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Influence of Gamma Radiation on Nonlinear Optical, Semiconducting and Dielectrical Properties of $In_{0.95}Mn_{0.05}Se$ Thin Films

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Abstract

$In_{0.95}Mn_{0.05}Se$ films with of thickness 750 nm were evaporated by using thermal evaporation technique, this film was irradiated by γ radiation with doses (0,40 and 120 KGy). Both of dispersion energy (E_d) and oscillating energy (E_o) were determined. The values of lattice dielectric constant (ε_L) and free carrier concentration/effective mass) (N/m*) were calculated. On the other hand, the values of first order of moment (M_{-1}), the third order of moment (M_{-3}) and static refractive index (n_o), were determined. Both of dielectric loss ($\varepsilon^{\backslash}$) and dielectric tangent loss ($\varepsilon^{\backslash\backslash}$) for these films increased with photon energy (hν). Also, the same behavior was noticed for the real part of optical conductivity (σ_1) and imaginary part of optical conductivity (σ_2). The Linear optical susceptibility ($\chi^{(1)}$) increases with (hν)for all compositions. The nonlinear optical parameters such as, nonlinear refractive index (n_2), the third-order nonlinear optical susceptibility ($\chi^{(3)}$), non-linear absorption coefficient (β_c) , were determined theoretically. Both of the electrical susceptibility (χ_e) and relative permittivity (ε_r) increase with photon energy and had a highest value near the energy gap. The semiconducting results such as, density of the valence band, conduction band and Fermi level position (E_f) were calculated.
Keywords: $In_{1-x}Mn_xSe$ thin films; γ radiation; Dielectrical results; Semiconducting results; non- linear optical properties.
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1. Introduction

AIIIBVI semiconductors such as, $Zn_{1-x}Mn_xS$ [1-4], $Ga_{1-x}Mn_xS$ [5,6] and $In_{1-x}Mn_xSe$ [7-9]. (InSe) is promising optical and electrical properties for use as thin film solar cells [10], Schottky diodes [11] and Li-solid-state batteries [12]. The structural and physical properties of InSe were investigated [13-17], the InSe thin films had an amorphous structure [18, 19], Which changed to polycrystalline structure after heat treatment [20-23], the optical properties of InSe thin films were studied [24-30], it was noticed that, the thickness decreased the absorption edge from 3.3 to 1.4 eV [26], band gap of InSe thin film is 1.90 eV [27], 1.35 ± 0.02 eV [28], 1.10 eV [29], and (2.5 to 3.34 eV) [30]. On the other hand, the effect of radiation on physical properties on InSe thin films were studied [31-33], γ radiation affected on photoelectric parameters [32]. The nonlinear optical properties for InSe were studied [34,35]. Optical properties of MnSe thin films were studied [36-40], MnSe had energy gap (1.13 – 1.25 eV) [37,38]. The electrical and dielectrical properties had been investigated [41-42], the electrical resistivity of MnSe decreased with temperature [42]. The transport properties of In1-xMnxSe had been studied [9, 43-47], the energy gap and structure dependence on composition of $In_{1-x}Mn_xSe$ thin films and bulk materials had studied [47-48], these thin films had an amorphous structure [47], the energy gap increases with the x value for both thin films bulk material [48]. The radiation effect on physical properties of In1-xMnxSe thin films had been studied [49]

The aim of the present work is studying the effect of γ radiation on dielectrical loss ($\varepsilon^{\backslash}$) and dielectric tangent loss ($\varepsilon^{\backslash\backslash}$), both of real and imaginary part of optical conductivity(σ_1 and σ_2) respectively, electrical susceptibility ($\chi^{(e)}$), linear optical susceptibility ($\chi^{(1)}$), the non-linear optical results such as, nonlinear refractive index (n_2), nonlinear absorption coefficient (β_c), non-optical susceptibility ($\chi^{(3)}$), dielectrical results and finally electronic properties such as Fermi level position (E_f) and density of both of valence

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conduction band (N_v) and conduction band (N_c) of In0.95Mn0.05Se thin films of thickness 750 nm. In this recent paper we studied the effect of γ radiation on the physical properties of In1-xMnxSe thin films such as, nonlinear optical properties, dielectrical results and finally both of semiconducting results and the position of Fermi level.

2. Experimental work:

In 0.95Mn0.05Se thin films of thickness 750 nm were prepared by thermal evaporating. The compounds were kept in Molybdenum boat and then deposited on ultrasonically cleaned unheated glass substrates under the vacuum pressure of 10-5 torr using Edward E306 A coating units. Thickness of the films was measured using an optical multibeam interfotmeter. The X-ray diffraction (XRD) patternsof the prepared thin films were investigated by Emprean (pananlytical) diffractometer. Ni-filtered CuKa radiation at45 kV and 30 mA was used showing that the amorphous nature and the composition were determined by (EDAX) Philips (XL30 attached with EDX unit). Transmittance (T) and reflectance(R) of the as-deposited thin films on precleaned glass substrates were determined at normal incidence using a Jasco(V-570) spectrophotometer from 500 to 2500 nm to determine some optical parameters of In1-xMnxSe. The optical measurements were carried out at room temperature. Irradiation for thin films with doses (40 and 120 KGy) was performed using a Co_{60} gamma ray source.

3. Results and Discussions

3.1. Dielectric, optical conductivity and linear optical susceptibility results

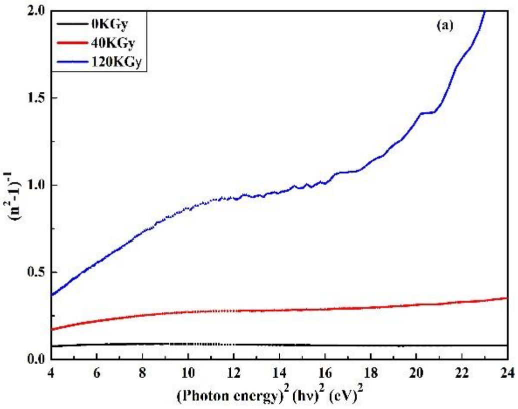
The influence of γ radiation doses on optical transmittance (T) and reflectance (R) were measured and discussed in previous work [49]. The single oscillator theory was expressed by the Wemple–DiDomenico relationship [50]:

$$n^2(E) - 1 = \frac{E_o \cdot E_d}{E_o^2 - E^2} \quad (1)$$

Where n is the refractive index values of these samples which is determined in previous work [49], E is the photon energy (hν). Fig 1.a shows the relation between (n_2-1)-1 and (hν)2, The values of E_o and E_d with different doses of γ radiation are shown in table 1. Figure 1b shows the relation of (n_2) and (wavelength)2 (λ_2) to determine the effective mass ratio with the carrier concentration using the following equation [51]:

$$n^2 - k^2 = \varepsilon_L - \left(\frac{eN}{4\pi c^2 \varepsilon_o m^*}\right)\lambda^2 \quad (2)$$

Where ε_L is the lattice dielectric constant, ε_o is the permittivity of free space, e is the charge of electron, n, k is the liner refractive index and the absorption index of these films respectively, which was determined in previous work [49], N is the free carrier concentration for these films, and c is the speed of light, so the values of (N/m*) is shown in table 1. From this table it was noticed that, the doses values affected on the ratio of (N/m*), the access of radiation dose, the access of electrons.



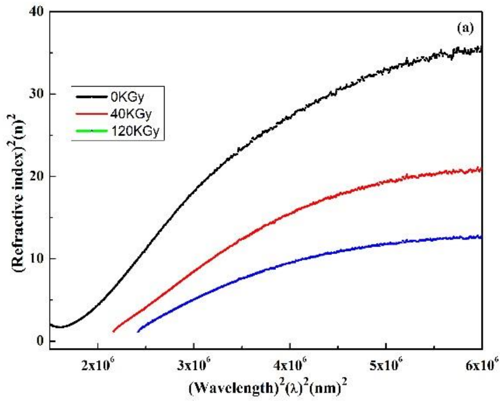


Fig. 1. (a) Relation between $(n^2-1)^{-1}$ and $(h\nu)^2$, (b) Relation between (n^2) and $(wavelength)^2$for $In_{0.95}Mn_{0.05}Se$ films, which irradiated with different γ radiation doses (0,40 and 120 KGy).

The values of (M_{-1}) and (M_{-3}) derived from the relations [51]:

$$E_d^2 = \frac{M_{-1}^3}{M_{-3}} \quad (3)$$

$$E_o^2 = \frac{M_{-1}}{M_{-3}} \quad (4)$$

Table 1 shows, the values of the M_{-1} and M_{-3} for these thin films. The oscillator strength (f) which was calculated as follow [52]:

$$f = E_o \cdot E_d \quad (5)$$

The values of the f are shown in table 1. Another important parameter depending on both of E_o and E_d is that, static refractive index (n_o) which was determined using following equation [53]:

$$n_o = \left[\left(\frac{E_d}{E_o}\right) + 1\right]^{0.5} \quad (6)$$

The values of no for all these samples are shown in table 1.

Fig. 1b represents the relation between (n2-1)-1 vs. (hν)2 for these thin films. It is shown that (n2-1)-1 increases as the radiation doses. The values of both of (ε\) and (ε\\) for these films were calculated as follow [54]:

$$\varepsilon^{\backslash} = (n^2 + k^2) \quad (7)$$

$$\varepsilon^{\backslash\backslash} = \left[(n^2 + k^2)^2 - (n^2 - k^2)^{0.5}\right] \quad (8)$$

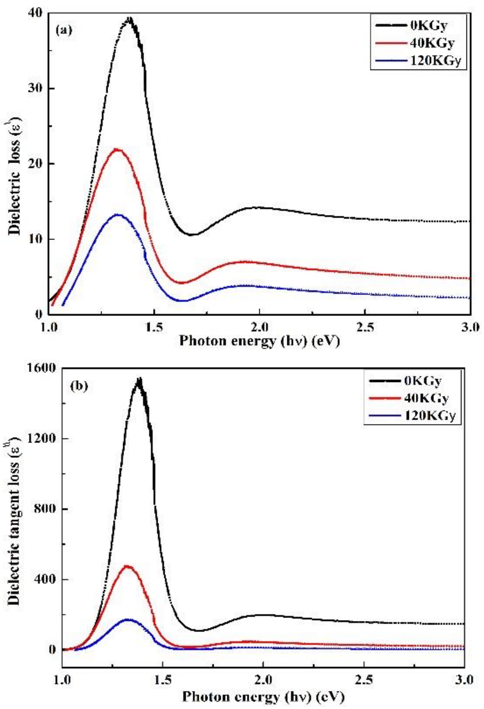


Fig. 2. Relation between dielectric loss ($\varepsilon^{\backslash}$) and (hν) (a) and dielectric tangent loss ($\varepsilon^{\backslash\backslash}$) and (hν) (b) for $In_{0.95}Mn_{0.05}Se$ films, which irradiated with different γ radiation doses (0,40 and 120 KGy).

Figs. 2(a,b) show both of ($\varepsilon^{\backslash}$) and ($\varepsilon^{\backslash\backslash}$) versus (hν) for these films. From this Figure, it was seen that, both of ($\varepsilon^{\backslash}$) and ($\varepsilon^{\backslash\backslash}$) had a maximum peaks values lower than (E_g) for all different doses, these values decrease to minimum values around (E_g), while peak maximum values decreased with increasing radiation doses, this is due to the increasing of electron motilities with (γ) doses.

The optical conductivity was calculated from the following equations [55]:

$$\sigma_1 = \left(\frac{\varepsilon^{\backslash\backslash} \cdot c}{2\lambda}\right) \quad (9)$$

$$\sigma_2 = \frac{(1 - \varepsilon^{\backslash}) \cdot c}{4\lambda} \quad (10)$$

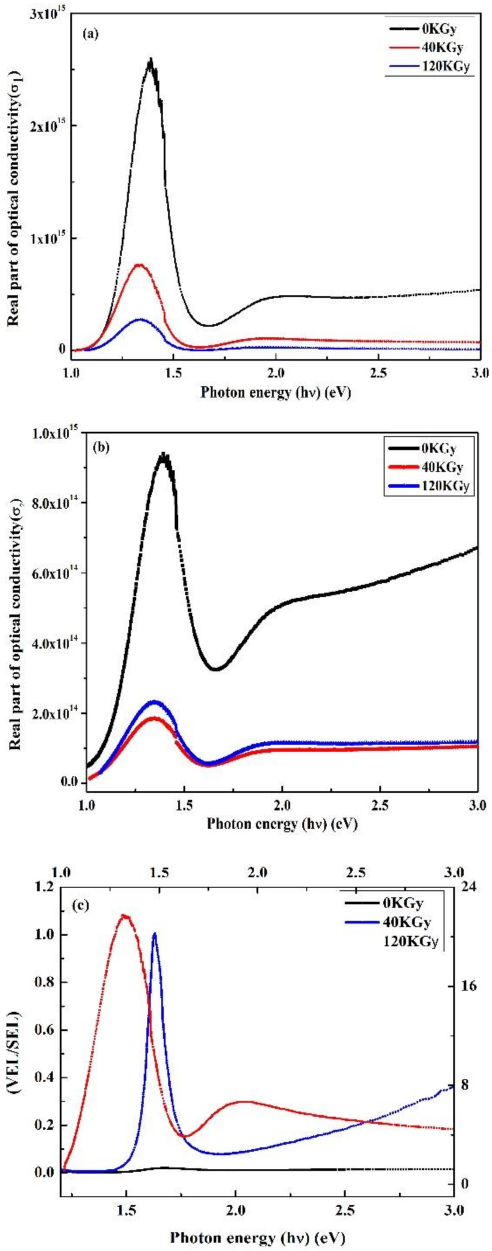


Fig. 3. (a) Influence of (hν) (a) on real part of photoconductivity (σ_1), (b) imaginary part of photoconductivity (σ_2) and (c) VELF/SELF for $In_{0.95}Mn_{0.05}Se$ films, which irradiated with different γ radiation doses (0,40 and 120 KGy).

Figs. 3 (a,b) show, the both of (σ_1) and (σ_2) dependence on (hν) for these films. The behavior of both (σ_1) and (σ_2) for all these studied films is the same with (hν), and the peak values for these samples decrease with dose radiation as a result of increasing the values of ($\varepsilon^{\backslash}$) and ($\varepsilon^{\backslash\backslash}$).

The values of Volume Energy Loss (VEL) and Surface Energy Loss (SEL) for these films were determined optically as follow [51]:

$$VEL = \frac{\varepsilon^{//}}{\varepsilon^{/2} + \varepsilon^{//2}} \quad (11)$$

$$SEL = \frac{\varepsilon^{//}}{(\varepsilon^{/} + 1)^2 + \varepsilon^{//2}} \quad (12)$$

The relation between VEL/SEL for these thin films is shown in figure 3c. Linear optical susceptibility (χ(1)) describes the response of the material to an optical wave length, (χ(1)) was determined using the following relation [56]:

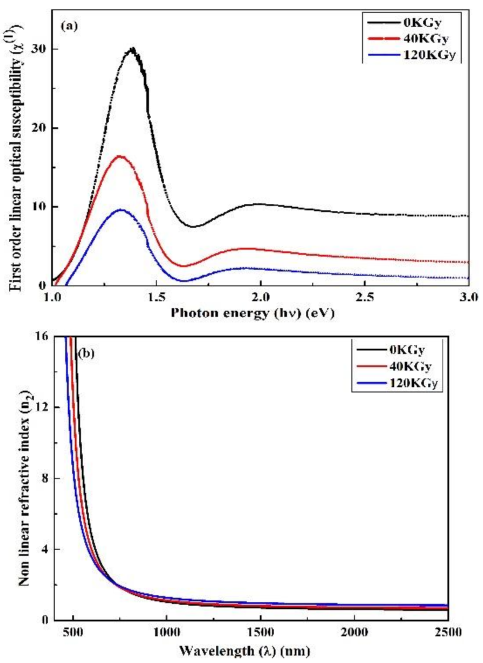
$$\chi^{(1)} = \frac{(n^2 - 1)}{4\pi} \quad (13)$$

The relation between ($\chi^{(1)}$) and (hν) for these investigates samples is shown in Fig. 4a, from this Fig. it was seen that, the ($\chi^{(1)}$) increased with (hν), this means that, there is a possibility of wide change in optical properties with radiation doses, while the values of ($\chi^{(1)}$) decreased with dose radiation due to the activation energy decreased with radiation doses[49].

3.2. Nonlinear optical properties

An important parameter of the non-linear optical parameters is that the nonlinear refractive index (n_2), which can be explained as, when light with high intensity propagates through a medium, this causes nonlinear effects[57], n_2 was determined from the following simple equation [58-59]:

$$n_2 = \left(12\pi\chi^{(3)}\right) / n_o \quad (14)$$



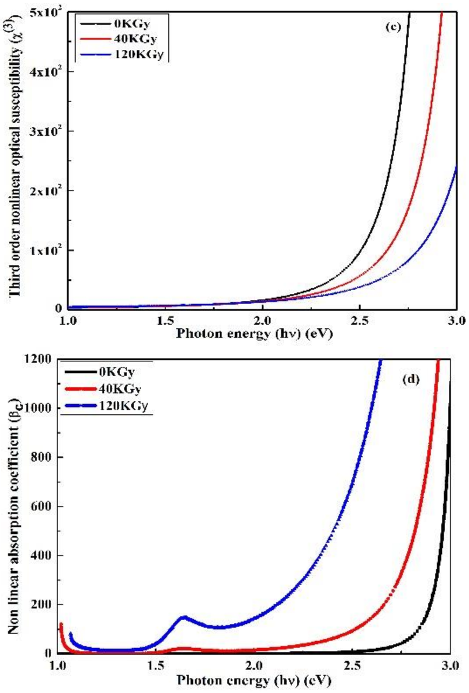


Fig. 4.(a) influence of (hν) on ($\chi^{(1)}$), (b) relation between (n_2)and (λ), (c) dependence of ($\chi^{(3)}$) on (hν), (d) Relation between (β_c) and (hν) for $In_{0.95}Mn_{0.05}Se$ films with thickness 750 nm which irradiated with different γ radiation doses (0,40 and 120 KGy).

The dependence of (n_2) on (λ) for these samples is shown in Fig.4b. The values of (n_2) decrease with (λ)for all these studied samples. An important parameter to assess the degree of nonlinearities is the third-order nonlinear optical susceptibility ($\chi^{(3)}$), which was determined using the following equation [60]:

$$\chi^{(3)} = A\left[\frac{E_o \cdot E_d}{4\pi(E_o^2 - (h\nu)^2)}\right]^4 \quad (15)$$

Where A is a quantity that is assumed to be frequency independent and nearly the same for all materials =1.7 x 10-10 e.s.u [60]. The dependance of ($\chi^{(3)}$) on and (hν) for these films is shown in Fig.4c. It was noticed that, the behavior of ($\chi^{(3)}$) is the same for all the studied samples, the values of ($\chi^{(3)}$) increases with (hν), this is due to, when (hν) increased the deflection of the incident light beam increase, while ($\chi^{(3)}$) decreases with radiations doses this is due to, when radiation dose increase the good arrangement of the grains, which leads to decrease of deflection of the incident light.

On the other hand, another important nonlinear parameter such was non-linear absorption coefficient (β_c) which, determined as follows [61]:

$$\beta_c = \frac{48 \cdot \pi^3 . \chi^{(3)}}{n^2 \cdot c \cdot \lambda} \quad (16)$$

Fig.4d shows the influence of hν on (β_c). It is observed that, the values of (β_c) increases with radiation doses for all these samples as shown in figure 9. Because of the higher values of radiation doses, the large number of excited electrons which overcome the band gap.

3.3. Electrical results

Electrical susceptibility ($\chi_{(e)}$) was determined using the following relation [62]:

$$\chi_{(e)} = \frac{\left(n^2 - k^2 - \varepsilon_o\right)}{4\pi} \quad (17)$$

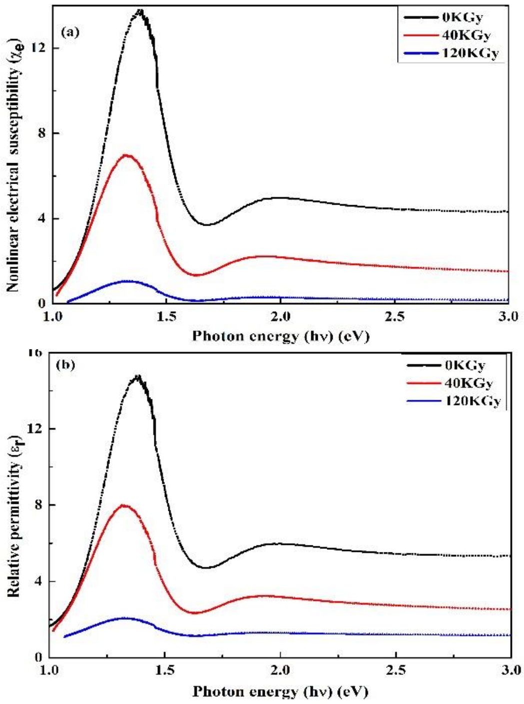


Fig. 5. Relation between (hν) and (a) electrical susceptibility (χ_e), (b) relative permittivity (ε_r) for $In_{0.95}Mn_{0.05}Se$ films of thickness 750 nm, which irradiated with different γ radiation doses (0,40 and 120 KGy).

Fig. 5a shows the electrical susceptibility ($\chi^{(e)}$) dependence on (hν) of these investigated samples. From this figure it is clear that, the values of ($\chi_{(e)}$) increase with (hν) and had a maximum values smaller than E_g for these samples, and also the($\chi_{(e)}$) decrease with radiation doses this is due to, the electron mobility increases with radiation doses.

The relative permittivity ε_r was calculated using the following relation [63]

$$\varepsilon_r = (\chi_e + 1) \quad (18)$$

The relation between relative permittivity (ε_r) and (λ) for for $In_{0.95}Mn_{0.05}Se$ films with doses (0,40 and 120 KGy) is shown in Fig.5b. It is clear that, the values of (ε_r) increase with (hν) for all these samples; this could be attributed to, the electron mobility increases with (hν).

3.4. Semiconducting and electronic results

The density of states (DOS) of a system describes the number of states per interval of energy at each energy level available to be occupied. The N_v and N_c play very important rule of examination the linear optical transition and non-linear optical properties. The N_v and N_c were calculated as follow [64]: -

$$N_v = 2\left[\frac{(2\pi m^*_h KT)}{h^2}\right]^{3/2} \quad (19)$$

$$N_c = 2\left[\frac{(2\pi m^*_e KT)}{h^2}\right]^{3/2} \quad (20)$$

Where N_v and N_c were the density of states for both valence and conduction bands respectively, effective mass of electrons m*e (InSe) = 0.14 [65], m*e (MnSe)= 0.15 [66], effective mass of holes m*h (InSe) = 0.37 [65] and K is a Boltzmann constant. The determined values for both N_v, N_c were shown in table 1. Another important factor was determined theoretically is the position of Fermi level [60]:

$$E_f = \left(\frac{KT}{q}\right) \cdot \ln\left(\frac{N_c}{N_v}\right) \quad (21)$$

The values of Fermi level position for these investigated thin films are shown in table 1.

Table 1. The influence of radiation doses on the determined physical parameters for $In_{0.95}Mn_{0.05}Se$ thin films.

Radiation dose	lattice dielectric constant ε_L	Oscillation energy E_o (eV)	Dispersion energy E_d (eV)	M_{-1} (eV)	M_{-3} (eV)	Field strength (*f*) $(eV)^2$	n_o	N/m*	N_C/m^*_h	N_V	Fermi Level Position (eV)
0 KGy	03.00	3.14	4.22	3.64	2.05	13.25	1.53	1.1E+49	9.3E+20	4.10E+21	0.24
40 KGy	02.80	3.42	4.80	4.05	2.19	16.42	1.55	1.5E+49	9.3E+20	4.15E+21	0.20
120 KGy	02.50	3.70	5.50	4.51	2.35	20.35	1.58	1.6E+49	9.3E+20	4.18E+21	0.18

4. Conclusions

The effect of (γ) radiation does on optical, dielectrical and semiconducting results of In0.95Mn0.05Se thin film of thickness 750 nm was studied. The values of both (E_o) and (E_d) increased slightly with radiations doses, and also the determined values of both (M_{-1}), (M_{-3}) and (f) increased with radiation doses, this is duo the increase of free electrons number and also electrons mobility's with radiation doses. The values of both of ($\varepsilon^{\backslash}$), ($\varepsilon^{\backslash\backslash}$) and also ($\sigma_1$) , ($\sigma_2$) with (hν) increases with (hν), and had a maximum values at (1.34 eV) the maximum values decrease with increase radiation dose. ($\chi^{(1)}$) increases with (hν) for all radiation doses, this means that, the optical response of these films to increase with (hν), while ($\chi^{(3)}$) increased with (hν). This means that these samples had a high ability to changing its optical properties by changing wavelength and applied field. The non-linear absorption coefficient (β_c) increased with (hν) for these samples, also both of the ($\chi^{(e)}$) and (ε^r) increase with (hν) and had a highest value near the energy gap. The gamma radiation doses affected on the values of both of N_v and N_c, while E_f affected slightly with radiation doses.

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