

# Jordan Journal of Physics

## ARTICLE

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### Effects of Ultrasound in Etching and Detecting Parameters of CR-39 Detector

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*Received on: 3/4/2012      Accepted on: 18/3/2014*

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**Abstract:** Effect of 40 kHz ultrasound (US) in chemical etching of alpha-particle tracks in CR-39 solid state nuclear track detector were investigated. Alpha-particle irradiations (using 1  $\mu\text{Ci}$   $^{241}\text{Am}$  source) were made with different energies under normal incidence. All track etch rates  $V_D$ ,  $V_B$ ,  $V_T$  and  $V$  increased, but the critical angle of the detector  $\theta_C$  decreased. The maximum increase in the bulk etch rate  $V_B$ , the track's diameter growing rate  $V_D$ , the etch rate ratio  $V$ , the etching efficiency  $\eta$  and sensitivity  $S$  were about 12% , 20%, 25%, 12.5% and 27.2%, respectively, while the decrease in the critical angle was about 15.2%. These results were in agreement with those found by [1, 2]. A minimum detection threshold energy of alpha-particle  $\sim 0.2$  MeV was recorded.

**Keywords:** CR-39; Ultrasound; Track Etch; Alpha Particle.

## Introduction

The environmental factors play an important role in estimating the real effects of charged particles in solid state nuclear track detectors (SSNTDs). SSNTDs, especially plastic ones, can be subjected to one or more factors which may produce physical or chemical changes in the registration and detection properties of the detector [3,4,5]. The environmental conditions improve the etching and detecting parameters of the detectors, such as the bulk etch rate  $V_B$ , the track etch rate  $V_T$ , the etching rate ratio (the sensitivity)  $V$ , as well as the angular and energy responses. The produced enhancement increases the ability of the detectors to detect particles having low energies [6].

Ultrasound (US) is considered one of the factors which affect the properties of the solid state nuclear detectors [1]. The vibration produced by the ultrasound source may excite the molecules of the detector material and the

free radicals formed in the damaged regions through particle irradiations. The excitation induced by ultrasound increases the latent energy of the damaged regions produced by the incident particles which get more degradation through etching than the damaged regions etched without ultrasound. Therefore, any increase in degradation of the damaged regions leads to increase the track etch rate which subsequently leads to increase the track's diameter and size.

The effects of different factors on the parameters of solid state nuclear track detectors have been investigated. The effects of high doses of electromagnetic radiations such as: Gamma rays , X-rays , Laser and UV lights [4, 7-12], Ultrasonic waves [1,2,13], electric field [6] and annealing temperature [14] have

been studied. Other conditions were also taken into consideration; the concentration and temperature of the etching solution [15], the

chemical additives to the etching solution [16], effects of stirring [17, 18] as well as the presence of oxygen and the humidity during particle irradiation of the detector [19].

All these factors showed significant effects on the characteristics of solid state nuclear track detectors such as: the track's diameter and size, the track depth, the energy response, the bulk etch rate  $V_B$ , the track etch rate  $V_T$  and the etch rate ratio or detector sensitivity  $V$ , in CR-39, LR-115, cellulose nitrate and PM-355 detectors.

In the present work, the possible effects of ultrasound energy in the chemical etching of particle tracks in plastic solid state nuclear track detectors CR-39 were investigated.

## Methodology

CR-39 detectors of 550  $\mu\text{m}$  thickness were used from Page Mouldings (Worcestershire, England). Two sets of alpha-particle irradiated detectors were prepared: (1) only chemically etched (2) chemically etched under ultrasound impact for different etching durations.

Alpha-particle irradiations (using 1  $\mu\text{Ci}$   $^{241}\text{Am}$  source, main emitted alpha energy = 5.495 MeV) were made with energies of 0.2, 0.5, 1, 1.5, 2.5, 3.5, 4.5, 5.49 MeV under normal incidence. The alpha-particle energies were varied by changing the source to detector distance in air under atmospheric pressure. Ultrasound-induced chemical etching of alpha-particle irradiated detectors was performed using an ultrasonic bath (ULTRASONIC CLEANER MODEL FXP 20, Australia) at 40 kHz. Both sets of detectors were etched in a 6.25N aqueous solution of KOH at  $70 \pm 1^\circ\text{C}$ . The gravitational method [3, 4, 20] was used to measure the bulk etch rate  $V_B$ . The track openings diameters were measured under an optical microscope with a magnification of  $40\times$  attached to digital camera [MDCE-5A] connected to a computer.

The following equations [3] have been used to estimate the etch rate ratio  $V$ , also called sensitivity of the etchable track detector due to normal incidence of charged particles. The track etch rate  $V_B$  is measured by the change in the weight of the detector using the relation:

$$V_B = \frac{1}{2\rho A} \frac{\Delta m}{\Delta t} \quad (1)$$

where  $A(\text{cm}^2)$  and  $\rho(\text{gm/cm}^3)$  are the area of the detector surface and the density of the detector material respectively, while the quantity  $(\frac{\Delta m}{\Delta t})$

is the amount of the bulk material removed from the surface of the detector sheet during etching. The weight of the detectors was measured before and after etching for 2 hours in both ultrasound-induced chemical etching (CE+US) and conventional chemical etching (CCE) detectors.

The surface diameter of the track  $D$  is given by:

$$D = 2V_B t \sqrt{\frac{V_T - V_B}{V_T + V_B}} \quad (2)$$

$$\frac{D}{t} = V_D \quad (3)$$

where  $V_D$  is the rate of diameter growing of the track. From (2) and (3), one can get that the track etch rate  $V_T$  is:

$$V_T = V_B \frac{4V_B^2 + V_D^2}{4V_B^2 - V_D^2} \quad (4)$$

The etch rate ratio or detector sensitivity  $V$ , can easily be estimated by using the relation:

$$V = \frac{V_T}{V_B} \quad (5)$$

Further parameters related to the etch rate ratio  $V$  such as the critical angle (angular response)  $\theta_C$ , etching efficiency  $\eta$  and etching sensitivity  $S$  can be estimated from the following equations [21]:

$$\theta_C = \sin^{-1}\left(\frac{1}{V}\right) \quad (6)$$

$$\eta = 1 - \frac{1}{V} \quad (7)$$

$$S = V - 1 \quad (8)$$

## Results and Discussion

The relation between the track's opening diameter and alpha energies is shown in Figs. 1 and 2 for both sets of detectors of ultrasound-induced chemical etching (CE+US) and conventional chemical etching (CCE) of particle tracks, respectively. One can see in Fig. 1 that the revealing of ultrasound-induced chemical

etching tracks was faster than that of conventional chemical etching ones. The diameters were found to increase for ultrasound-induced chemical etching tracks over conventional chemical etching. However, the change in the track's diameter was maximum and ranged between (10-100%) when the energy of alpha particle was about 1.5 MeV. Fig. 3 shows the difference between the tracks' diameters of used alpha-particle energies etched for 2 h in CE+US and CCE methods.

The minimum energy  $E_{min}$  of alpha particle that could show etched tracks in CR-39 was  $\sim 0.2$  MeV in both (CE+US) and CCE methods of etching. This value is called the threshold energy of the detector and the particles having energies less than the threshold energy cannot reveal etched tracks [3, 6].

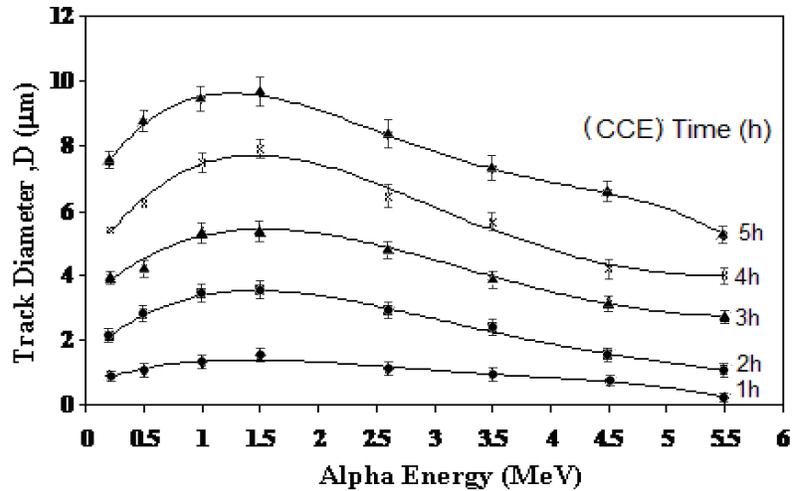


FIG. 1. Track diameter *versus* alpha-particle energy in conventional chemical etching (CCE).

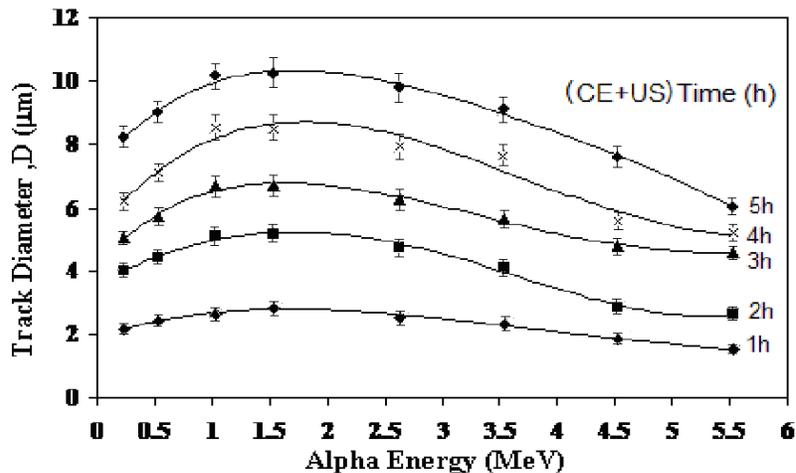


FIG. 2. Track diameter *versus* alpha-particle energy in ultrasound-induced chemical etching (CE+US).

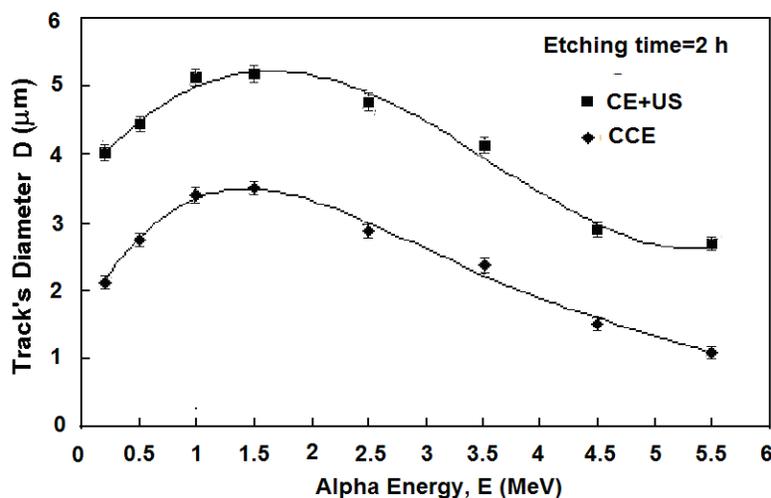


FIG. 3. Track diameter *versus* alpha-particle energy for an etching time of 2h in both (CE+US) and CCE methods.

The increase in tracks' diameters observed in ultrasound-induced etching (CE+US) method is due to the increase in the etching rates of the detector. The vibration energy of the ultrasound increases the reaction energy between etching solution and detector molecules which in turn increases the ability of interacted molecules to overcome the barrier energy separating the interacted and the resultant materials. The exposure of the etching solution to the ultrasound energy accelerated the degradation of the detector molecules which resulted in an enhancement of the tracks growing rate  $V_D$ , the bulk etch rate  $V_B$ , the track etch rate  $V_T$  and the detector sensitivity  $V$  at a given etching time. Afifi *et al.* [2] also indicated an increase in diameter and size of the tracks in CR-39 detectors chemically etched under ultrasound of 2 MHz.

On irradiating the etching medium by ultrasound, its temperature is controlled by using a thermocouple to keep the solution temperature constant at  $(70 \pm 1)$  °C and to minimize any effects on tracks due to raising the temperature of the etching solution.

The variation of the track growing rate  $V_D$  and track etch rate  $V_T$  with alpha-particle energy is shown in Figs. 4 and 5. It was found that  $V_D$  and  $V_T$  increase with alpha-particle energies with a maximum value at  $\sim 1.5$  MeV.

The exposing of the chemical etching solution to US increased both  $V_D$  and  $V_T$  up to 20% and 25%, respectively as compared with those of CCE detectors.

The relation between etching rate ratio or sensitivity  $V$  and the incident alpha-particle energy for both ultrasound-induced chemical etching (CE+US) and conventional chemical (CCE) etching methods is shown in Fig. 6. One can see that the behavior of  $V$  against alpha energy is similar to the behavior of  $V_T$  and  $V_D$ . The detector sensitivity  $V(=V_T/V_B)$  was studied by measuring the bulk etch rate  $V_B$  for both ultrasound-induced chemical etching and conventional chemical etching detectors. The bulk etch rate  $V_B$  was found equal to  $1.74 \mu\text{m}\cdot\text{h}^{-1}$  for ultrasound-induced chemical etching (CE+US) and  $1.56 \mu\text{m}\cdot\text{h}^{-1}$  for conventional chemical etching (CCE) detectors.  $V_B$  is considered constant up to 7  $\mu\text{m}$  of etched depth in the detector, and any variation in  $V_T$  was accompanied by a variation in  $V$  according to the relation above.

The (CE+US) etching method showed an enhancement in the detector sensitivity  $V$  up to 16% over the CCE etching method for alpha energy of 1.5 MeV. Su [22] found that ultrasound-induced chemical etching of Lexan and LR-115 detectors increased the sensitivity about (20-50)%.

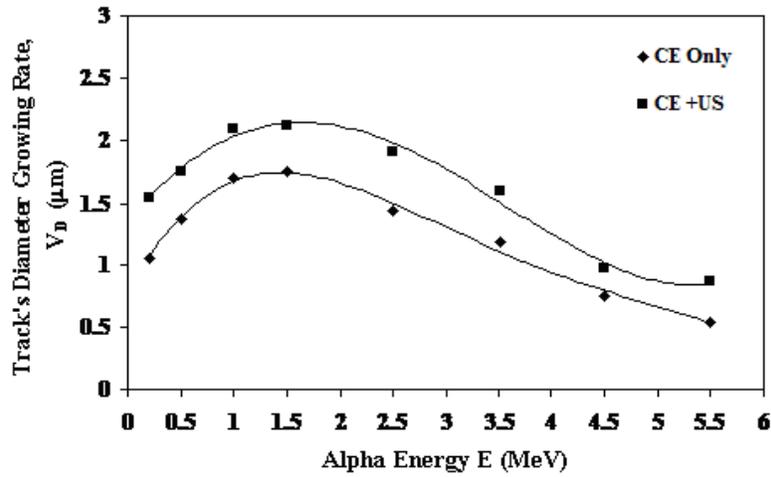


FIG. 4. Track's diameter growing rate *versus* alpha-particle energy for an etching time of 2 h in both (CE+US) and CCE methods.

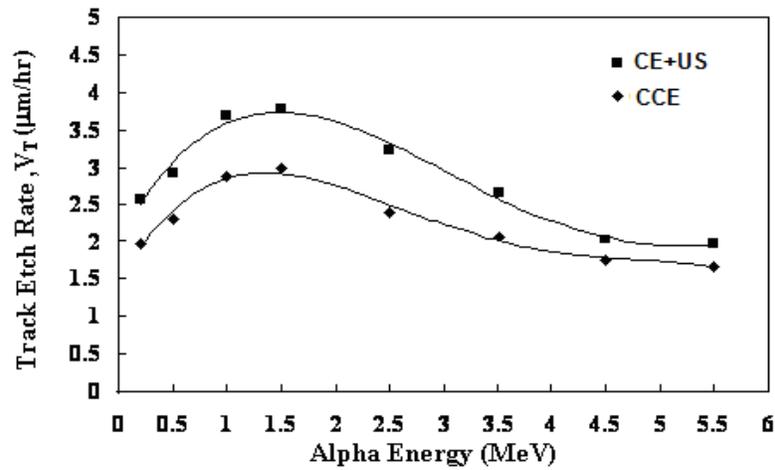


FIG. 5. Track etch rate *versus* alpha-particle energy.

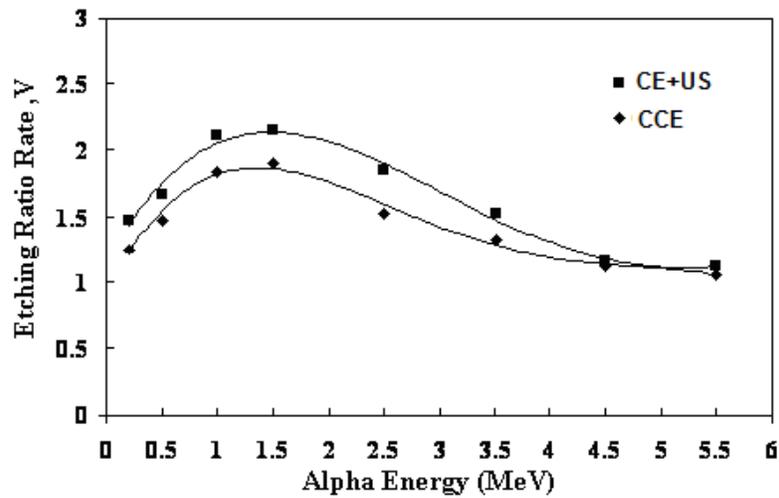


FIG. 6. Etch rate ratio or detector sensitivity *versus* alpha-particle energy.

Etching sensitivity  $S$  and etching efficiency  $\eta$  as functions of alpha-particle energy are shown in Figs.7 and 8, respectively. The chemical etching under ultrasound impact (CE+US) produced an enhancement in  $\eta$  and  $S$  of about 12.5% and 27.19%, respectively for alpha-particle irradiation energy of 1.5 MeV as compared to conventional chemical etching (CCE). Pandey *et al.* [1] and Afifi *et al.* [2] also found an enhancement in  $S$ ,  $\eta$  and  $\theta_c$  in etching CN-85 and Lexan detectors under ultrasound effect.

The critical angle  $\theta_c$ , is defined as the minimum incident angle of the particle below which the etched tracks cannot be revealed. The variation of the critical angle as a function of alpha-particle energy is shown in Fig. 9.

CR-39 detectors showed a maximum decrease in the critical angle for alpha-particle at an energy of 1.5 MeV, which means an increase in the angular response of the detector to the incident particles. It is shown from Fig. 9 that the angular response of CR-39 to alpha particle is increased on ultrasound-induced chemical etching over the conventional chemical etching and having a maximum value at alpha energy of 1.5 MeV.

The effect of the ultrasound on the angular response of CR-39 to alpha-particles is obviously seen at an energy of 1.5 MeV through dropping of the critical angle from  $31.39^\circ$  in conventional chemical etching (CCE) to  $27.25^\circ$  degree in ultrasound-induced chemical etching (CE+US).

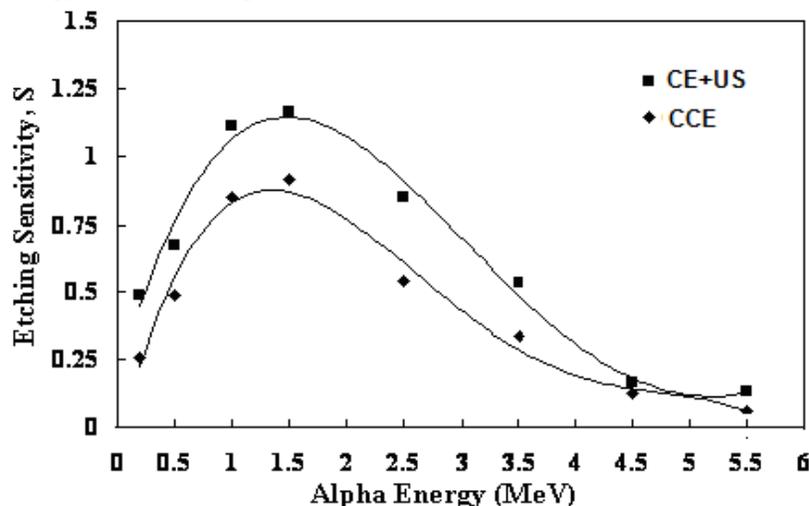


FIG. 7. Etching sensitivity *versus* alpha-particle energy.

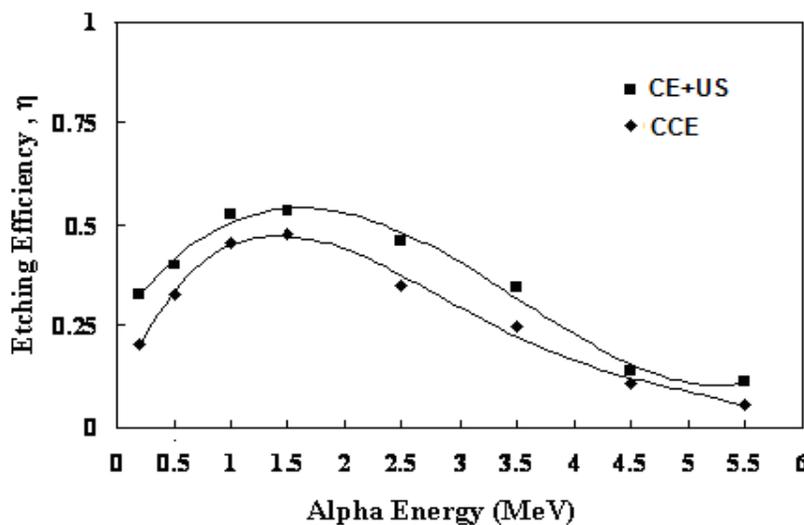


FIG. 8. Etching efficiency *versus* alpha-particle energy.

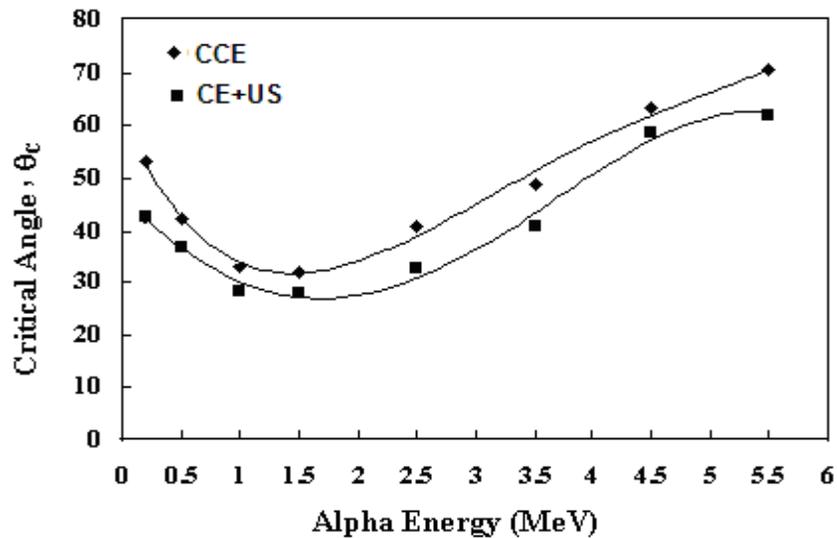


FIG. 9. Critical angle *versus* alpha-particle energy.

## Conclusion

The results showed significant changes in revealing the track properties of particle tracks in CR-39 detector in ultrasound-induced etching as compared to conventional chemical etching method. The significant advantages of ultrasound-induced chemical etching over conventional chemical etching of particle tracks are: reduction in etching time, larger track-etch rates  $V_B$ ,  $V_T$  and  $V$ , larger etching sensitivity  $\eta$

and efficiency  $S$ , and lower critical angle  $\theta_c$  of the detector, leading to an overall improvement in the track revealing process. The decrease in the critical angle in ultrasound-induced etching means an improvement in the angular response of the detector which leads to increase the ability of CR-39 detector to detect particles with lower incident angles as compared to conventional chemical etching detectors.

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