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Interrelated temperature dependence of bulk etch rate and track length saturation time in CR-39 detector

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ABSTRACT

Experimental measurements of the etching solution temperature dependence of bulk etch rate using two independent methods revealed a few interesting properties. It is found that while the track saturation length is independent of etching temperature, the etching time needed to reach saturation is strongly temperature-dependent. It is demonstrated that there is systematic simple inverse relation between track saturation time, and etching solution temperature. In addition, and although, the relation between the bulk etch rate and etching solution temperature can be reasonably described by a modified form of the Arrhenius equation, better fits can be obtained by another equation suggested in this work.

1. Introduction

Two types of temperature effects on the detection properties of solid states nuclear track detectors are usually studied. The first involves the study of changes in detector optical properties, such as absorbance and transmittance, caused by heat treatment of the detector prior and/or after the irradiation. In this type of study, the detector is subjected to different temperatures for different lengths of time, and track diameters and/or length development is studied [1–8]. The second type of study is related to the effects of etching solution temperature and concentration on track properties. One example in this respect is the work of Hermsdorf et al. [9] where the etching solution concentration and temperature were varied in the range of $0.5\ \mathrm{mol\,l^{-1}} < c < 22\ \mathrm{mol\,l^{-1}}$, and $313 < T < 353$ K respectively. The main two detector parameters that govern the track development are the bulk etch rate V_B and the track etch rate V_T [10–13]. The former represents the direct result of removal of detector's undamaged layers by the chemical reaction of the detector material with the etching solution. This results in layer by layer removal with the net result of reduced detector thickness.

Critical assessment of the behavior of V_B against varying the above mentioned conditions in general and temperature in particular, becomes necessary in various applications of SSNTD [14,15]. Several methods are used in such studies. These can be categorized into indirect and direct methods [16]. One commonly-used method involves the direct measurement of thickness eroded from the detector surface during the etching after different etching times, using un-irradiated detector. The average bulk etch rate in this case is given as [16]:

$$V_B = \frac{1}{2}\frac{\Delta h}{\Delta t} \tag{1}$$

where Δh is the change of thickness in Δt etching time. The factor "2" above takes account of the removal of the thickness from both sides of the flat surfaces of a detector sheet. Although the above mentioned method is the simplest one, it has been widely known to yield erroneous results [17,18]. This is due to the fact that the surfaces of the detector becoming uneven after etching. Uneven surfaces yield different values of thickness at various locations on the detector surface. Moreover, for the short etching time intervals, prior to the stabilization of the water absorption from the etching solution, the net thickness of CR-39 increases in spite of the surface removed. It is due to these reasons that Eq. (1) has been modified by substituting $\Delta m/\rho A$ in place of Δh [4]:

$$V_B = \frac{1}{2}\frac{\Delta m}{\Delta t \rho A} \tag{2}$$

where "Δm" is the mass of the removed surfaces, "A" is the area of one of the flat surfaces and "ρ" is the detector density.

The other method used to measure V_B is called the *L–D* method. It is based on studying the relation between the tracks length L and diameter D for irradiated detectors, and using the relation [19]:

$$V_B = \frac{D^2}{4tL}\left[1 + \sqrt{1 + \frac{4L^2}{D^2}}\right]. \tag{3}$$

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In this work, we try to use both methods with the invocation of computer image processing technique to measure, Δh, L, and D. This technique gives more accurate results due to the fact that measurements accuracies are governed by the image pixel size calculations. The measurement accuracy of this method is estimated to be better than 3%.

2. Experimental

Computer digital image processing techniques are used to obtain the V_B values using both methods discussed above. For the removed thickness measurement method, un-irradiated 1×1 cm, 200 μm thick CR-39 detectors made by Page Moldings (Pershore, UK) was etched for several time intervals, followed by washing and drying. A lateral microscope digital image was obtained. A typical image is shown in Fig. 1. The pictures were later analyzed to obtain the remaining detector thickness thorough application of digital pixels to micron thickness conversion. The value of V_B after each etching process was obtained from defining sharp boundaries between contrasting picture regions derived from color contours

Fig. 1. Digital image of the lateral view of etched un-irradiated detector.

In order to obtain track longitudinal profiles and track diameters at different etching temperature and etching times, detectors were exposed to alpha particles from a ^{241}Am source with 3.2 MeV energy. The exposure system involves narrow collimation in order to obtain an almost perpendicular incidence angle. The detectors are sharply broken at the small 1 mm^2 exposed area. The etching is carried out in 6.25 N NaOH solutions, at temperatures of 338–358 ± 1 K in 5 K steps. The detector is etched for 15 min and then digitally photographed by a digital USB camera (OPTICA 4083.B5) attached to OPTIKA B-193 microscope. The obtained images are directly saved on the PC Typical such images are shown in Fig.2. The etching process is repeated over several 15 min periods, and a digital picture for the longitudinal and lateral development of the tracks are captured and saved for further analysis.

3. Results and discussions

Thickness results from the first method discussed above are used to calculate V_B using Eq. (1). The bulk etch rate is determined by performing a linear fit of Δh versus t. The results are presented in Fig. 3, which shows the experimental data and linear fit results at solution temperatures of 65, 70, 75, 80, and 85 °C. Values of V_B as calculated from Eq. (1) are shown in Table 1.

Results of measurements of L and D versus etching time are shown in Fig. 4. Values of L prior to track length saturation together with the corresponding D values are substituted in Eq. (3) to calculate V_B. The results related to the time development of V_B are presented in Fig. 4c. This indicates that there are no significant variations of V_B with the exception of those related to the highest temperature. The time averaged results of all V_B values are presented on the third column of Table 1. It may be worth mentioning here that the track saturation length in Fig. 4a is independent of etching temperature. This gives further credibility to the measurement technique used. Fig. 5 shows the results of track saturation time t_{sat} relation to temperature as derived from Fig. 4a. These data are well described by the exponential form relation:

$$t_{sat} = a_1 e^{-\frac{T}{a_2}} - a_3 \quad (4)$$

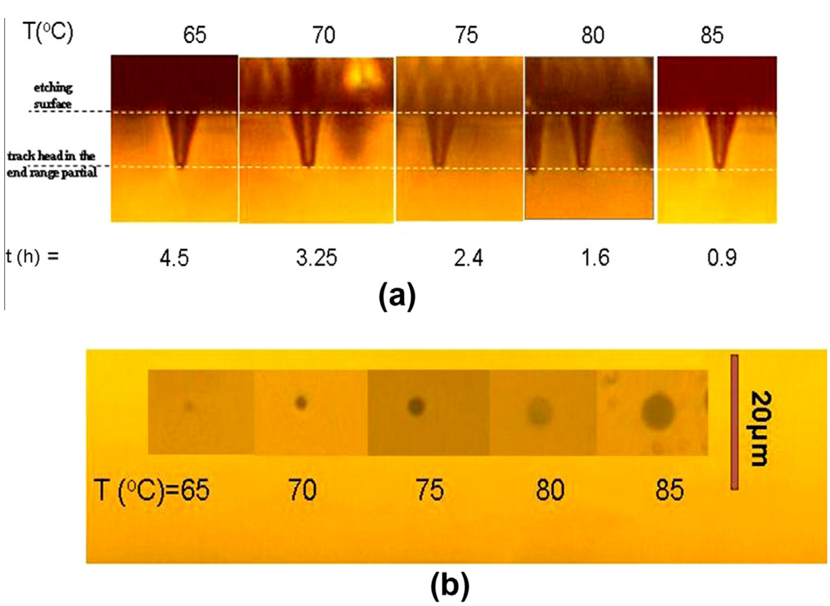

Fig. 2. Digital images of: (a) track length, (b) track diameter at 1 h for E = 3.2 MeV.