Track parameters investigate of oblique incident of alpha particles irradiated CR-39 detector

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Abstract
In this work, the track etch-rate $V_T$ and etch-rate ratio $V$ of CR-39 detector irradiated by alpha particles was investigated at different incident angles. The change of the track etch-rate and etch-rate ratio along the particle trajectories showed that these functions are not affected by the inclination of the particle trajectory with respect to the normal on the detector surface.

Keywords: Oblique incident; Track etch-rate; Alpha particle; SSNTD; CR-39 detector.

1. Introduction

There are many Applications of CR-39 detectors in nuclear physics, radon and neutron dosimetry, space physics, cosmic ray physics, particle accelerator physics, archeology, geology needs to know the detector efficiency at given etching conditions in dependence on energy and direction of type particles or charged particles[1-5]. This function can be determined by calibration experiments only partially [6]. The empirical modeling is used as an alternative option to describe the CR-39 results. This comes from the fact that there is no analytical method that fully describes the formation and evolution of the track as a function of etching time at different irradiation energies [7-12]. However, to understand the track growth mechanism, numerous theoretical studies have been reported in the past. The etch rate ratio, $V$, represents the ratio between of the track etch rate, $V_T$, to the bulk etch rate, $V_B$, all are crucial in
describing the track formation mechanism. The condition that makes latent track to appear can be verified when the track etch rate is larger than the bulk etch rate of the undamaged detector material \( V_T > V_B \) or \( V > 1 \) [13, 14]. They both depend on several parameters: (i) mass, charge and energy of incident particle; (ii) the type, temperature and concentration of the etching solution [15,16] (Azooz and Al-Jubbori, 2016; Bahrami et al., 2016). Different efficiency of CR-39 (V functions) have also been summarized by several authors including Green et al [17] Fromm et al [18], Burn et al [19] Nikezic et al [20], Yu et al 2005[21,22], Hermsdorf 2009 [23], Al-Jubbori 2020 [24]. The current study aims to establish a new set data for track length, track etch-rate and the etch-rate ratio \( V \) at energy 2.4 MeV with incident angle \( (0, 10, 30, 50)^\circ \).

2. Experimental

CR-39 using to implement all experiments with a thickness of 200 µm. Samples of detector (size: \( 1 \times 1 \text{ cm}^2 \)) were irradiated by alpha particles from \(^{241}\text{Am} \) with energy of 2.4 MeV. Oblique particle incidence has been achieved by mounting the detectors on wedges of a definite sloping angle. The present studies were carried out, therefore, at angles of incidence of \( \theta =0 ,10, 30 \) and 50 with respect to the normal on the detector surface. The angular uncertainty was about \( \pm 1.25^\circ \). Etching of the samples was performed in 6.25 N NaOH at 70°C resulting in a bulk etch rate of \( V_B = 1.55 \pm 0.05 \text{ mh}^{-1} \). This value has been determined by removed thicknesses layer method. The detector evaluation was carried out using a NIKON microscope linked with a camera 5ACDC.

3. Results and Discussions
The etch track generated by an alpha particle with energy $E$ and angle of incidence $\theta$ with respect to the normal showed in Fig. 1. During the etching time $t$ a detector layer $h=V_B t$ is removed by bulk etching with the etch rate $V_B$. After the same time the depth of track $x$ is reached by etching along the particle trajectory with the track etch rate $v_T$. To determine the track etch rate $V_T$ at the etching time $t$ that $\theta$ is smaller than a critical angle, $\theta_C$, given by $\theta_C = \arccos \left( \frac{V_B}{V_T} \right)$ where $V_B$ means the bulk etch-rate. However, the track etching is overtaken by the bulk etching. The condition $\theta_C \geq \theta$ is valid already at the beginning of the etching process and that the track is not over etched, the relation of length and the track etch rate, is

$$L = \cos(\theta) \int_0^t V_T dt - h \quad (1)$$

Where, $h=V_B t$

To obtund the $V_T$ derivation Eq. (1)

$$V_T = \frac{1}{\cos(\theta)} \left[ \frac{dL}{dt} + V_B \right] \quad (2)$$

The relation between track length, $L$, and track depth $x$ is

$$x = \frac{L+h}{\cos(\theta)} \quad (3)$$

The residual range ($R'$) is

$$R' = R - x \quad (4)$$

where $R$ range of alpha particle in CR-39
Fig. 1. Schematic diagram of the etching track.

Fig. 2 show the track length( L) as a function of etching time at alpha particle energy 2.4 MeV with incident angles (0, 10, 30 and 50)°. It can be seen from figure (2) that there is a non-linear relation between the track length and the etching time before reaching the saturation. After that, the track length remains constant for the rest of etching time.

Fig. 3 show the track etch-rates V_T have been calculated from Eqs. (2) using the functions L measured at perpendicular and oblique particle incidence. Fig. 3 illustrate the results for alpha particles with initial energy 2.4 MeV. It is apparent from Fig. 3 that the V_T values do not differ at \( \theta = 0^\circ \) (perpendicular incident) and 10°, 30°, 50° (oblique incident) for the alpha particles studied. That means, the variation of the track etch-rate along the particle trajectory is independent of its inclination to the normal on detector.
Fig. 2 Track length (L) measured as a function of etching time (t)

Fig. 3 Track etch-rate as a function of the etching time.
Fig. 4 shows the values of etch-rate ratio \( (V = V_T / V_B) \) versus residual range \( (R') \) for four incident angles of alpha particle energy. It can be clearly seen from the figure that \( V \) rapidly increases with \( R' \) reaching maximum value and then slowly decreases as well as that reflects the Bragg curve. That means the etch-rate ratio is independent on incident angle, this was confirmed by Dörschel et al. (2003) [25].

![Etch-rate ratio versus residual range](image)

**Fig. 4 Etch-rate ratio versus residual range**

**Conclusions**

To summarize, CR-39 was exposed to alpha particle source and the length of the generated tracks were measured as a function of etching time. The result are then used to calculate the track etch-rate and etch-rate ratio as a function of etching time and the residual range respectively. Based on the above, the change of track etch-rate along the alpha trajectories show that it does not depend of the inclination of the alpha trajectory with respect to the normal on the detector surface for
homogeneous detector material. This fact has been checked experimentally for detectors exposed to alpha particles of four different angles. No difference between the results for perpendicular and oblique particle incidence was found for track etch-rate ratio and etch-rate ratio.

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