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The effect of infrared laser on the activation energy of CR-39 polymeric detector

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ABSTRACT

The effect of infrared laser of wavelength ($\lambda = 1064$ nm), pulse energy of 40 mJ/pulse at a repetition rate of 10 Hz, on the activation energy of CR-39 polymer, solid state nuclear track detector, has been investigated. Fifteen detectors were divided into three sets of equal numbers. The first set (un-exposed to laser beam), used as a reference set, was irradiated in close contact with an alpha source (^{241}Am). The second set (post-exposed) was first exposed to alpha radiation in close contact to the same ^{241}Am source and then treated in air with laser at energy intensity 8 J/cm^2. For the third set (pre-exposed), the process was reversed (laser+alpha) under the same conditions. The activation energies of bulk etch (E_B) for unexposed, post-exposed and pre-exposed are found to be equal to 0.98, 0.91, and 1.0 eV, respectively. The respective activation energies of track etch (E_T) for unexposed, post-exposed and pre-exposed are found to be equal to 0.71, 0.75, and 0.97 eV.

These results show that E_B for post-exposed and pre-exposed samples remain, to within the experimental uncertainty, comparable to that of un-exposed sample which indicates that laser irradiation has a small effect on E_B. Also, the results of E_T for post-exposed and un-exposed samples are in close proximity with a slight increase for the former. The increase in E_T of pre-exposed CR-39 polymer due to IR exposure is discussed on the basis of cross linking processes occurring during the exposure. This increase in E_T leads to the hardening of the detector material of the pre-exposed sample. The hardening of the detector material is crucial in applications of CR-39 polymer such as in cosmic ray and cold fusion research.

1. Introduction

It is well proved that registration characteristics of Solid State Nuclear Track Detectors (SSNTDs) are affected by the radiation of Low Linear Energy Transfer (LLET) [1–3]. 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. In addition to the above mentioned processes, emission of molecules such as (CO, CO_2 and H_2), resulting from cut in the long chain of CR-39 polymer (Polyallyl diglycol carbonate, AADC; [$(C_{12}H_{18}O_7)n$]), also occur. During simultaneous chain scission and cross-linking reactions, if the probability of cross-linking reaction is larger than that of the chain scission, the polymer would become hardened, otherwise 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). In general, infrared (IR) laser interaction with SSNTDs can induce thermal effects [1], while ultraviolet (UV) laser will give rise to photoablation or photodecomposition [2]. Many authors [3–22] 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. However, the change of one or all these factors will change the observed effects and produce new results. Effects of IR-laser [1,20,23–25] and UV-laser [2,20,26,27] on the properties of CR-39 polymer detector have been reported.

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 [28–32] studied the activation energy of the CR-39 polymer detector.

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The effect of gamma irradiation on the activation energy of CR-39 polymer detector was reported by [31,32]. Table 1 [28] summarizes the activation energy values of the CR-39 polymer detector for different ions.

CR-39 polymer detector is extensively used in various experiments in space science, nuclear science, cold fusion research and radiation detection and identification of the nature of nuclear particles [33–37]. Therefore, it is important to study how LLET radiation can change the track registration properties of CR-39 polymer detector due to IR irradiation process. As the works reporting the effect of IR laser on the activation energy of CR-39 polymer detector are scarce, this paper presents the effect of IR laser ($\lambda = 1064$ nm) on the activation energy of CR-39 polymer detector with the purpose of obtaining further insight on this effect. Also, this paper is a continuation of our previous works [26,27].

2. Material and method

CR-39 detector (2 cm × 2 cm) of thickness (1 mm) produced by (Fukuvi chemical industry Co., Ltd, Japan) was used in this study.

Table 1
Activation energy of etching for Acrylic CR-39 using different ions [28].

Ion	LE200 (keV/μm)	E_B (eV)	E_T (eV)
N	20	0.78 ± 0.03*	0.77 ± 0.03*
Fe	110	0.78 ± 0.03*	0.78 ± 0.03*
ff	$(5-10) \times 10^3$	0.67 ± 0.03*	0.67 ± 0.02*
ff	$(5-10) \times 10^3$	0.80 ± 0.04**	0.79 ± 0.03**

* By using the weight difference method.
** By using the ff track diameter method measured using the automatic system at the University of Siegen.

Fifteen detectors were divided into three sets, each of five samples. The first one served as a control set and its samples were exposed only to alpha radiation with close contact to ^{241}Am source of activity 74 kBq. The second set (post-exposed) was first exposed to the same alpha source and then treated in air with IR laser of $\lambda = 1064$ nm, pulse energy 40 mJ/pulse and at repetition rate 10 Hz. The laser source power is calibrated at 40 mJ/pulse with a power meter and a homogenizer is used to achieve uniform laser irradiation. Each sample was exposed to the total laser energy intensity of 8 J/cm^2. The third set (pre-exposed) was irradiated in reverse process (laser + alpha) with the same sources as the second set and under the same conditions. All the samples were etched in 6.25 M NaOH solution at five different temperatures, ranging from 343 K to 351 K, for 3 h. An equal temperature increment of 2 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. The bulk etch rate, V_B, is calculated by

$$V_B = \frac{d_1 - d_2}{2t} \quad (1)$$

where d_1 and d_2 are the detector thickness (in μm) before and after etching; t is the etching time (in h). The reduced etch rate (sensitivity), V, for circular tracks is given by [28]

$$V = \frac{h^2 + r^2}{h^2 - r^2} \quad (2)$$

and the track etch rate, V_T, is obtained via the relation

$$V = \frac{V_T}{V_B} \quad (3)$$

where $h = d_1 - d_2$ is the thickness of the removed layer (in μm), r is the track radius (in μm). An example of the circular tracks

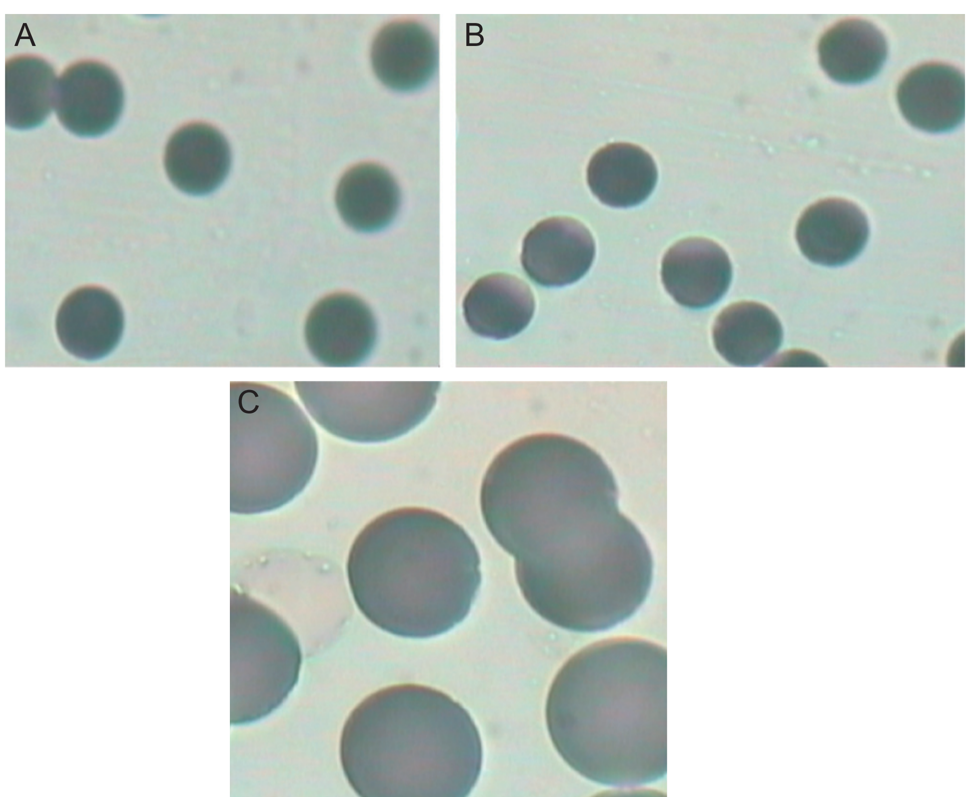

Fig. 1. The effect of IR laser on the tracks. (A) Post-exposed sample (alpha + laser) (B) un-exposed sample (only alpha radiation) (C) pre-exposed sample (laser + alpha). The three samples are exposed to the same laser energy intensity and etched in the same condition.

obtained for un-exposed, post-exposed and pre-exposed samples is displayed in Fig. 1.

The dependence of V_B, V_T on temperature follows the Arrhenius type of law and is given by

$$V_B(V_T) = A_e^{-E_B/kT} \tag{4}$$

where E_B is the activation energy for bulk etch rate and A is a fitting parameter. A similar equation applies for track etch rate, V_T, by replacing E_B by E_T in Eq. (4).

3. Results and discussion

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. 2 and 3, 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 2. The measured values show small 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 increase as 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. Fig. 4 displays

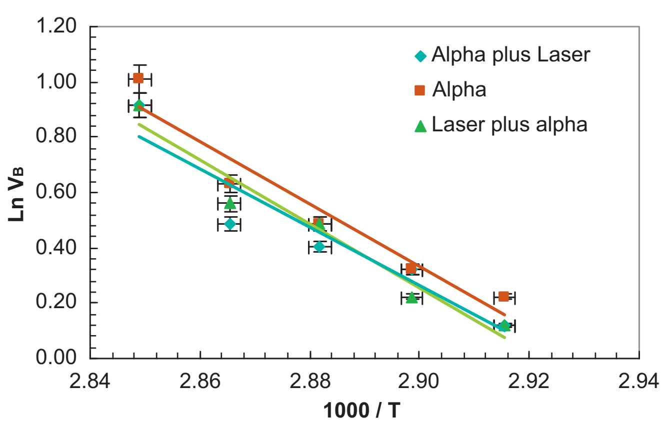

Fig. 2. The dependence of LnV_B versus reciprocal temperature for un-exposed, post-exposed and pre-exposed CR-39 detectors.

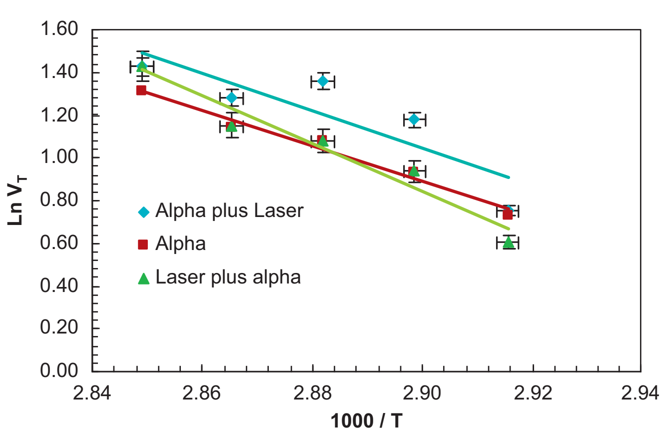

Fig. 3. The dependence of LnV_T versus reciprocal temperature for un-exposed, post-exposed and pre-exposed CR-39 detectors.

Table 2
Activation energy of CR-39 detector (Present work).

Irradiation type	E_B (eV)($\pm$0.06)	E_T (eV) ($\pm$0.02)
Alpha	0.98	0.71
Alpha and laser	0.91	0.75
Laser and alpha	1.00	0.97

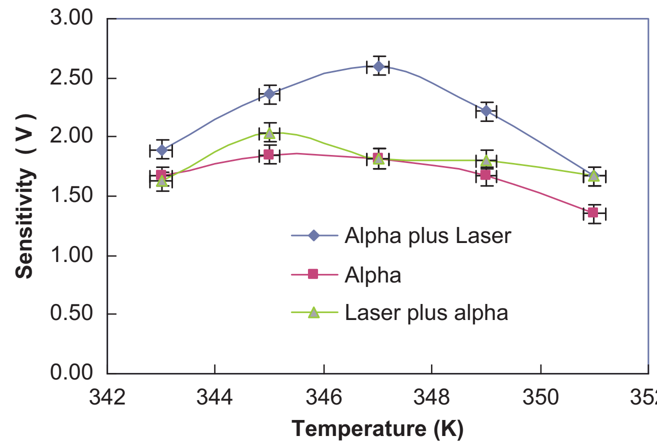

Fig. 4. Variation of the sensitivity, V, for un-exposed, post-exposed and pre-exposed CR-39 detectors.

the effect of IR laser irradiation on the sensitivity of CR-39 polymer detector. As can be noted from this figure, the sensitivity for post-exposed samples is higher than that of pre-exposed and un-exposed samples and it peaks at the etching temperature of 347 K. Thus this temperature can be considered as the temperature for the optimum sensitivity for post-exposed samples. The decrease in the sensitivity, corresponding to an increase in the hardening of the detector material, for post-exposed samples for temperatures larger than 347 K, is associated with the larger increase in V_B as compared to that of V_T. It is also interesting to note from Fig. 4 that the sensitivity, for both un-exposed and pre-exposed samples decreases for temperatures larger than 347 K. Presumably, a combined heat effect from the IR laser and the etchant solution, for temperatures larger than 347 K, is responsible for this observed decrease in the sensitivity. Thus the heat energy of the etching solution plays a significant role in maximizing or/minimizing the laser effect on the etching characteristics of the CR-39 polymer detector. This opens the possibility for applying CR-39 polymer for the detection of particles according to their energy. That is to say, if one wishes to detect high energy particles, such as cosmic rays, then it is preferable to treat the CR-39 polymer detector by laser before its use. On the other hand, for the detection of low energy particles it is better to expose the samples to the laser beam after their exposure to ion radiation and then etch them at 347 K.

4. Conclusions

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. The significant increase in E_T for pre-exposed samples, compared to un-exposed and post-exposed samples, results from the hardening of the detector material. This hardening of pre-exposed CR-39 polymer detector can find applications in the detection of high energy particles without the need to increase the detector thickness.

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