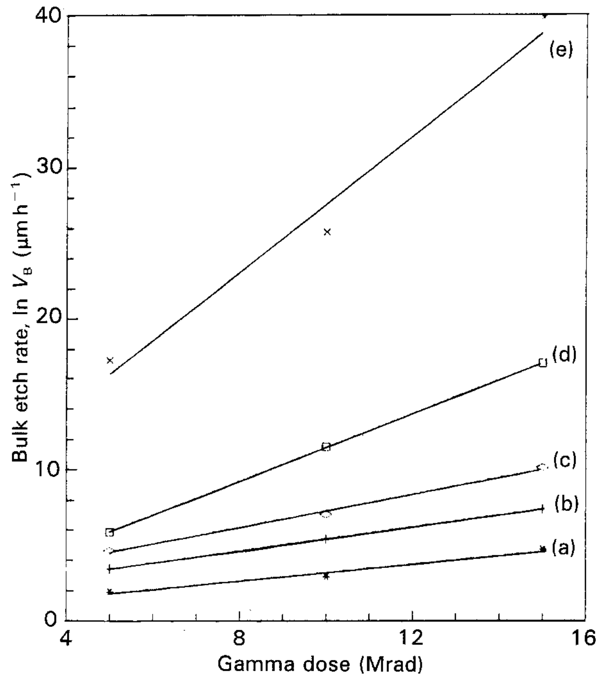

Figure 4 Variation of bulk etch rate (V_B, μm h^{-1}) versus gamma dose (Mrad) for CR-39; curves a, b, c, d and e represent samples etched in 6.25 N NaOH at 55, 60, 65, 70 and 80 °C, respectively.

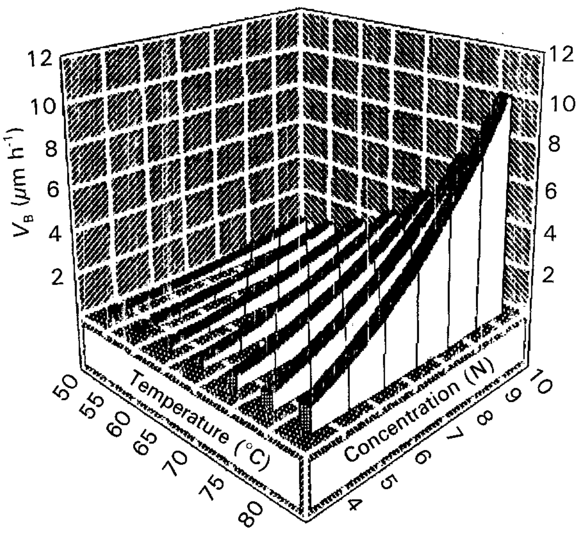

Figure 5 The dependence of bulk etch rate (V_B) on both etching temperature and concentration.

laboratory, especially those arising from gamma rays, it was necessary to study the effect of gamma doses on the value of E_b. For this purpose, samples of CR-39 detectors were exposed to 5, 10 and 15 Mrad gamma doses.

The bulk etch rate values of such irradiated samples were determined at various temperatures from 50 to 80 °C. Fig. 3 shows the variations of ln V_B versus T^{-1} for samples etched in 6.25 N NaOH. It is clear from this figure that V_B still varies with T through an Arrhenius equation, and the value of E_b was then extracted from the slope of the straight lines. E_b values of 0.83, 0.85 and 0.86 were obtained for plastic samples exposed to 5.0, 10.0 and 15 Mrad γ-doses, respectively. This result reflects the independence of E_b with regard to the absorbed gamma dose in the plastic samples. The values of V_B are gamma dose-dependent (see Fig. 4), where V_B is plotted against gamma dose for samples etched in 6.25 N NaOH at temperatures of 55, 60, 65, 70 and 80 °C. Fig. 4 illustrates the linear dependence of V_B on gamma dose, where V_B increases with increasing gamma dose. Fig. 5 illustrates a three-dimensional representation which shows the dependence of V_B on both etchant normality and temperature for unirradiated detectors.

Analysis of the data given in Figs 1 and 2 leads us to express the bulk etch rate in an explicit form, as a function of both concentration and temperature, through the relationship

$$V_B(C, T) = AC^{2.46} \exp - (0.83/kT)\ \mu\text{m h}^{-1} \qquad (3)$$

where A is the proportionality constant and is found to vary with etchant temperature. Values of A are given in Table I.

From the above results it can be concluded that V_B is obviously a strong function of C and T (see Equation 3) and the data obtained would furnish a V_B map that can be used in selecting the optimum etching conditions for any further experiment.

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