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Using UV Irradiation to Shorten Track Formation Time on CR-39 Detector.

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ABSTRACT

Solid state nuclear track detectors (SSNTDs) have found application in different branches of science. Polyally diglycol carbonate (CR-39) is widely used as etched track type particle detector. FTIR spectroscopic measurements shows maintenance of the main vibrational band with minor changes results from changing irradiation times. UV/vis optical absorption spectrum reveals an obvious change in the optical energy gap with irradiation times. The effect of ultraviolet (UV) irradiation on the bulk etching rate was studied. The bulk etching rate of CR-39 detector was measured experimentally before and after irradiation using UV radiation. From the results we found that the values of the bulk etching rate before irradiation are 1.18 µm and after irradiation has ranged from 1.20 to 1.70 µm depending on the time of irradiation. From the results we can use UV irradiation to shorten track formation time on these thin PADC films.

Keywords: CR-39, SSNTDs, UV, Bulk etching, Exposure

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INTRODUCTION

CR-39 is used in Physics as nuclear track detector in different fields as for example heavy ion collision studies, for the detection of cosmic ray nuclei, to search for magnetic monopoles. The CR-39 nuclear track detector can also use for radon and neutron dosimetry (Sinha, 2012). Polyallyldiglycol carbonate (CR-39) is a class of plastic detectors which has been most widely used in many fields of science and industry (Sinha et al., 2001). CR-39 is a polymeric nuclear track detector being used for fast neutron dosimetry. It is a perfect dosimeter should preserve most of the dose information under different environmental conditions. During use, nuclear track detectors can be exposed to temperatures higher than ambient levels. Eminent temperatures can induce changes in the bulk etching rate of the polymeric material of detector and also in the latent damage tracks. The temperature effect on the material and on tracks registration depends on whether the material has been subjected to heating prior or after the formation of radiation induced latent tracks. There are two temperature effects called pre- irradiation and post-irradiation annealing effects (Ogura and Tamai, 1982). Pre-irradiation annealing alters the property of the bulk etching rate of the material and post-irradiation annealing affects both the bulk material as well as the latent tracks. UV radiation has a very large effect on the sensitivity of the detector. The exposure to UV sources results in an increase of the mean track size, bulk and track etch rates at two peaks corresponding to 254 and 350 nm lines, while at 300 nm decrease (Babak el al., 2004). The effect of ultraviolet radiation on CR-39 investigated in many studies. It was found that on extended exposure to UV radiation, CR-39 detector slowly degrades and turns progressively yellow due to changes of its chemical and physical properties (Hussain et al., 2015).

UV A) radiation is easily diffused through air and glass. The UV spectral band of UV (A) absorption band at (315-400 nm) is less photobiologically active than the rest of the ultraviolet; UV(B) (280-315 nm) and UV(C) (180-280 nm). UV (B) and UV (C) radiation is transmitted through air and through quartz but absorbed by ordinary glass. Absorption of these wavelengths by the ozone layer of the upper atmosphere is the reason why solar radiation on the earth's surface is almost devoid of wavelengths below 320 nm. UV radiation below 315 nm is primarily absorbed by the cornea or the top epithelial skin layer. UV radiation with wavelengths below 200 nm is not easily transmitted through air and usually exists only in a vacuum. (UV Radiation Guide, 1992; Biswa, 2010)

The present work aimed to study the structural and optical properties of a nuclear track detector CR39 and the effect of UV irradiation on its structural properties and their bulk etching rate, because CR-39 detector used as ultraviolet radiation dosimeter in many fields such as an environmental solar ultraviolet radiation, ultraviolet laboratory measurements and industrial.

MATERIAL AND METHODS

CR-39 of 700 µm thickness form American technical plastics Inc. It has a molecular formula ($C_{12}H_{18}O_7$), density of 1.32 g/cm^3 and glass transition temperature of 85^{o}C. The material of CR-39 detector is transparent the visible spectrum and almost completely opaque in the ultraviolet range. It has high abrasion resistance. Before using SSND sheet was cut to small piece with area (1.5x1.5) cm^2 and weighted carefully by using digital balance of accuracy 0.0001gm before and after chemical etching. Thirty six samples were divided into six groups, each group consists of six detectors wer**e** irradiated using ultraviolet radiation. The irradiation system was built in our laboratory. The system consists of two UV lamps, each lamp 15 Watt and its wavelength equal 254 nm with power intensity 1W/cm^2, manufactured by General Electric Company, Made in Japan. The samples were irradiated for different time (1, 2, 4, 8, and 16) hour. The samples were irradiation at constant distance for the source of UV equal 30 cm. CR-39 detectors were etched in 6.25 N of NaOH at 70 ±1^{o}C in a water bath (Hafez et al., 2001; Nikezic and Yu, 2004) for (0.5, 1,….., 5) hour. All pieces were washed in running water for ten minutes in order to remove all products from the surfaces and washed for five minutes in solution from acetic acid with concentration 5% and dried in air. The bulk etching rate was measured by using the following relation (Ibrahium et al., 2000; Hussein et al., 2015):

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

Where, Δm is the difference between the mass before and after etching, A is the surface area of the detector, t is the etching time and ρ is the density of the detector material.

RESULTS AND DISCUSSION

FTIR absorption spectra

ATR-FTIR spectra shown in figure (1) reveals maintenance of the characteristic spectral bands corresponding to the polymer monomer before and after subjecting to different doses of UV irradiation.

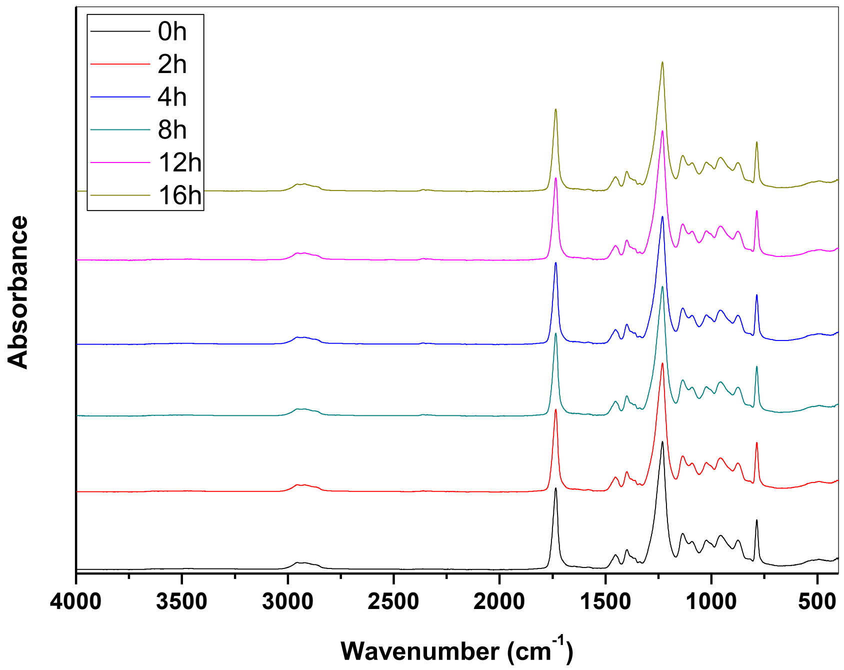


Figure 1: FTIR spectra of pristine and irradiated samples

The structural changes in the polymer have been retraced by the relative changes in the band intensities and/or position of the functional groups in the monomeric unit. A strong absorption band from carbonate ester bond (C=O) at 1725 cm^{-1} along with 1650 cm-1 of double bonded carbons conjugated to carbonyl groups have been observed for pristine CR-39. The peaks at 1581 and 2214 cm^{-1} notify the presence of [-(C=O)-C=C] and C-O-C species indicating the partial polymerization of the monomer. The intensity of the bands has been found to increase with irradiation process pointing the increase in the unsaturated behavior of the polymer. The band corresponding to carboxylate ions found to disappear with increasing radiation dose. The increase in the intensity of the band corresponding to CO_2 and the decrease in the intensity of >C=O band have also been observed. It may be due to the cleavage of chain at carbonate linkage causing the production of CO_2 and carboxylic acids. Thus this linkage may be assumed as radiation sensitive linkage. The broadening of >C=O band with irradiation has been observed and may be due to the inter-hydrogen bonding. Shift of –OH band towards lower frequencies also evidences the hydrogen bonding and the bondage of free –OH group to other free radicals and ions. The increase in the intensity of the –OH band may attributed to the abstraction of H atom from the back bone of the polymeric unit and the formation of alcohols and carboxylic acids.

UV absorption and optical energy gap

Measurement of the UV/vis. optical absorption spectra of materials is the straightest method to examine the band structure of solid materials. In the absorption process an electron is excited from a lower energy state to higher energy state by absorbing a specified energy in the form of photons. The changes in the absorbed radiation can adopt the types of possible electron transitions. Fundamental absorption refers to band-to-band or exaction transition which shows a sudden change in absorption intensity (absorption edge), which can give a direct indication of the variation in the optical band gap ($Eg = h\,c/\lambda$). Absorption coefficient α is a parameter that defines the relative rate of change in light intensity and calculated from absorbance data (A). Where $\alpha = 2.303A/d$; and d is the sample thickness.

Absorption coefficient for amorphous matter can be related to energy of the incident photon as reported by (Thutupalli and Tomlin, 1976):

$(\alpha h\nu) = \chi\,(h\nu - E_g)^n$ for $h\nu > E_g$. (2)

$(\alpha h\nu) = 0$ for $h\nu < E_g$. (3)

Where E_g is the optical energy gap, χ is a constant and n the power that can take values 1, 2, 3, 1/2 and 3/2, depending on the electron transitions responsible for the absorption. It is recognized that in case of indirect electronic transition n takes the value of 2 and 1/2 in case of direct electronic transition across energy gap in the k space. (Davis and Shalliday, 1960) reported that; near fundamental band edge, both indirect and direct transitions may occurs and can be obtained by plotting $(\alpha h\nu)^2$ or $(\alpha h\nu)^{1/2}$ versus photon energy ($h\nu$).

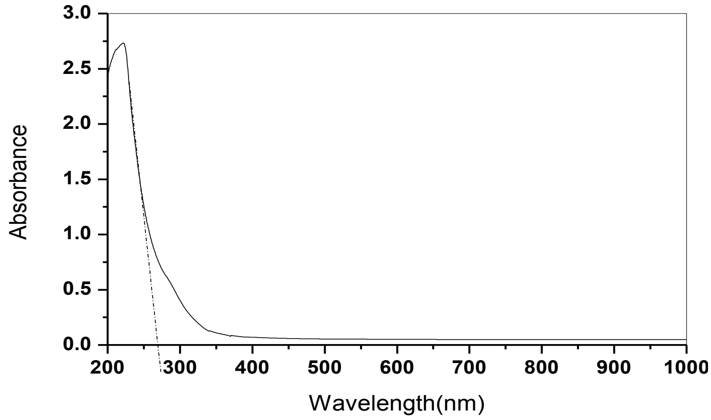
Fig. 2a, b and c show the optical energy gap that obtained from direct calculations of optical absorption curves and that calculated using Tacu's plot of the $(\alpha h\nu)^{1/2}$ and/or $(\alpha h\nu)^2$ as a function of photon energy ($h\nu$) for selected sample that subjected to 16h irradiation dose; these obtained values are listed in table 1.

Obtained results are compatible with that obtained for different materials by (Abdelghany et al., 2012) irradiated with gamma irradiation.

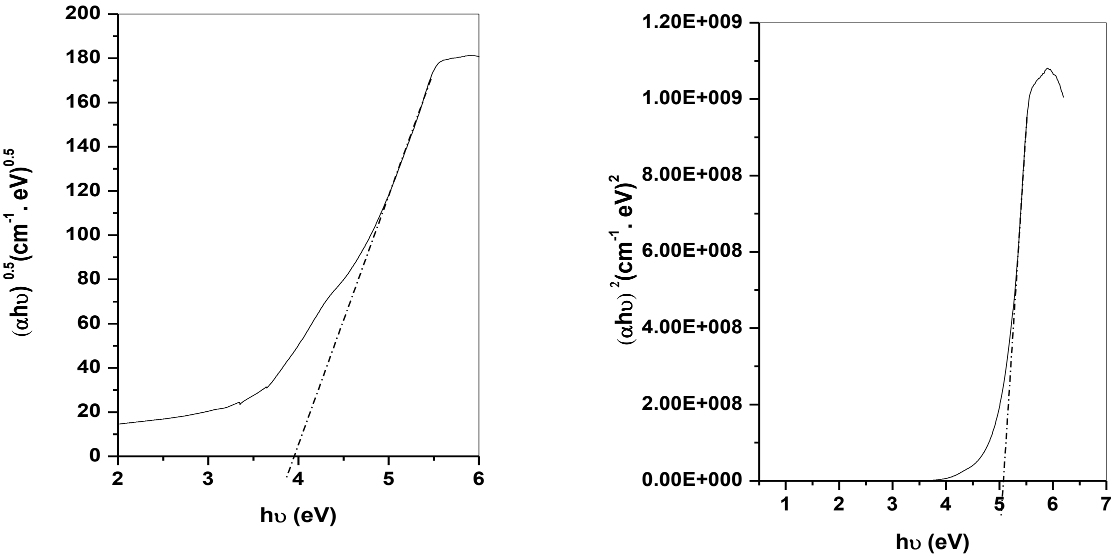
Table (1): change in the optical energy gap with irradiation times

Time (h)	Wavelength λ (nm)	Optical Energy Gap (eV)		
		Tacu's	Direct	Indirect
0	283.391	4.3755	3.7767	4.9181
2	279.930	4.4296	3.7352	4.8994
4	279.930	4.4296	3.8652	4.8970
8	276.470	4.4851	3.7991	5.0067
12	276.470	4.4851	3.8427	4.9406
16	266.306	4.6562	3.9749	5.0727

Nature of optical transition and width of the energy band gaps can be optimized form both figure 2a and b, in addition, the wavelength at absorption edge was retraced by extrapolating linear portions of absorption curves. Direct energy band gap values were obtained from the plots of $(\alpha h\nu)^2$ versus $h\nu$ while indirect optical energy band gap values were obtained from the plots of $(\alpha h\nu)^{1/2}$ versus $h\nu$. It is clear from the data presented in table 1 that both direct and indirect energy gap values showed an increase with increasing irradiation times or doses. This changes may be attributed to the cleavage or formation of defects in the polymeric matrix.



(a)



(b) (c)

Figure 2: Determination of the optical energy gap

The Effect of UV on Bulk Etching Rate:

From the obtained experimental results **Figure 3** shows the relation between etching time and mass change of CR-39 detectors for UV irradiation. By using equation 2 and this relation we can calculate the bulk etching rate of CR-39 detectors at different irradiation time for UV radiation. **Figure 4** gives the relation between UV irradiation time and the bulk etching rate of CR-39 detectors. From the obtained results we find the values of bulk etching rate ranged from 1.20 to 1.70 μmh^{-1}, this means that the values of V_B increasing with increasing irradiation time. From the results we can use UV irradiation to shorten track formation time on CR-39 detectors.

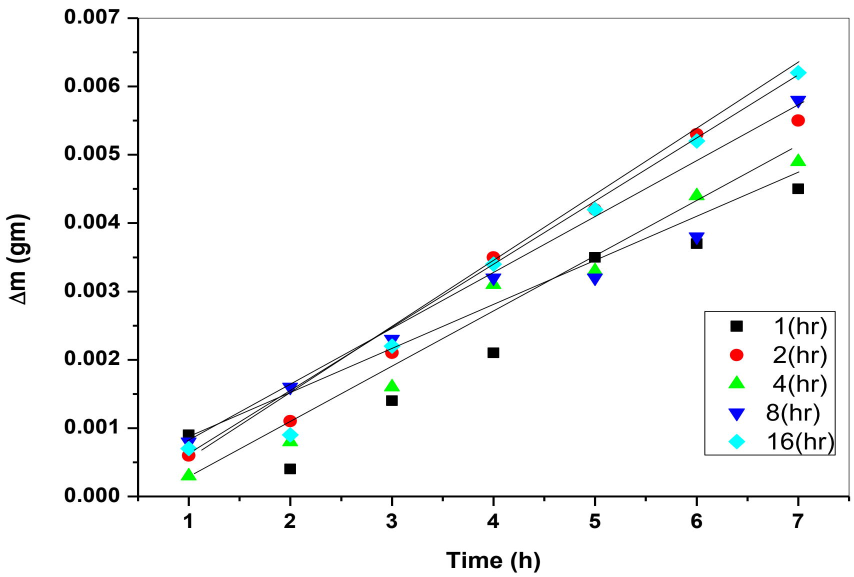


Figure 3: The relation between etching time and mass change

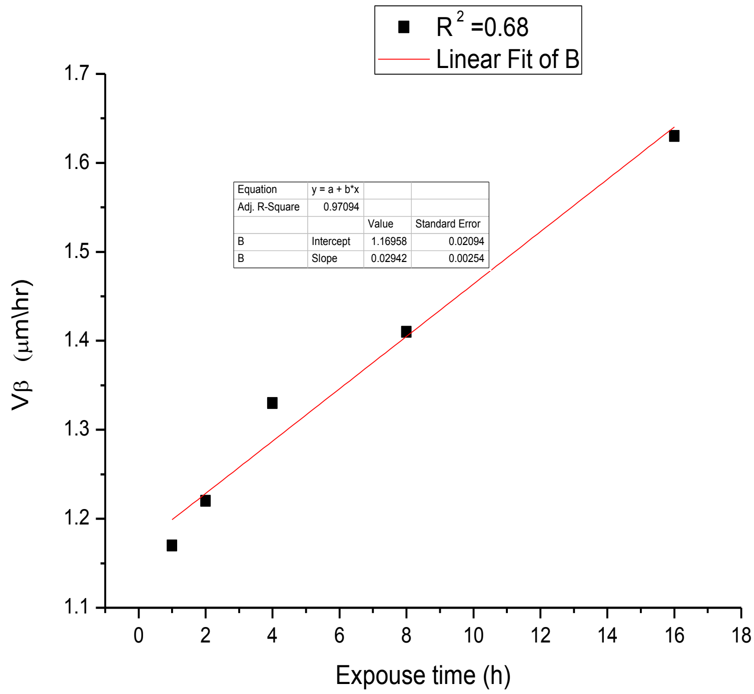


Figure 4: Relation between exposure time and bulk etching rate

CONCLUSION

Ultraviolet absorbance studies are powerful techniques for the indication of structural changes within a material. FTIR spectroscopic measurements shows maintenance of the main vibrational band with minor changes results from changing irradiation times. UV/vis optical absorption spectrum reveals an obvious change in the optical energy gap with irradiation times. The exposure of the detector at 253.7 nm leads to an increase of $V_{B.}$ UV irradiation cause increase bulk velocity of V_B slightly varies during the etching process, lowering the threshold for particle detection. Moreover, an application was proposed to measure personal doses due to UV radiation based on the large increase in the observed mean track diameter. The effect of exposing the CR-39 to the UV light sources has shown the increase of V_B as UV exposure time increases, so that, UV exposure can be used to sensitize detectors as both etch rates increase. From the obtained results the values of the bulk etching rate before irradiation are 1.18 µm and after irradiation has ranged from 1.20 to 1.70 µm depending on the time of irradiation. From the results we can conclude that, we can use UV irradiation to shorten track formation time on these thin PADC films.

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