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Role of alpha particles in the bulk etching rate of CR-39 nuclear track detector

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Abstract

Solid state nuclear track detectors have different application in different branches of science, because it has been used as a passive system to detect the alpha particles. It is important to measure the bulk-etching rate for CR-39 detector, which is sensitive to all alpha particles reaching its surface at normal incidence. The effect of irradiation α-particles intensity emitted from ^{241}Am with energy 5.49 MeV on CR-39 detector was studied. From the obtained results the values of bulk etching rate decrease with increasing alpha energy and the number of tracks increasing with increasing alpha energy. It is important to identify the time required for the chemical etching process at certain alpha energy.

Keywords: detector, irradiation, alpha particles and bulk etching

Introduction

CR-39 plastic nuclear track detectors (PNTDs) can also measure radiation from high energy, proton and neutrons through their secondary charged particles. The composition of CR-39 material is $C_{12}H_{18}O_7$ and it's sensitive to high linear energy transfer. Operation of the solid state nuclear track detector is based on the fact that a heavy charged particle will cause extensive ionization of the material when pass through it. The passing of alpha particles through CR-39 sample causes ionization, which triggers a series of new chemical processes that result in the creation of free chemical radicals and other chemical species. Charged particles deposit energy along their trail when they move through the matter of plastic materials. The energy loss creates a submicroscopic cylinder of 50-100 A° radius of damaged molecules, so called latent track. Tracks formed in SSNTDs have different shapes, diameter and opacities depending on the energy and the angle of incidence of the alpha particles. If, however, one places of the detector material in chemical etching solution, the volume around the latent track will be attacked preferentially, so that the track of the nuclear particle becomes visible by an optical microscope. For studying etched holes of nuclear tracks under an optical microscope, the plastic materials has of course to be transparent, the plastic detector material comes in sheets of 100-1000 µm thickness. The etching process or procedure, which results in the formation of visible tracks, can be described. For a plastic detector, we have actually two kinds of etching rate first the bulk or material etching rate V_B µmh^{-1} at which the etching solution precedes along the latent track. The latter the track etching rate, depends on strongly on the energy loss of the ion. The formation of an etch cone around the path of an ion can be easily understood when we apply the Huygens principle.

Review of literature

T. Yamauchi (2003) [6] The core radii of the latent tracks in the CR-39 detector are within several nanometers, depending on the heavy ion species and energies .

M.A. Stanojev Pereira, J.G.R. Marques, J.P. Santos (2014) [9] The energy deposited by the 1.5 MeV alpha particle is sufficient to dissociate all bonds in the CR-39 detector, even the strongest one –C=C– which has a dissociation energy of 6.4 eV .

Rajta *et al*. (2005) [8] optimized the particle fluence in micromachining of CR-39 detector irradiated with proton and alpha particles.

Gaillard *et al*. (2007) [7] studied the optical properties of the saturation of CR-39 detectors at high fluence.

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Material and Methods

Forty nine pieces of CR-39 detector divided into seven groups were irradiated with different energies of alpha particles at the constant time. A pieces of CR-39 detector each of area 1.5×1.5 cm^2 irradiate using a thin alpha source of ^{241}Am was electroplated on a stainless steel disc with area 0.12 cm^2, diameter 4 mm, activity 0.98μCi ± 5% = 3.63x 10^4 Bq. The alpha source used was a collimated ^{241}Am has an alpha particles of energies 5.49 MeV. The energy of alpha particles at different distances in air was calculated. The alpha source is a bone seeking and long lived radionuclide (manufactured by Spectrum Techniques, Inc. Oak Ridge, USA). The detectors were irradiated in air using alpha source ^{241}Am has an energy of 5.49 MeV, irradiation system consists of cupper collimator with 4mm diameter placed between the detector and the source at different distance which gives different energies. For counting tracks, we used only normal incidence alpha particles on the detectors as shown Figure 1. The figure was taken using optical microscope (Misr Fatrams 2011) of the magnification power lens 40x, and the CCD Camera (Hitachi Denshi, Ltd., model KP-M2E/K of lens with magnification power 62.5x, made in Japan and the total magnification power is 2500x. The energy at the surface of the detector was calculated using the following relation:

$$E = \left[\frac{(R_{air} - d)}{0.322} \right]^{\frac{2}{3}}$$

$$\text{Where,} \quad R_{air} = 0.322 E^{\frac{3}{2}}$$

Where, E is the initial energy of alpha particles (5.49 MeV), R_{air} is the range of alpha particles in air (cm) at NTP and d is the distance between the source and the detector surface (cm) in air. The detectors irradiated with alpha particles having known energies (5.49, 4.57, 4.06, 3.53, 2.96, 2.32, 1.58) MeV under normal incidence through the collimator by using an exposure system made in our laboratory. After radiation exposure CR-39 detectors are chemically etched in 6.25N NaOH at 70°C for (1, 2,....., 7) hours. After etching CR-39 detectors were washed in distilled water and then dipped for few minutes in a 3% acetic acid solution, washed again with distilled water and finally dried. The bulk etching rate was calculated using the following equation:

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

Where, Δm is the difference between the mass of CR-39 detector before and after etching, A is the surface area of CR-39 detector, ρ is the density of the detector material and t is the etching time. The results of chemical etching will form etched cones on the surface of CR-39 detector. These etched cones are distributed along the particles trajectory and can be observed microscopically. After etching CR-39 detectors, the tracks were counted using an optical microscope with a magnification of 640x, which calibrated using scale slide before it used. The number of tracks per field was average over fields counted for each detector, which etched time 7hr and the track density was obtained by α-track cm^{-2}. The background of the track density was determined at the same conditions and subtracted from the results.
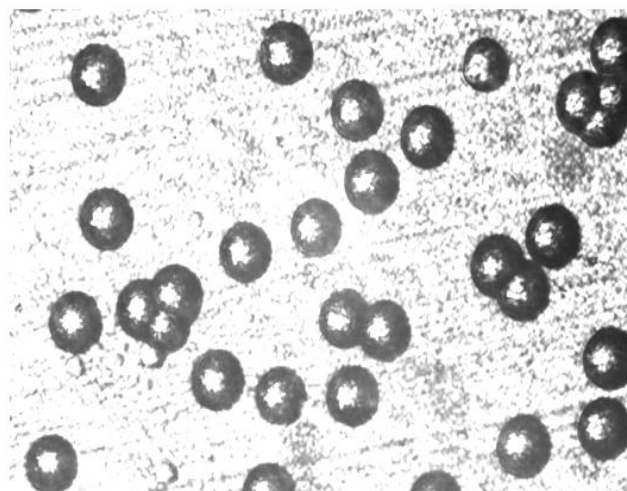

Fig 1: Microphotograph of tracks for α-particles energy at normal incidence

Results and Discussion

The energy of alpha particles at different distance and the track density were given in Table 1. Figure 2 shows the relation between distance and energy of alpha particles and the correlation coefficient ($R^2 = 0.98$), which is very good correlation and it is given importation a good results. The values of alpha energy decrease by increase the distance between the alpha source and the detector. Figure 3 shows the relation between energy of alpha particles and track density. This indicates that the values of track density increase with increasing alpha energy.

The value of bulk etching rate was determined experimentally without irradiation and it equal 1.51 μmh^{-1} as shown in Figure 4. The relation between etching time and mass change of CR-39 detectors at different energies was given by Figure 5. Table 2 gives the values of the bulk etching rate at different energies.

Figure 6 shows the relation between alpha particles energies and the values of the bulk etching rate of CR-39 detectors. From the figure we find that the values of the bulk etching rate decrease with increasing alpha energy, and the correlation coefficient equal ($R^2 = 0.94$). This is a good correlation relation between alpha energies and the bulk etching rate of CR-39 detector. The highest value of bulk etching rate was found at energy 1.58 MeV, but the lowest value at 5.49 MeV, this means that the values of bulk etching rate inversely with energy value. This due to the value of diameter is directly proportional to the bulk etching rate, this is one of the methods set to determine bulk etching rate ($D = 2V_B t$), but the values of diameter inversely with energy which reported by many authors, 12-14]. The obtained results in the present study have a good agreement with the results of other investigators in similar type of work.

Table 1: The relation between energy, distance and track density for CR-39 detector using ^{241}Am source at the constant time

Distance (cm)	Energy (MeV)	Track density (α-tracks cm^{-2})
0	5.49	119204$\pm$3331
1	4.57	55435$\pm$1941
1.5	4.06	36522$\pm$1383
2	3.53	17934$\pm$709
2.5	2.96	11316$\pm$471
3	2.32	6144$\pm$350
3.5	1.58	3580$\pm$213

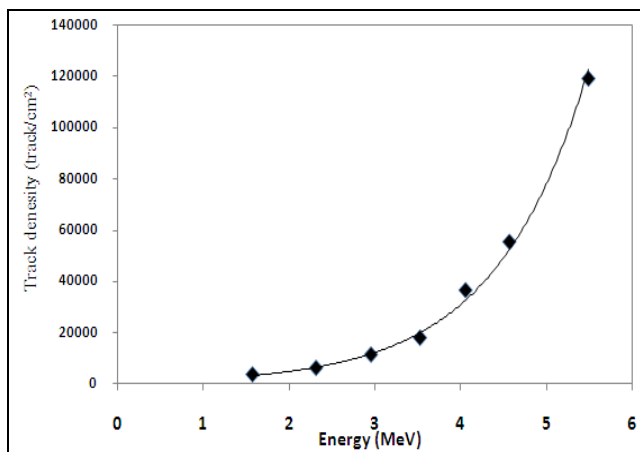**Fig 2:** The relation between distance and energy of alpha particles

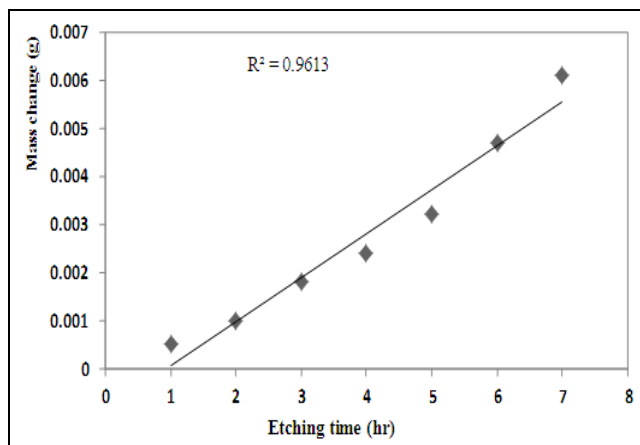**Fig 3:** The relation between energy of alpha particles and track density

Fig 4: The relation between etching time and mass change without exposure to ^{241}Am source
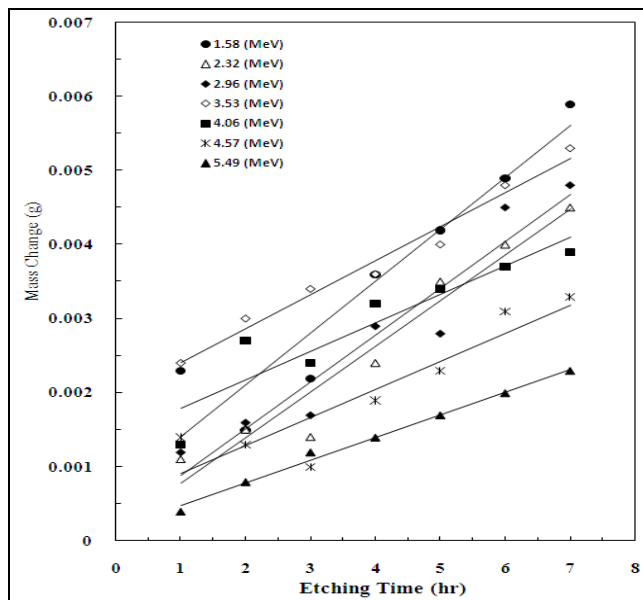

Fig 5: The relation between etching time and mass change at exposure to alpha particles with different energy

Table 2: The values of alpha energy and the bulk etching rate at different energies

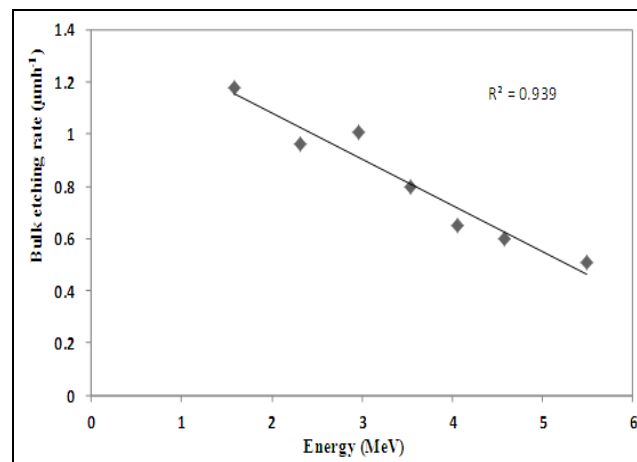| E (MeV)	1.58	2.32	2.96	3.53	4.06	4.57	5.49
V$_B$ (μ mh^{-1})	1.18	0.96	1.01	0.80	0.65	6.60	0.51

Fig 6: The relation between alpha energy and bulk etching rate of CR-39 detector

Conclusions

CR-39 detectors have been used successfully as detecting devices to detect alpha contamination. The bulk etch rate is one of the crucial factors controlling tracks developments in nuclear track detectors. This work is presents the relation between the bulk etching rate of CR-39 detector and different alpha energies from ^{241}Am source with different energies. The alpha particles destruction the place of the tracks only this means that the values of the bulk etching rate decrease with increasing the alpha energy this due to using more time to make the etching process for the CR-39 detectors it helps the emergence of clearly track shape. It is important to identify the time required for the chemical etching process at certain alpha energy.

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