

Determination the Effect of Gamma Radiation and Thermal Neutron on PM-355 Detector by Using FTIR Spectroscopy

Hussain Ali Al-Jobouri

Department of Physics, College of Science, AL-Nahrain University, Baghdad, Iraq

Email: hahmed54@gmail.com

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Abstract

The effect of gamma on nuclear track detector type PM-355 (at the dose range 200 to 1600 kGy) and thermal neutron (flux $10^5 \text{ n}\cdot\text{cm}^{-2}\cdot\text{s}^{-1}$) was calculated by using of two irradiation methods. First method (G + N) was an irradiation PM-355 detector by gamma radiation and then irradiation by thermal neutrons, and another method (N + G) was irradiated by thermal neutrons and then gamma radiation. FTIR-spectroscopy was used to measure the change in deferent of transmission percent $\Delta T\%$ at the wavenumber 1260 cm^{-1} with wavenumber 2962 cm^{-1} [$\Delta T\%$] $_{1260-2962}$ and wavenumber 1138 cm^{-1} [$\Delta T\%$] $_{1260-1138}$. The values of [$\Delta T\%$] $_{1260-2962}$ and [$\Delta T\%$] $_{1260-1138}$ were increasing with the increase of gamma irradiation with maximum response at 820 kGy and then drop after this dose until to 1600 kGy. This study determined the linear equations relation between the effect of gamma radiation on PM-355 detector and the change of [$\Delta T\%$] $_{1260-2962}$ and [$\Delta T\%$] $_{1260-1138}$, and this change appeared in (N + G) irradiation method better than in (G + N) irradiation method. The appearance of wavenumber 2964 cm^{-1} in (G + N) irradiation method referred to alkyl asymmetry C-H bond stretched out of skelated plane after changes in chemical structure of PM-355 detector by gamma or neutrons radiation.

Keywords

PM-355, Nuclear track Detectors, Gamma Radiation, Thermal Neutron, FTIR-Spectroscopy

1. Introduction

The effect of gamma and neutron radiation on non conducting polymers as polyallyl diglycol carbonate—PADC [1], polyethylene terephthalate—PET [2], Makrofol-KGand PM-355 have been demonstrated in many studies [3]. PM-355 represents one of the types of nuclear track detectors—NTDs and the changes of PM-355 including

of optical, chemical and structural properties. These properties are measured by using different techniques. The techniques which are used to study the changes in the PM-355 are X-ray diffracted—XRD [1] [4], micro-Raman spectroscopy [1], UV-visible spectroscopy [5] and Fourier transformer infrared—FTIR [6]. The numbers of tracks per incident neutron of the CR-39, PM-355 and PM-500 track detectors have been investigated for each detector [7]. Also, it is obtained that the thermal properties and the absorbance of the PM-355 are dependent on the neutron energy [8]. While some studies [9] indicate that each of the bulk etch rate— V_b , the track etch rate— V_t and the sensitivity— V of the PM-355 detectors increase with the high gamma absorbed dose up to 500 kGy. The absorption spectra which are measured by UV-visible spectroscopy of PM-355 with gamma irradiation dose within 300 - 1600 kGy change with the increase of radiation dose [5]. The energy gap of PM-355 is decreasing with absorbed dose systematically and it can be used as a second tool to determine the dosimeter range [5]. The effects of gamma at the range 10 - 250 kGy and electron beam irradiation on the color changes of PM-355 nuclear track detector are investigated [10].

The modification of chemical and structural properties of PM-355 films is investigated after the irradiation of 1.25 MeV ^{60}Co gamma—radiations at doses ranging from 0 - 675 kGy [1], and shows that the Raman spectra of the films are highly disordered at the highest gamma dose. Although it shows that the analysis reveals a significant increase in micro strain, dislocation density and distortion parameter with an increase of gamma dose after the study of the XRD pattern of PM-355. As well as, many physical properties of NTDs change with the effects of gamma radiation and one of these properties is DC-conductivity. These DC-conductivity measurements of PM-555 indicate that both the degree of ordering or disordering and the anisotropic character of the PM-555 are dependent on the gamma dose at the range 5 - 63 kGy by using of X-ray diffraction—XRD and refractive index [4]. While the dielectric constant of PM-355 is absorbed, the gamma irradiation dose will increase [11]. In 2013 Emad Hassan Aly [12] obtained the microstructural investigation of PM-355 from the response of low dose gamma irradiation by using a positron annihilation lifetime study. On other side, the studies which include both the effects of gamma and neutron radiation are taken into account [13] [14].

The estimation of gamma and neutron dose based on the use of changes in activation energy of degradation of the Lexan and CR-39 track detectors is due to gamma-neutron irradiation as a means of dosimetry [15]. And calculating the linear relationship observed between the decrease in activation energy and the gamma-neutron dose being received by the detectors suggests the possibility of the use of these detectors as gamma and neutron dosimeters [15]. Abdel Raouf *et al.* 2013 [14] studied the effects of irradiated gamma rays, X-rays and alpha particles on CR-39 by FTIR-spectroscopy, which show the optical density of the detector was calculated and then it was used to determine alpha range [14]. In this study, the relation between the radiation dose of gamma radiation and thermal neutron on PM-355 detector and some values of transmission percent which measured by FTIR-spectroscopy will be determined.

2. Experimental

Polymetylen type PM-355 sheets was perpetrated with size 2×3 cm dimensions and 500 μm thickness. The source of gamma radiation was Co-60 with dose rate 4.23 Gy/min (423 Rad/min) at the dose range 300 - 1600 kGy. Thermal neutron radiation from ^{241}Am - ^9Be with neutron flux $10^5 \text{ n}\cdot\text{cm}^{-2}\cdot\text{s}^{-1}$. The PM-355 sheets were irradiated by two irradiation methods, first method was irradiated PM-355 sheets by thermal neutron radiation for 24 h and then irradiation with gamma radiation at the range 300 - 1600 kGy which labeled (N + G) irradiation method. The second method was irradiation with gamma radiation at the range 300 - 1600 kGy and then irradiation by thermal neutron radiation also, for 24 h which labeled (G + N) irradiation method. The wave numbers was measured and analyzed by FTIR-spectrometer model FTIR-8300 from Shimadzu Company. This technique was operated to measuring of transmission percent-T% for irradiated PM-355 sheets at the wavenumber range 400 - 4000 cm^{-1} .

3. Results and Discussion

Figure 1 shows FTIR-spectrum of un-irradiated PM-355 detector at the wavenumber range from 400 cm^{-1} to 4000 cm^{-1} . The mean peak of wavenumbers were 2962 cm^{-1} , 1743 cm^{-1} , 1260 cm^{-1} , 1134 cm^{-1} , and 474.49 cm^{-1} . **Figure 1** takes as un-irradiated PM-355 sample detector which compare with other irradiated samples. The calculation of FTIR-spectrum measurement for (N + G) and (G + N) irradiation methods depend on the change different in transmission percent-T%.

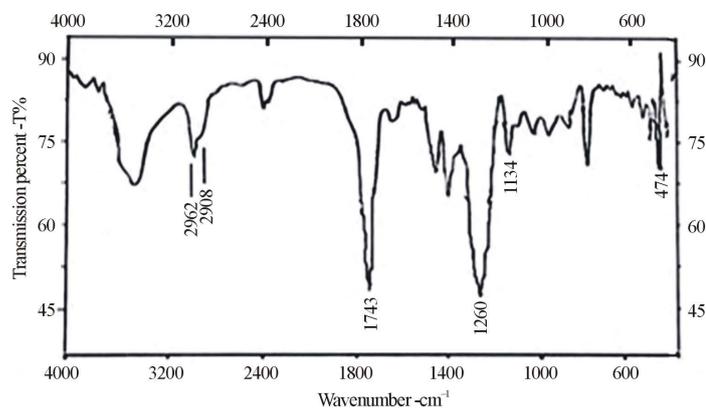


Figure 1. FTIR-spectrum at the range 400 - 4000 cm^{-1} for un-irradiated PM-355 detector with wavenumbers 2962, 2908, 1260, 1134 cm^{-1} .

The change different determined by measurement the transmission percent-T% of the wavenumber 1260 cm^{-1} with wavenumber 2963 cm^{-1} $[\Delta T\%]_{1260-2962}$ and the change of wavenumber 1260 cm^{-1} with wavenumber 1138 cm^{-1} $[\Delta T\%]_{1260-1138}$ which calculated by following equations.

$$[\Delta T\%]_{1260-2962} = [T\%]_{1260} - [T\%]_{2962} \quad (1)$$

$$[\Delta T\%]_{1260-1138} = [T\%]_{1260} - [T\%]_{1138} \quad (2)$$

where $[\Delta T\%]_{1260-2962}$ and $[\Delta T\%]_{1260-1138}$ are the change different in transmission percent-T% of the wavenumber 1260 cm^{-1} with wavenumber 2963 cm^{-1} and with wavenumber 1138 cm^{-1} respectively. The uses of the wavenumber 1260 cm^{-1} in above equations since this wavenumber was continue appear for all PM-355 FTIR spectrum with gamma irradiation dose. From **Figure 2(a)** show the change in the value of $[\Delta T\%]_{1260-2962}$ for (N + G) irradiation method was increase with increase of gamma radiation and high linearity sloop with maximum response at 820 kGy and then drop after this dose until to 1600 kGy. The maximum gamma response was show the high sensitivity of the PM-355 detector increase with high gamma absorbed dose up to 500 kGy [9]. Where in this study obtained the maximum response appear at 820 kGy. As shown the relation in **Figure 2(b)** between the value of $[\Delta T\%]_{1260-1138}$ for (N + G) irradiation which increase with gamma irradiation dose. The behavior of this relation was low linearity sloop with maximum response until to 820 kGy and then drop after this dose until to 1600 kGy. **Figure 3(a)** and **Figure 3(b)** determine from **Figure 2(a)** and **Figure 2(b)** respectively at the range of irradiation dose 0 - 800 kGy. Equations (3) and (4) were calculated by straight line between $[\Delta T\%]_{1260-2962}$ and $[\Delta T\%]_{1260-1138}$ with gamma radiation dose-D as shown in **Figure 3(a)** and **Figure 3(b)** respectively.

$$[\Delta T\%]_{1260-2962} = 0.047D + 23.88 \quad (3)$$

$$[\Delta T\%]_{1260-1138} = 0.039D + 22.26 \quad (4)$$

where D: gamma irradiation dose (kGy).

Figure 3(a) and **Figure 3(b)** show the relation between $[\Delta T\%]_{1260-1138}$ and $[\Delta T\%]_{1260-2962}$ with PM-355 detector irradiation dose by gamma radiation respectively. The Equations (3) and (4) may be use to assessment of gamma radiation after exposure to neutron source as (N + G) irradiation method until to 820 kGy. The linearity of straight line which appears in **Figure 3(a)** by Equation (3) for change different at wavenumber 2962 cm^{-1} was better than the linearity of straight line which appear in **Figure 3(b)** by Equation (4). The slope of straight line was equal to 0.047 which determine by Equation (3) and this value of slope is nearly to slope value of 0.030 which calculate also for PM-355 detector between absorption coefficient in unit (mm^{-1}) as a gamma radiation with gamma irradiation response [5].

The change in wavenumber 2962 cm^{-1} with gamma irradiation dose was also appear in Raman spectroscopy technique [15] when measurement the Raman intensity with Raman shift in unit cm^{-1} from gamma irradiation dose 150 kGy to 670 kGy for PM-355 detector. Where for (G + N) irradiation method the change different in the

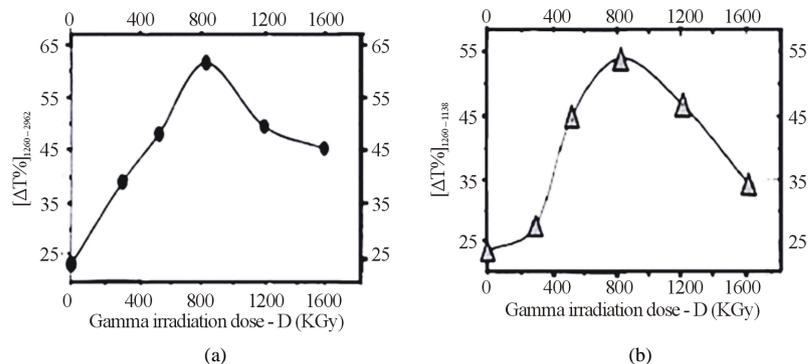


Figure 2. Change different in transmission percent- $\Delta T\%$ for (N + G) irradiation method with gamma radiation to PM-355 detector at: (a): $[\Delta T\%]_{1260-2962}$, (b): $[\Delta T\%]_{1260-1138}$.

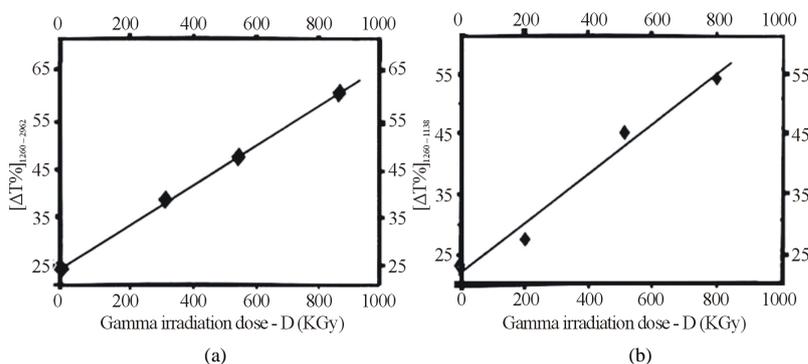


Figure 3. The relationship between the change different transmission percent with gamma irradiation dose for (N + G) irradiation method to PM-355 detector at (a): $[\Delta T\%]_{1260-2962}$, (b): $[\Delta T\%]_{1260-1138}$.

logarithmic values of transmission percent- $T\%$ $[\Delta T\%]_{1260-2962}$ and $[\Delta T\%]_{1260-1138}$ for PM-355 detector which irradiation with gamma irradiation dose from 300 kGy to 1600 kGy were calculated as shown in **Figure 4(a)** and **Figure 4(b)** respectively. Equation (5) and Equation (6) reflected the gamma irradiation dose-Dat (G + N) irradiation method after determine the values of $[\Delta T\%]_{1260-2962}$ and $[\Delta T\%]_{1260-1138}$ which calculation from **Figure 4(a)** and **Figure 4(b)** respectively.

$$[\Delta T\%]_{1260-2962} = 0.098D + 20.92 \quad (5)$$

$$[\Delta T\%]_{1260-1138} = 0.060D + 22.42 \quad (6)$$

where D: gamma irradiation dose (kGy).

The straight line obtained in **Figure 4(a)** and **Figure 4(b)** may be use to assessment of gamma radiation dose in PM-355 detector after known the value of $[\Delta T\%]_{1260-2962}$ and $[\Delta T\%]_{1260-1138}$.

Figure 5 shows the change of wavenumber 2962 cm^{-1} in (G + N) irradiation method with gamma irradiation dose from 300 kGy to 1600 kGy. The change in shape of spectrum at wavenumber 2962 cm^{-1} may be also use to reflect the effect of neutron source after irradiation with gamma radiation dose. Irradiation method (G + N) also, shown the wavenumber 2908 cm^{-1} which obtained in un-irradiation sample was disappear with increase of gamma radiation dose until to 1600 kGy, **Figure 6**. Where there was appearance of wavenumber 2920 cm^{-1} at the radiation dose 1600 kGy which lead to C-H stretch anti symmetry [15]. And this anti symmetry related with ordinary or disordinary and the anisotropic charter the detector are dependent on the gammadose [4].

The gamma radiation dose response at wavenumber 2962 cm^{-1} was appear as a result of alkyl asymmetry C-H bond stretch out of skelated plane [14] after change in chemical structure of PM-355 by gamma or neutron radiation. But the gamma radiation response of wavenumber 1265 cm^{-1} was appear as a result to deformation of a

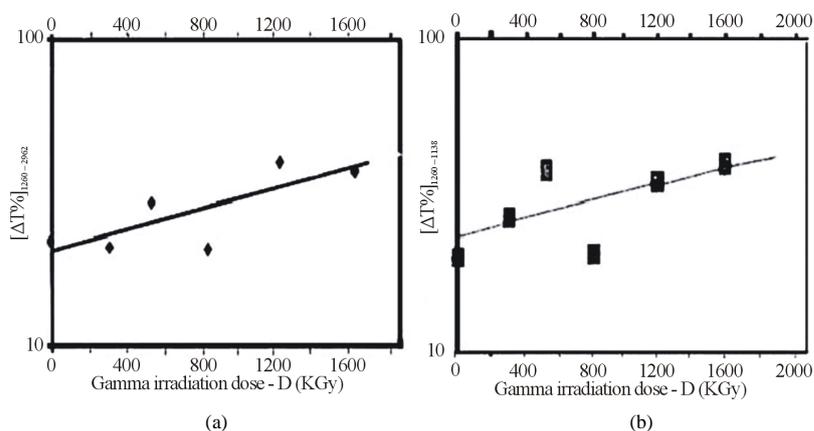


Figure 4. The relationship between the change different transmission percent with gamma irradiation dose for (G + N) irradiation method to PM-355 detector at (a): $[\Delta T\%]_{1260-2962}$, (b): $[\Delta T\%]_{1260-1138}$.

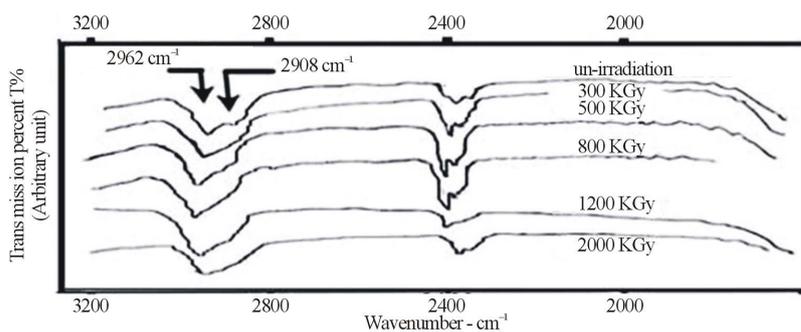


Figure 5. The change in wavenumber 2908 cm^{-1} in FTIR-spectrum of PM-355 detector for (G + N) radiation method with gamma irradiation dose from 300 KGy to 1600 KGy.

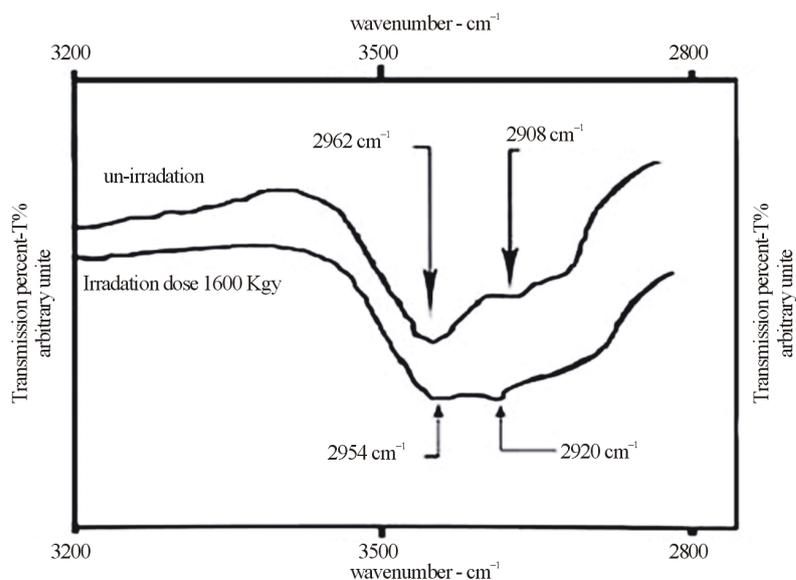


Figure 6. The appearance of the new wavenumber 2920 cm^{-1} for irradiated PM-355 detector to 1600 kGy by (G + N) irradiation method comparing with un-irradiated detector.

weak absorption for C-C bond for structure of PM-355. The behavior of relation between $[\Delta T\%]_{1260-2962}$ and gamma irradiation dose in (N + G) irradiation method for PM-355 was nearly the same behavior of absorption coefficient gamma radiation dose [5]. That means the effect of thermal neutron radiation before gamma radiation no adding any change in chemical structure of PM-355 detector. While at (G + N) irradiation method the effect of neutron radiation was high appear for PM-355 detector which irradiation with gamma radiation before neutron exposure. This reflects the effect of gamma on PM-355 was increase in photo degradation [11] which lead to formed electron and hole take place causing changing in wave number in FTIR spectrum.

4. Conclusion

The study indicates the possibility of the using of nuclear track detector type PM-355 for the estimation of gamma radiation dose during thermal neutron effects based on the use of changes in the transmission percent-T% from FTIR-spectroscopy. And it indicates that each of the bulk etch rate— V_b , the track etch rate— V_t and the sensitivity— V of the PM-355 detectors increase with the high gamma absorbed dose up to 500 kGy. And it can use PM-355 detector as the gamma radiation dosimeter at this exposure range by using of the change measurements of the difference in transmission percent-T% $[\Delta T\%]_{1260-2962}$ and $[\Delta T\%]_{1260-1138}$ from FTIR-spectroscopy.

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