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The measurements of laser beam transmission through exposed/etched CR-39 and CN-85 detectors

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ABSTRACT

In the present trackology work, CR-39 and CN-85, solid state nuclear track detectors (SSNTDs) were irradiated with alpha particles and gamma rays for different irradiation times. These detector foils were chemically etched by NaOH solution with specified normality. The intensity of transmitted laser light (λ=650 nm) through irradiated and etched detectors was measured using a photodiode. The method appeared as a good technique for dose measuring but it is extremely dependent on the etching time, the type of incident particles and the type of the detector. It is found that the response of CN-85 detector looks faster and better than CR-39 detector.

1. Introduction

Ionizing particles passing through polymeric detectors produce latent tracks that are trials of radiation damage [1]. Tracks of ionizing particles can be easily developed by means of a suitable selective chemical etch in dielectric track detector. The bulk etch rate for solid state nuclear track detectors (SSNTDs) depends on several parameters: temperature, concentration of etching solution and etching time. The rate of track formation shows a complex behavior due to the combination of physical and chemical reaction which makes it hard for simple numerical model to establish [2,3]. The traditional method for extracting information from the etched SSNTDs is the visual counting of tracks using an optical microscope with an appropriate magnification. Another line has been developed by measuring the optical density of the transmitted light through the etched SSNTD and by studying the scattering of the coherent light from the etched pits in CR-39 [4–6]. The optical track scanning method which was based on the measurement of laser light transmission through CR-39 was, performed recently [7].

In this work, the diode laser direct (at 0° angle) transmission through etched CR-39 and CN-85 detectors was irradiated with alpha particles or gamma rays.

2. Theoretical background

If light radiation of initial intensity $I_{0\lambda}$ passes through a medium, the intensity decreases by dI. The relative decrease in the intensity can be written as [8]

$$\frac{dI}{I_\lambda} = -k_\lambda \rho l \quad (1)$$

where l is the thickness of the traversed layer, ρ is the medium density and k_λ is the specific absorption coefficient. In case of normal incidence, ρl is called density weighed path length. Integrating Eq. (1) from 0 to L, the detector thickness, one obtains

$$I_\lambda = I_{0\lambda} \exp(\sigma_\lambda) \quad (2)$$

where

$$\sigma_\lambda = \int_0^L k_\lambda \, dl \quad (3)$$

which is called the optical depth (or thickness).

In the absence of scattering, the transmittance is given by

$$T_\lambda = \exp(\sigma_\lambda). \quad (4)$$

If ρ and k_λ are independent of the path in the medium, then the optical thickness is simply written as

$$\sigma_\lambda = \rho k_\lambda L. \quad (5)$$

3. Experimental

3.1. Irradiations

A set of 10 films of CR-39 (with thickness 1000 μm, supplied by Pershore Moulding, England) and CN-85 (with thickness 100 μm, supplied by Kodak-Pathe, France) with dimensions 1×1 cm^2 were

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prepared. The irradiations were carried out in air, so the results did not suffer from the vacuum effect in track properties. One detector piece from each set kept unirradiated, affected by natural background only, to use as the control sample and the others were irradiated as follows.

3.1.1. Alpha particles

Two foils of each detectors were irradiated with alpha particles from ^{241}Am (in contact with mean energy 5.49 MeV) for 2 and 94 h. The activity of the source was 555 Bq and supplied by Radio-Chemical Ltd., Amersham, England.

3.1.2. Gamma rays

Two foils of each detector sets were irradiated with gamma rays from ^{137}Cs (in contact) for 10 and 15 days. The source activity was 12 Ci, supplied by J.L. Shepherd and Associates, California, USA.

3.2. Etching

A standardized etching procedure was adopted by using NaOH solution of 6.25 N, 70 °C and 5 N, 50 °C for CR-39 and CN-85, respectively. The variation in set value for etching temperature was not more ± 1 °C. Different etching times were used, with maximum estimated error ± 30 s. Before performing any experiment using SSNTD, it should be established that the etching behavior of the different detector pieces is the same at the same etching conditions and irradiation particle or electromagnetic radiation energies [9,10].

3.3. Laser system arrangement

Transmittance measurements at normal incidence were undertaken for 20 samples at wavelength ($\lambda = 650$ nm), the sample transmittance is $T_\lambda = I_\lambda / I_{0\lambda}$ where $I_{0\lambda}$ is the incident intensity and I_λ is the transmitted intensity. A schematic diagram of the experimental setup is shown in Fig. 1. A light beam from 650 nm continuous-wave diode laser of 50 mW output power, perpendicular to the rear surface of the detector, enters and then passes through the detector. The track etch detector has been placed at a distance of 20 cm from the aperture of diode laser apparatus. The illuminated area is circular and has a diameter of 1.2 mm. The illuminated region was chosen so as to minimize the effects of singular scatterers such as impurities or scratches in the material. Part of the transmitted light is scattered by the etched tracks on the rear surface of the detector. The scattering coherent cone depends on the size, shape and density of the scatterers.

To measure the intensity of the scattered transmitted light, a photodiode with a sensitive area of 12.5 mm^2 was used and located at a distance of 5 cm from positive glass lens of +50 mm focal length. The received signal from the photodiode was read by a digital voltmeter. The incident light was monitored by using a beam splitter to a reference photodiode.

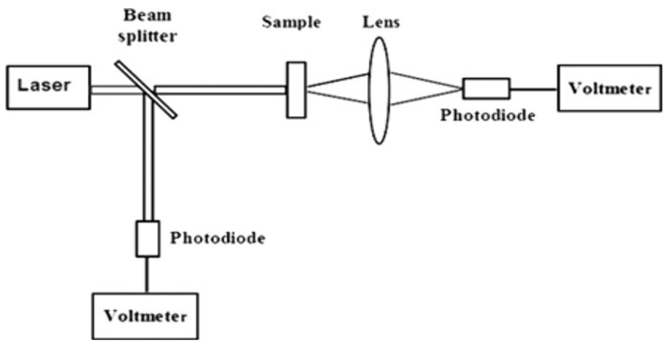

Fig. 1. Schematic diagram of the experimental setup.

4. Results and discussion

4.1. Alpha particles

Figs. 2 and 3 show the behavior of the laser light transmission through the etched CR-39 and CN-85 foils in the normal incidence case (0°) versus chemical etching time starting from 1 to 10 h. In the case of non-irradiated samples, one can notice that there is no change in the intensity of the laser light as the etching time increases for both CR-39 and CN-85 remain transparent.

For the samples of CR-39 and CN-85 irradiated for 2 h with alpha particles we note that the transmission of the laser light decreases slowly and reaches saturation very fast as the etching time increases. As alpha particles dose highly increases (94 h of irradiation time), the shape of the transmission curve changed clearly and one can notice an important decrease followed by an increase in the transmitted laser light through both CR-39 and CN-85 as etching time increases. This behavior could be interpreted as follows.

The scattered laser light by tracks depends on track density, track sizes and track orientations, so, as etching time increases (for both doses) the track diameter increases making a decrease in the transmitted laser light at 0° angle via light scattering [6].

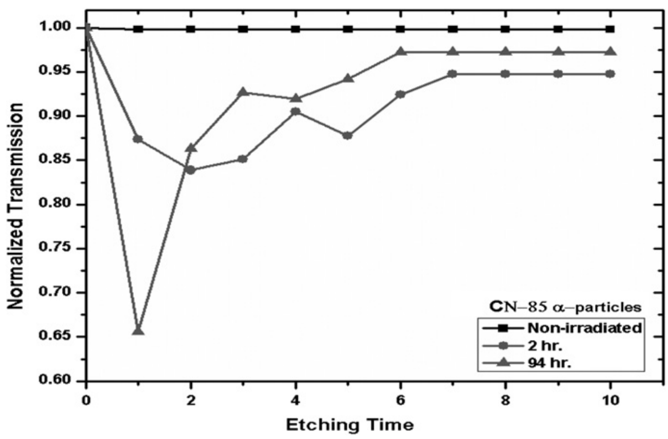

Fig. 2. Transmission of diode laser through etched CN-85 irradiated with alpha particles.

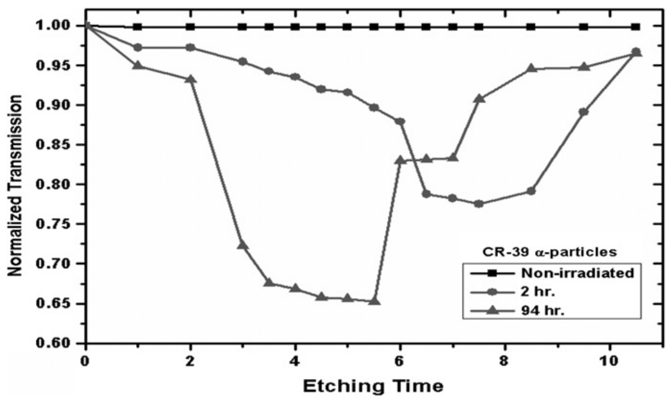

Fig. 3. Transmission of diode laser through etched CR-39 irradiated with alpha particles.

In both cases of irradiation time, 2 h and 94 h, and low etching times (> 6 h) in the case of CN-85 and (> 10 h) the case of CR-39, the transmitted laser light significantly decreases, approximately linearly, with increasing etching times. This feature is attributed to the tracks that overlapped with their neighbors, resulting in an increase in the scattering of light and consequently a decrease in the transmittance. It should be noted that the overlapping of tracks was due to the enlargement of their diameters and depths with the increasing etching time for both short and long irradiations. The rate of decreases in the transmission through the etched SSNTD foils with the average track density ρ_d can be estimated according to the relationship [11]

$$D = -\log T = -\log[T_t + (T_f - T_t)\exp(-\pi r^2 \rho_d)] \quad (6)$$

where D is the optical density, T is the fraction of light transmitted by the detector foil, T_t and T_f are the light transmissions through an individual track and through the track free area on the SSNTD respectively, r is the track radius and ρ_d is the average track density.

Figs. 2 and 3 show that the response of CN-85 to the change in the transmission of laser light which is greater and faster than for CR-39. However both detectors foil response is quite fast in the relatively short etching time, which indicates that this technique is especially useful in the cases of track geometry.

In the case of high irradiation time, 94 h, both detector foils reach to the minimum transmission rate, 0.65, but after different etching times (CN-85 after 2 h and CR-39 after 5.8 h) and this is related to the detector thickness. This is also applied to the saturation or maximum transmission; CN-85 foils reach saturation after 7 h while CR-39 reaches saturation after 10 h. In the case of low irradiation time, 2 h, the CN-85 foils reach minimum transmission 82.5% or tracks overlapped after 2 h etching time, while CR-39 foils reach the minimum transmission of 77.5% after 7.8 h etching time. This is also related to the thickness and chemical structure of both detector foils. Bear in mind that increasing the etching time cylindrical latent tracks damage will form for both detectors foils [12,13].

4.2. Gamma rays

The irradiation of polymers with gamma rays results predominantly in ionization and excitation. Subsequently the chemical

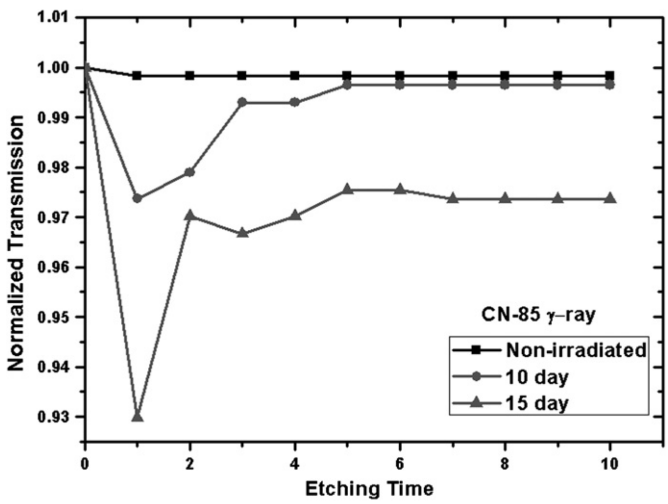

Fig. 4. Transmission of diode laser through etched CN-85 irradiated with gamma rays.

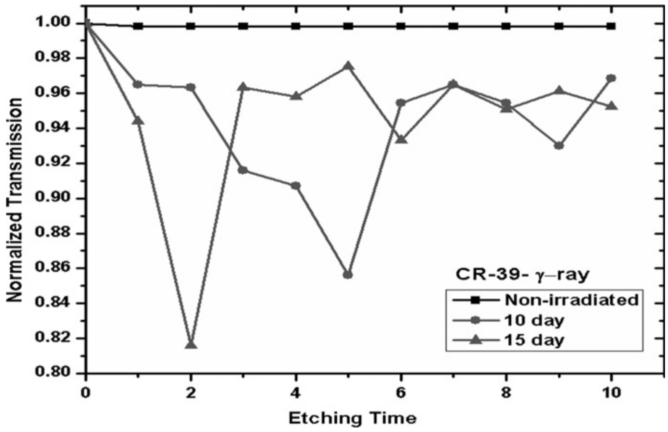

Fig. 5. Transmission of diode laser through etched CR-39 irradiated with gamma rays.

bonds are ruptured yielding fragments of the large polymer molecules which may retain unpaired electrons from the broken bonds.

Figs. 4 and 5 show the relation between the laser light transmission and etching time for irradiated CR-39 and CN-85 with two doses ^{137}Cs gamma rays (irradiated for 10 and 15 days) which appears as continuously decreasing in the transmission of laser light through the detectors which could be ascribed to the following: gamma rays create tracks in SSNTDs indirectly by nuclear reactions with their constituted nuclei. These recoil tracks are produced within the detector volume and at different depths from its original surface. As etching time increases new tracks will emerge continuously and being enlarged, making a continuous decrease to the transmission of the laser light as shown in Figs. 4 and 5. For CR-39 and CN-85 the increasing of bulk etch rate with increasing gamma dose suggests the predominance scission of the polymer when irradiated with gamma rays.

The overlapping of tracks, that causes the increase in the transmission of laser light for alpha particles, in Figs. 2 and 3, should be compensated continuously for gamma rays, in Figs. 4 and 5 (with less systematic), by the newly etched tracks as etching time increases. If overlapping occurs the optical properties in the overlapped region will be different from those of non-overlapped, i.e. single track [10]. In some cases there will be a double and triple overlappings in the track, which increases the optical density of the films.

The minimum transmission for CN-85 developed at the same etching time for both doses (10 and 15 days), while the minimum transmission shifted in time between 2 and 5 times. Also the CN-85 reaches stable transmission much faster than CR-39. From the behavior of the etched CR-39 foils, in Fig. 5, one can conclude that the transmission in this detector is not stable and tacks quite large etching time to reach the transmission stability.

From Eq. (6), if one considers the normalized transmission ratio for laser light of two etched SSNTDs foil as

$$\log(T_{(CN)}/T_{(CR)}) = \log \frac{[T_{t(CN)} + (T_{f(CN)} - T_{t(CN)})\exp(-\pi r^2_{(CN)} \rho_{d(CN)})]}{[T_{t(CR)} + (T_{f(CR)} - T_{t(CR)})\exp(-\pi r^2_{(CR)} \rho_{d(CR)})]} \quad (7)$$

This equation is presented experimentally in Figs. 6 and 7 where the relative capacity of CN-85 to CR-39 detectors to transmit laser light is drawn as a function of etching time. This parameter (T_{CN}/T_{CR}), defined here, is helpful in quantifying the comparative response of the detectors investigated. From these figures one can draw the following notes also.

All the transmission ratios are less or equal to one, means that, the transmission of CN-85 is less than CR-39 in most cases due to

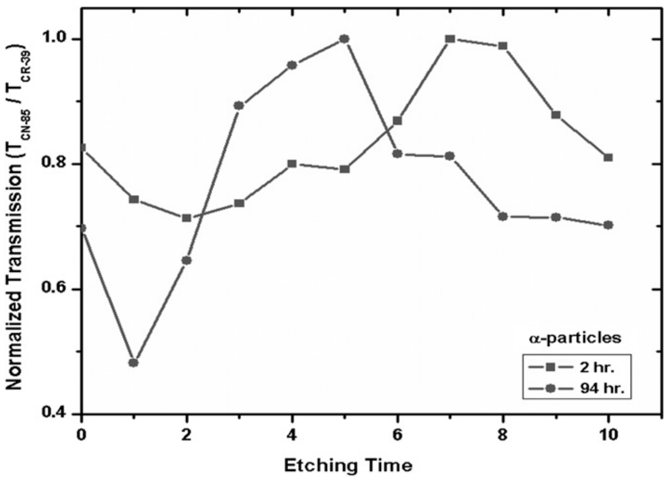

Fig. 6. Transmission ratios through CN-85 to CR-39 plotted as a function of etching time for alpha exposure.

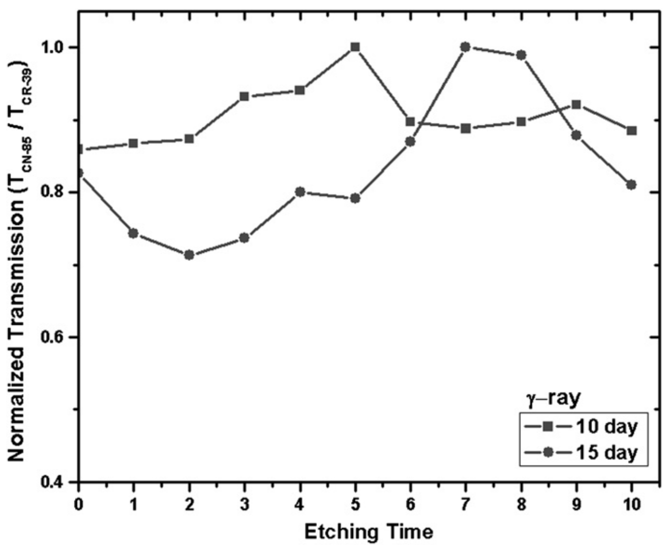

Fig. 7. Transmission ratios through CN-85 to CR-39 plotted as a function of etching time for gamma exposure.

the large number of tracks produced. At high doses for both alpha and gamma with etching time (> 5 h), the normalized transmission ratios are relatively small and this is also due to the increases of the number of tracks. At etching time more than 10 h, both detectors and for the two irradiated doses, behave in the same manner.

5. Conclusion

A new method of radiation dose measurement via investigation densities and geometries was performed in the present experimental work. This method applied modern optics to demonstrate a reasonable relationship between optical densities and tracks dimension produced in the SSNTDs. Laser light transmission through CR-39 and CN-85 detectors has proved to be a convenient tool for the scanning of etched alpha and gamma tracks, even with high effluence, of radiation producing overlapping tracks. In the saturation phenomena track appearance can occur, when the etched period continues to increase. In addition, the method is relatively very simple, fast and cheap when compared to other available techniques.

References

[1] A.F. Saad, S.T. Atwa, N. Yasuda, M. Fujii, Radiation Measurements 34 (2001) 51, http://dx.doi.org/10.1016/S1350-4487(01)00119-6.
[2] D. Hermsdorf, M. Hunger, S. Starke, F. Weickert, Radiation Measurements 42 (2007) 1, http://dx.doi.org/10.1016/j.radmeas.2006.06.009.
[3] D. Hermsdorf, Radiation Measurements 46 (2011) 396, http://dx.doi.org/10.1016/j.radmeas.2011.02.012.
[4] R. Ilic, M. Najzer, Nuclear Tracks and Radiation Measurements 17 (1990) 453, http://dx.doi.org/10.1016/1359-0189(90)90002-F.
[5] J.E. Groetz, A. Lacourt, A. Chambaudet, Nuclear Instruments and Methods in Physics Research Section B 142 (1998) 503, http://dx.doi.org/10.1016/S0168-583X(98)00342-5.
[6] J.E. Groetz, A. Lacourt, P. Meyer, M. Fromm, A. Chambaudet, J. Potter, Radiation Protection Dosimetry 85 (1999) 447.
[7] A.F. Saad, A.A. El-Namrouty, A. Solyman, S.T. Atwa, Journal of the Korean Physical Society 58 (2011) 701, http://dx.doi.org/10.3938/jkps.58.701.
[8] K.M. Abumurad, A.M. Ismail, H. Abu-Safia, Radiation Measurements 40 (2005) 303, http://dx.doi.org/10.1016/j.radmeas.2005.03.020.
[9] M.A. Rana, Nuclear Instruments and Methods in Physics Research Section A 592 (2008) 354, http://dx.doi.org/10.1016/j.nima.2008.04.025.
[10] D. Hermsdorf, Radiation Measurements 44 (2009) 283, http://dx.doi.org/10.1016/j.radmeas.2009.03.028.
[11] A. Mostofizadeh, X. Sun, M.R. Kardan, Journal of Applied Sciences 7 (2007) 2261.
[12] M.A. Rana, Nuclear Instruments and Methods in Physics Research Section B 266 (2008) 271, http://dx.doi.org/10.1016/j.nimb.2007.10.036.
[13] T. Yamauchi, D. Mineyama, H. Nakai, K. Oda, N. Yasuda, Nuclear Instruments and Methods in Physics Research Section B 208 (2003) 149, http://dx.doi.org/10.1016/S0168-583X(03)00623-2303-306.