Journal of Al-Nahrain University Science
Vol.15 (4), December, 2012, pp.١٣8-١43

Effect of X-Ray Radiation on Electro-Optical Characteristics of CR-39 Sheets by Using Microwave and FTIR Spectroscopy Techniques

Hussain Ali Al-Jobouri[*], Jameel M. A. Sulaiman[**] and Ahamed S. Jarallah[***]

[*] Department of Physics, College of Science, Al-Nahrain University, Baghdad-Iraq.

[**]College of Dentistry, University of Mosul, Mosul-Iraq.

[***]College of Engineering, University of Mosul, Mosul-Iraq.

Abstract

The effect of x-ray radiation has been studied by measurement of the permittivity (ε_p) and transmission ratio (T%) on CR-39 sheets a nuclear solid state track detector by microwave and Fourier Transformer Infrared)FTIR(spectroscopy techniques respectively. The permittivity (ε_p) increases with dose increase of x-ray radiation from 2-6.032 mGy. In addition, obtained there was dropping in the permittivity (ε_p) from the value 600 $CV^{-1}m^{-1}$ at the radiation dose 6.032 mGy to the value 47 $CV^{-1}m^{-1}$. And there was reciprocal point at 10.5 mGy, then still (εp) value constant at this value with increasing of radiation dose until to 18 mGy. The absolute difference (D_T) of the transmission ratio (T%), which is measured by FTIR spectroscopy between irradiated-T_R and unirradiated-T_0 [$D_R = |T_R - T_0|$] of CR-39 sheets, has been decreased at the wave number 2250 cm^{-1} and 2450 cm^{-1} to a reciprocal point of 14. 0 mGy and then increased to 18.0 mGy. This study suggest the use of CR-39 sheets as dosimeter for x-ray radiation by measuring the permittivity (ε_p) and the transmission ratio (T%).

Keywords: Nuclear solid state track detector, X-ray radiation, FTIR spectroscopy.

Introduction

The influence of ionizing radiation as gamma ray on the electro-optical properties of CR-39 polymer, whose chemical formula is given in Fig.(1), has been investigated by capacitance and interferometer measurements to see the order and tendency of irradiation effects on polymer CR-39 (which is commonly used in track detectors).

Eren San, 2005[1] studied the effect of gamma radiation on the electro-optical characteristics of CR-39 material which was extensively satisfactory for some other possible uses, from carbon-implanted insulators. Experimental results show radiation -dependent degradation even at relatively low doses. Modulation of electronic properties can be exploited as an alternative diagnosis tool. CR-39 is well-known polymer which has excellent properties for various materials in detector application[2-6.]

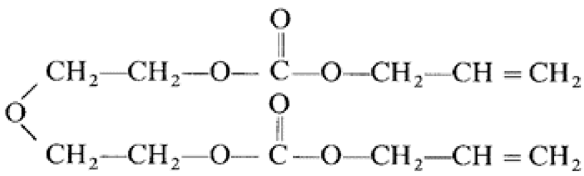

Fig.(1) Chemical formula of CR-39 polymer chemically poly allyl diglycol carbonate monomer is an ester formed by transesterification of diallyl carbonate within diethylene glycol [1].

The permittivity (ε_p) and dielectric loss factor have been measured in the frequency range 50-10^5 Hz for the solid track detector CR-39 irradiated with gamma ray dose at the range 5-100 kGy[7]. The variation of ε_p with gamma dose have been interpreted in terms of structural changes as emphasized from infrared spectra.

A mathematical model has been introduced describing the use of CR-39 as a dielectric dosimeter[7]. The effect of gamma radiation on etching characteristic of some solid state track recorders, viz CR-39 plastic, glass and phlogopite mica preexposed to 252 ^oC

fission fragments are irradiated with gamma radiation dose varying from 50 krad to 50 Mrad in order to study the effect of gamma irradiation on etching characteristics of these detector. It has been found that all these detectors are dose rate dependent. CR-39 is found to be more sensitive to gamma rays than any other solid[8].

Optical absorption of CR-39 is influenced by the irradiation dose while, for SR-90, it is found to be an inverse function of higher doses[9]. Systematic studies have been made concerning the effects of gamma dose on the track registration properties of solid-state track detector (SSTD). The changes in bulk and track etch rates in CR-39 plastics as well as insensitivity due gamma rays in the dose range of 0-10^3 kGy at different temperatures 338-353 ^{o}K, discussed on the basis of degradation and cross-linking mechanisms, have been studied by Surinder Singh and Neerija[10]. Various studies have been made to determine the response of solid state track detectors like Lexan polymer to gamma irradiations.

In 2007 Neerja S. P. and Surinder S.[11] studied the activation energy associated with track and bulk etch rates at a given temperature and found that the activation energy decreases with gamma-dose. Zaki[12] studied gamma-induced modification on optical band gap of CR-39 as a solid state nuclear track detector (SSNTD), although the effect of gamma irradiation on optical absorption of nuclear track detectors CR-39 was studied in different absorbed doses using Ultraviolet-visible UV-VIS spectroscopy. The present study used CR-39 as a dosimeter for ionizing radiation by measuring the permittivity (ε_p) and transmission ratio (T%).

Materials and Methods

Ten measurement samples of CR-39 sheet were purchased from China, Changzhou Welding Co., each sample has a thickness of 1.2 mm and 16×12 mm. The permittivity values were determined by measuring* the quality factor and dielectric material properties as a microwave technique[13]. Measurements were carried out at 8 GHz spot frequency. Furthermore spectroscopic analysis was performed with FTIR spectrophotometer bruker tensor-27 at wave number range 1800-2600 cm^{-1}. The above mentioned samples were exposed to radiation doses from x-ray generated at 70 kV and 100 mA. X-ray radiation dosimetry was performed using densitometer model DT1105 with Kodak Dental Film -Data Sheet, 2002.

Results and Discussions

Fig.(2) shows the effect of x-ray radiation on CR-39 sheets as obtained in this study by measuring the permittivity (ε_p) values. There is an increase in (ε_p) from 100 $CV^{-1}m^{-1}$ to 600 $CV^{-1}m^{-1}$ with radiation dose in the range of 2 – 6.032 mGy. A drop in the permittivity after the radiation dose 6.032 mGy from the value 600 $CV^{-1}m^{-1}$ to 47 $CV^{-1}m^{-1}$ ending in the radiation dose of 10.5 mGy which represent a reciprocal point of ε_p at this dose is noticed. After radiation dose of 12.08 mGy, the (ε_p) value stays constant with increasing radiation dose.

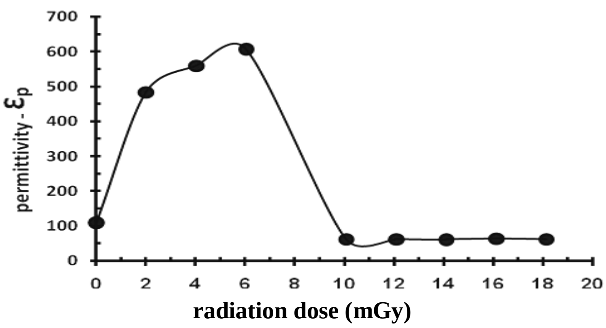

Fig.(2) Permittivity (ε_p) $CV^{-1}m^{-1}$ of CR-39 sheets measured by microwave technique with x-ray radiation dose range 0-18.128 mGy.

The decrease of ε_p, shown in Fig.(2), is similar to the results found by Eren. San, 2005[(1)] between the capacitance-Cp and gamma radiation dose where he obtained two reciprocal points at 20 kGy and 60 kGy for CR-39 sheets with a thickness of 760 mm. The capacitance of capacitor depends on the permittivity (ε_p) of the dielectric layer by the following equation[15].

$$C_p = \varepsilon_p (A / d) \qquad (1)$$

* *The measurements was recorded in the laboratory of the College of Engineering University of Mosul.*

where C_p is capacitance, ε_p is permittivity, *A* is the area of plate capacitance, and *d* is the separation distance between the two conductive plates.

The drop in magnitude of ε_p from its maximum value, in this study, was 70 % which is comparable to the drop in magnitude of Cp (65% at the Eren San[1] study is reported). The drop in the magnitude of ε_p which appear as a result of broken bonds for the CR-39 structure Fig.(1) as shown in other studies[14].

The relation between ε_p and radiation dose at the range 2-6.032 mGy which is shown in Fig.(2) has been plotted ε_p in Fig.(3). A linear behavior can be attributed to the experimental values and a fit is applied as indicated by the inset equation.

$$\text{Dose (mGy)} = 0.032\,\varepsilon_p - 13.65 \quad \text{.....................(2)}$$

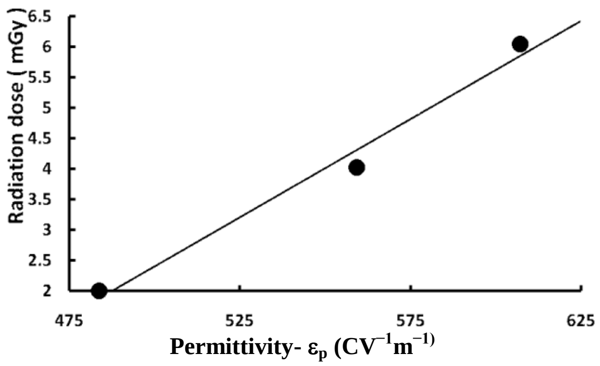

Fig.(3) Permittivity (ε_p) in $CV^{-1}m^{-1}$ of CR-39 sheets and radiation dose in the range 2 - 6.032 mGy.

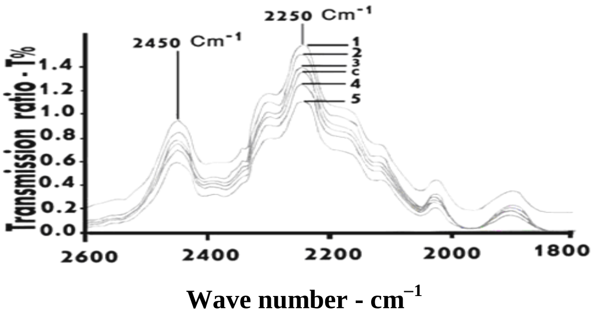

Fig.(4) FTIR Spectrum at the wave number range 1800 - 2600 cm^{-1} for which irradiated CR-39 sheet samples 1, 2, 3, C, 4, 5. mentioned in (Table (1)) in range of radiation dose 10.064 - 18.128 mGy.

Table (1)
Transmission Ratio (T%) at wave numbers 2250 cm^{-1} and 2450 cm^{-1} for CR-39 sheets irradiated with x-ray radiation dose range from 10.064 to 18.128 mGy.

Sample number	*Radiation Dose(mGy)*	*Transmission Ratio(T%) at wave number*	
		2250 cm^{-1}	*2450 cm^{-1}*
1	10.064	154	0.95
2	12.080	147	0.84
3	14.000	138	0.77
C	0	135	0.75
4	16.112	125	0.68
5	18.128	11	0.59

Fig.(4) displays the variable change in FTIR spectrum at wave number range 2600-1800 cm^{-1} for the irradiated CR-39 sheets at the range of 10.064 - 18.128 mGy. A decrease in transmission ratio (T%) of FTIR spectrum with increase of radiation dose on CR-39 is observed, which obtained also in the maximum change in transmission ratio (T%) happened at the wave number 2547.83-2409.38 cm^{-1} and 2340.31-2194.59 cm^{-1}.

The absolute difference of the transmission ratio (T%), which is measured by FTIR spectroscopy between irradiated-T_R and unirradiated – T_0 of CR-39 sheets [$D_R = \Delta T\% = |T_0\% - T_R\%| = |T_0 - T_R|$] decreases at the wave number 2250 cm^{-1} and 2450 Cm^{-1} at the reciprocal point 14.0 mGy as shown in Fig.(5). After this point, D_R increases with increasing radiation dose until 18.123 mGy.

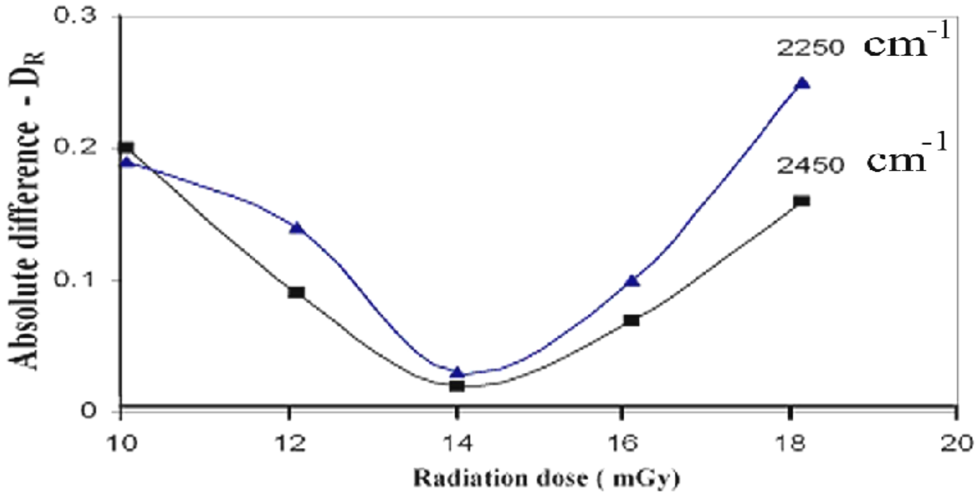

Fig.(5) Absolute difference (D_R) of the transmission ratio (T%) between irradiated-T_R and un-irradiated –T_0 of CR-39 sheets at the wave number 2250 and 2450 cm^{-1} with the radiation dose (mGy).

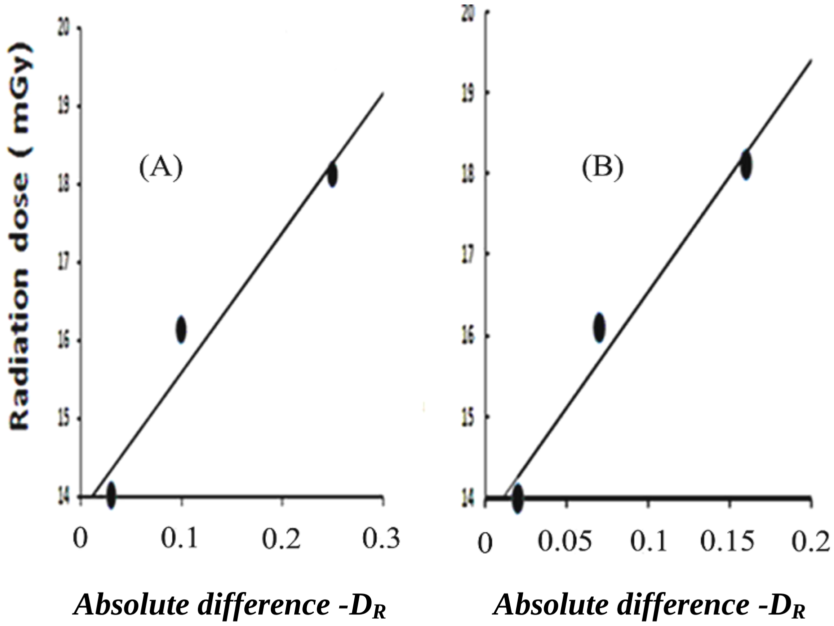

Fig.(6) Absolute difference (D_R)* for irradiated CR-39 sheets with range radiation dose 14 - 20 mGy at the wave numbers 2245 cm^{-1} (A) and 2450 cm^{-1} (B) with linear equation 4 and equation 5 respectively.

* *[$D_R = \Delta T\% = |T_0\% - T_R\%| = |T_0 - T_R|$], where T_0: transmission ratio-T% for un-irradiated CR-39, T_R: transmission ratio-T% for irradiated CR-39.*

The behavior of absolute difference (D_R) with radiation dose as straight line is seen in equation (3) and (4) for the wave number 2250 cm^{-1} and 2450 cm^{-1} respectively and shown in Fig.(6).

Dose (mGy)=17.92 D_R+13.81,

for 2250 cm^{-1}..(3)

Dose (mGy)=28.64 D_R+13.69,

for 2450 cm^{-1} ....(4)

Table (2) shows the radiation dose range of the response of CR-39 which is calculated by measuring ε_p and transmission-T% by using microwave and FTIR spectroscopy techniques respectively.

Table (2)
Radiation dose ranges and equations calculated by measuring permittivity (ε_p) and absolute difference (D_R) for CR-39 sheets with reciprocal point using microwave and FTIR spectroscopy techniques respectively.

Radiation dose range (mGy)	*Equation calculated*	*Reciprocal Point (mGy)*	*Measuring parameter*	*Technique*
2-6	Dose (mGy) = $0.032\varepsilon_p-13.65$	10.5	ε_p	microwave
14-18	Dose (mGy) = 17.92D_R+13.81 at 2250 Cm^{-1} Dose (mGy) = 28.64D_R+13.69 at 2450 Cm^{-1}	14	D_R	FTIR spectroscopy

This present study uses CR-39 sheets as the radiation dosimeter for x-ray radiation for two ranges of radiation doses. The first is for low dose range (2-6 mGy) by using microwave technique from measuring permittivity (ε_p), and the second is for the high dose range (14-18 mGy) by using FTIR spectroscopy technique from measuring D_R as shown in Table 2. The reciprocal points at 10.5 mGy and 14.0 mGy (Table (2)) for microwave and FTIR spectroscopy respectively which determined in this study, were less the that values appeared in Eren San (2005) study at 20 mGy and 60 mGy.

This deviation in the reciprocal points for the radiation dose in this study, although large, but is arranged in the same order comparable with Eren San(2005). The difference of thickness of CR-39 sheetsmay be responsible for such deviation.

References

[1] Eren San, S., "The influence of gamma radiation on the electro-optical characteristics of CR-39 polymer", J. Radiol. Prot. 25, 93-96, 2005.

[2] Vareille, J. C., Decossas, J. L., Sadaka, S. and Teyssier, J. L., "CR 39 used as a detector in a neutron dosimeter Polymer", Nucl. Instrum. Methods phys., Res. B 17, 280-284, 1986**.**

[3] Zapparoil, G. Tommasino, L. Djeffal, S. and Maiorana, A., "Additional results with electrochemically etched CR 39 neutron dosemeters“, Int. J. Radiat. Appl. Instrum., D 12, 675-678, 1986.

[4] Ralarosy, J. Debeauvais, M. Adloff, J. C., Zamani, M., Femandez, F., Jokic, S. and Todorovic, Z., "Interpretation of the 3-pronged events from the ^{238}U+Au reaction registered within CR 39 solid state nuclear track detectors“, Int. J, Radiat. Appl. Instrum, D 19, 651, 1991.

[5] Barillion, R. Klein, D., Chambaudet, A., Membrey, F. and Formm, M., "Additional uses of polymeric nuclear track detectors (CR 39 and LR 115) for measuring radon emanation", Int. J. Radiat. Appl. Instrum. D 19, 291, 1991.

[6] Bordy, J. M., Medioni, R. and portal, G., "Spectrophotometric measurement of track density in CR39 for high neutron dose determinations", Int. J. Radiat. Appl. Instrum. D, 241-244, 1991.

[7] M. EL-Shahawy, A. Hussein, "CR-39 as a gamma dosimeter: dielectric and infrared studies", Journal of materials science 27, 6605-6608, 1992.

[8] Surinder Singh, Balwinder Singh, "The effect of gamma radiation on etching characteristic of some solid state track recorders", Tracks and Radiation Measurements, Vol. 15, issues 1-4, 199-202, 1992.

[9] Saad, A. F., Atwa, S. T., Yokota, R. and Fujiii, M., November, "Radiation-induced Modifications on spectroscopic and thermal properties of CR-39 and SR-90 nuclear track detectors", Radiation measurements, Vol.40. Issues 2-6, 780-784, 2005.

[10] Surinder Singh, Neerja, "The effect of gamma-irradiation on the activation energy of bulk and track etching in CR-39 plastic track detector", Radmeas. J. radmeas., doi: 10.1016, 09.007, 2007.

[11] Neerija, Sangeeta Prasher, Surinder Singh, "The effect of gamma irradiation on the activation energy of bulk and track etching in Lexan track detector", Radiation Measurement, Vol. 42. Issue 9, October, 1507-1509, 2007.

[12] M.F.Zaki, "Gamma-induced modification on optical band gap of CR-39 SSNTD", Braz. J. Phys. Vol.38. No.4. Sapaulo, 2008.

[13] Lance, A.L., "Introduction to microwave theory and measurements", McGraw-Hill (New York) 1964.

[14] S. A. Nouh, "Physical changes associated with gamma doses of PM- 555 solid-state nuclear track detector, Radiation Measurements", Vol.38, Issue 2, 167-172, 2004.

[15] John W. Mc Farland Capacitors, Dielectrics and Induced Charge, March 8, Physics 122L-01, 2005.

الخلاصة

تم دراسة تأثير الأشعة السينية على شرائح CR-39 باعتبارها أحد أنواع كواشف الأثر النووي بقياس الممانعة- ε_p والنفاذية النسبية-T% باستخدام تقنيتي الأشعة المايكروية ومطيافية - FTIR على التوالي. تبين ازدياد قيمة الممانعة- ε_p مع زيادة جرعة الأشعة السينية عند المدى من 2 mGy الى 6.032 mGy. بالإضافة إلى ذلك لوحظ هبوط في قيمة - ε_p بعد الجرعة 6.032 mGy من قيمة الممانعة 600 $CV^{-1}m^{-1}$ إلى 47 $CV^{-1}m^{-1}$ وهناك انقلابية حصلت عند الجرعة 10.5 mGy، وبعدها تستقر قيمة- ε_p بقيمة ثابتة مع زيادة الجرعة الإشعاعية حتى الجرعة 18 mGy وجد ان صافي التغيير – D_T للنفاذية النسبية T% لشرائح الـ CR-39 المشعة– T_R وغير المشعة– T_0، ($D_R = \Delta|T_R - T_0|$) يقل عند العددين الموجبين 2250 Cm^{-1} و 2450 Cm^{-1} حتى نقطة الأنقلابية 14.0 mGy، وبعدها تزداد حتى الجرعة 18.0 mGy. هذه الدراسة تبين إمكانية استخدام شرائح الـ CR-39 كمجراع للأشعة السينية من خلال قياس الممانعة - ε_p والنفاذية النسبية T% .