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Preliminary Study of Natural Alpha Particle Track Through Solid State Nuclear Track Detector, CR-39.

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Abstract: Measurements of alpha particle tracks parameters from $^{10}B(n,\alpha)^{7}Li$ nuclear reaction by thermal neutron emitted from ^{241}Am-Be neutron source were reported by using solid state nuclear track detector CR-39 the said detectors were chemically etched in a 6.25 N aqueous solution of NaOH at 70°C for periods of 1 to 5 hours. The dependence of track diameters as a function of whole etching time, the divergence of the alpha's track etch rate and the etch rate ratio as a function of different incident energies of alpha particle are presented and discussed.

Keywords: Alpha particle tracks parameters; $^{10}B(n,\alpha)^{7}Li$; thermal neutron radiation; ^{241}Am-Be; nuclear solid state track detector, CR-39l etching solution; track diameters;

1. Introduction:

Nuclear Solid State Track detectors (NSSTDs), CR-39 are used considerably to give data on different types of charged particles [1]. The CR-39 detector is extensively practical in space radiation experiments [2]. It has a high sensibility for energetic ions as alpha particles while is barely affected by light charged particles as electrons, until if the numbering of electrons are considerable. This indicates that the CR-39 detector can be effectively applied for the detection of ion beams[3]. The registration of charged particles as alpha in (SSNTDs) CR-39 detector is based in the fact that the track of radiation disorders along the particle's path can be enlarged to a visible print by a strong alkali chemical etching process [4]. A rapidly charged particle crossing through the NSSTDs, can drop out a radiation damage trail invited a "latent track," that can appear by means of chemical etching process in a fit etchant as strong NaOH solution. Development of charged particles paths in material through etching process has attracted much heed careful for a long-time. Formulation of the track of particle as a effect of the happening of a charged particles is consequent to the simultaneous effective of the NaOH etching chemical solution with two coefficients, i.e., the variable rate along the way of the incident charged particle V_T and bulk etch rate V_B[5-6]. The bulk etch rate can be calculated by many methods like the fission fragment track diameter, the weight difference before and after etching, and a laser interferometer used during the chemical etching [7]. Everyone of these processes possesses its advantages and disadvantages over the others and the option of the manner depends upon [7,8]. When ^{10}B captures slow neutrons, it can decays into an α-particle with energy1.47 MeV and ^{7}Li ion with energy 0.84 MeV, both with high linear energy transferred [9]. The experimental parameterization describing the track of alpha particles in nuclear detector is expanded to explain longitudinal track profiles as function of etching period for alpha particles and proton. MATLAB based software is developed, which calculates and plots the depth, diameter, range, track length, saturation time, and etch rate versus etching time [10].

The aim of this study is to investigate the depth, range, diameter, track etch rate, track etch ratio, track length, and etch rate versus etching time.

2. Material and method:

2.1 Materials: Boric acid, sodium tetraborate, gelatin, sodium hydroxide, hydrochloric acid, glycerin were obtained as ANALAR grade and used without purification.

2.2 Solid state nuclear track detector: Nuclear detectors (SSNTD) CR-39 used in this study were obtained from Moulding Ltd, UK with 500 μm thickness, and density of 1.3 g/cm^3 [11]. The CR-39 detectors with samples were exposed at various time, 5.0 cm away from the neutron source, and the space was occupied by wax to insure the receiving of thermal neutrons. Sheets of CR-39 detectors were cut into pieces square with dimension of 1.0 cm × 1.0 cm. Microscope description was performed by using Olympus BH-2.

2.3 Neutron source: All samples were irradiated with neutron at ambient temperature with an ^{241}Am-Be neutron source was supplied by Radio-Chemical, Ltd., England, with flux of 10^5 neutron.cm^{-2}.sec^{-1} shown in the Figure 1. Thermal neutron bam was obtained by placing petroleum wax around the source, such a way the distance of samples from the source is 5.0 cm.

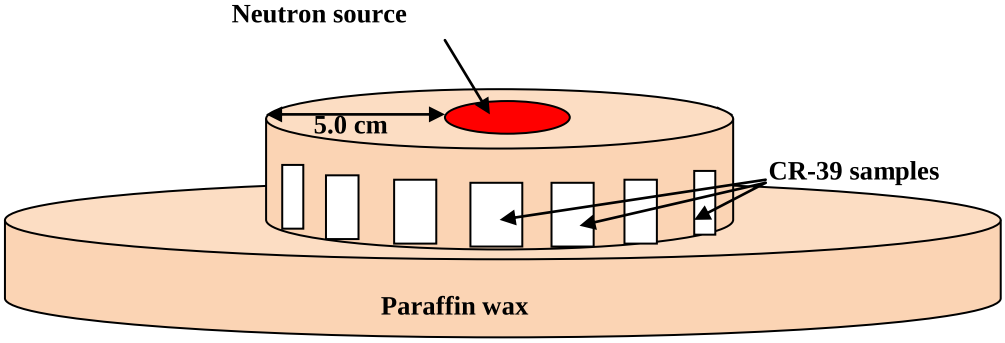

Figure 1: Representative design of the neutron source and its sample positions.

2.4 The samples disc preparation: In this method boron samples were pressed as uniform disc by using mechanical press supplied with stainless steel dye of 10 mm diameter with a pressure 4.0 Tons. The following variables were studied, to find the best adjustment to obtain good reproducibility for interaction of alpha particles with boron**.**

2.4.1 Bulk etching rate V_B : It is one of the crucial coefficient controlling the track development in SSNTDs. There are abundant methods to calculate the bulk etch rate for SSNTDs. The method used relies on measuring the CR-39 detector mass before and after the etching process. Based on the mass difference and the known density of the detector, it is possible to calculate the thickness of the detached layer and in turn, bulk etch rate V_B [12].

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

where Δm is the mass difference; A is the etched surface, Δt is the interval of time, ρ is the density of the detector. The factor 2 in above equation takes account of the removal of the thickness from both sides of the surfaces of a detector.

2.4.2 Depth X(t): Track depth symbolize the distance from the original surface of the nuclear detector to the etched track head at any etching period. The track depth is given by the following formula[13]:

$$X(t) = L(t)+V_B t. \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad 2$$

Where L(t) is the track length as a function of time (t).

2.4.3 Track length L: It can be given by [13]:

$$\frac{dL}{dt} = V_T(t) - V_B \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad 3$$

2.4.4 Etching velocity rate V_T: the etching rate is calculated toward of track depth length along of charged particle trajectory for every energy as [14]:

$$V_T = V_B\left[\frac{4V_B^2 + V_D^2}{4V_B^2 - V_D^2}\right] \qquad \ldots\ldots.. \quad 4$$

Where V_D is the track diameter growth rate.

2.4.5 Etching rate ratio V: The important coefficient of track detector is the etching rate ratio or sensitivity of alpha particle registered with CR-39 is defined as the ratio of the etch velocity rate of a track and bulk rate (V_T /V_B), given by[15] :

$$V = \frac{V_T}{V_B} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad 5$$

The reciprocal of above ratio is a function of energy loss or stopping power.

2.4.6 Residual range R′: The residual range R′ of incident particle in detector can be calculated from track depth according to the following equation[16]:

$$R' = R_\alpha - X(t) \qquad \ldots\ldots\ldots\ldots\ldots\ldots.. \quad 6$$

where R_α is the range of particle in the detector.

The etching rate ratio V(R′) was plotted as a function of residual range.

5. Results and discussion:

The alpha particle effect at a low-energy on the CR-39 track detector is limited to its top surface, which means that a attentive and fast treatment is needful for the chemical etching method of detectors.

Bulk etch rate V_B: It is measured by a removal layer thickness (μm) as a function of etching time is shown in figure 2.

The etching process was carried out in 6.25 N NaOH at 70°C± 1°C temperature, resulting in a bulk rate of V_B= 1.39 ±0.05μm/h. Both the bulk and track etch rate rely on concentration and temperature of chemical solution. To hold over these quantities constant requires special attention since few tenths of the degree change in the temperature can affect the measure of the removed layer, which is responsible for the track etch rate [17].

Track depth: The track depth was measured for normal incident angle and different alpha energies ranging from 0.8 MeV to 1.47MeV in step of 0.1MeV for different etching periods as shown in figure 3. For a small etching time, most of the curves are overlapped. The same meaning, the cone lengths are degenerate. When the alpha paths are completely etched, the bulk etch rate, V_B, with the further etching proceeds in all directions causing in a rounded etch track, that may weaken the contrast of the track shape. All the track depth reach to maximum values between 1.5 to 3 hour from etching time, after the first hour of the start of the etching process, all particles track start emerge for all energies and getting a nonlinear increase until it.

reaches the saturation state at almost the same time (often 1.5 hour) per each energy. This figure gives a package of deep energies, where the linear relationship between them. This process is useful to know the energies of the minority over the depth and that cannot hold her etching through a long period of time to obtain adequate measurements.

Track diameter: The diameter of alpha tracks as a function of incident mean alpha particle energy in CR-39 detector was studied, as shown in figure 4. We observed that alpha tracks start to appear after first hour from the beginning of etching. It can be observed that the pit diameter increases with the increasing of etching time for incident alpha particle energy from 0.8 to 1.47 MeV. It is significant to note that the shape of each individual curve various of the track diameter with alpha particle energy as figure 5. The size of etch track in CR-39 detectors increases as LET of incident-alpha particles increases [18]. The track diameters formed in the nuclear detectors depends on several variables of the particle is the mass, energy and charge. Knowledge of differing diameters tracks formed in the detector enables us to distinguish particles bombarding in the detector for use as a spectrometer to characterize the particle type and energy. Notice from the figure that the diameters of tracks formed in the detector change with the alpha particle energies directly proportional to the fact that the greatest total energy of alpha emitted from the boron neutron reaction are small compared with the energies of alpha particles in other reactions, the particles with energy (greater than 1.5 MeV) be tracks smaller than its formation with low energies is least, because the loss energy rate per unit path in the detector is a little. Thus, the amount of damage resulting from the unit of the path is few and the diameters of the tracks formed in the detector change inversely with their energies, figure 6, shows the tracks require a longer etching time because the particle range is greater. In contrast to particles with low energies that have tracks close to the surface of the detector, they need less etching time. Also shows the main characteristics for the SSNTD, CR-39 detector. It was also verified that the behavior is good agreement with another researcher [19]. Figure 6 show the image of alpha particles on the CR-39 detector with various etching time. The image of tracks start to be observable at first hour of etching time. A longer etching time (3 hours) has been used here to produce larger tracks that are more conspicuous on the image shown.

The track length: Figure 7 represented the track length as a function of etching time for the same energy ranges of alpha-particles. This figure divided into two regions: first; the track length is increases nonlinear with etching time, second; the track length is constant, which depends on energy of incident particle with etching conditions constant and detector type.

Etch velocity rate V_T: The appearance of tracks etched depends on the particle energy, i.e. when $V_T > V_B$ as a condition for the tracks to appear. At the beginning of the process of etching when $V_T < V_B$ the tracks cannot be seen but when etching process continued the increasing amount of energy lost along the particle path to become equal to the bulk etching rate $V_T = V_B$, here the beginning of tracks appear and be very small., And as V_T increasing comparison with V_B fixed. Energy lost increases with depth within the detector material to reach the highest value at the top of Bragg, and this is consistent with the findings of them [20]. Figure 8 show that V_T increases gradually with etching time. It is up at different times depending on the energy of alpha particle interacting with the material of detector. The maximum value of V_{Tmax} corresponding to the Bragg top of the energy loss that then gets the greatest loss of energy of the particle before stopping, the same point at which they grow up along the tail far as it can before arriving at the state of saturation. Then it begins the sudden relation dramatically over a short period of time and will continue to decline until it becomes equal to the bulk rate $V_T = V_B$ and after then become full etching. The trail head is a spherical shape and this is consistent with the images we have obtained to the tracks of the energies used for alpha particles. From figure 9 show that the results for the track etch rate as a function of the depth within the detector، qualitatively similar curves result as shown in figure 8, The maximum track etch rate exists at the depth where the maximum energy loss of the alpha is reached. For deeper layers the track etch rate decreases very strongly down to the value of the bulk etch rate at a depth which corresponds to the alpha particle range. The etch velocity rate v_T curve shape is like behavior of the restricted energy loss (REL) as a function of the track depth within the CR-39 detector [21]. The track etch rate along the way the alpha particle trajectory

shows a identical feature according to the Bragg low as given in Figure 9 Bragg ionizing for alpha particles of various energies in poly-allyl-diglycol carbonate comparison to refer to in the etching velocity rate, V_T, vs depth in the CR-39 detector [21,22].

The etching rate ratio V (**Sensitivity:** The dependence of the sensitivity on the etching time, track depth, residual range and energy were plotted in figures 10, 11 and 12 respectively. In figure 10 at begins with roughly constant value at small depths the etching rate ratio grows up to a maximum and falls down after that to the $V_T = V_B$. The etching rate ratio function V (called sensitivity or response) is the most significant quanta in the theoretical modeling of the nuclear track formlization mechanism. To measure the entire V function, the track of particle evoluted from the conic start phase near the detector surface to reach to the ending of track round the Bragg peak has to be observed. Comparing the function behavior of the alpha particle energy subjection of the stoppage power (dE/dx) with those of the reliance of the etching rate ratio V on the residual , a powerful likeness can be spotted. This is due to the stoppage power and the alpha particle domain are correlated by particle's energy [23]. The response function**,** the etch rate ratio V versus the residual range R in CR-39 derived by track length method. It can be shown from figure 12 that etch rate ratio relate reasonably with the ending of the Bragg peak there is difference in the shape of the response curves between the energies of alpha particles, particularly in the width of the peaks near the alpha track end-points correspondent to the Bragg's peaks. It is impossible to distinguish the energies of alpha through simple images of etch-pit openings. But it can clearly distinguish them from the form of the response functions under a definite condition where the track growth style should not suffer the missing track effect. This is compatible with [24,25].

The residual range: the relation between the residual range and the etching time of alpha particles with different energies in CR-39 detector were plotted as shown in figure 13. It can observed from this figure that the residual range equal the total range of alpha particle in the detector at etch time t=0. The residual range decreases with etching time increase act bulk etching rate. The procedure of the residual range with etching time as a semi exponential form because the variation of the etching velocity rate is compatible with [26].

6. Conclusions:

It may infer that the parameterization offered above can reproduce the most significant advantages of experimental data of pit length, etch rate ratio, track depth and track etching rates of alpha particles in CR-39 nuclear detectors. It would be interesting to test these coefficients for other kinds of incident charged particles and detector under a different domain of etching process conditions.

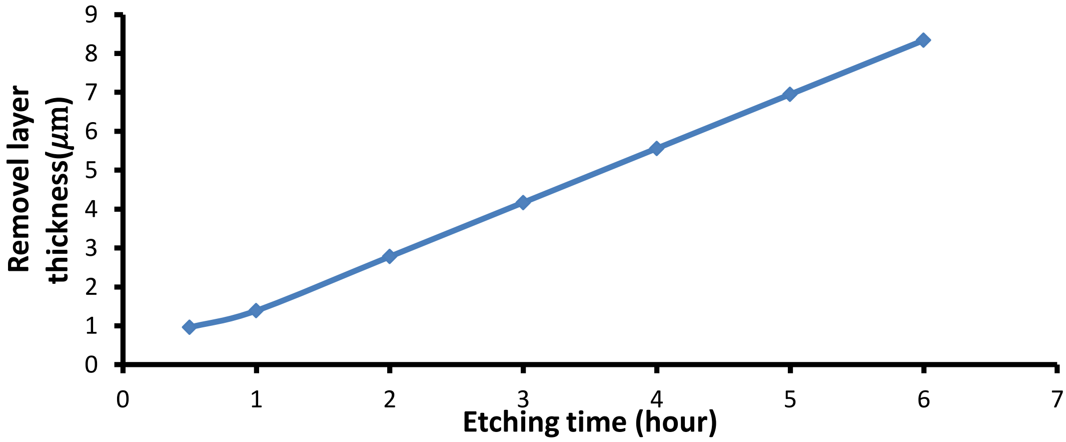

Figure 2: Removed layer thickness as a function of etching time.

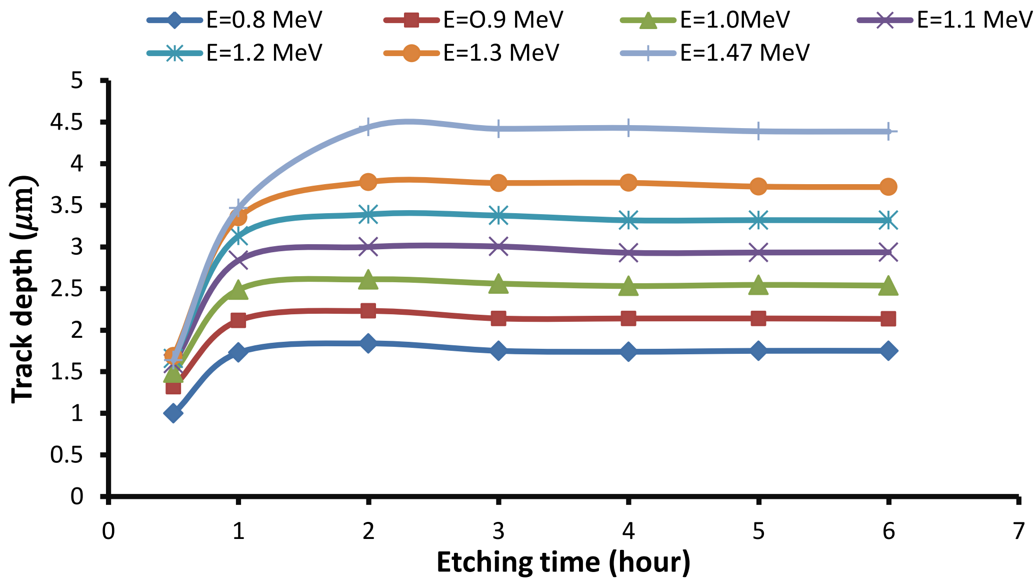

Figure 3: Track depth of alpha particle as a function of etching time with different energies

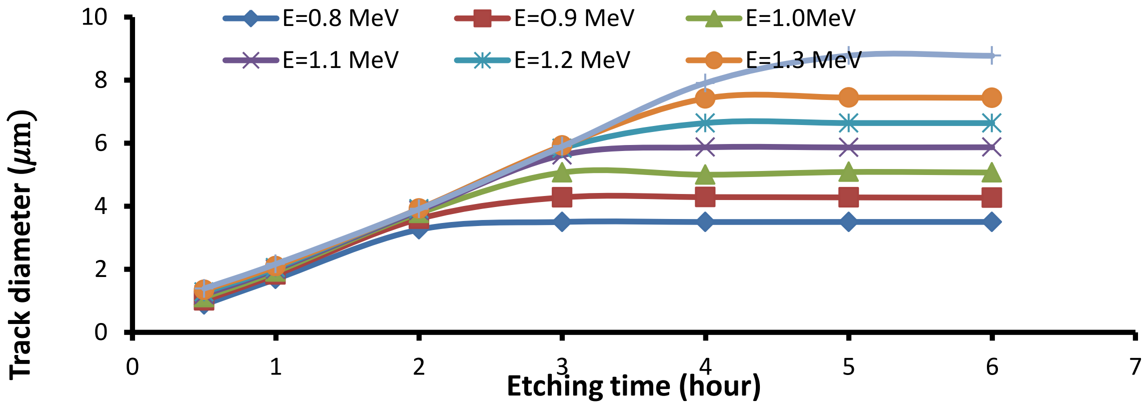

Figure 4: Variation of the measured alpha-particle track diameter as a function of the etching time in CR-39 detector with various energy.

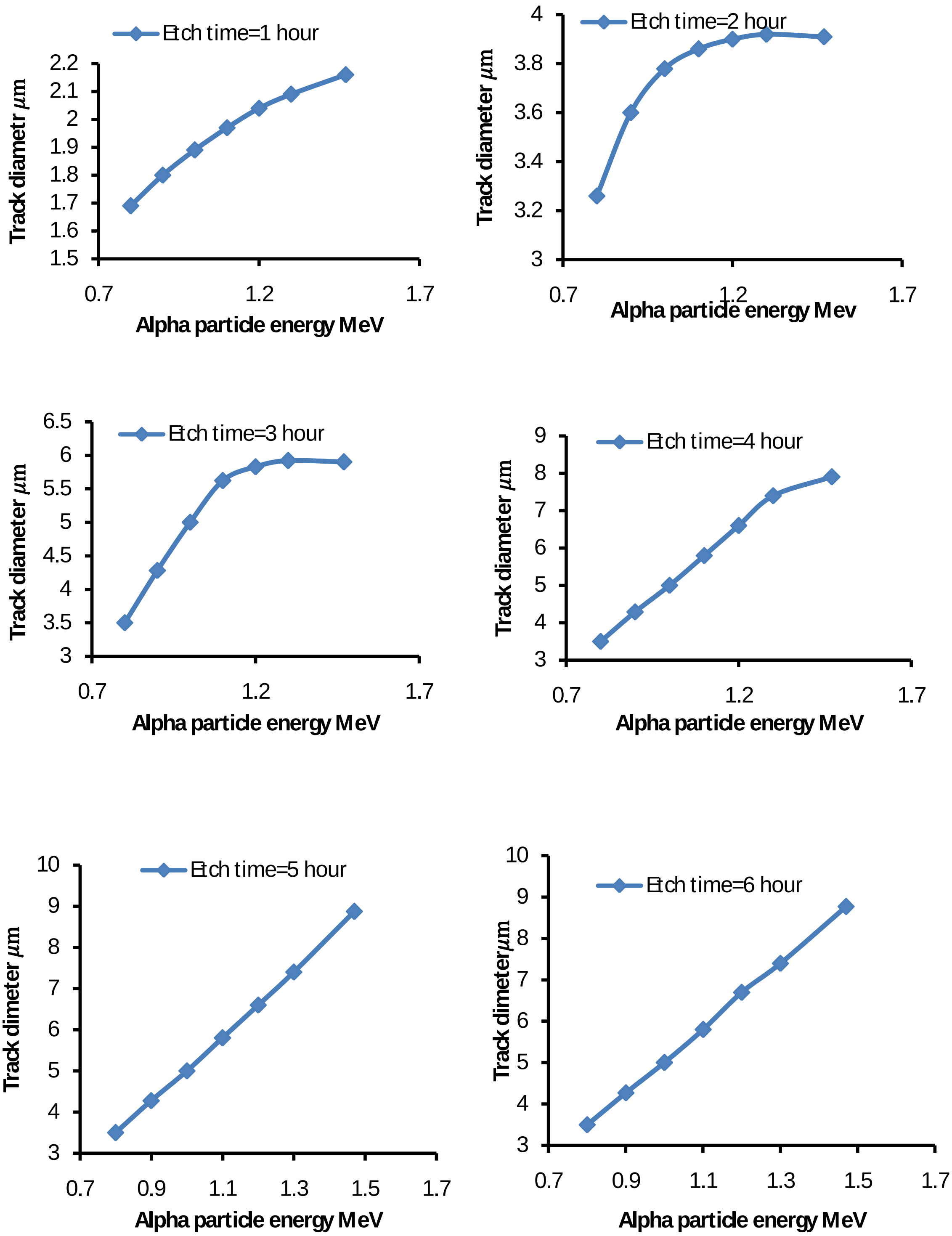

Figure 5: The increasing of alpha track diameter with increasing of etching time when alpha particle energy is constant.

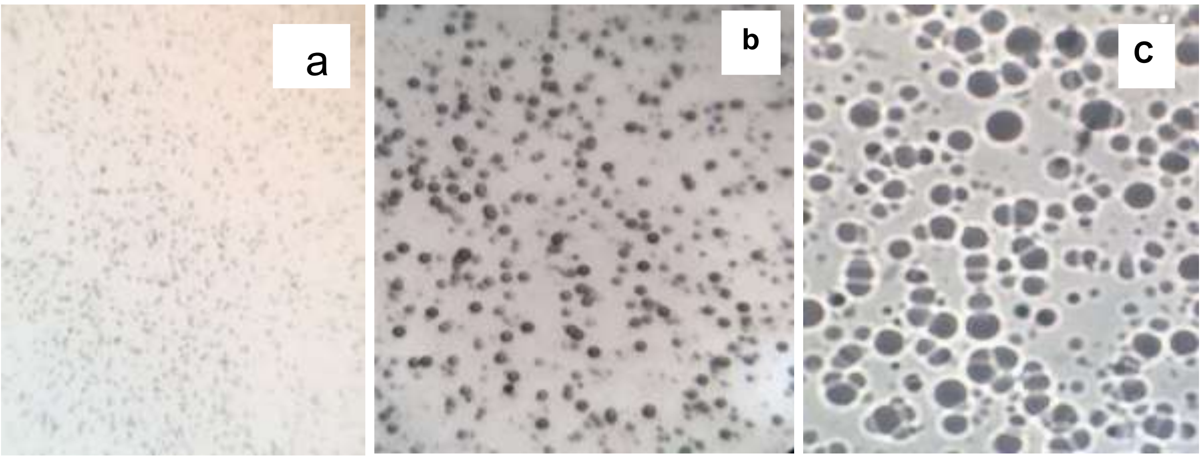

Figure 6: Track formation of alpha particle as a function of different etching time, a one hour, b two hours and c three hours.

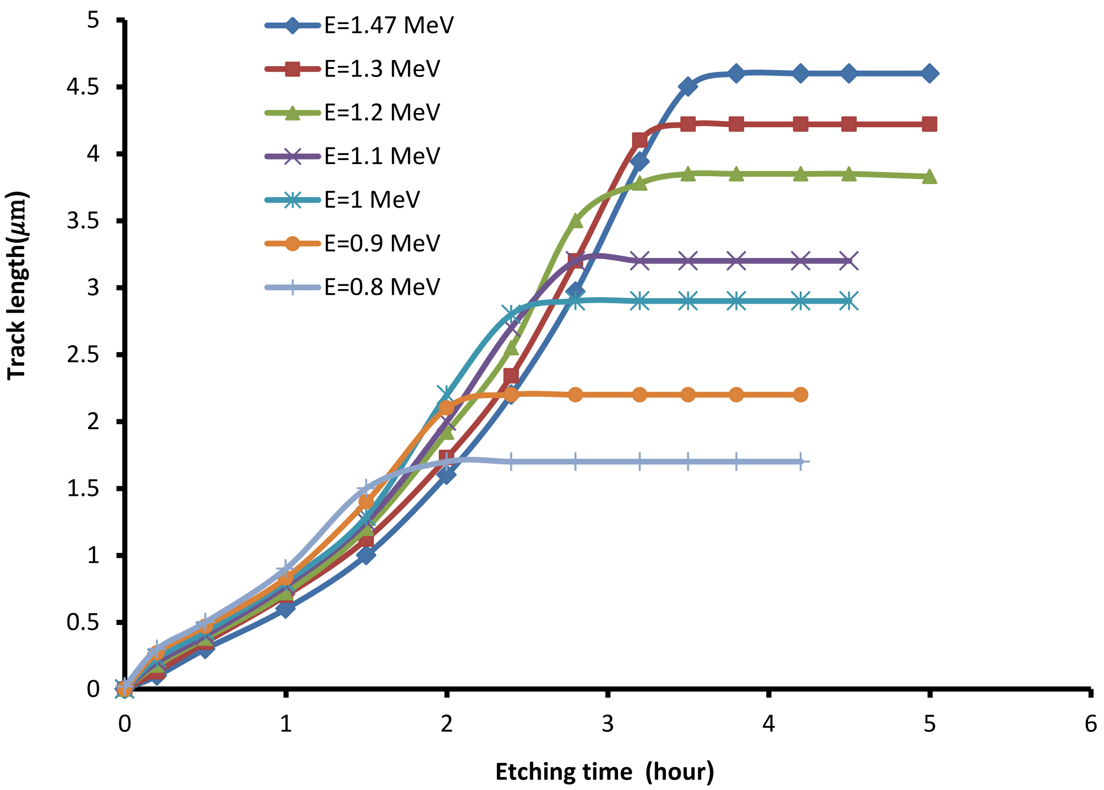

Figure 7: Track length of alpha particle as a function of etching time with different energies.

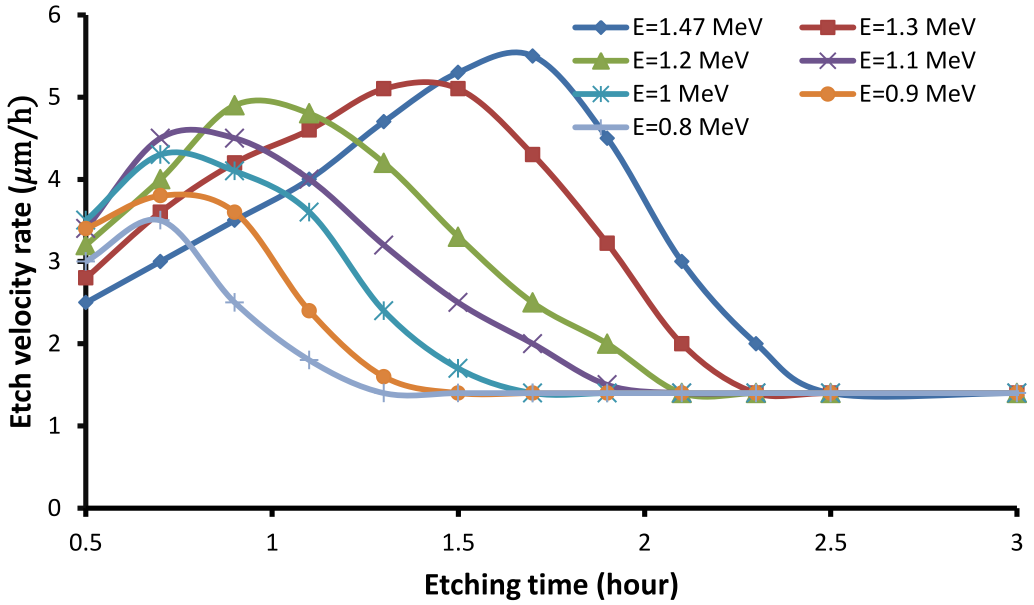

Figure 8: Etch velocity rate VT as a function of etching time for various alpha particle energy.

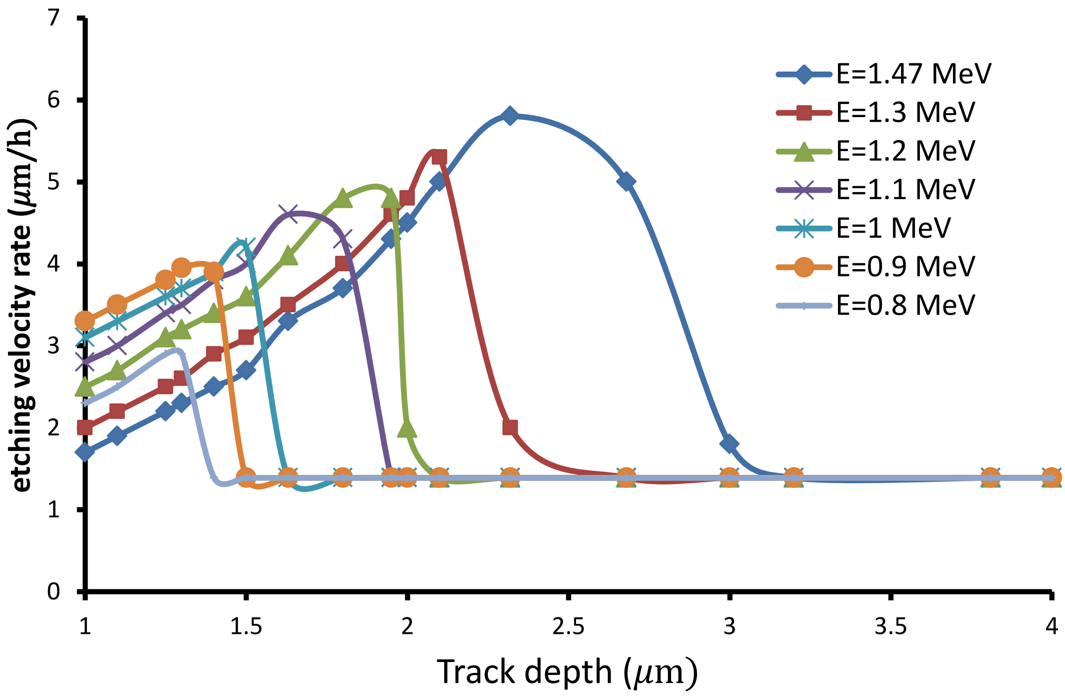

Figure 9: Etch velocity rate VT as a function of etching time for various alpha particle energy.

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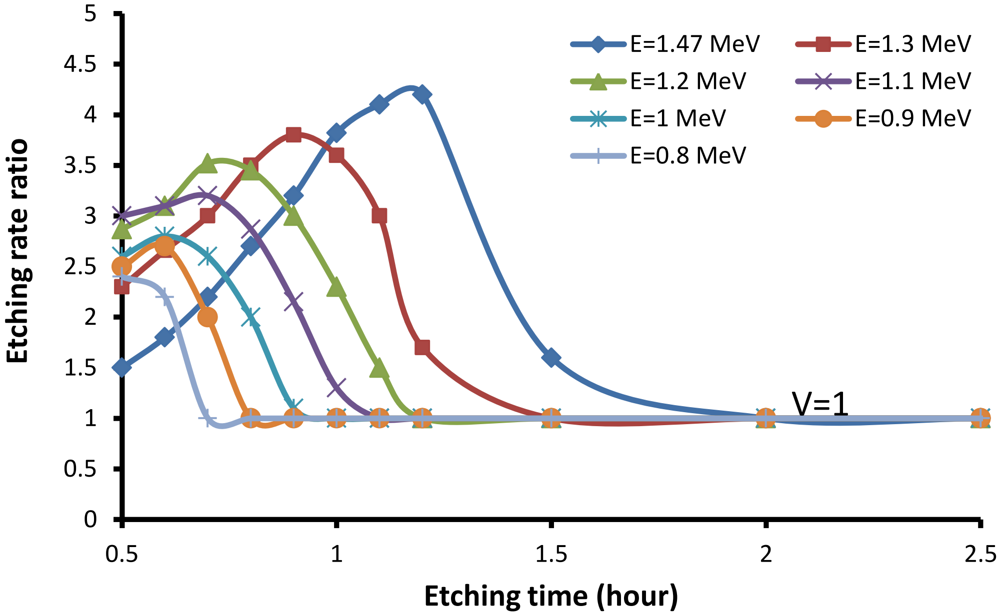

Figure 10: Etch rate ratio V as a function of etching time for various alpha particle energy.

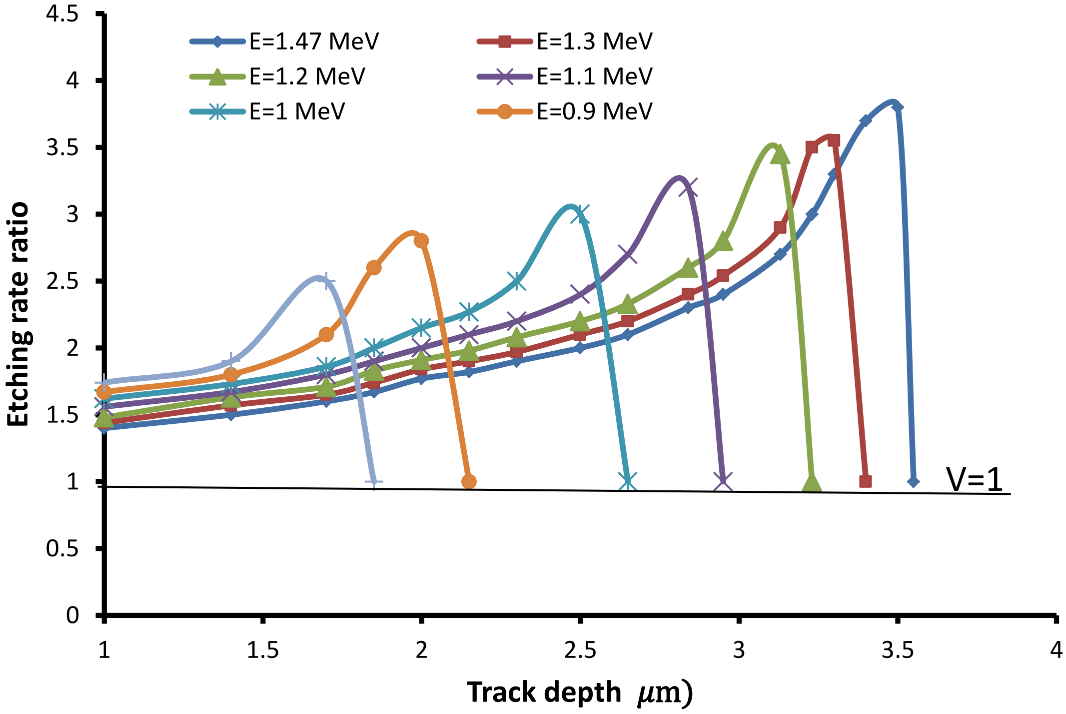

Figure 11: Etch rate ratio V as a function of track depth for various wit alpha particle Energy.

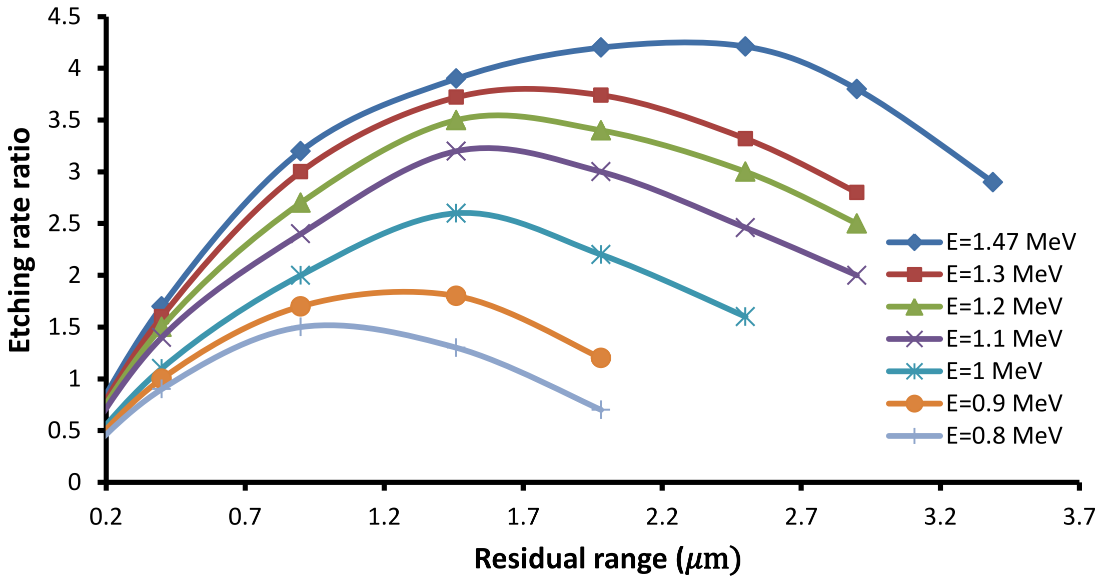

Figure 12: Etching rate ratio as a function of the residual range of alpha particles in the CR-39 detector.

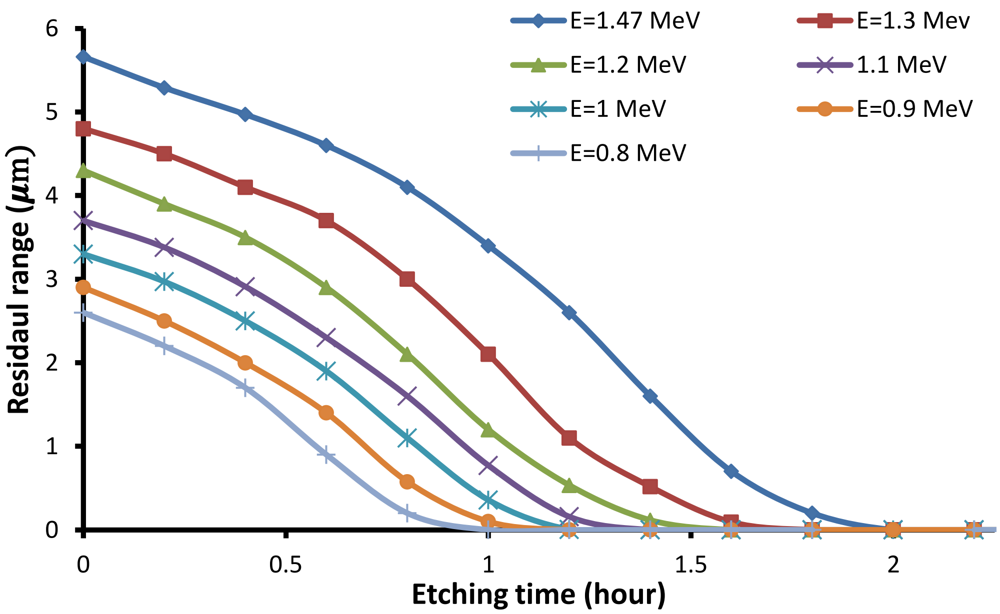

Figure 13: The residual range as a function of etching time of alpha particle.

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دراسة اولية لطبيعة اثر جسيمة الفا خلال كاشف اثرالحالة الصلبة النووي CR-39

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الخلاصة

قياسات معلمات اثر جسيمة الفا للتفاعل النووي $^{10}B(n,\alpha)^{7}Li$ بواسطة النيوترونات الحرارية المنبعثة من المصدر النيوتروني امريسيوم- بيريليوم $^{241}Am-Be$ سجلت بواسطة كاشف اثرالحالة الصلبة النووي CR-39. عملية القشط الكيميائي لسطح الكاشف تمت باستخدام محلول هيدروكسيد الصوديوم NaOH ذو عيارية 6.25 N بدرجة حرارة 70°C بفترات زمنية من ساعة الى ٥ ساعات. اعتماد اقطار الاثار كدالة لزمن القشط الكلي وانحراف معدل قشط الاثر ونسبة معدل القشط كدالة لطاقات سقوط مختلفة لجسية الفا تمت مناقشتها.