Effect of gamma irradiation on the bulk –etch rates of lexan polycarbonate solid state nuclear track detector.

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Abstract:-

In the present work, we have determined the bulk-etch rates of lexan polycarbonate $(C_{16}H_{14}O_3)n$ nuclear track detector at different temperatures to deduce its activation energy, the effects of gamma irradiation on this detector in the dose range of 23 – 71.3 kGy have been studied by using the etching technique. The bulks etch rates increase and the activation energies for bulk etching decrease with the increase in gamma dose. These results have been explained on the basis of chain scission of the detector due to gamma irradiation.

Keywords: Lexan polycarbonate, Gamma radiation, etching technique, Bulk-etch rate, activation energies for bulk etching.

1. Introduction

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-rays, electrons and gamma) do not register tracks in these detectors but they can degrade the detector material [1]. The exposure to low LET radiations causes physical and chemical changes in the detector. In case of polymers, the energy deposition by low LET radiations mainly leads to radical formation that ultimately results in scission or cross-linking of the detector as pointed out in Fleischer et al. (1975). Whether scission or cross-linking will predominate for a particular detector largely depends on the detector material and somewhat on the radiation type and total dose received by the detector. These changes also find widespread applications in different scientific and technological fields[2]. Recently ,some studies(Sharma etal.,2007; Singh and Prasher, 2004; Agarwaletal.,2006) on the effects of gamma irradiation on the track registration of some nuclear track detectors such asCR-39 $(C_{12}H_{18}O_7)n$, Makrofol $(C_{16}H_{14}O_3)n$ and polyester$(C_{10}H_8O_4)n$ have been reported. Arecent review article in 2004(Nikezic andYu,2004) has also summarized the influence of radiations on various SSNTDs .Investigations include those on the effects of irradiation to gamma

rays, electrons, protons, ultraviolet and infrared radiations. The common finding in all the studies is the increase in bulk etch rate with the increase in dose of radiation. This review article does not contain much data on radiation effects on polycarbonate track detectors except poly allyl diglycol carbonate(PADC)(CR-39)detector[1].

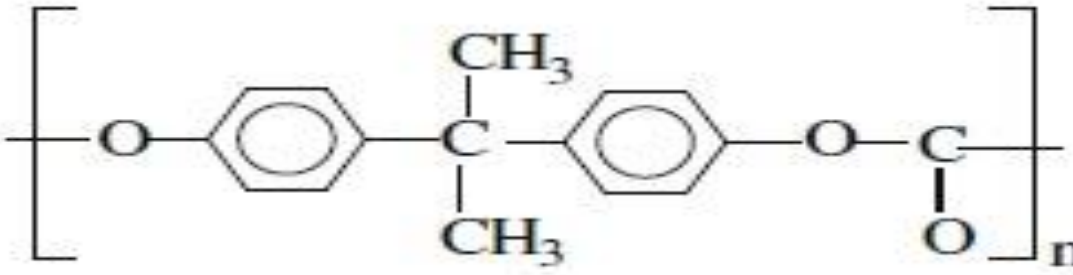
Lexan polycarbonate (PC) is widely used for ion track recording and to prepare track-etched membranes as micro filters. Now PC particle track-etched membranes (nano-PTM) with pore shape and size very well controlled with in diameters from 10 to100 nm [3,4] have been produced. These membranes are used for the manufacturing of nano tubes and nano wires [5,6]. Swift Heavy Ion degradation of polymers has been analyzed by various researchers [7,8] in a wide range of energies. The sensitivity of a polymer [9] to the registration of particle tracks is closely related to its sensitivity to the formation of chain scission under irradiation .It provides strong evidence that chain scission is of primary importance in the track formation process in track storing materials.

A measure of the sensitivity of a track detector is expressed in terms of Z/B (the ratio of charge, Z, to the velocity relative to light , B) for a charged particle to produce an etch able track in that material .The more sensitive the detector, the smaller this value. Although the chemical composition of the Lexan polycarbonate track detector is also the same as for Tuffak polycarbonate, but it has been fabricated in such a manner that the Z/B value for this track detector is 60 as compared to value of 52 for Tuffak polycarbonate (Soman, 1995), a distinct improvement in track recording properties[1]. In the present work , we have studied the effects of gamma irradiation in the dose range of 23 – 71.3 kGy by measuring the changes in the activation energy of bulk etching of this detector using bulk etch techniques.

2. Experimental

2.1. Sample irradiation

Lexan polycarbonate (PC) detector (thickness= 250µm, density=1.29 g/cm^3) were exposed to gamma radiation, and the irradiation was carried out with Co-60 gamma rays in air at a dose rate of 33 Gy/h .The samples were uniformly irradiated for various times and the total gamma doses obtained were 23,47.5and 71.3 KGy . The chemical structure of Lexan Polycarbonate is given as [10]:



2.2. The etching technique

The un irradiated and irradiated detectors were cut in 1x 1.4 cm^2 sizes and were subjected to chemical etching for 1h in 6.25N NaOH solution maintained at fixed temperatures(60,70 and 80 ^oC) for bulk etch measurements, the bulk etch rates were determined at different temperatures to deduce activation energies for bulk etching. After etching, the detectors were thoroughly washed with dematerialized water and air-dried. The bulk etches rates (Vb) for these films were determined by measuring the weight of the sample before and after the etching (weight loss method) and using the following expression [2]:

$$V_b = \frac{\Delta m}{(2A\rho t)} \text{-----}(1)$$

Where Δm is the weight loss due to etching for a time period t, A is the surface area and r is the density of the sample.

The concentration of etching molecules and their mobility to the etching front in the growing narrow track, and flushing etch products out of narrow growing tracks control the etching process. The initiation of preferential etching of the track and etchant flow In to it up to its diameter in nanoscale range is complicated. It might be one of the reasons for etch induction time which is the delay in the first appearance of track at micrometer scale. Fig. (1) shows a schematic of the typical situation of chemical etching of a latent nuclear track in a solid utilizing the etching schemes by Ditlov [10] and Schulz et al. [11].

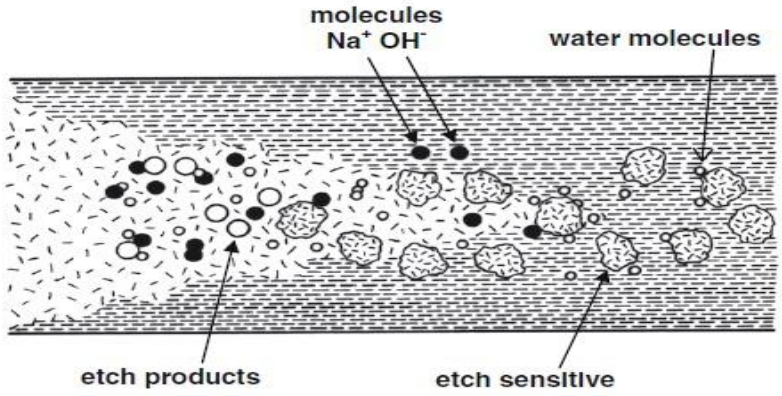


Fig .1. Pictorial representation of the etching process of an ion induced damage in a dielectric solid. This picture is a further development of chemical etching schemes by Ditlov [10] and Schulz et al. [11].

3. Results and discussion

Table 1 gives the values of bulk etch rate determined at different temperatures for different gamma doses.. The bulk etch rate is seen to increase with the increase in the gamma dose at each temperature . This increase in the values of bulk etch rate with gamma dose may be due to the chain scission of the

detector molecules by gamma irradiation that enhances the dissolution rates, gamma irradiation leads to degradation of the detector material, converting it into an easily etchable material. In the present studies the process of degradation seen from the increase in the bulk etch rate values of the detector with increase in gamma dose has been supported by estimating activation energy for bulk etching. For calculating the activation energies for bulk etching, the bulk etch rates were determined at different temperatures (Fig. 2). In Fig.3, we have plotted ln V_b against the reciprocals of the absolute temperatures for the unirradiated and the gamma-irradiated detectors. These plots confirm to the expression $V_b = Ae^{-E/kT}$ where E is the activation energy for bulk etching, A is a constant for a given medium etchant combination, k is Boltzmann constant and T is the temperature in K[1]. In Table 1 we have listed the values of E and A for the unirradiated and the gamma-irradiated detectors. The value of A is a constant for a particular detector-etchant system but it will change for the gamma irradiated detectors as the gamma irradiation changes the properties of the detector. The activation energy values have been found to decrease with increase in gamma dose. This decrease in activation energy values also indicates the chain scission of the polymeric molecules by gamma rays, the activation energy (E) obtained for the Lexan Polycarbonate is is given in Table 1 along with the E values reported in the literature for some commonly used nuclear track detectors (Dwivedi and Mukherji, 1979; Neerja Prasher and Singh,2007; Agarwal et al., 2006; Nikezic and Yu, 2004). There seems to be good agreement between the values obtained by us for the new track detector and the values reported for the most commonly used track detectors which show in table (2). A slightly higher activation energy observed in the present work may possibly be due to a small difference in the concentration of the etchant used (Dwivedi and Mukherji, 1979)[12].

Table 1 Gamma irradiation effects on track etching characteristics of Lexan polycarbonate nuclear track detector.

Gamma dose (KGy)	V_b(µm/h) at temperature			Activation energy for bulk etching E(ev)	Constant A (µm/h)
	60 °C	70 °C	80 °C		
0	0.45	0.9	1.6	0.74	$7.13x10^{10}$
23	0.94	1.35	1.92	0.42	$2.14x10^{6}$
47.5	1.22	1.73	2.1	0.32	$8.5x10^{4}$

71.3	1.34	1.77	2.21	0.29	$4.6x10^4$

Table 2 Value of the activation energy for bulk etching of the track detector lexan polycarbonate with the values reported in the literature for the commonly used nuclear track detectors.

Nuclear track detector	**Activation energy for bulk etching, E (eV)**
Lexan	0.74(present work)
Lexan	0.74± not quoted (Neerja Prasher and Singh, 2007)
Makrofol KG	0.9970±04 (Nikezic and Yu, 2004)
Makrofol N	0.8970±04 (Nikezic and Yu, 2004)
CR-39 (Type unknown)	0.92±not quoted (Nikezic and Yu, 2004)
Lexan	0.7570±04 (Dwivedi and Mukherji, 1979)
Cellulose acetate	0.9570±01 (Dwivedi and Mukherji, 1979)
CR-39 (Pitsburgh)	0.8570±05 (Nikezic and Yu, 2004)
CR-39 (Homalite)	0.8970±04 (Nikezic and Yu, 2004)
CR-39 (Homalite)	0.8370±.04 (Nikezic and Yu, 2004)
CR-39 (Pershore)	0.7870 ±03 (Nikezic and Yu, 2004)
Polyester	0.94±not quoted (Agarwal et al., 2006)
Makrofol KL	1.1870.08 (Nikezic and Yu, 2004)

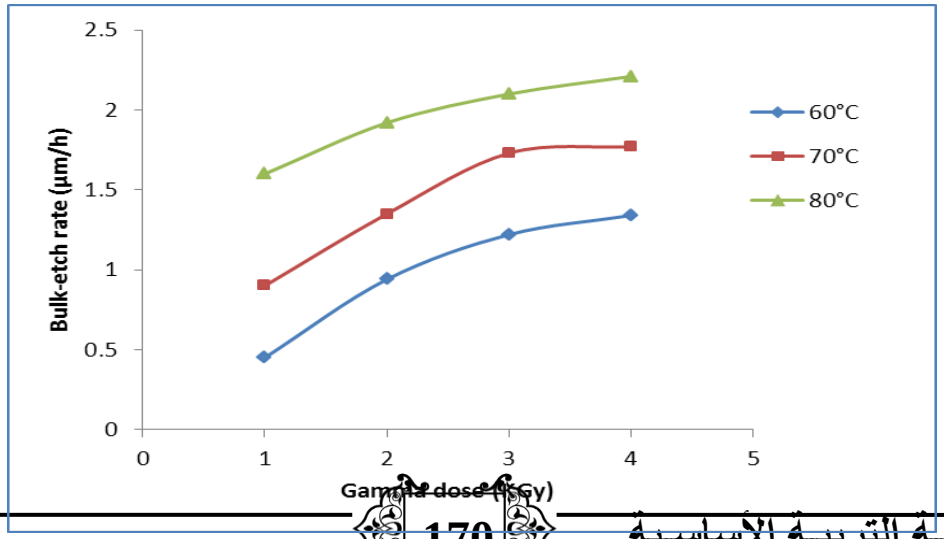


Fig.2. Plot of bulk-etch rate vs. gamma dose at different at different Temperature.

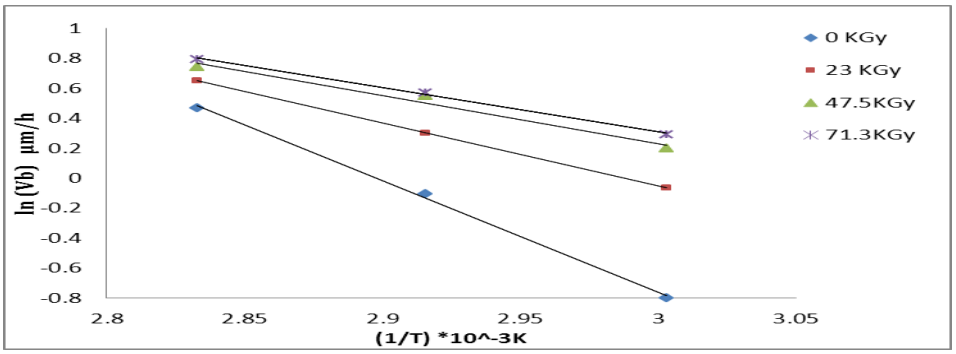


Fig. 3. The plot of ln V_b vs. 1/T for lexan polycarbonate at different gamma dose.

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تأثير اشعة كاما على معدل القشط لسطح كاشف الاثر النووي للحالة الصلبة

Lexan Polycarbonate

الخلاصــة:-

في هذا البحث تم حساب معدل القشط لسطح كاشف الاثر النووي للحاله الصلبة Lexan Polycarbonateالصيغة الكيميائية $(C_{16}H_{14}O_3)n$ عند درجات حرارة مختلفة لاستخراج طاقة التنشيط لمعدلات القشط لسطح الكاشف،وكما تم دراسة تأثير جرع مختلفة من اشعة كاما (23-71.3 KGy) على معدلات القشط لسطح الكاشف من خلال استخدام تقنية القشط بمحلول قاشط . حيث وجد ان معدل القشط لسطح الكاشف تزداد وطاقة التنشيط تقل بزيادة جرعة اشعة كاما ويعود السبب في ذلك الى ان اشعة كاما تعمل على شق سلاسل البوليمرية لمادة الكاشف .