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A Study of Alpha Particles Effects with Different Energies on the Optical Properties of LR115 Detector by Using Spectrophotometer

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Abstract

The optical properties of solid state nuclear track detectors (LR115) films are studied. The detectors (LR115) films have been irradiated with Alpha particles of different energy (E_α= 1, 2, 3, 4, 5 MeV). The optical properties are studied (for pristine and irradiated films) by using measurements from ultraviolet-visible (UV/VIS) spectrophotometer at wavelengths within the range (600-1000 nm). The optical results show that the absorption of (LR115) films are increased with increase irradiation (energy of alpha particles). The optical constants are calculated before and after irradiation. Also the values of the optical energy band gaps for (LR115) films, whichwas non-irradiated with direct and indirect influence, has been found (2.145, 1.89 eV) respectively. Whereas the values of direct and indirect optical energy gaps after irradiated with α-particles (2.02, 1.75eV) respectively.

From these results, we can reveal that the values of energy band gaps in a direct-coincidence before and after irradiation are greater than that for indirect one.

Keywords*:* Optical band energy; LR115 detector; alpha irradiation; UV/VIS Spectroscopy; optical properties.

1. Introduction

During the last few decades the importance of polymers has increased very rapidly because of their low cost, easy process ability, low weight, high quality surfaces and easy fabrication of thick and thin samples, etc. One of the most importantpolymers is LR115, which is used in different applications.These applications include fission and nuclear physics; space physics;the study of meteoritic and lunar samples; cosmic rays; particle accelerators and reactors; metallurgy, geology and archaeology medicine and biology; and many others. When a polymeric nuclear track detector, modifications in their structural, physical and chemical properties [1]. The changes in these properties after exposureto high energy radiation have been evaluated by many techniques [1,2].

LR115 plastic detector is one of the Solid State Nuclear Track Detectors (SSNTD,s) frequently used cellulose nitrate which has the basic material , which contains the element of component $(C_{12}H_{17}O_{16}N_3)_n$. In recent years the solid state nuclear track detectors (SSNTDs) have wide applications such as radon and progeny measurements [2,3,4].

Different studies on LR115 polymer have shown the effect of irradiation to various modifications in the physical and chemical properties such as optical, electrical and mechanical on the polymeric materials, which depends on the irradiation flounce and energy of radiation used [6]. The interaction of the radiation or highly energetic charged ion strikes a polymer target; it loses most of its energy in exciting or ionizing the atoms along its trajectory [5,6].

The LR115 type film is sensitive for α-particles such that when α-particle hits the film it causes localized damage to the molecular structure of the cellulose nitrate layer. This damage can be visually observed through microscope when the exposed film is etched in a bath of diluted sodium hydroxide solution amongst other specific conditions. After this processing small holes are visible under the microscope which is able to be counted. The holes exhibit different diameters, due to α-particles. A wide range of colors can be achieved by dyeing the surface or the bulk of the material. The use of ion beams to modify polymer properties opened to a wide area of research and utilization in various fields like industry, agriculture, ecology, sensors, microelectronics and nanotechnology. The damage processes triggered by ions are differing than those induced by classical low ionizing particles as electrons or gamma rays. This is due to the very high electronic stopping power of these ions [1,7]. A gradual increase in absorbance, generation of chromo-phoric groups, loss of crystalline, formation of carbonized inclusions along with a gradual phase transition, as well as creation of three-dimensional network and triple bonds have been found in polymers due to ion bombardment. In most cases the amount of energy deposited in the host polymer is enough for extensive breaking of the chemical bonds within the track, which makes that strong modification of the bombarded polymer material, is possible. The energy released by the ion during slowing down is deposited in the target by means of two basically different mechanisms, electronic excitation and nuclear collision, which induce quite different processes of polymer matrix rearrangement [8,9].

2. Experimental details:

2.1 Materials

LR115 is one of the trademarks of the family of cellulose nitrate with red colored. The chemical composition of LR115 is $(C_{12}H_{17}O_{16}N_3)n$ where C content is 31.4%wt, H content is 3.7%wt, O content is 55.8%wt and N content is 9.1%wt. Sheet used in this study were manufactured by Kodak, Pathe-France. This sheet is cut into (1x2) cm^2 sized samples.

2.2 Irradiation facility

Irradiation produces faults in polymer films structure (band rupture, free radical, etc.) which increases the electronic disorder inducing the creation of a permit state in the forbidden (interdict) band or the deformation of the valence band.Furthermore, thevalues of indirect band gap have been foundto be lower than the corresponding values for the direct band.

Samples of (LR115) were exposed to a collimated beam of Alpha particles falling on the detector surface at right angle from intense ^{241}Am source. The source supplied by the Radiochemical Ltd, Amersham, England. Irradiations were carried out inside Canberra cylindrical chamber (Model 7400) with an internal diameter of 13.5 cm. LR115 samples were exposed to alpha particles fluxes of energies from (1 to 5) MeV at the same conditions.

2.3 Optical measurements

In the current work, the optical properties of the pristine and all the irradiated LR115 samples were subjected to spectral studies in the visible(red) and infrared regions. These studies were carried out by using (6800UV/VIS Jenway Double Beam Spectrophotometer – England) UV-VIS spectrophotometer in the wave length range of (600 – 1000)nm .

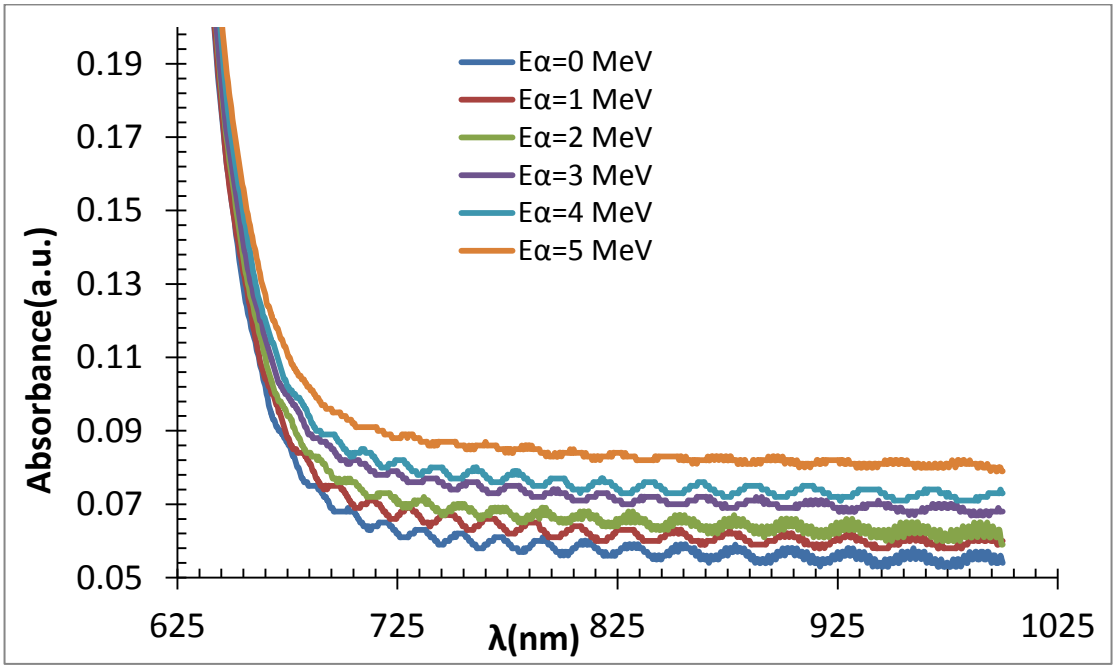
3. Results and Discussions:

The optical properties of (LR115) plastic detector films (the pristine and alpha irradiated samples) were determined from transmission and absorption measurements in the range (600-1000) nm were recorded by using UV-VIS spectrophotometer.

The analysis of the absorption coefficient has been carried out to obtain the direct and indirect optical energy gap E_g and also the analysis of the refractive index n with the help of the absorption index k has been carried out to obtain the real and imaginary part of complex dielectric constant (ε_r , ε_i), average interband oscillator wave length λ_o , average oscillator strength S_o and N/m^* (N the free charge carrier, m^* the effective mass of the free charge carrier).

3.1 The Absorption, Transmission and Reflectance spectra

The plastic detectorLR115 filmshave exhibited good absorption at red wave length region for pristine and alpha irradiated films (with alpha particles energy E_α=1 , 2 , 3 , 4 , 5 MeV) , then the absorption decreased at long wave lengths. From these spectra, displayed in Fig.(1), it is clear that a shift of absorption edge towards longer wavelengthswith increasing α-particles energy (E_α) can be readily observed. The absorption peak with increasing (E_α) is seen to change into a broad one. This behavior is generally interpreted as caused by the formation of extended systems of conjugate bonds i.e. possible formation of carbon clusters. The absorption bands in the investigated range of wavelength are associated to theπ-π*electronic



Fig(1):The Absorbance spectraof LR115 films pristine and irradiated with the α-particles of different energies (Eα).

transitions. This type of transitions occurs in the unsaturated centers of the moleculesi.e. in compounds containing double or triple bonds and also in aromatics. The excitation of π electron requires smaller energy and hence, transition of this type occurs at longer wavelengths.[10].

The transmission and reflectance spectrums of pristine and alpha irradiated LR115 films (with alpha particle energy E_α=1 , 2 , 3 , 4 , 5 MeV) , are shown in Fig.(2) and Fig.(3) respectively. From figures can be seen that the films have high transparency in wavelength related to low absorbance and low reflectance. As seen from figures (1 and 3) that the absorbance and reflectance have the same behavior.

The reflectance spectrum (R) can be calculated from absorption spectrum (A) and transmittance spectrum (T) using the relation [11, 12]:

$$A + T + R = 1 \qquad (1)$$

3.2 The band gap energy (E_g)

The relationship between incident intensity and penetrating light intensity is given by Equation [13]:

$$I = I_o e^{-\alpha t} \qquad (2)$$

where t is the thickness of the films in (cm) and αis the absorption coefficient in (cm^{-1}),

$$\alpha\, t = 2.303(\log I/I_o) \qquad (3)$$

where the amount of log I/I_o represents the absorbance (A).

The absorption coefficient can be calculated by,[13]

$$\alpha = 2.303(A/t) \qquad (4)$$

If the amount of absorptioncoefficient is $\alpha > 10^4$ cm^{-1}, the electronic transitions are direct. And if the amount of theabsorptioncoefficient is $\alpha < 10^4$ cm^{-1}, the electronic transitions are indirect. The amount of optical energy gap from this region can be evaluated by the relation: [14]

$$\alpha h\nu = A\,(h\nu - E_g)^n \qquad (5)$$

Where hv is the energy of incident photon, A is the proportional constant, E_g is the allowed or forbidden energy gap of direct or indirect transition. Parameter nis the power coefficient

with the value that is determined by the type of possible electronictransitions, i.e., n=1/2, 3/2, 2 or 3 for direct allowed, direct forbidden, indirect allowed and indirect forbidden, respectively [15].

Here the electronic transitionsare both direct and indirect, because the range of absorption coefficient α values according to the (equ. 4) extends the values from less than $10^4 cm^{-1}$to greater than $10^4 cm^{-1}$respectively.

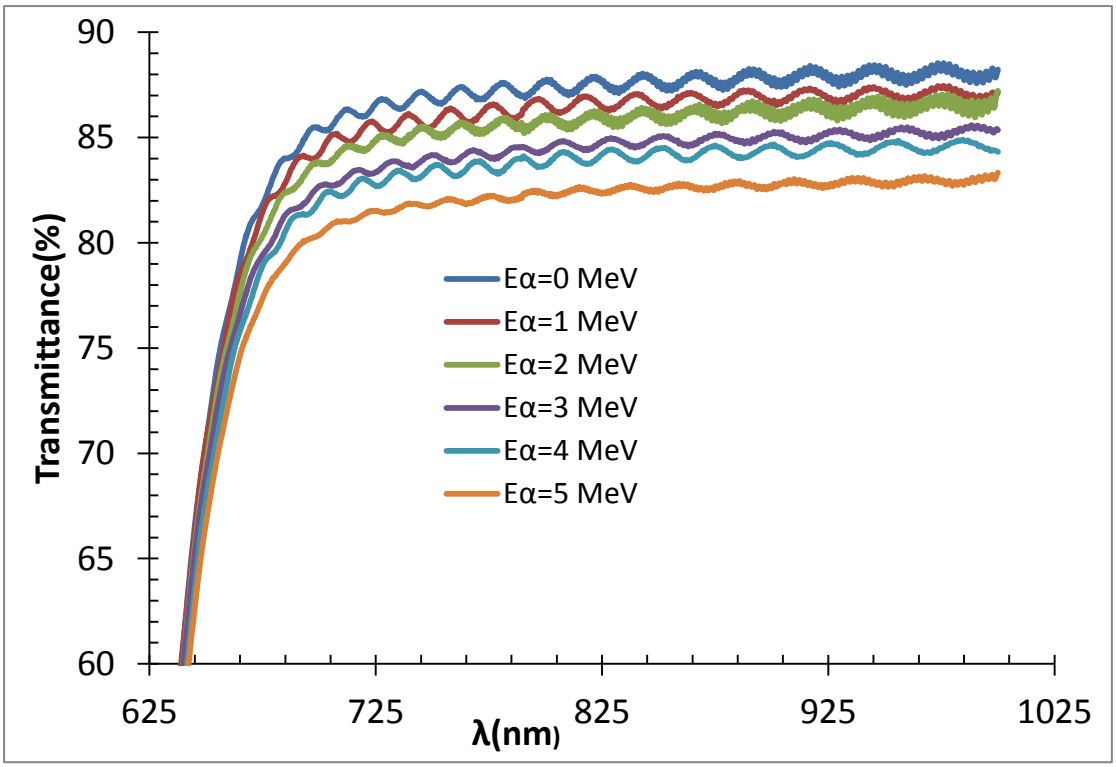
The usual method for determine the values of direct (indirect) band gapE_g are involves by plotting $(\alpha hv)^2$,$((\alpha hv)^{½})$ as a function of photon energy hv respectively , as shown in Figs(4,5)of pristine and alpha irradiated LR115 filmswith alpha particle energy (E_α=1 , 2 , 3 , 4 , 5 MeV) . From extrapolating the straight line portion of $(\alpha hv)^2$ and $((\alpha hv)^{½})$ as a function of photon energy hv the direct and indirect band gaps have been determinedrespectively (as shown in table(1) and Figs.(4 and 5). Furthermore, the values of direct band gap have been found to be higher than the corresponding values for the indirect band gap as shown in Fig. (6). The simultaneous existence of indirect as well as direct band gap in LR115 polymer hasrarely been reported [16], although such a coexistence of direct and indirect band gap have been observed in some other materials[17;18;19;20]for all the energies of alpha particles. We also note that the energy gap ofLR115 films irradiated by alpha particles is less than the energy gap of the films which is not irradiated with alpha particles(pristine film). We also notice that all the films irradiated with alpha particles of different energy have the same energy gap due to the same dose irradiated by gross alpha despite the different energies of alpha particles. This is, in turn, clearly indicates the simultaneous existence of direct and indirect band gap LR115 polymer with decreasing tendency at irradiate alpha energy. This result confirms that the irradiation produces faults in LR115 polymer structure (band rupture, grain size, free radical, etc.) which increases the electronic disorder inducing the creation of a permit state in the forbidden (interdict) band or the deformation of the valence band.[10,21].

3.3 The extinction coefficient(k)

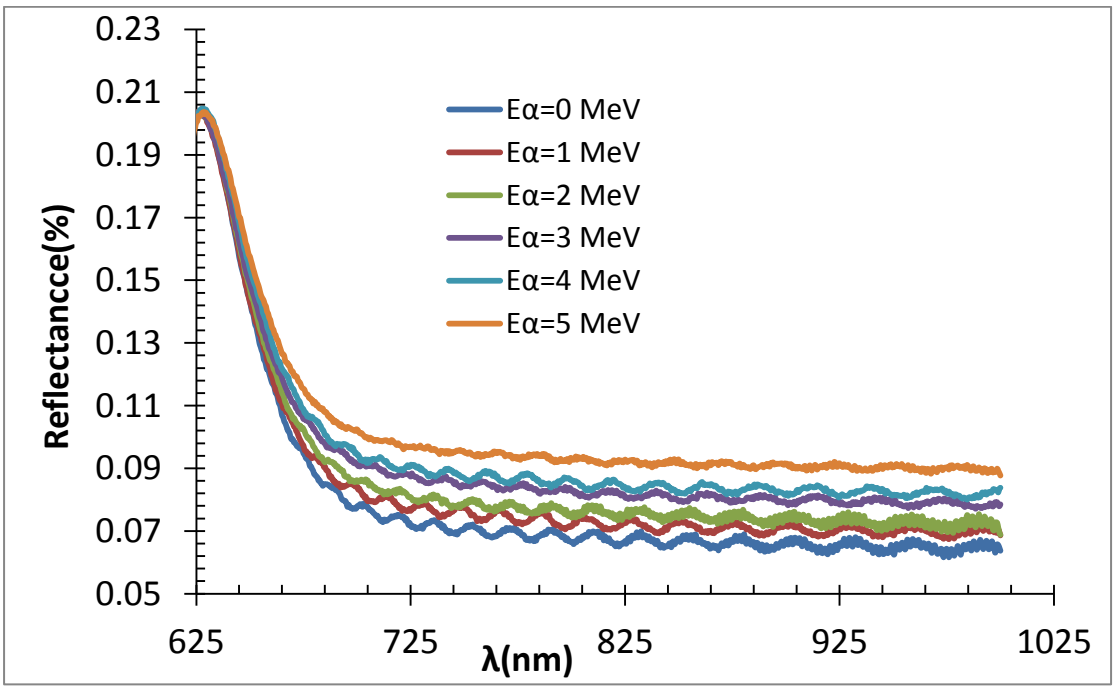
The extinction coefficient (k) is a measure of the fraction of light lost due to scattering and absorption per unit distance of the penetration medium. It can be estimated in the range (600-1000)nm from the values of α and λ using the following relation [22]:

$$k = \alpha\lambda/4\pi \qquad (6)$$

Fig(7) shows the dependence of extinction coefficient on the wavelength for pristine and alpha irradiated films (with alpha particle energy E_α=1 , 2 , 3 , 4 , 5 MeV). As seen from the figure, the extinction coefficient has high value at visible (red color) region and it is rapidly decreased in the infrared region (λ>700 nm) for all(LR115) films (pristine and irradiated), the decrease in extinction coefficient at red color region (λ<700 nm) is due to the high absorbance of (LR115) films in this wavelengths region. The decrease in extinction coefficient with increase in wavelength (λ>700 nm) shows that the fraction of light lost due to scattering and absorbance decreases. Furthermore, the optical absorption edge can be seen clearly for pristine and alpha irradiated films



Fig(2):The Transmittance spectra of LR115 films pristine and irradiated with the α-particles of different energies (Eα).



Fig(3):The Reflectance spectraof LR115 films pristine and irradiated with the α-particles of different energies (Eα).

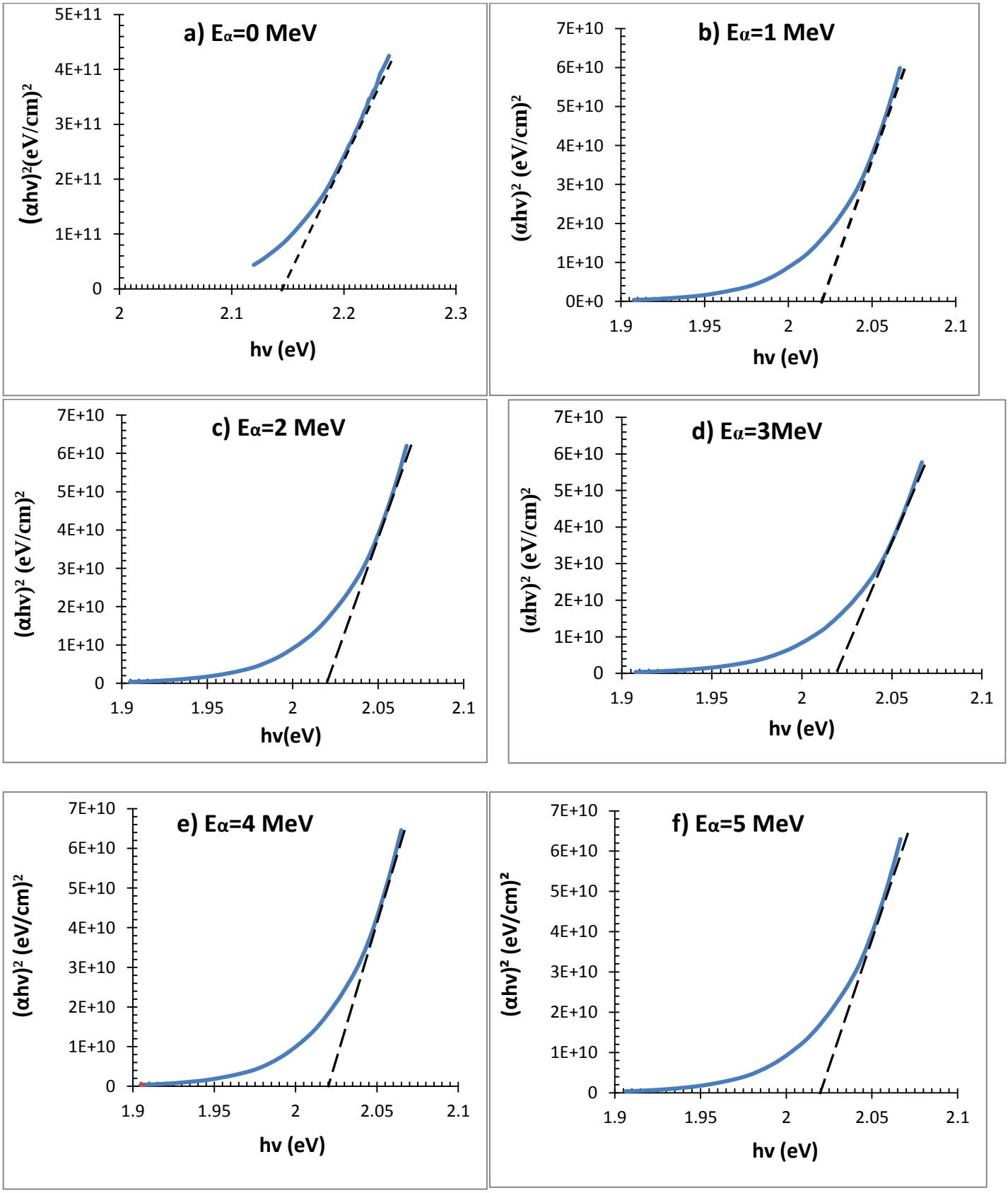


Fig (4): The optical energy gap for the direct allowed transition of LR115 films for Pristine and irradiated with the α-particles of different energies (Eα).

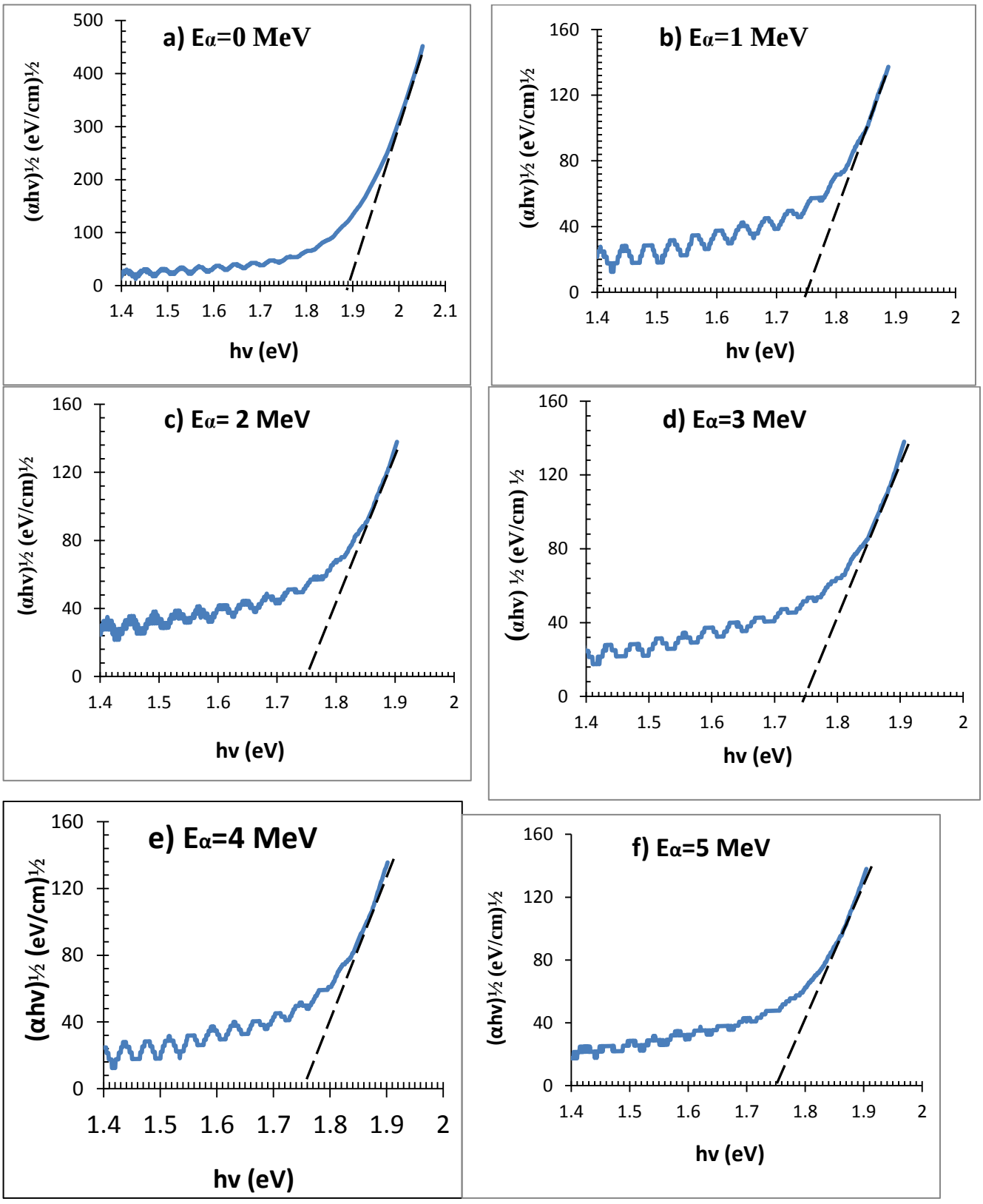
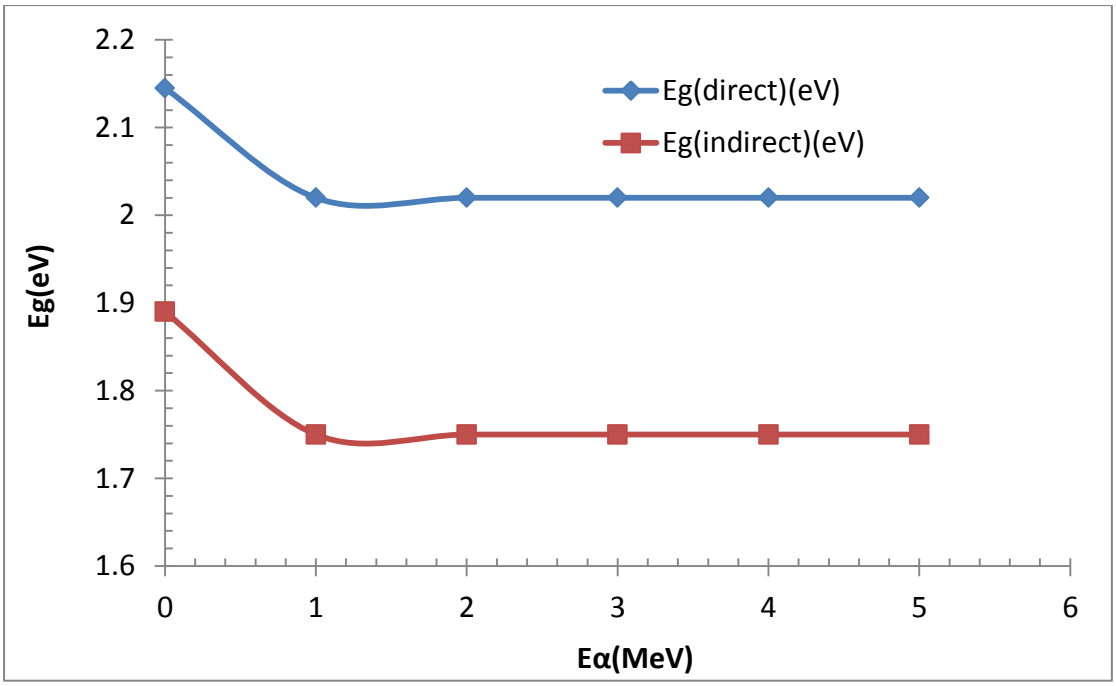


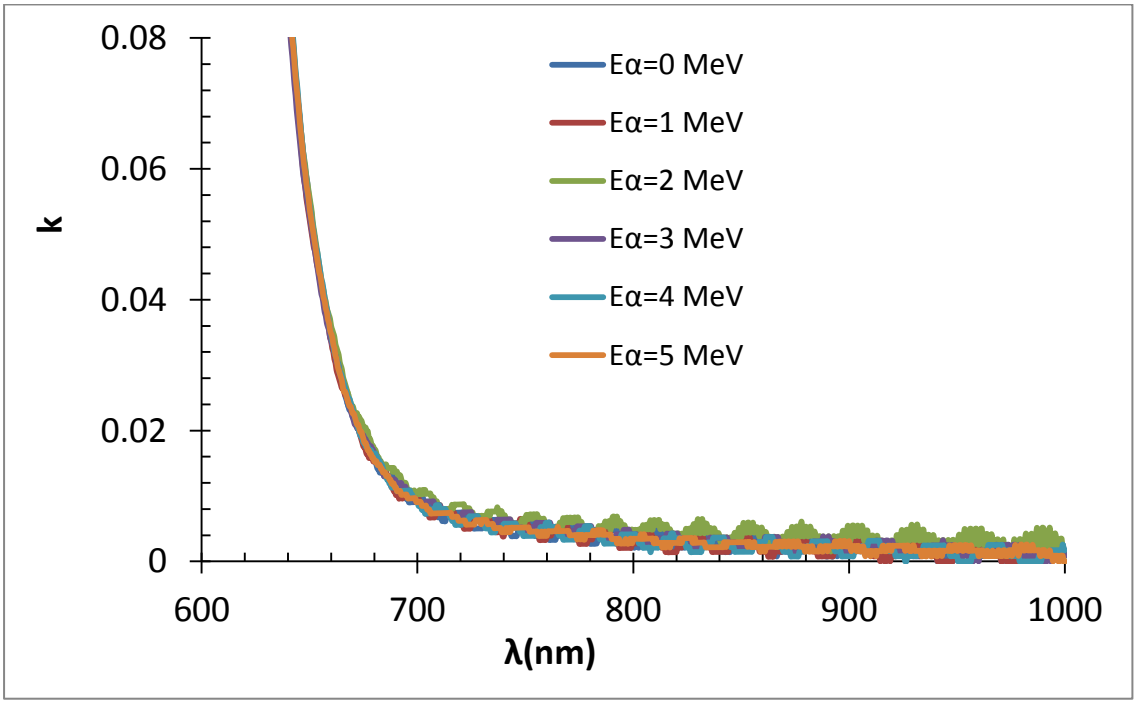
Fig (5) : The optical energy gap for the indirect allowed transition of LR115 films for pristine and irradiated with the α-particles of different energies (E_α).

Table(1): ***The values of optical parameters for (LR115) polymer films pristine and Irradiated with α-particles of different energies(E_α=1 , 2 , 3 , 4 , 5 MeV).***

E_α(MeV) → / Parameter ↓	0	1	2	3	4	5
E_g (eV)direct	2.145	2.02	2.02	2.02	2.02	2.02
E_g (eV)indirect	1.89	1.75	1.75	1.75	1.75	1.75
E_0(eV)	3.96	3.84	3.95	4.17	4.32	4.88
E_d (eV)	6.49	6.51	7.02	8.14	8.9	11.08
$E_{opt.}^{W.D.}(eV)$	1.98	1.92	1.98	2.02	2.16	2.44
$\varepsilon_{\infty(1)}= n^2$	3.1	3.22	3.37	3.44	3.54	3.63
$\varepsilon_{\infty(2)}(= n_0^2)$	2.644	2.703	2.812	3.01	3.04	3.27
λ_0(nm)	301.9	331.2	304.05	265.57	378.44	257.29
S_o (m^{-2})	18.0×10^{12}	15.5×10^{12}	19.6×10^{12}	28.5×10^{12}	24.7×10^{12}	34.3×10^{12}
N/ m*($m^{-3}kg^{-1}$)	3.67×10^{56}	3.76×10^{56}	4.65×10^{56}	3.70×10^{56}	4.16×10^{56}	3.69×10^{56}
n	1.76	1.79	1.84	1.86	1.88	1.91
n_0	1.63	1.64	1.68	1.73	1.74	1.81



Fig(6): The relation between Energy band gap(E_g) and Energy of α-particles irradiate (LR115) films.



Fig(7): The extinction coefficient as a function to the Wavelength of LR115 films pristine and irradiated with the α-particles of different energies (Eα).

The relation betweenextinction coefficient (k) and photon energy (hv) for pristine and alpha irradiated films with alpha particle energy(E_α=1 , 2 , 3 , 4 , 5 MeV)is shown in fig.(8) , there is a little increase in the extinction coefficientwithphoton energy range (1.24-1.8 eV) then rapidly increase for (hv>1.8 eV).

3.4 Refractive index (n)

The refractive index n of the LR115 films can be determined from a transmittance spectrum and absorbance spectrum (or reflectance spectrum) in the wave length range (600-1000) nm for pristine and alpha irradiated films (with alpha particle energy E_α=1 , 2 , 3 , 4 , 5 MeV). by using Swanepoel's method [23] applying the following equation [24]:

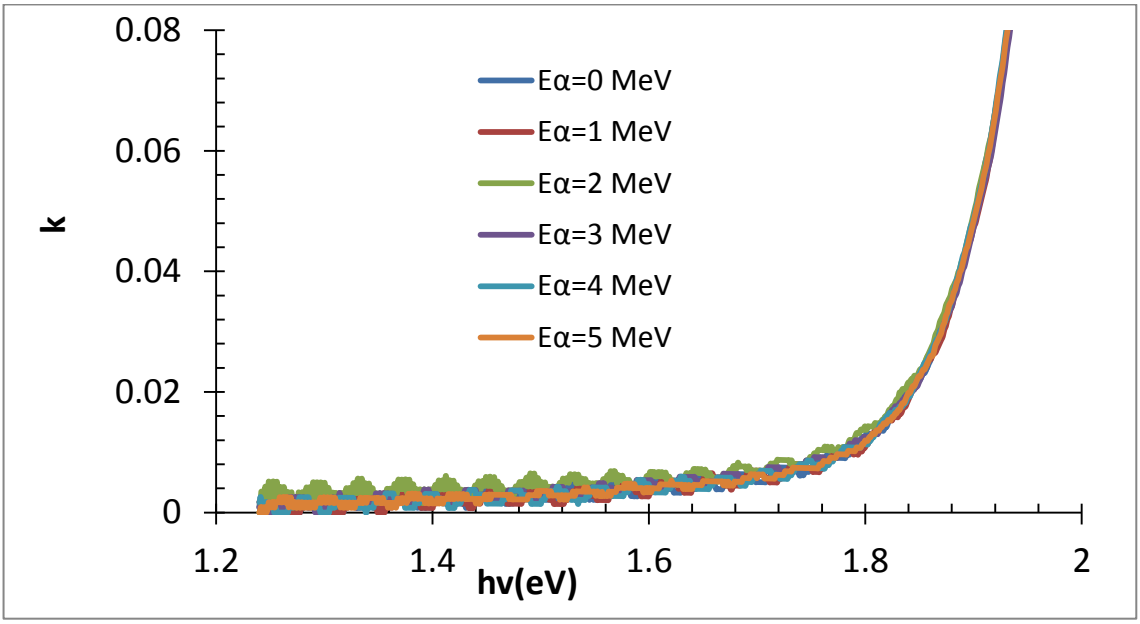
$$n = \frac{1+\sqrt{R}}{1-\sqrt{R}} \qquad (7)$$

where, R is the reflectance of LR115 film.

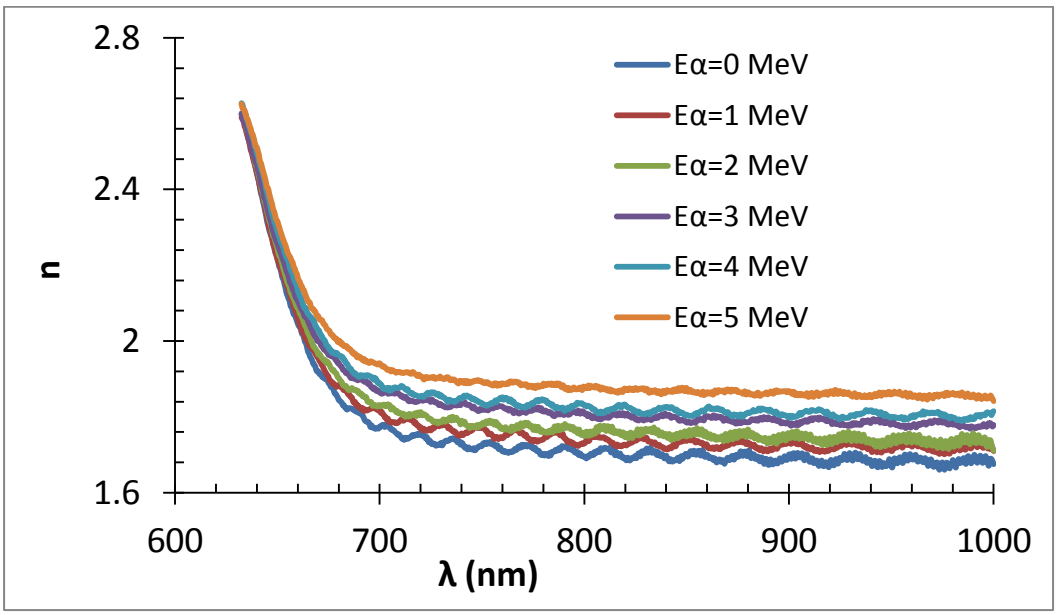
As shown in figure(9), there is a sharp decrease in the refractive indexes for pristine and alpha irradiated films (with alpha particle energy E_α=1 , 2 , 3 , 4 , 5 MeV)for LR115 films in the wave lengths range(630-700)nm. After that in the infrared region (wave length range 700-1000 nm), the refractive indexes decrease slightly and steadily. The average of refractive indexes increase with increasing alpha particles energy E_α incident on the LR115 irradiated films. (as indicated in figure (9)), which is due to the increase of pores and surface roughness (the movement of the atoms or molecules on film surface) as the alpha particles energy incident on the LR115 films increase.

3.5 The dielectric constants (Ɛ , $Ɛ_r$, $Ɛ_i$):

The complex dielectric constant is a fundamental intrinsic property of the material. The real part of the dielectric constant shows how much it will slow down the speed of light in the material,



Fig(8): The extinction coefficient as a function of the photon energy of LR115 films for pristine and irradiated samples with the α- particles of different energies (Eα).



Fig(9): The refractive index as a function of the wavelength of LR115 films pristine and irradiated with the α-particles of different energies (Eα).

whereas the imaginary part shows how a dielectric material absorbs energy from an electric field due to dipole motion. The knowledge of the real and the imaginary parts of the dielectric constant provides information about the loss factor which is the ratio of the imaginary part to the real part of the dielectric constant.

The analysis of the absorption coefficient has been carried out to obtain the optical energy gap E_g and also, the analysis of the refractive index n with the help of the extinction coefficient k has been carried out to obtain the real and imaginary part of complex dielectric constants (ε_r , ε_i). Wemple and Didomenico [25, 26] use a single-oscillator description of the frequency - dependent dielectric

constant to define a dispersion energy parameters E_d and E_o. According to the single-effective oscillator model proposed by Wemple and Didomenico, the optical data can be described to an excellent approximation by the relation [25,26]:

$$n^2 - 1 = \frac{E_0 E_d}{E_0^2 - (h\nu)^2} \quad (8),$$

where E(=hv) is the photon energy, n is refractive index, E_d is the single-oscillator constants, E_o is the energy of the effective dispersion oscillator, E_d the so-called dispersion energy, which is a measure of the average strength of interband optical transitions. The oscillator energy E_o is an average of the optical band gap, E_g, can be obtained from the Wemple–Didomenico model. Experimental verification of equation (8) can be obtained by plotting $(n^2-1)^{-1}$against $E^2(=(hv)^2)$ as illustrated in figures(10) for the detector LR115 films of pristine and alpha irradiated films (with alpha particles energy E_α=1 , 2 , 3 , 4 , 5 MeV). Which gives the oscillator parameters by fitting a straight line for normal behavior having the slope $(E_oE_d)^{-1}$and the intercept with the vertical axis equal to (E_o/E_d). The values of the parameters E_o and E_d estimated from figures (10) as listed in table (1). Furthermore, the values of the static refractive index (n_o) can be calculated by extrapolating the Wemple - Didomenico dispersion equation to energy approach to zero. The calculated values of n_o are shown in table (1).

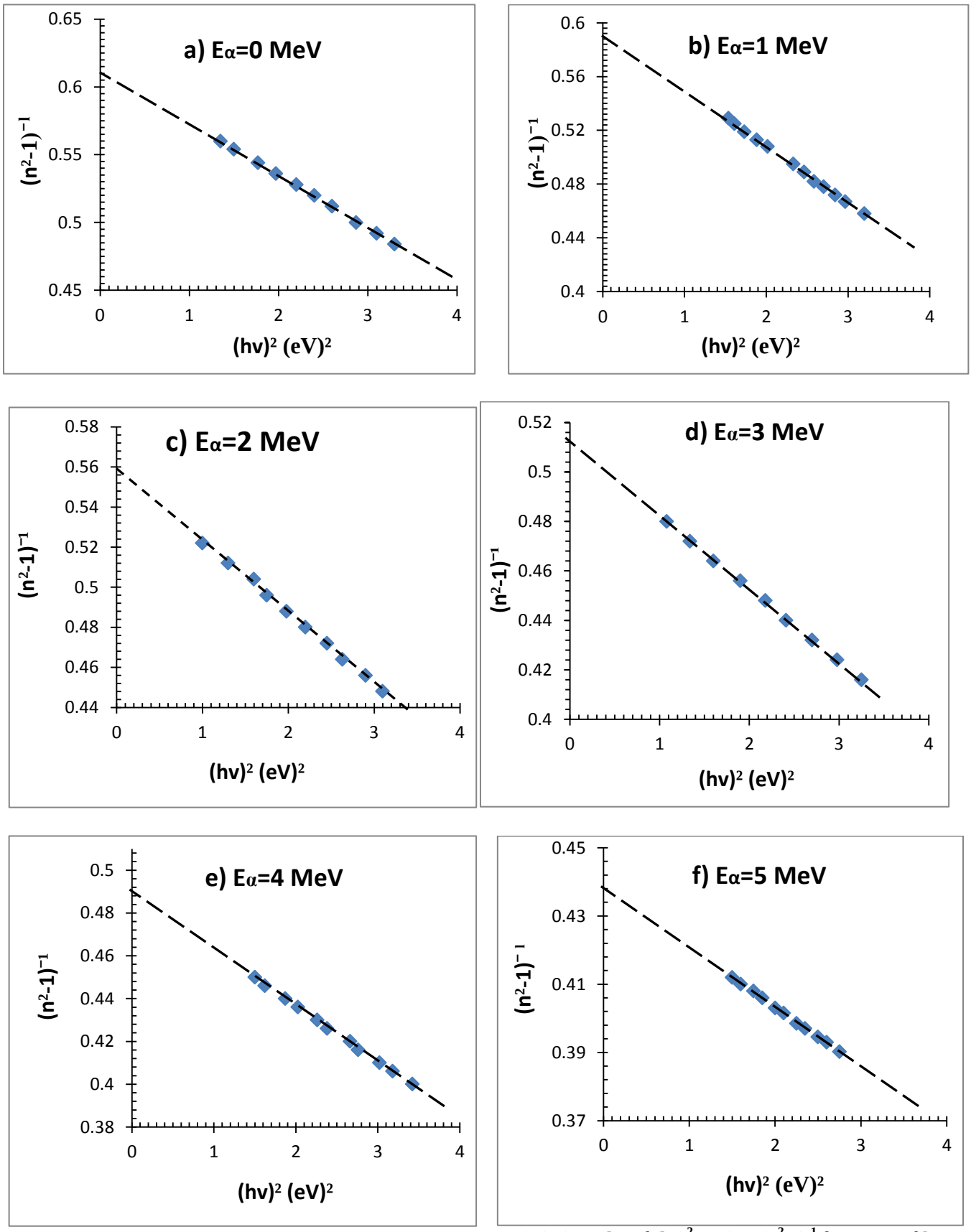
To obtain a reliable value for the high frequency dielectric constant, we used both procedures. The following equation can be used to obtain the high frequency dielectric constant [27]:

$$\varepsilon_r = \varepsilon_{\infty(1)} - B\lambda^2 (9)$$
$$B = e^2 N / 4\pi^2 c^2 \varepsilon_0 m^* (10)$$

Where$\varepsilon_r$is the real part of dielectric constant, $\varepsilon_{\infty(1)}$the lattice dielectric constant or (the high frequency dielectric constant) according to the first analysis, λ the wavelength, N the free charge carrier concentration, ε_0 the permittivity of free space (ε_0=8.854×10^{-12} F/m), m* the effective mass of the charge carrier and c the velocity oflight. The real part of dielectric constants (ε_r= n^2) was calculated at different values of λ . Then, the obtained values of ε_r are plotted as a function of$\lambda^2$for the detector LR115 films of pristine and alpha irradiated films (with alpha particle energy E_α=1, 2 , 3 , 4 , 5 MeV) as shown in figures (11). From the intersection and slop of the linear part of this dependent measure the values of $\varepsilon_{\infty(1)}$ and N/m* , as given in table(1).

The high frequency dielectric constant can be calculatedby applying the following simple classical dispersion relation [27]:

$$\frac{n_0^2-1}{n^2-1} = 1 - (\frac{\lambda_0}{\lambda})^2 \quad (11)$$



Fig(10):A plot of $(hv)^2$ against $(n^2-1)^{-1}$ for LR115 films pristine andirradiated with the α-particles of different energies(E_α).

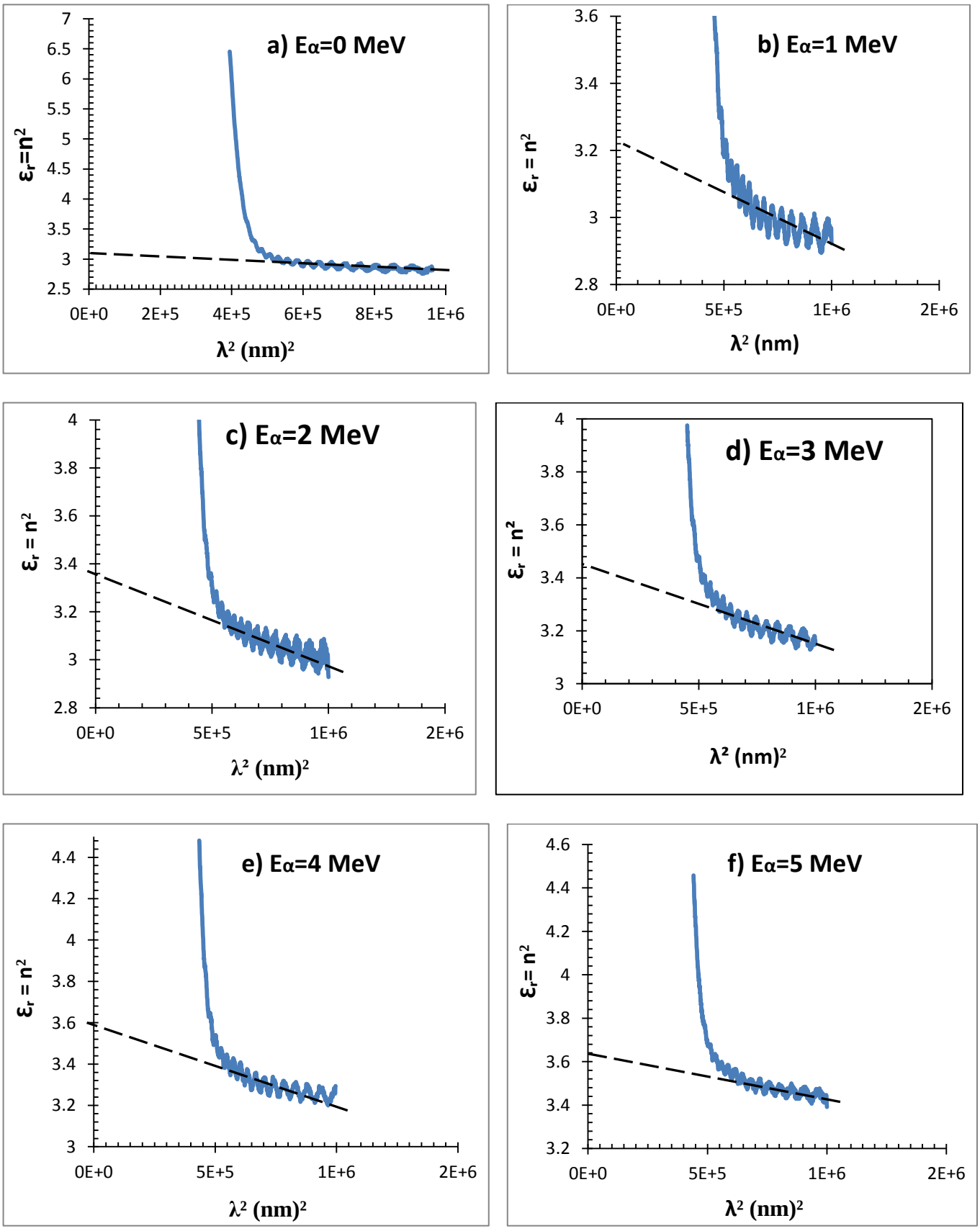


Fig (11) : A plot of ($\varepsilon_r = n^2$) as a function of λ^2 for LR115 pristine and irradiated with the α-particles of different energies (E_α).

Figs.(12) illustrated the relation between $(n^2-1)^{-1}$ againstλ^{-2} which showed linear part, was below the absorption edge. The intersection with $(n^2-1)^{-1}$ axis is$(n_0^2-1)^{-1}$and hencen_0^2 at λ_0 equal to $\varepsilon_{\infty(2)}$(highfrequency dielectric constant). Values of $\varepsilon_{\infty(2)}$ are given in table (1).

The simple classicaldispersion relation (equation 11) can be written as [28]:

$$n^2-1=\frac{S_0\lambda_0^2}{\frac{\lambda^2}{\lambda_0^2}-1} \qquad (12)$$

where S_o is the average oscillator strength which is equal to:

$$S_0=\frac{n_0^2-1}{\lambda_0^2} \quad (13)$$

The obtained values of S_o and λ_o are given in table(1).

The real and the imaginary parts of the dielectric constant can be estimated using the relations [29]:

$$\varepsilon_r = n^2-k^2 \text{ and } \varepsilon_i = 2nk \quad (14)$$

Figures (13,14) show the variation of the real and the imaginary parts of the dielectricconstant as a function of photon energy for the detector LR115 films of pristine and alpha irradiated films (with alpha particle energy E_α=1 , 2 , 3 , 4 , 5 MeV). It can be seen clearly from the figures that both the real and imaginary parts of the dielectric constant increase with photon energy. The real part of the dielectric constant increases slowly with photon energy but increased sharply in the higher energy region whereas the imaginary part increases sharply with photon energy.

4. Conclusions

The optical absorbance and transmittance of (LR115) films, pristine and irradiated with α-particles of different energy was measured by (6800 UV/VIS Jenway Double Beam Spectrophotometer –England) UV-Vis spectrophotometer within the wavelengths range of (600-1000)nm. It was observed that the absorbance increase whereas transmittance decrease with increasing energy of incidentα-particles. This is may be as a result of variation in the crystalline nature, morphology and structural characteristics of (LR115) polymer films as a result of alpha irradiation.

The optical energy band gaps (E_g) of pristine and irradiated (LR115) filmswere calculated. There is simultaneous existence of direct band gap as well as indirect band gap in (LR115) polymer films. The values of direct energy band gaps have to be higher than the corresponding values of the indirect energy band gaps.

The value of direct band gap decrease from 2.145 eV for pristine sample to 2.02 eV samples irradiated with α-particles. It was noticed that the indirect band gaps for LR115 reduced from 1.89 eV for pristine sample to 1.75 eV for irradiated samples. The decrease in optical energy band gap after irradiation may be due to the enhanced diffusion rate of π-electrons in the forbidden energy levels of LR115 polymer, formation of defects and/or creation of carbonaceous clusters due to partial release of hydrogen molecules.

The refractive indexes (n) increase with increasing α-particles energy, due to increase in diameters and numbers of tracks, pores and surface roughness (with α-particles of high energy).

The dielectric constants (real ε_r and imaginary ε_i) are observed be increase

with increasing α-particles energy E_α (as shown in table (1)). This might be attributed to breaking of chemical bonds and conversion of the polymeric structure into hydrogen depleted carbon network due to the escape of hydrogen as hydrogen molecules, which results in the increase of free radicals. And the increase in dielectric constant (real and imaginary) value is probably due to irregularity in the polymer chains caused by irradiation. This irregularity gives rise to a hopping mechanism which enhances the polarization in the polymer matrix.

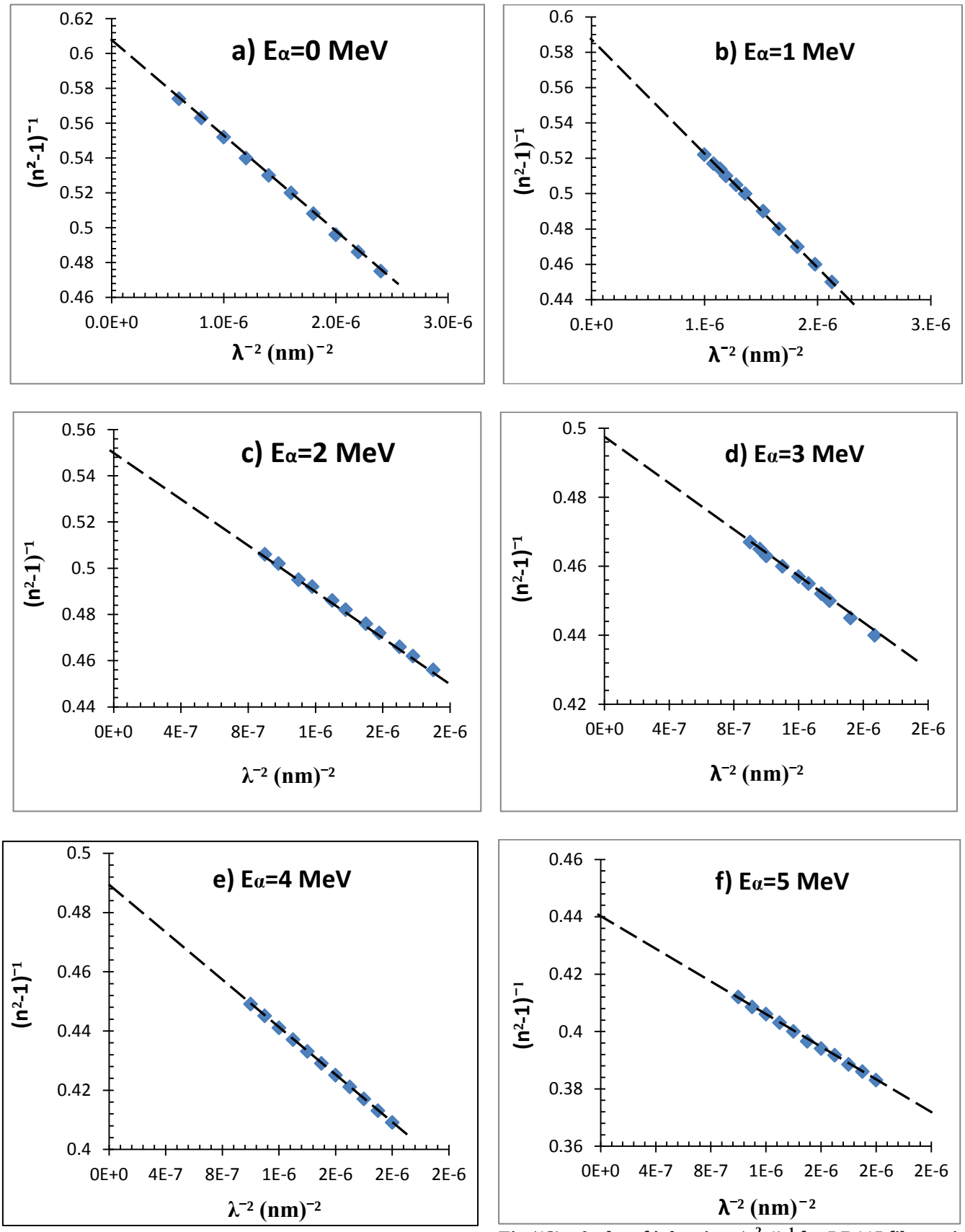
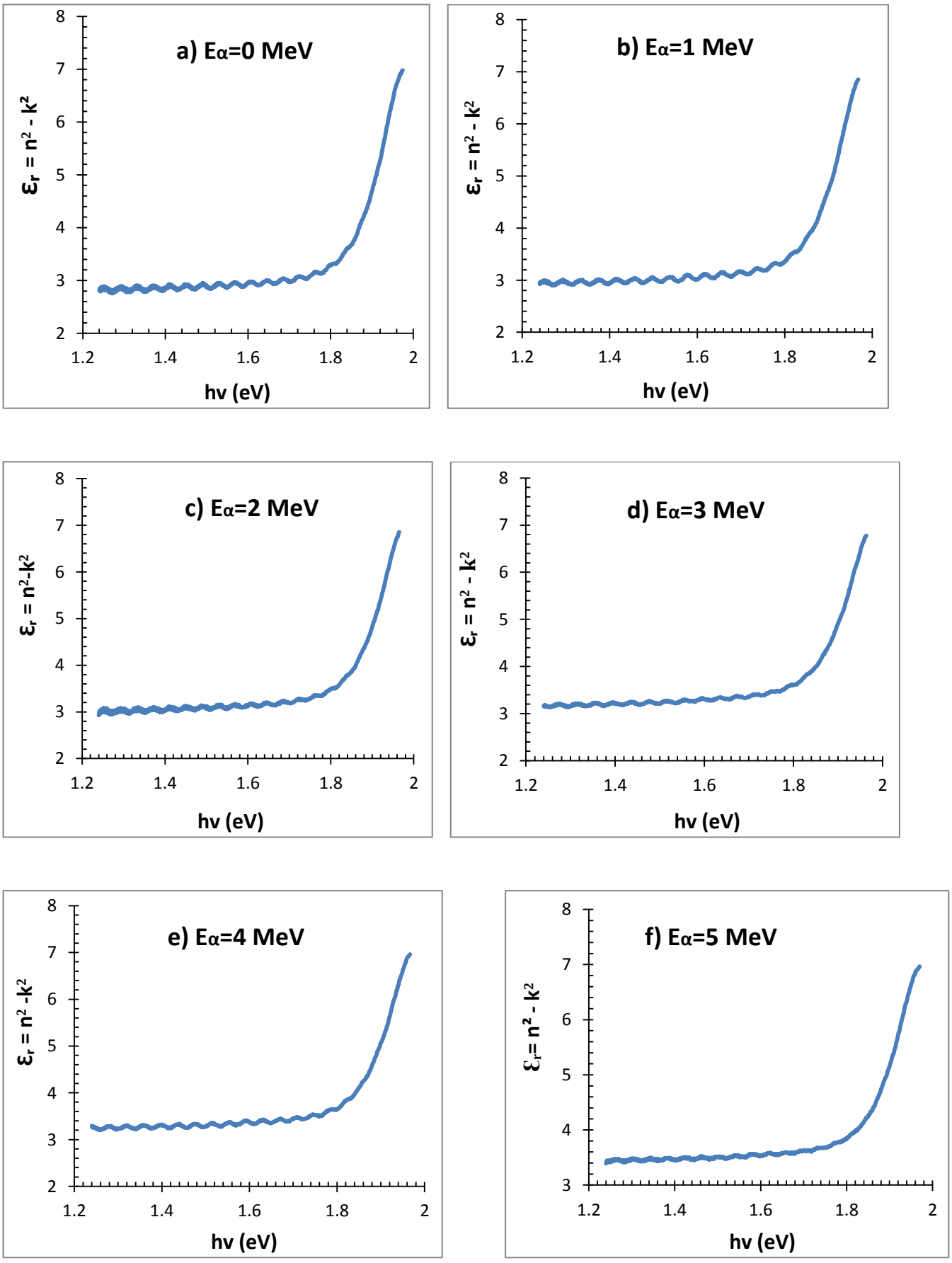
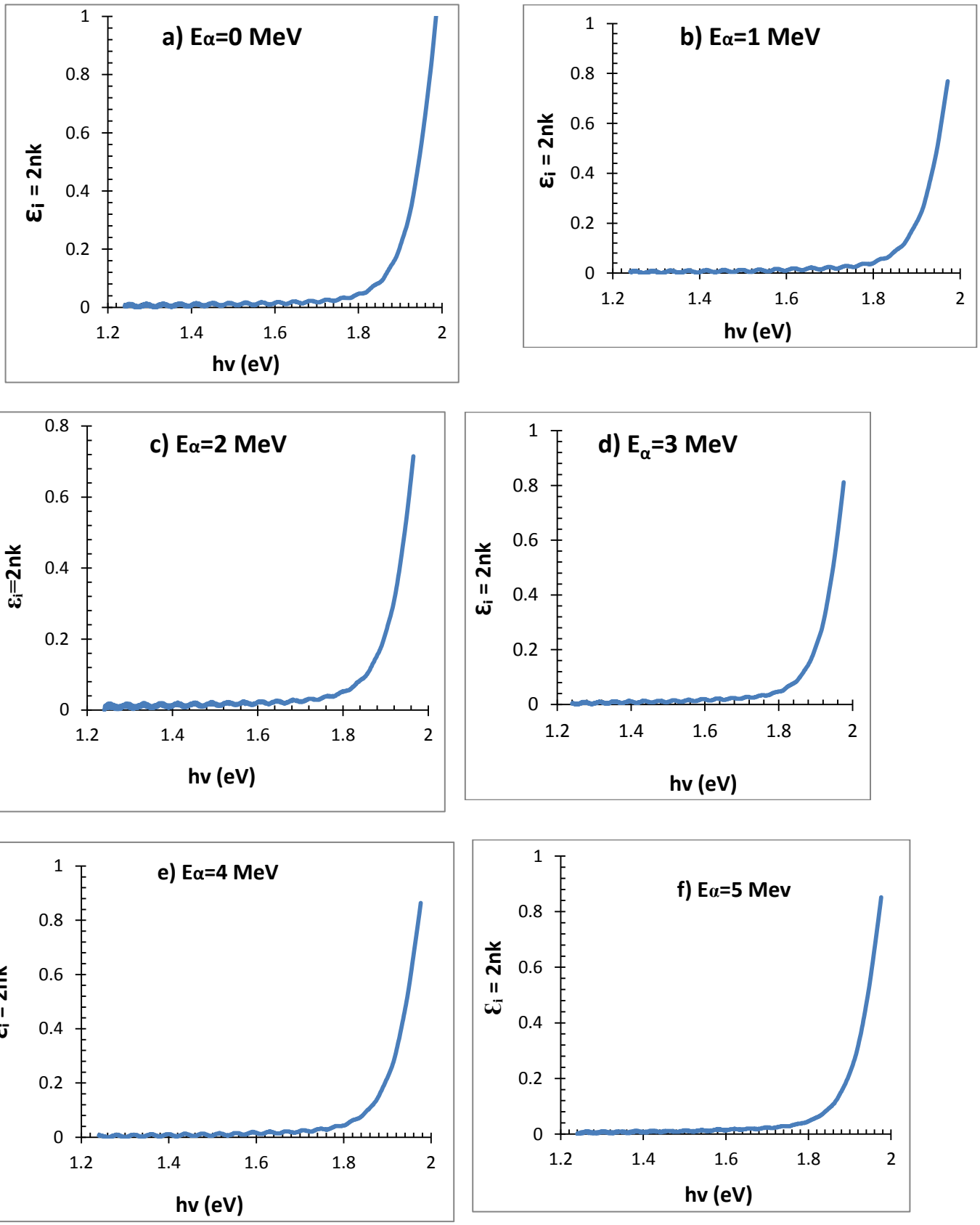


Fig (12) : A plot of λ^{-2}against $(n^2-1)^{-1}$ for LR115 films pristine and irradiated with the α- particles of different energies (Eα).



Fig(13): Real dielectric constant as a function of photon energy for LR115 films pristine and irradiated with the α-particles of different energies(Eα).



Fig(14): Imaginary dielectric constant as a function of photon energy for LR115 films pristine and irradiated with the α-particles of different energies (Eα).

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دراسة تأثير جسيمات الفا ذات طاقات مختلفة على الخصائص البصرية للكاشف LR115 بأستخدام المطياف

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المستخلـص:

تم دراسة الخصائص البصرية لكواشف الآثار النووية الصلبة لأفلام الكاشف (LR115) . حيث شعع الكاشف بجسيمات الفا وبطاقات مختلفة (E_α=1,2,3,4, 5 MeV) .قمنا بدراسة الخصائص البصرية (لأفلام مشععة وغير مشععة) بأستخدام مطياف الأشعة فوق البنفسجية–المرئية (UV/VIS) وعند مدى أطوال موجية (1000–600 nm) . أظهرت النتائج البصرية أن الامتصاصية لأفلام (LR115) تزداد بزيادة طاقة جسيمات الفا. تم حساب الثوابت البصرية قبل وبعد التشعيع, وكما وجد ان قيم فجوات الطاقة البصرية لأفلام الكاشف(LR115) , غير المشععة للانتقالات المباشرة وغير المباشرة تساوي (2.145 , 1.89) إلكترون فولت على التوالي. في حين أن قيم فجوات الطاقة البصرية المباشرة بعد التشعيع بجسيمات الفا تساوي (17.50, 2.02)الكترون فولت على التوالي. من هذه النتائج يمكن استنتاج ان قيم فجوات الطاقة المباشرة متوافقة قبل وبعد التشعيع كونها اكبر من نظيراتها غير المباشرة.