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Laser Effect on the Activation Energies, Bulk Etch Rate and Track Etch Rate of CR-39 Polymeric Detector

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Abstract The aim of this paper is to find the effect of Nd: YAG laser of wavelength (532 nm), laser power 150 MW on the CR-39 polymer. Twenty three detectors were divided in to three sets. The first set (ten detectors) (post-exposed) was first exposed to alpha radiation from ^{241}Am source at 3MeV and then treated in air with laser at different exposure time started from 10 minutes to 100 minutes with ten minutes differ between them (alpha + laser). For the second set (ten detectors) (pre-exposed), the process was reversed (laser +alpha) under the same conditions, for the last set (three detectors) (un-exposed to laser), used as a control set, was irradiated with an alpha source (241Am). Alpha track diameters, bulk etching velocity (V_B), track etching velocity (V_T), etching efficiency (η), etching ratio (V) were determined. The activation energies of bulk etch (E_B) and track etch (E_T) for unexposed, post-exposed and pre-exposed are found to be equal to 1.10, 0.92, 0.82 eV and 1.07, 0.86, 0.79 eV respectively.

Keywords: *nuclear track detectors, CR-39, activation energy of bulk etch (EB) and track etch (ET), etching conditions*

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1. Introduction

Nuclear track techniques are very important in many fields of science and technology. A solid state nuclear track detector namely CR-39 [poly-allyl-diglycol carbonate (C12H18O7)] is widely used for the detection of low Z and high Z particles. [1]. The interaction of electromagnetic radiation with the detector material results in structural changes. These changes depend on several factors such as detector structure, exposure condition, radiation type and energy, irradiation condition, etching process etc. Two competing processes, bond secession and crosslink, occur as a result of irradiation with (LLET) radiation. Bond secession lead to the degradation of the surface and as a result increases the bulk and track etch rates while crosslink results in hardening of the

Surface and subsequently decreases the bulk and track etch rates.[2]. The laser effect on the (SSNTDs) depends on laser properties (laser wavelength, laser repetition rate and energy density) and on the detector properties (density, thickness, etc). In general, infrared (IR) laser interaction with SSNTDs can induce thermal effects [3], while ultraviolet (UV) laser will give rise to photoablation or photodecomposition [4]. Many authors reported the effects of incoherent UV radiation on the etching properties of SSNTDs. These effects depend on several factors: radiation parameters, detector property and irradiation condition [5]. Activation energy of CR-39 polymer detector (bulk or track) is defined as the energy required to activate the reaction between the detector material and the etchant solution. Many works studied the activation energy of the CR-39 polymer detector [6,7]. The effect of gamma irradiation on the activation energy of CR-39 polymer detector was reported by [8].

2. Materials and Method

2.1. To find Laser effect on CR-39

CR-39 detector (1cm2) of thickness (0.5 mm). Twenty three detectors were divided into three sets, The third set(three detectors) served as a control set and its samples were exposed only to alpha radiation with close contact to 241 Am, The first set (ten detectors) (post-exposed) was first exposed to alpha radiation from 241Am source and then treated in air with laser at different exposure time started from 10 minutes to 100 minutes with ten minutes differ between them (alpha + laser). For the second set (ten detectors) (pre-exposed), the process was reversed (laser +alpha) under the same conditions. All the samples were etched in 6.25 M NaOH solution at 343 ^{o}K.

2.1.1. To Find the Activation Energy:

Fifteen detectors were divided into three sets, The first set (five detectors) (post-exposed) was first exposed to alpha radiation from 241Am source and then treated in air with laser at 60 minutes (alpha + laser), the second set (Five detectors) (pre-exposed), the process was reversed (laser +alpha) under the same conditions and the the third set served as a control set and its samples were exposed only to alpha radiation with close contact to 241 Am,. All the samples were etched in 6.25 M NaOH solution at five different temperatures, ranging from 338 K to 358 K, for 3

h. An equal temperature increment of 5 K was used. After etching, CR-39 detectors were thoroughly washed with distilled water and dried in open air. The thickness of the removed layer as a result of etching was found using a sensitive micrometer with digital camera. The bulk etch rate, V_B, is calculated by

$$V_B = (d1 - d2 / 2t) \quad (1)$$

Where d1 and d2 are the detector thickness (in mm) before and after etching;

t: is the etching time (in h).

The track etching rate VT for a given alpha particle was determined by measuring the etch –cone length Le after an etching time t, such that

$$Le = V_T t - V_B t \quad (2)$$

with V_B and t known [9], the measured value of Le immediately yields the value V_T.

The etch rate (sensitivity) V for circular tracks is given by

$$V = (V_B / V_T) \quad (3)$$

The dependence of VB, VT on temperature follows the Arrhenius

Type of law and is given by

$$V_B (V_T) = Ae - E_B / Kt \quad (4)$$

Where E_B is the activation energy for bulk etch rate and A is a constant.

K is the Boltzmann constant, A similar equation applies for track etch rate, VT, by replacing EB by ET by taking a natural log of above equation and plotting the graph between ln V_B (V_T) and $10^3/Tk^{-1}$, the slope gives the value of E_B (E_T).

3. Result and Discussion

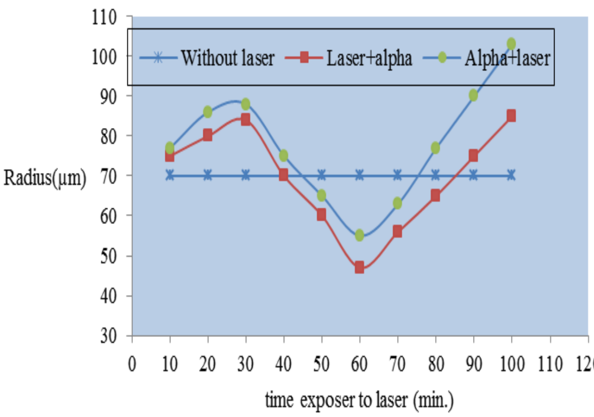

Figure 1. laser effect on CR-39

Figure 1 shows the effect laser radiation on CR-39 at different exposure time, The results showed that we have obtained an increase in the response of the detector irradiated with alpha particles and exposure to lasers, the increasing the size and speed of growth diameters effects formed a gradual increase with increasing to laser exposure time that value reached the highest value at exposure time is equal to 30min This indicates an increase in ductility Detector and get the decomposition in molecular chains and resulted in the acceleration of the process of the emergence of impact, and increase the time of exposure to a laser beam at 60min began diameters decreasing gradually until it reached a minimum value close to the diameters Detector record, which is due to increase in the complexity of chains of polymeric (Cross Linking) and hardening Detector this results agree with results in [10] references.

Table 1 and Table 2 shows the V_B and V_T value under at 60 minutes exposure time for laser radiation at different solution temperatures of three cases (laser+ alpha), (alpha +laser) and alpha only

Table 1. The value of V_B under laser radiation at different temperatures

	Laser + alpha	laser + Alpha	alpha
T °K	V_B(μm/hr)	V_B(μm/hr)	V_B(μm/hr)
338	0.4	0.813	1.152
343	0.813	1.08	1.355
348	1.49	2.168	2.64
353	2.168	2.71	3.25
358	2.64	3.32	4.065

Table 2. The value of V_T under laser radiation at different temperatures

	Laser + alpha	laser + Alpha	alpha
T °K	V_T(μm/hr)	V_T(μm/hr)	V_T(μm/hr)
338	0.424	0.839	1.184
343	0.876	1.1344	1.418
348	1.529	2.21	2.697
353	2.2	2.76	3.35
358	2.696	3.421	4.177

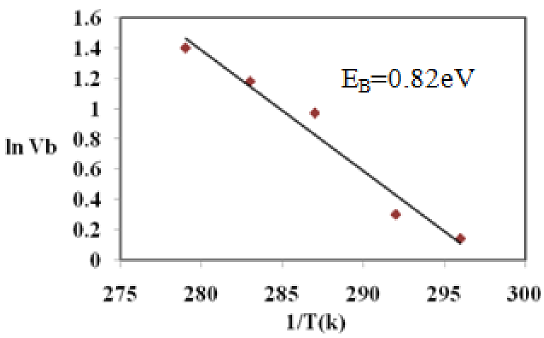

Figure 2. The activation energies for bulk (E_B) etch rate for alpha

The linear dependence of ln V_B and ln V_T versus reciprocal temperature, for reference, post-exposed and pre-exposed samples are depicted in Figs. Figure 2 and Figure 3 shows the variation of ln (vb) versus 1/T for alpha + laser, laser +alpha and alpha only of tracks to find the activation energies bulk in CR-39 by using the Arrhenius equation, the results of alpha only case is equal to 0.82 eV was less than from the another two cases alpha+ laser and laser + alpha there were 0.92 eV and 1.01eV respectively. The differences in value because the laser effects on the CR-39 polymer detector such as the (Cross Linking) and hardening Detector these effects lead to increase in activation energies of bulk etching. Again we can shows in Figure 5, Figure 6 and Figure 7 the variation of ln (V_T) versus 1/T for alpha + laser, laser +alpha and alpha only of tracks to find the activation energies track etching in CR-39 by using the Arrhenius equation, the results of alpha only case is equal to 0.79 eV was less than from the another two cases alpha+ laser and laser + alpha there were 1.07 eV and 0.86eV respectively. The activation energies for bulk (E_B) and track (E_T) etch rates, for each set, were calculated from the slopes of these linear plots. These values are listed in Table 3.

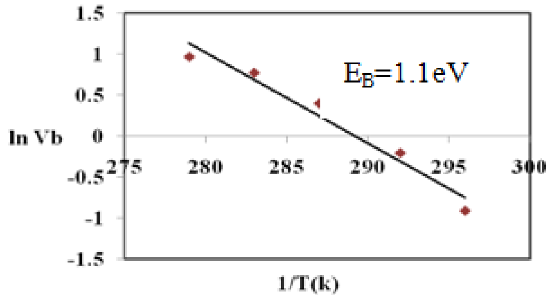

Figure 3. The activation energies for bulk (E_B) etch rate for laser+alpha

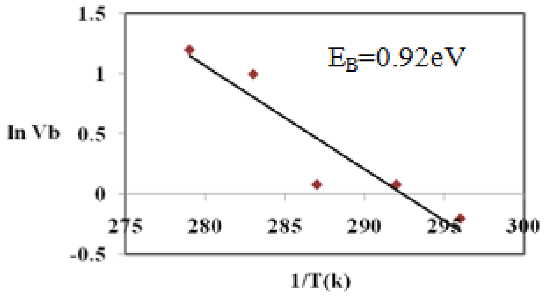

Figure 4 The activation energies for bulk (E_B) etch rate for alpha + laser

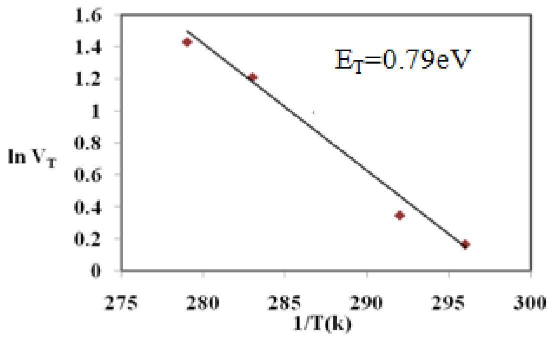

Figure 5. The activation energies for bulk (E_T) etch rate for alpha

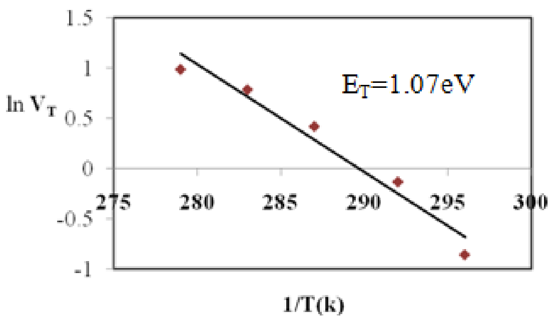

Figure 6. The activation energies for bulk E_T etch rate for laser+ alpha

Table 3. The values of The activation energies for bulk (E_B) and track (E_T) etch rates, for each set

Type of case	E_B (ev)	E_T(ev)
Laser+alpha	1.10	1.07
Alpha+ laser	0.92	0.86
Only alpha	0.82	0.79

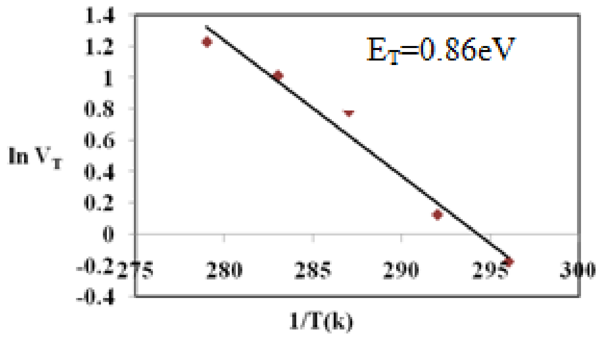

Figure 7. The activation energies for bulk (E_T) etch rate for alpha +laser

The measured values shows change in the activation energy of bulk etch rate for the irradiated samples as compared to the reference un-exposed sample. The activation energy of track etch rate for pre-exposed sample show an appreciable increases compared to that corresponding to the unexposed sample. This observed increase is indicative of the increase in hardening of CR-39 polymer detector resulting from the increase in cross-linking in the polymer. Also, the obtained values of E_T, in each set, are found to be less than those of E_B. This implies that the downward etch rate along the track is larger than that of bulk etch rate.

4. Conclutions

1: The activation energy of bulk etch rate, E_B, of CR-39 polymer detector is slightly affected by the laser treatment, This supports the proposal that E_B is a characteristic of the bulk material of the detector.

2: The significant increase in E_T for pre-exposed samples, compared to un-exposed and post-exposed samples, Track activation energy, E_T, has found to be lower than the bulk activation energy, E_B, for CR-39 detector in all different cases.

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