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Effect of (He-Ne) Laser on Etching Parameters of CR-39 Irradiated with Alpha Particles

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ABSTRACT

The effect (He-Ne) laser on the registration properties of alpha particle tracks on CR-39 track detector was studied. CR-39 detectors were exposed to different powers (1, 5 and 10 mW) of He-Ne laser beam at different times (5, 10 and 15 min) and then irradiated to alpha-particles from ^{226}Ra source (laser+α). Track diameters (D), track density (ρ) were determined using 6.25 N NaOH at 60°C. Bulk etching rate (VB), track etching rate (VT), critical angle (Θ_c), etching efficiency (η), Sensitivity (S), etching ratio rate (V) were calculated. It's found increase in the values of (D, ρ, V_B, V_T and Θ_c) with increase in the exposure times of laser at each power case, and decrease in the values of (η, S and V) with increase in the exposure time of laser at 1 mw power, while increasing within increase of exposed times of laser at (5 and 10 mW). The optimum etching time of CR-39 detectors was (4 h) with NaOH etchant solation and 6.25 at temperature 60°C.

Keywords: Laser, Polymeric materials

INTRODUCTION

Polymeric materials find several applications in different fields from everyday life to high technology engineering, especially Solid State Nuclear Track Detectors (SSNTDs) which are used in different applications and many articles are studied to understand and modify these polymers [1-3]. Since radiation is one of the major factors that change the structural properties of polymers, in particular solid state nuclear track detectors (SSNTDs), it would be worthwhile to study the modifications on their properties due to irradiation. The lower LET radiations (X-ray, electrons, gamma and laser) produce the bulk changes in the form of many broken molecular chains, leading to the change in bulk etch rate and optical response. These changed also find widespread applications in different scientific and technological fields [4]. It is well documented that Low Linear Energy Transfer (LLET) radiation has significant effect on the properties of track detectors. The modification in registration characteristics of track detectors is caused by radiation as a result of structure changes. The irradiation in track detectors yields (i) cross-linking which increases the molecular weight and decreases the etch rates, (ii) chain scission which decreases the molecular weight and subsequently increases the etch rates, in addition to emission of atoms and molecules (CO, CO_2 and H_2) which is resulting from cut in the long chain. During simultaneous chain scission and cross-linking reactions, if the probability of cross-linking reaction is larger than the other one, the polymer would become hardened, otherwise the polymer softening occurs. 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. Several studies [5-9] have been carried out to determine the main factors which affect the sensitivity and the properties of the CR-39 polymer as a track detector.

The passing of alpha particles through CR-39 sample causes ionization for almost all molecules which close to its path. This primary ionizing process triggers a series of new chemical processes that result in the creation of free chemical radicals and other chemical species. A zone enriched with free radicals and other chemical species is then created along the path of the alpha particle. This damage zone is called a latent track [10]. The latent track can be revealed through the chemical etching (erosion) in the material surface by using an acid or a base solution. In the chemical etching, the rate along the particle trajectory, track etch rate (VT), is faster than the rate of etching of the undamaged surface, bulk etch rate (VB). A pit is formed in the position of each track with etching progress [11].

MATERIALS AND METHODS

CR-39 detectors 500 µm thick were used. These sheets were cut into small pieces of 1.5 × 1.5 cm^2. CR-39 detectors polymer made by Pershore Moudling LTD Company, England.

CR-39 detectors were first exposed in air with (He-Ne) laser beam at powers (1,5,10 mW) and time (5,10 and 15 min) then irradiated with alpha particles from ^{226}Ra source of (10 µci) activity for 5 min at 2π geometry. The detectors were etched in 6.25 N NaOH solution at 60°C temperature at different etching times. After etching, CR-39 detectors were washed with distilled water and dried, the tracks densities and diameters (D) were measured with the use of the optical microscope with magnifies of 400x as shown in Figures 1-6.

The mass of detectors before and after etching at different etching time were measured as shown in Figures 7-9, the bulk etch rate V_B is calculated using the following equation:

$$v_B = \frac{1}{2\rho A}\frac{\Delta m}{\Delta t} \qquad (1)$$

Where ρ is the density of the detector, A area of the detector (1.5 × 1.5cm^2), Δt is the difference in etching time.

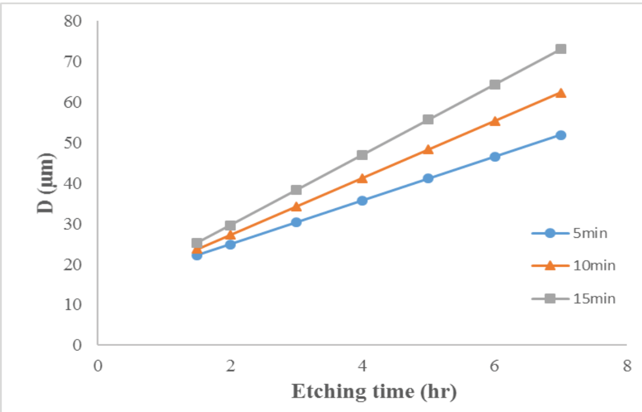

Figure 1: Alpha tracks diameter vs. etching time exposed to He-Ne laser beam at (1 mW) power etched in 6.25 N NaOH at 60°C

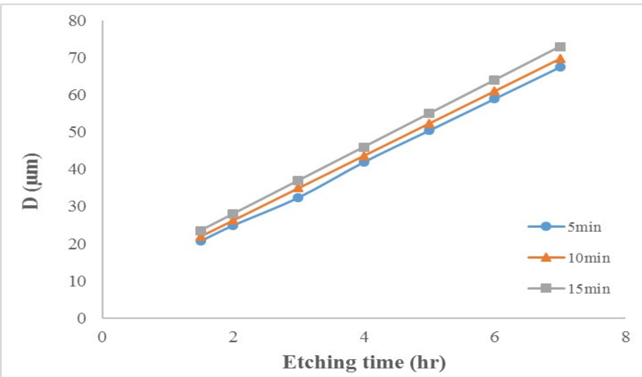

Figure 2: Alpha tracks diameter vs. etching time exposed to He-Ne laser beam at (5 mW) power etched in 6.25 N NaOH at 60°C

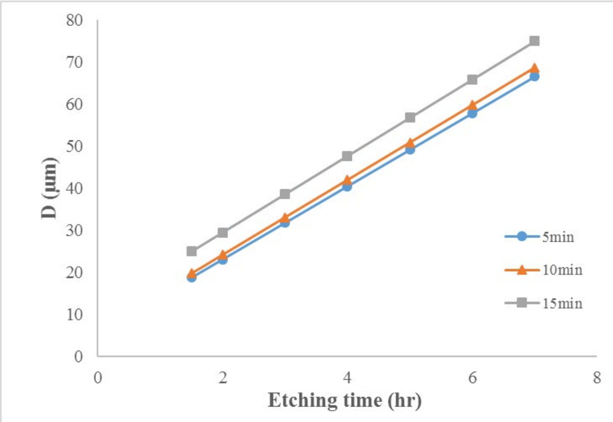

Figure 3: Alpha tracks diameter vs. etching time exposed to He-Ne laser beam at (10 mW) power etched in 6.25 N NaOH at 60°C

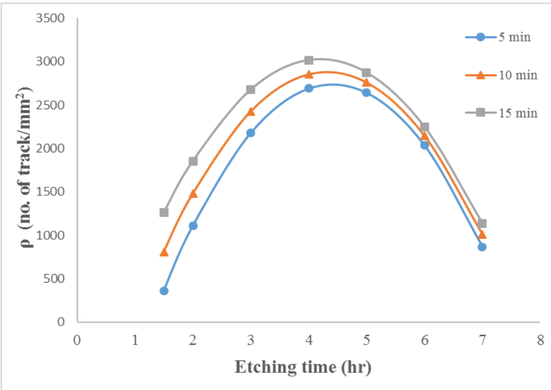

Figure 4: Alpha tracks densities vs. etching time exposed to He-Ne laser beam at power (1 mW) at different times etched in 6.25 N NaOH at 60°C

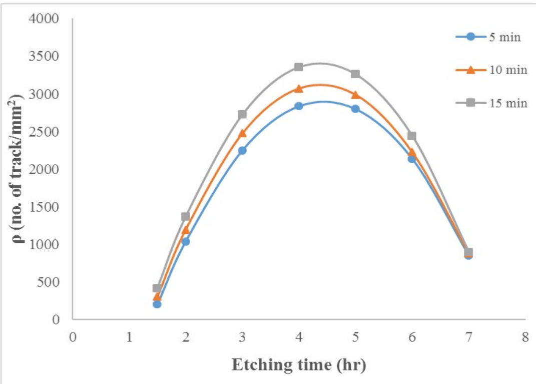

Figure 5: Alpha tracks densities vs. etching time exposed to He-Ne laser beam at power (5 mW) at different times etched in 6.25 N NaOH at 60°C

The diameter etch rate V_D is calculated by measured the diameter of alpha tracks at different etching times as shown in Figures 1-3 and calculated using the following equation:

$$v_D = \frac{\Delta D}{\Delta t} \quad (2)$$

The track etching rate VT was calculated using the following equations:

$$v_T = v_B \left[\frac{1 + v_{D^2} / v_{B^2}}{1 - v_{D^2} / v_{B^2}} \right] \quad (3)$$

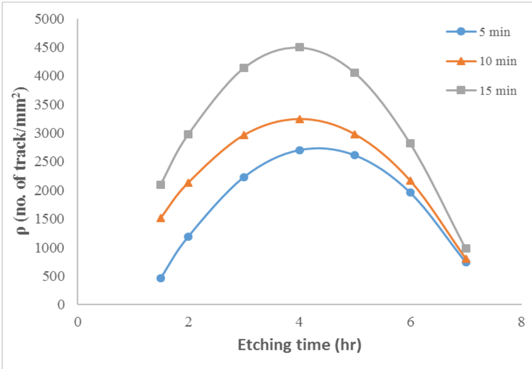

Figure 6: Alpha tracks densities vs. etching time exposed to He-Ne laser beam at power (10 mW) at different times etched in 6.25 N NaOH at 60°C

The etch rate ratio V for track detector is given by:

$$v_T = \frac{v_T}{v_B} \qquad (4)$$

For every SSNTD etched under a given condition, there is found to exist certain minimum angle called the critical angle (θc), measured using the following equation:

$$\theta_C = \sin^{-1}\frac{v_B}{v_T} \qquad (5)$$

The etching efficiency is defined as the ratio of the counted tracks and the number of particles incident on the detector surface, the efficiency (η) depends on the track etched rate V_T and the bulk etched rate V_B as present in equation:

$$\eta = 1 - \frac{v_B}{v_T} \qquad (6)$$

Etching sensitivity (S) was calculated by the following equation:

$$S = V - 1 \qquad (7)$$

RESULTS AND DISCUSSION

The CR-39 track detectors exposed to laser beam at different times (5, 10 and 15 min) and different powers (1, 5 and 10 mW) and irradiate with alpha particles. The relation between the track diameter and tracks densities at different etching time, using 6.25 NaOH at 60°C exposed to (He-Ne) laser beam at (1, 5 and 10 mW) powers were shown in figures from Figures 1-6.

We noticed that increasing in the tracks diameter and tracks densities response to increase in the etching time, and at high etching time show decrease in the track density and this interpretation that increase in time of etching lead to increase in the thickness of removed layer that responsible of track appearing and reach the minimum value due to increase in the track diameter at high etching time, also figures show that the density and diameter of track increase response to increase in the exposure time of laser beam at different power, because laser increase in elasticity of detector and get the decomposition in molecular chains main of detectors which cause new molecular chains, this chains have free radicals repulsive among themselves, and construct a new number from the free radicals as results of lost alpha-particles for its energies when it passed through the detectors, and when the etchant solution process the etchant will begins to attack the free radicals leading to remove it from molecule of detectors and thus free radicals repulsive away from the center of track and made a track with large diameter.

Tracks densities vs. Etching time for α-particles and He-Ne laser beam at powers (1,5,10 mW) at different exposure times were shown in Figures 4-6. The etching time for all groups using 6.25 N (NaOH) solution were (4 h). At (4 h) etching time shown that the maximum of tack density increase with increase in the time exposed of laser at each case of power, the track density has the maximum value at (10 mW) laser power, the reason of increase was because

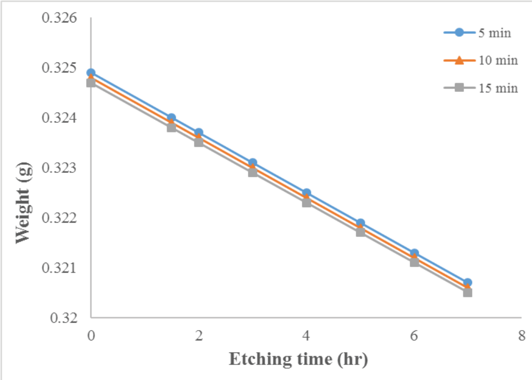

Figure 7: Weight of CR-39 detector vs. etching time at different exposed times to He-Ne laser beam at (1 mW)

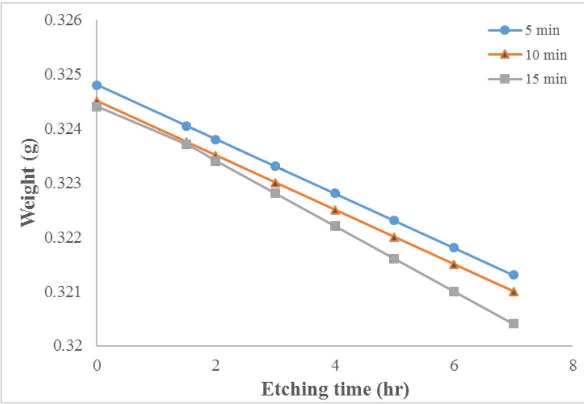

Figure 8: Weight of CR-39 detector vs. etching time at different exposed times to He-Ne laser beam at (5mW)

Table 1: Various track etching parameters of CR-39 nuclear track detectors exposed to He-Ne laser for (1, 5 1nd 10 mw) power at different times

P (mW)	t (min)	V_D (µm/h)	V_B (µm/h)	V_T (µm/h)	V	Θ_C	η	S
	5	5.4	1.72	2.1	1.22	54.78	0.183	0.22
	10	7	1.85	2.13	1.15	60.32	0.131	0.15
1	15	8.6	1.95	2.15	1.1	64.49	0.097	0.1
	5	8.549	1.81	1.984	1.094	66.07	0.086	0.094
	10	8.7	1.89	2.08	1.099	65.49	0.09	0.099
5	15	9	2.07	2.297	1.111	64.16	0.1001	0.111
	5	8.7	1.92	2.116	1.102	65.15	0.093	0.102
	10	8.9	2.09	2.34	1.117	63.54	0.105	0.117
10	15	9.1	2.22	2.503	1.127	62.53	0.112	0.127

increase in elasticity of detector at increase of time exposure and laser power.

Weight of CR-39 detector vs. etching time for different times exposed He-Ne laser beam at (1, 5, 10 mW) were shown in Figures 7-9, which shows that the increase in the exposure time of laser at different power cause to decrease in the weight of detectors after etching, because of increase in the thickness of remove layers from the detectors. The bulk etches rate calculated using equation (1) for CR-39 detectors at different powers of (He-Ne) laser beam and different time's exposure.

The etch rates (V_D and V_T) were calculated using equations (2) and (3) are shown in Table 1. The relation between the etch rates (V_D, V_B and V_T) for He-Ne laser at (1, 5 and 10 mW) exposed at different times were shown in figures from Figures 10-12, its show that increasing in exposure time of laser light for each power values lead to increase in

the values of etch rates. The relation between the etch ratio (V) and exposure time of laser light at different power

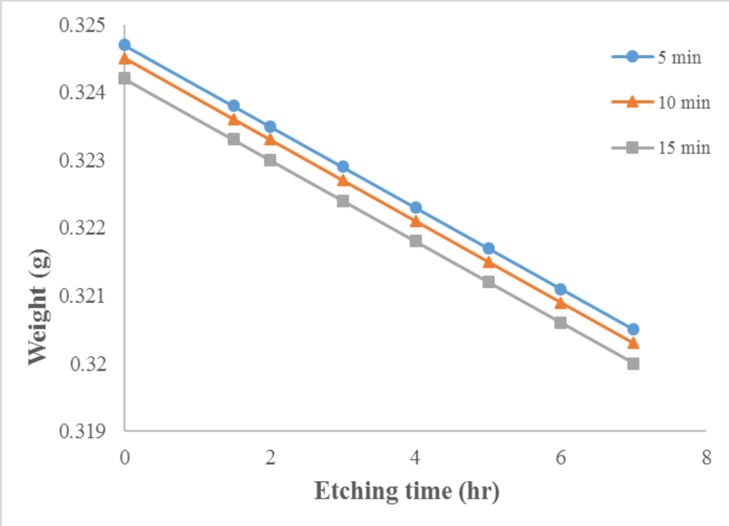

Figure 9: Weight of CR-39 detector vs. etching time at different exposed times to He-Ne laser beam at (10 mW)

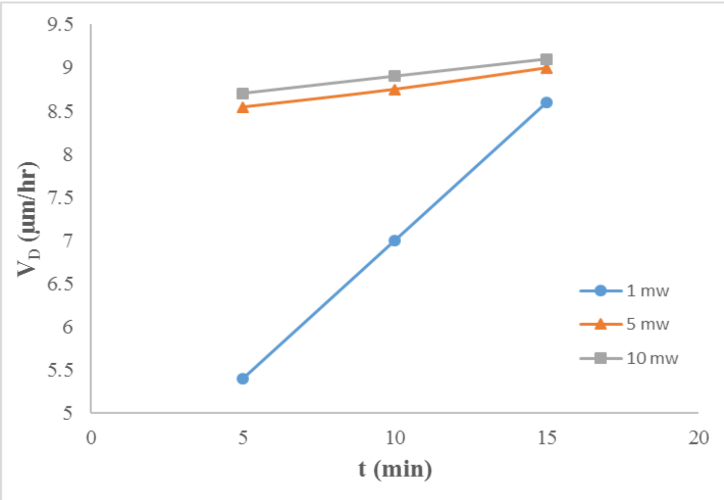

Figure 10: Diameter etch rate V_D vs. exposure time of He-Ne laser beam at different powers

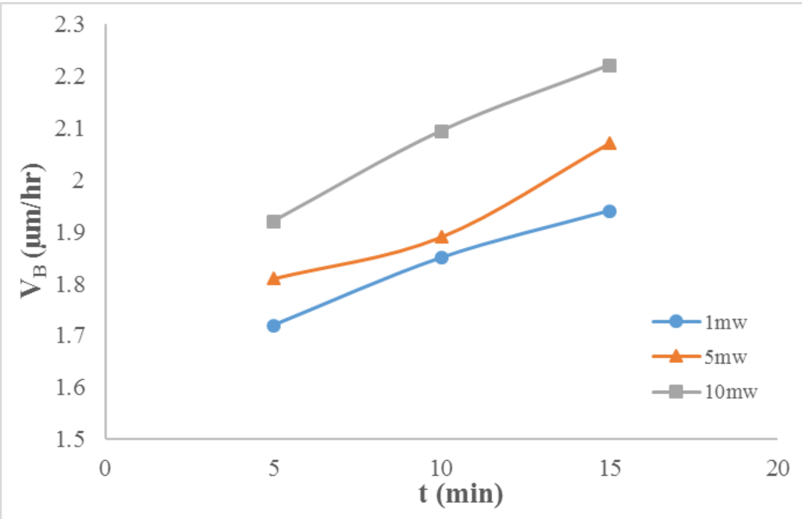

Figure 11: Bulk etch rate V_B vs. exposure time of He-Ne laser beam at different powers

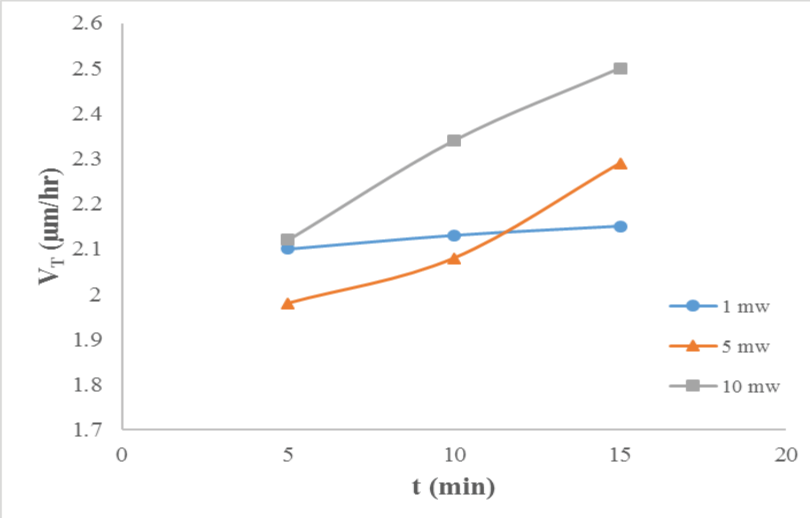

Figure 12: Track etch rate V_T vs. exposure time of He-Ne laser beam at different powers

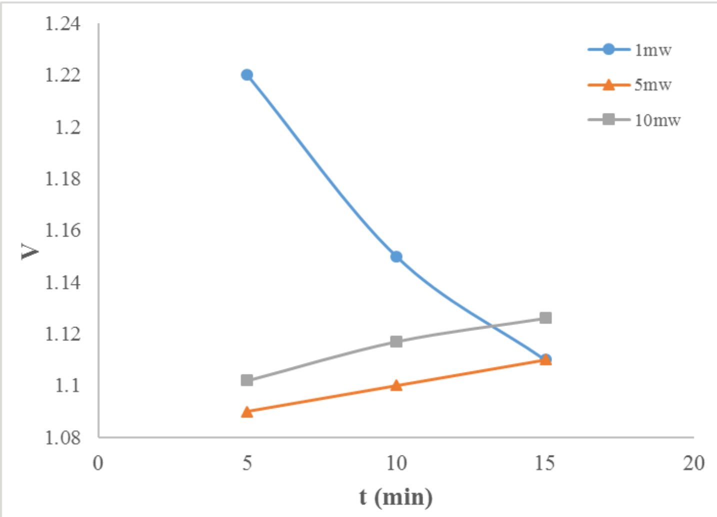

Figure 13: Etching rate ratio V vs. exposure time of He-Ne laser beam at different powers

were shown in Figure 13, it shows that in (1 mW) power decrease on the etch ratio at increase of exposure time of laser while for (5, 10 mW) power it shows that increasing in the etch ratio values at increase of exposure time of laser.

The values of critical angle (ϴc) and efficiency (η) at different exposure time of laser light for laser power (1, 5 and 10 mW) were shown in Table 1 and we conclude that increasing in the exposure time of laser for each case of power lead to increase critical angle value because of increasing in the values of the etch rates (V_B and V_T) and this lead to increase values of critical angle, while the efficiency of etching decrease at increase in the exposure time of laser for all power the reason was that the increasing in the values of etch rates (V_B and V_T) lead to increasing in values of (V_B/V_T) and thus to decrease in the efficiency of etching.

CONCLUSION

1- The optimum etching time of CR-39 detectors exposed to (α+laser) was (4 h) for etchant solution NaOH and 6 N normality at 60°C.

2- The increasing in the exposure times of laser at different powers lead to increasing in the tack density and track diameter and the best case its seen at (15 min) exposed of (10 mW) (He-Ne) laser beam because they recorded maximum values compared with other cases.

3- The increasing in the exposure times of laser at different powers lead to increasing in the etch rate parameter (V_B and V_T), critical angle and Sensitivity, the recorded the maximum value at (15 min) exposed of (10 mW) He-Ne laser beam.

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