

Studying the Effects of Irradiation with Alpha Particles and Etching on the Optical Energy Band Gap of LR115 Detector

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Abstract: LR 115 is one of the ideal Solid State Nuclear Track Detectors (SSNTD's), which is frequently used in the numerous application and studies in applied science. The effects of α -particles irradiation and etching with 2.5N NaOH aqueous solution at 60 °C by a water bath on the absorbance **A**, transmittance **T**, reflectance **R** and optical energy band gap **Eg** of LR115 are studied through the measurements of UV/Visible spectrophotometer with wave length range (200-1000)nm. The irradiations are performed by using ^{241}Am source at constant alpha particle energy 5.48 MeV normal incident for different irradiation times (0, 3, 6, 9, 12, 15)days. Exposure of LR115 detector to α -particles doses and etched, causes a great effect on the structural of LR115 films. The energy band gap of LR115 films irradiated with α -particles is calculated before and after etching. The values of optical energy band gap **Eg** are found between (1.885-1.870)eV without etching and between (1.875-1.800)eV with etching, for irradiation times (0-15) days respectively. From these results, we can reveal that the values of energy gaps without etching (before and after irradiation) greater than those with etching. Thus, variations in the optical energy band gap **Eg** values may be due to the formation of defects (radicals and organic species) in LR115 films due to alpha irradiation. The number of carbon atoms has been determined in each case for optical energy gap.

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Keywords: LR115 track etch polymer; etching time; Optical band gap energy; alpha irradiation; UV/VIS Spectroscopy; optical properties: number of carbon atoms.

1. Introduction

The irradiation of polymers with ionizing radiations leads to a wide variety of changes in their physic-chemical properties which can generally be traced back to the rearrangement taking place in the chemical structure of the polymer as a result of energy deposition [1-5]. In the last few decades the solid state nuclear detectors has proven to be one of the most efficient, useable and recommended group of detectors available in marketing, In recent years the (SSNTD's) have wide applications such as fission, nuclear physics, space physics, the study of meteoritic and lunar sample, cosmic rays, particle accelerators and reactors, metallurgy, geology, archaeology medicine, biology and many others. They acquire many advantages over the others, such as easily processional, low coast in manufacturing, low weight, excellent surface transparency, high efficiency in ion-registration, etc. [6-9].

LR115 plastic detector is one of the solid state nuclear track detectors frequently used cellulose nitrate which has the basic material, that contains the element of component $(\text{C}_{12}\text{H}_{17}\text{O}_{16}\text{N}_3)_n$. In recent years the solid state nuclear track detectors (SSNTDs) have wide applications such as radon and progeny measurements [10-13]. 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 able to be counted. The holes exhibit different diameters, due to α -particles [10-14]. 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]. The present work aims to study the effect of irradiation time and etching with 2.5N for 1 hour on some optical properties (the absorbance, transmittance, reflectance, optical energy band gap, number of carbon atoms per conjugation length and number of carbon atoms per cluster) of LR115 polymer irradiated with alpha particles at constant energy 5MeV, but at different irradiation times.

2. Experimental details

2-1. Materials and methods

Plastic LR115 detector sheet is one of trade marks of the family of cellulose nitrate with red colored, pursed from Kodak Path-France, molecular

composition (C₁₂H₁₇O₁₆N₃)_n, and thickness 12µm are cut in pieces of (2x2.5)cm². Samples of LR115 are exposed to perpendicularly incident alpha particles (main energy 5.483MeV in air) emitted from ²⁴¹Am source. The irradiation are carried out in air at room temperature at a distance from the source of 0.51cm which correspond to α-particles energy of 5MeV. The ²⁴¹Am source is free from collimators to be sure that the area of the target material LR115 (5cm²) is wholly irradiated. Several irradiation times are taken (3,6,9,12,15)days at the same conditions. Then LR115 is chemically etched with 2.5N solution of NaOH and kept at temperature 60°C by using automatic water bath for one hour.

2-2. Optical properties measurements

To study the induced changes and the dose dependence variation in the optical energy band gap of LR115 samples pristine alpha particles irradiation before and after etching, by using a UV/VIS spectrophotometer in the range of (200-1000)nm has been used. This study is carried out (6800UV/VIS Jenway Double Beam Spectrophotometer – England) UV/VIS spectrophotometer in the wave length range of (600 – 1000)nm.

Results and Discussions

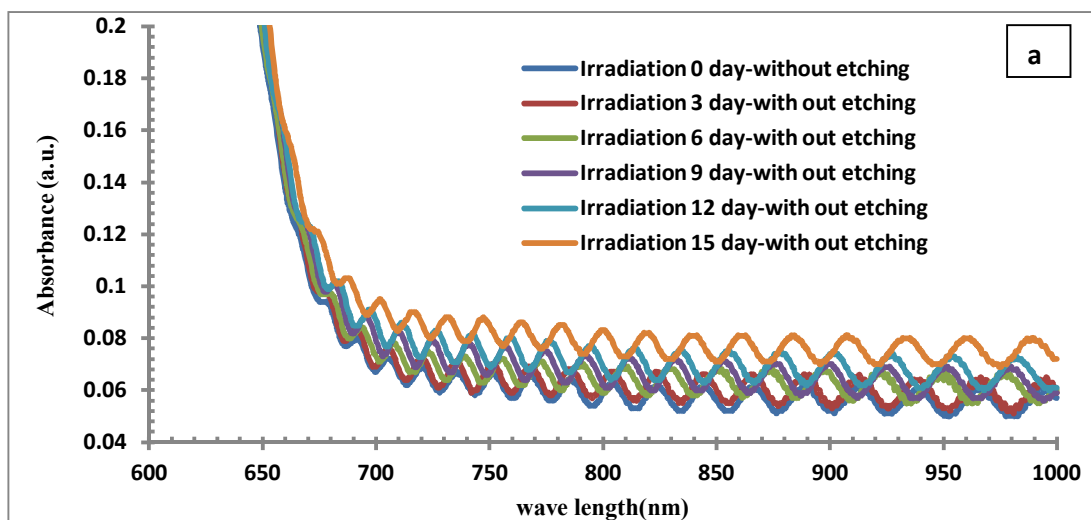
3-1 The UV/VIS spectral analysis

In the current work LR115 films absorbance and transmittance for un-irradiated (pristine) and irradiated films before and after etching are recorded in the rang (600-1000)nm by using the UV/Visible spectrophotometer. Figure (1) shows the UV-Visible spectra recorded for pristine and alpha irradiation LR115 samples for different times (3,6,9,12,15)days before and after etching. The absorption is good at red wavelength region for pristine and alpha irradiated

films, then the absorption decreases at long wave lengths. From spectra, shown in figure (1), it is clear that the absorption edge towards longer wave lengths are increasing with increasing the irradiation time of alpha particles (before and after etching). This shift in absorbance is thought to be caused by the formation of conjugate bonds, i.e. possible formation of carbon cluster, and/or defects (radicals and organic species). It is obvious from figure (1 a, b) that the absorption spectra shows fluctuation before etching but it becomes smooth after etching. Figure (2) shows a comparison for the same times of α-irradiation (before and after etching). We can see that the distance between the absorption spectra increases with increasing irradiation time (before and after etching) Figure (3) shows the transmission spectrum of pristine and alpha irradiation LR115 films, for different exposure times (3,6,8,12,15)days with and without etching. Figure (4) shows a comparison in the transmission spectra for same time of irradiation (before and after etching). The reflectance spectrum R can be calculated from absorption spectrum A and transmittance spectrum T by using the following relation [19,21]:

$$A+T+R=1..... (1)$$

Figure (5) shows the reflectance spectrum behavior of pristine and alpha irradiation LR115 films, for different exposure times (3,6,8,12,15)days with and without etching. Figure (6) shows a comparison between reflectance spectra for same time of irradiation (before and after etching). We can obtain from figures (1,3 and 5) that LR115 films have high transparency in wave length which is related to low absorbance and reflectance, while the absorbance and reflectance have the same behavior.



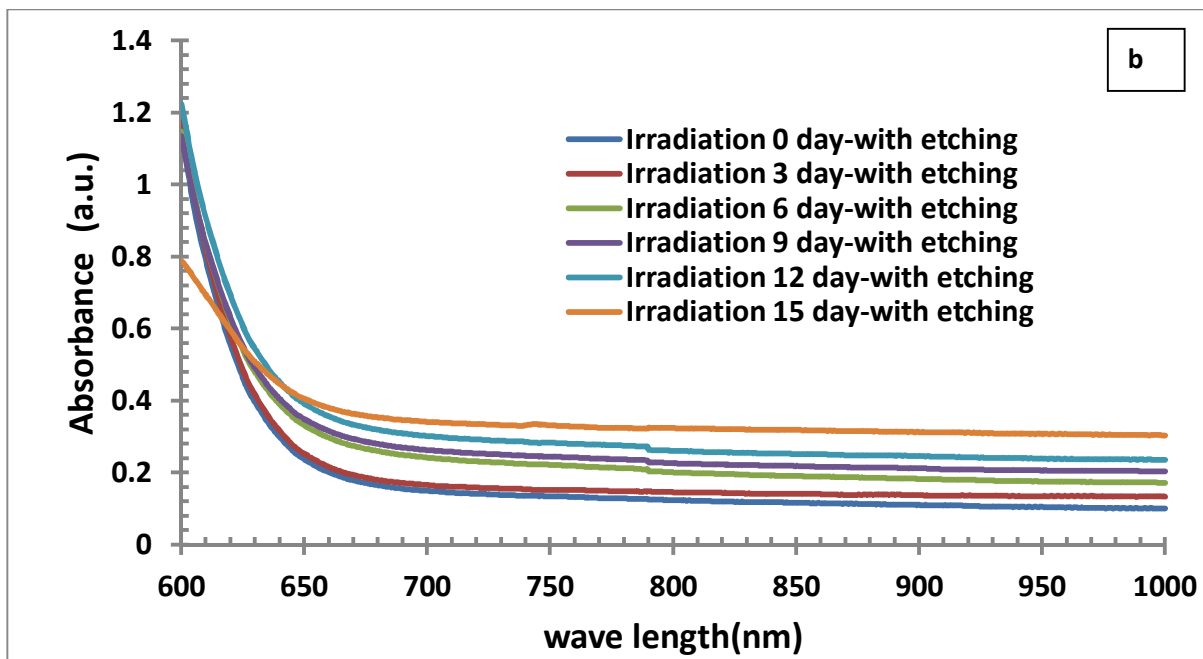
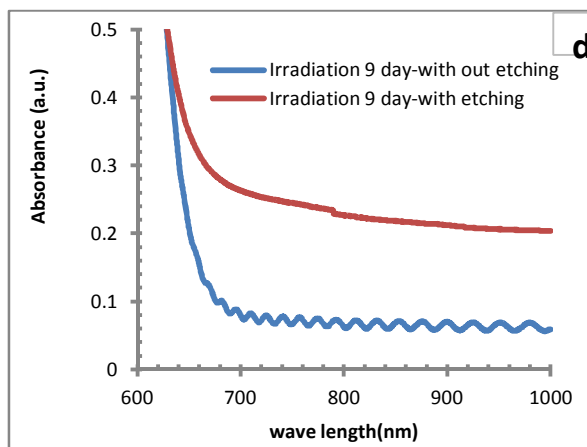
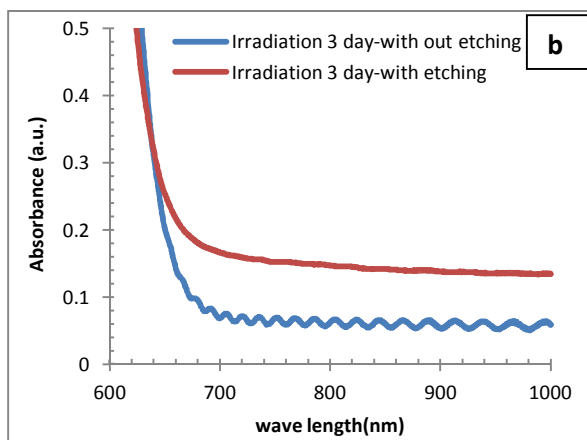
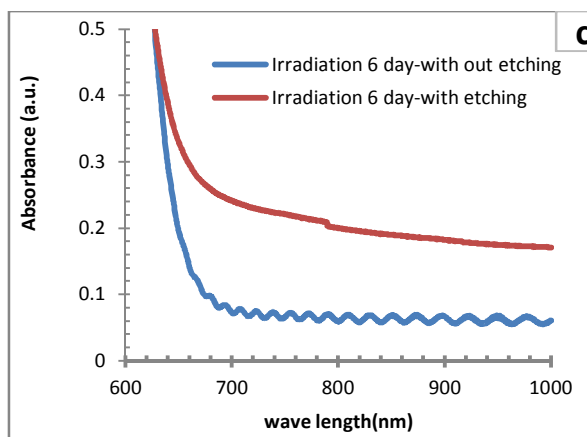
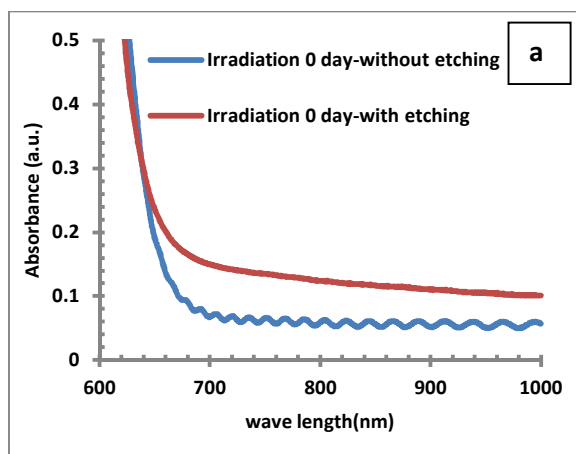


Fig. (1): The Absorbance spectra of LR115 films pristine and irradiated with the α -particles for different times a) without etching b) with etching.



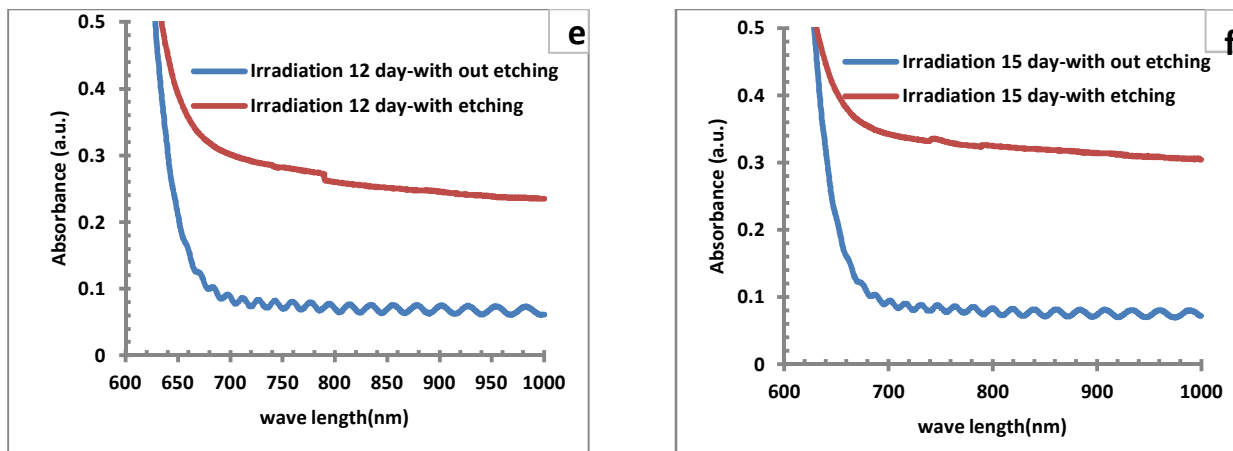
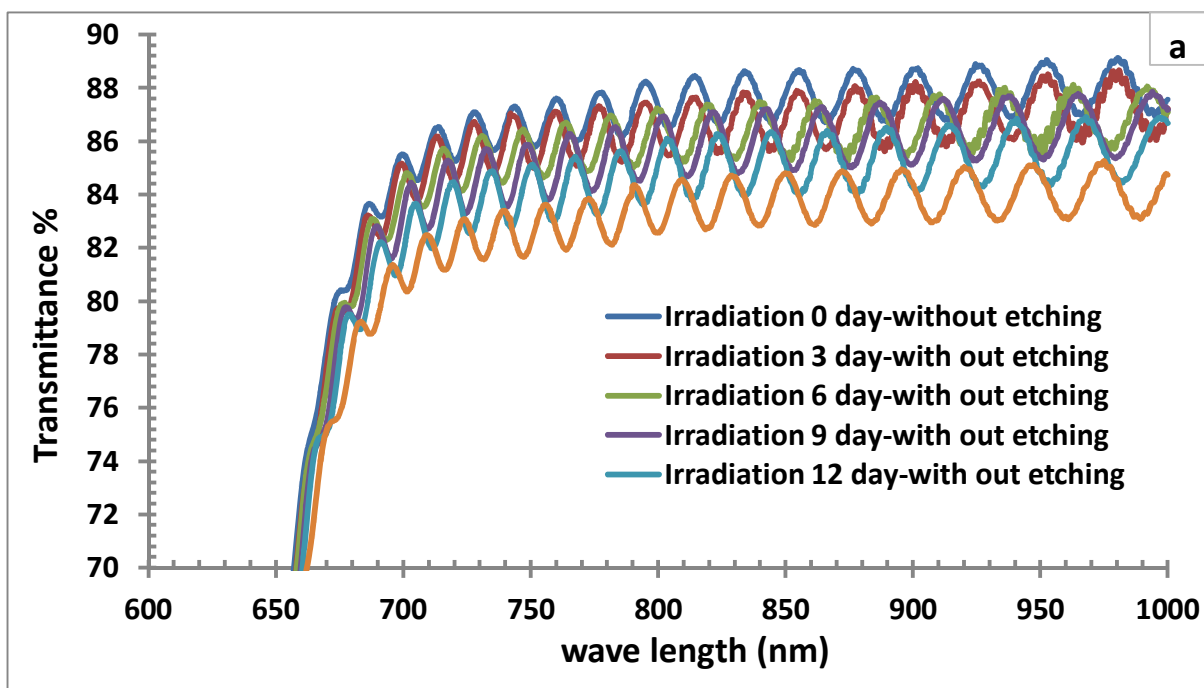


Fig. (2): Absorbance spectra of LR115 films with and without etching after irradiation with α - particles for different times a) not irradiation b) 3 days c) 6 days d) 9 days e) 12 days f) 15 days.



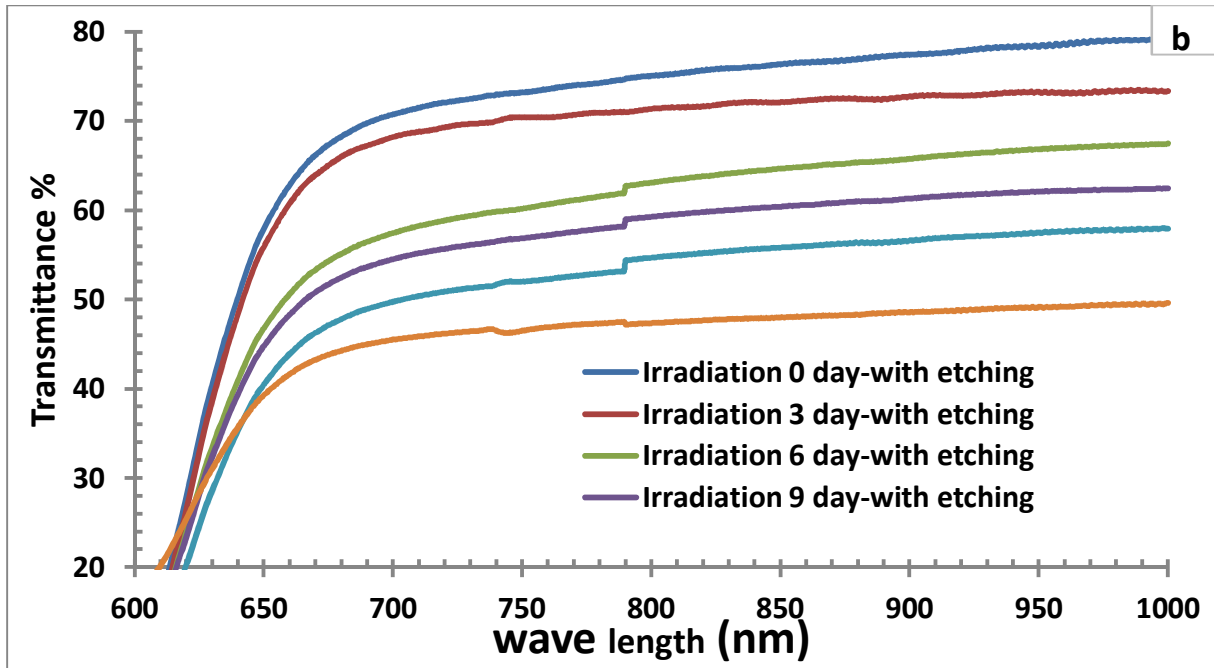
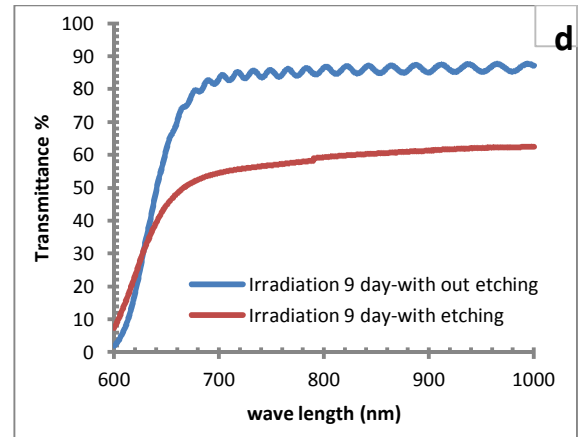
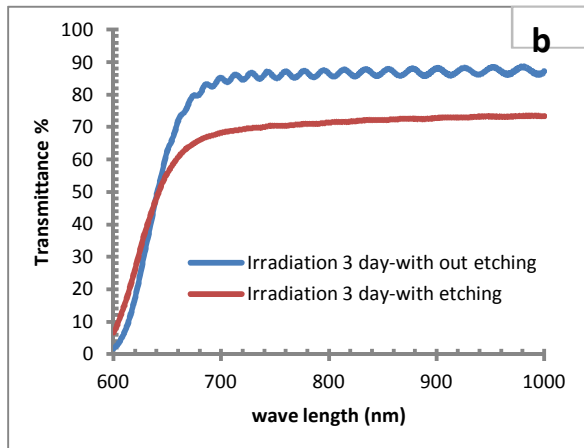
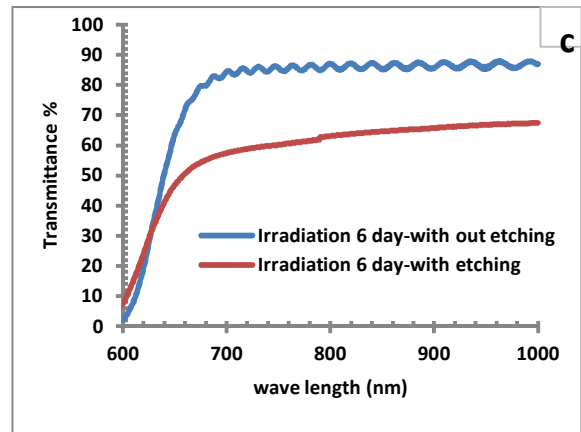
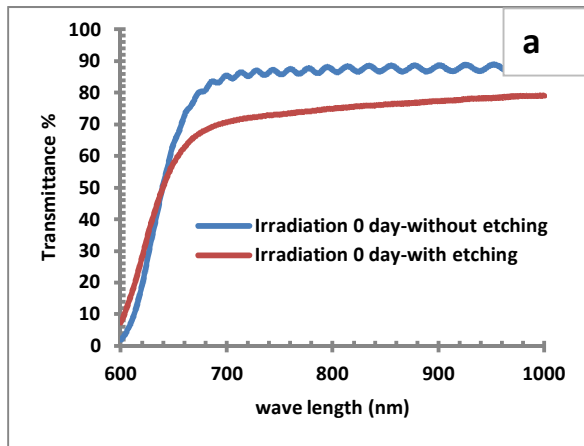


Fig. (3): The Transmittance spectra of LR15 films pristine and irradiated with the α -particles for different times a) without etching b) with etching.



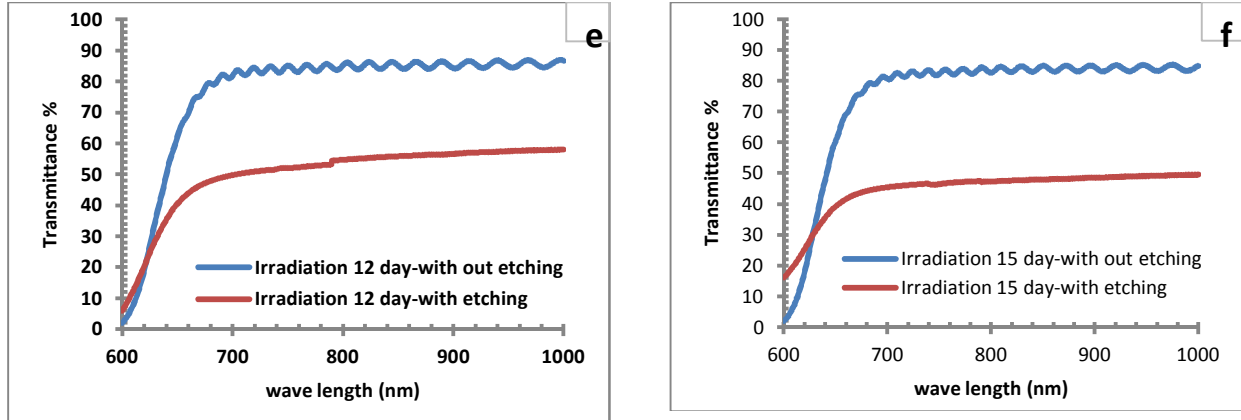
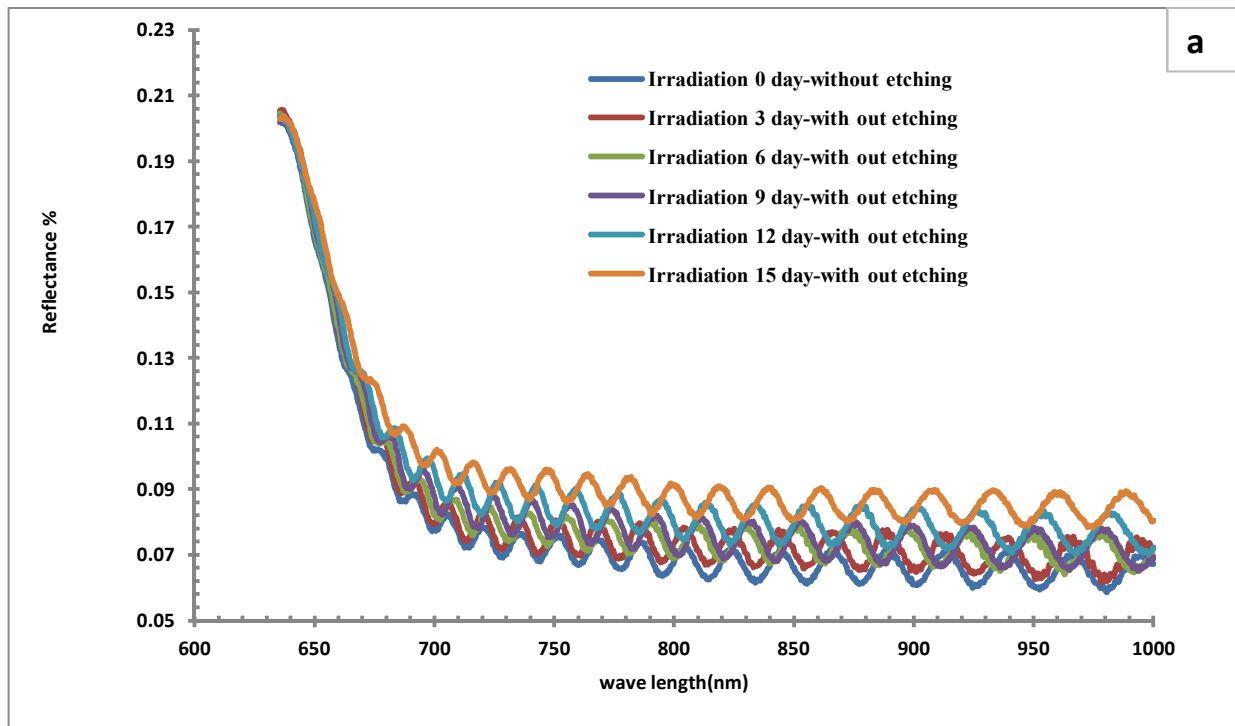


Fig. (4): Transmittance spectra of LR115 films with and without etching after irradiation with α - particles for different times a) not irradiation b) 3 days c) 6 days d) 9 days e) 12 days f) 15 days.



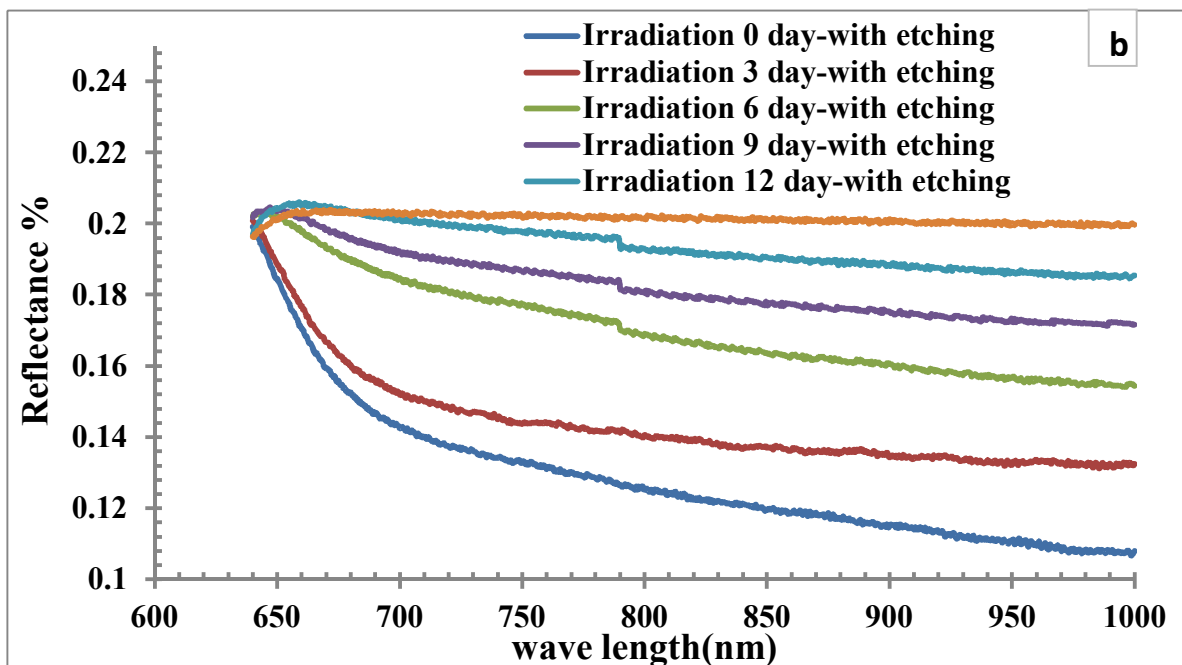
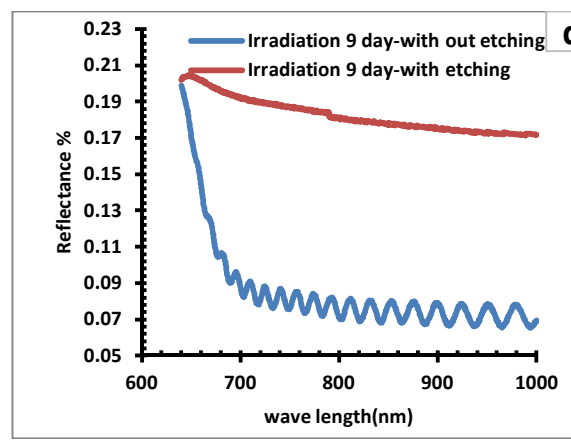
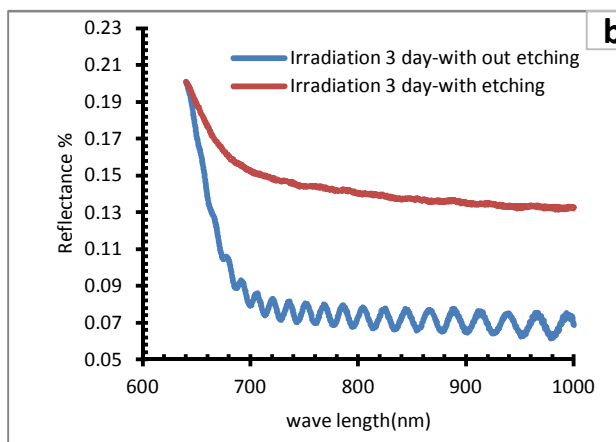
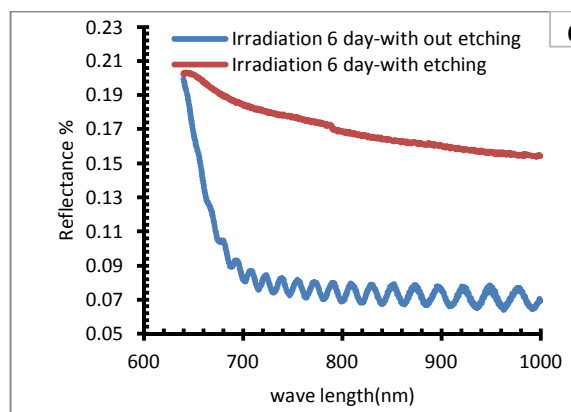
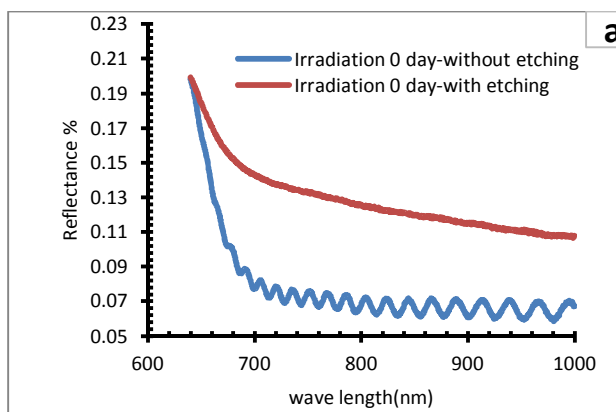


Fig. (5): The Reflectance spectra of LR115 films pristine and irradiated with the α -particles for different times a) without etching b) with etching.



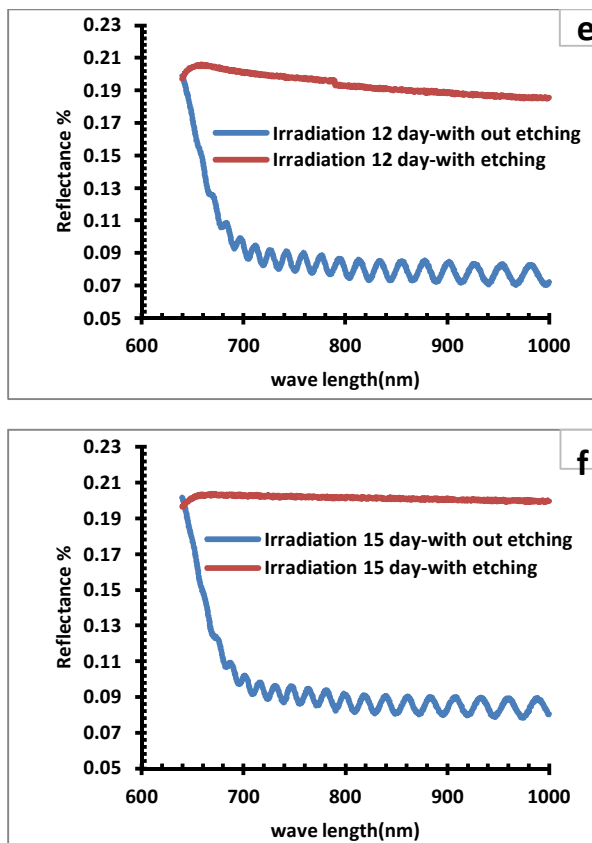


Fig. (6): Absorbance spectra of LR115 films with and without etching after irradiation with α -particles for different times a) not irradiation b) 3 days c) 6 days d) 9 days e) 12 days f) 15 days

3-2 The optical energy band gap (E_g)

The optical band gaps of pristine and various irradiated LR115 films (before and after etching) are determined from the UV/Visible spectra. The optical energy band gap E_g , can be obtained by applying the notation given by Tauc equation [21] as:

$$\alpha(h\nu) = B (h\nu - E_g)^n / h\nu \dots \dots \dots (2)$$

where α is the absorption coefficient, $h\nu$ is the energy of the incident photons, E_g is the value of the optical energy gap between the valence band and conduction band, B is the proportional constant and n is an index characterizes the electronics transition, whether it is direct or indirect during the absorption process in k -space. The index n can take the values $1/2$, $3/2$, 2 and 3 for direct allowed, direct forbidden, indirect allowed and indirect forbidden transitions respectively. The absorption coefficient α is calculated by using the following equation [4] ($\alpha = 2.303A/t$), where A is the absorbance and t is the thickness of the film in cm. Hence the electronics transitions are indirect because the absorption coefficient α values less than 10^4 cm^{-1} . The optical band gap is determined by plotting $(\alpha h\nu)^{1/2}$ versus the photon energy ($h\nu$). The

extrapolation of the straight parts of the curves to the energy axis ($h\nu$) yield indirect energy band gap for pristine and irradiated LR115 films with and without etching, as shown in figure (7), figure (8) and given in table (1). Figure (9) shows the relation between energy band gap E_g (with and without etching) for pristine and irradiated LR115 samples for various exposure time (3,6,9,12,15) days. We notice that the optical energy band gap E_g of LR115 films irradiated by alpha particles is less than that for un-irradiated (pristine) films, and it is slowly decreasing with increasing the irradiation times. The variation in the E_g value may be due to the formation of defects (radicals and organic species) after α -particles irradiation and/or the presence of carbon enriched clusters. Furthermore, the values of energy band gap for LR115 films etching with NaOH have are found to be lower than the corresponding values for the optical energy band gap of the not etching films as shown in table (1) which is illustrated in figure (9).

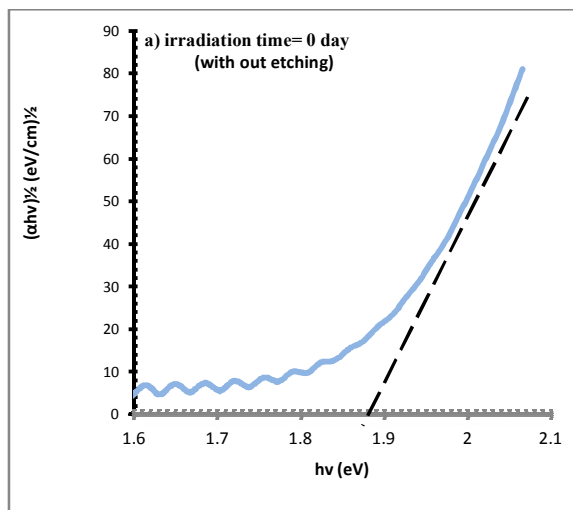
3-3 The number of Carbon atoms

The number of carbon atoms per conjugation length, N and the number of carbon atoms per cluster, M are important parameters that enhance the optical properties of the polymeric material. This is due to these parameters rich with charge carrier, which enhances the surface conductivity of the polymers. For a linear structure, N , is given by [22]:

$$N = 2\beta\pi/E_g \dots \dots \dots (3)$$

$\beta = -2.9 \text{ eV}$ as it is associated with $\pi-\pi^*$ optical transitions in $-C=C-$ structure. 2β gives the band structure energy of a pair of adjacent π sites. M , is given by [22]

$$M = [34.3/E_g]^2 \dots \dots \dots (4)$$



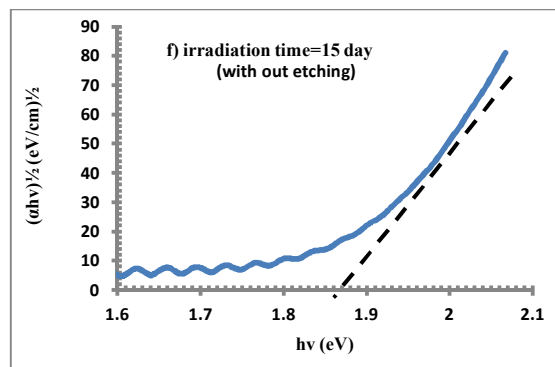
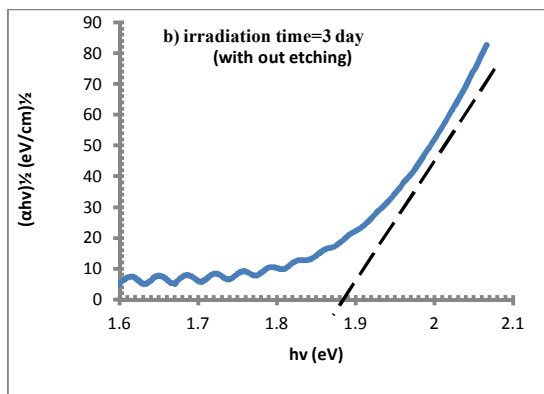
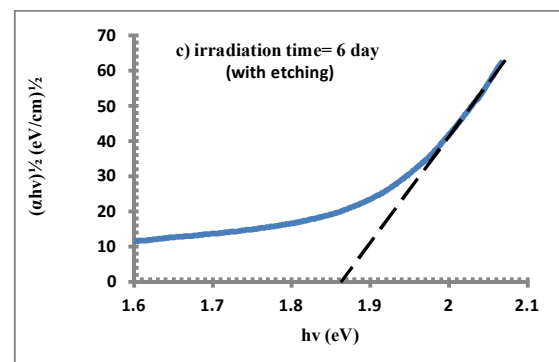
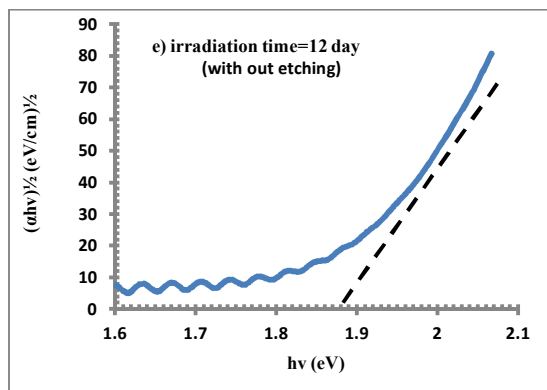
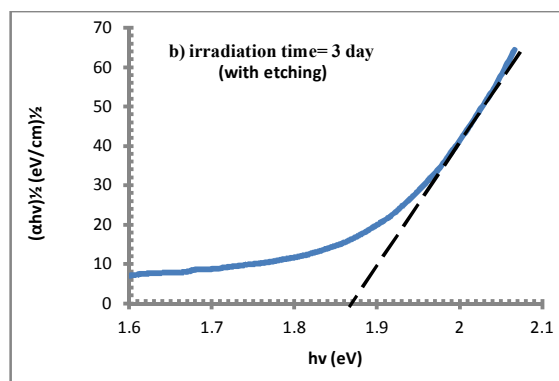
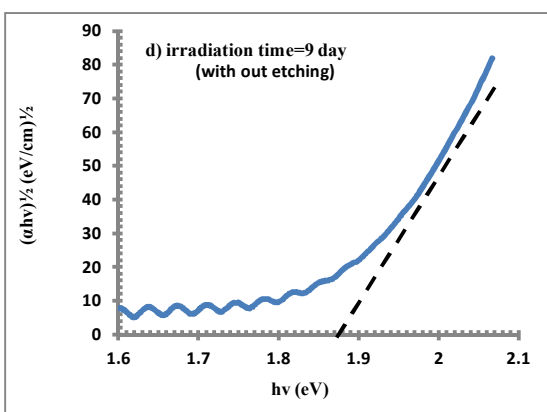
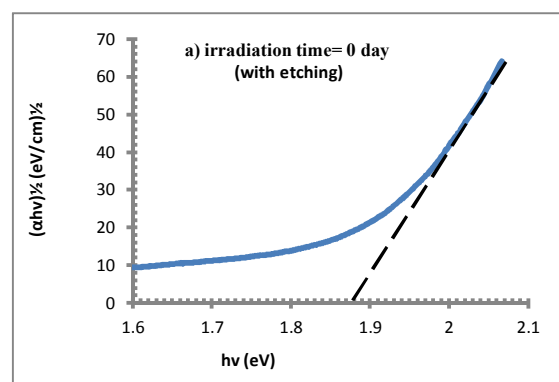
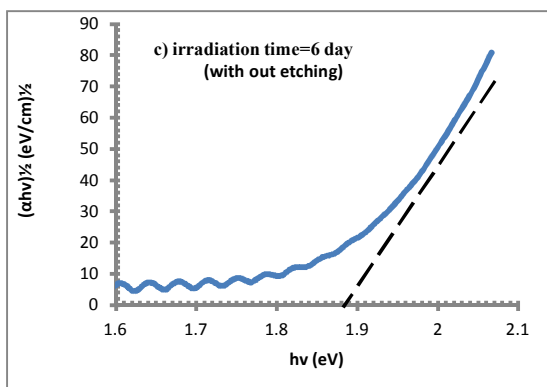


Fig. (7): The optical energy band gap of LR15 films without etching after irradiation with α -particles for different times a) not irradiation b) 3 days c) 6 days d) 9 days e) 12 days f) 15 days



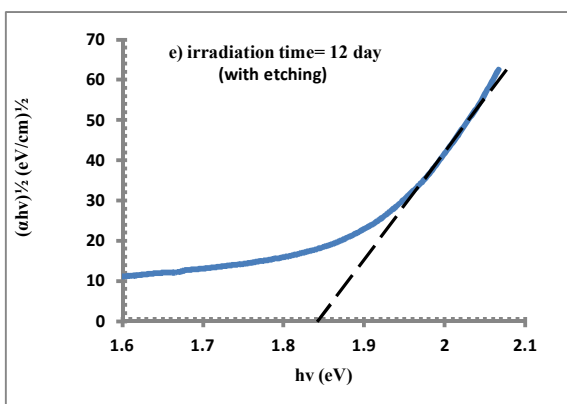
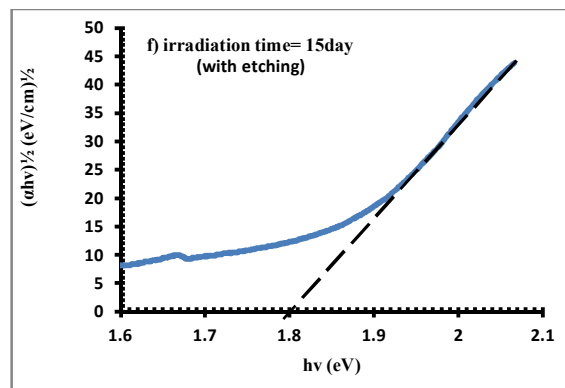
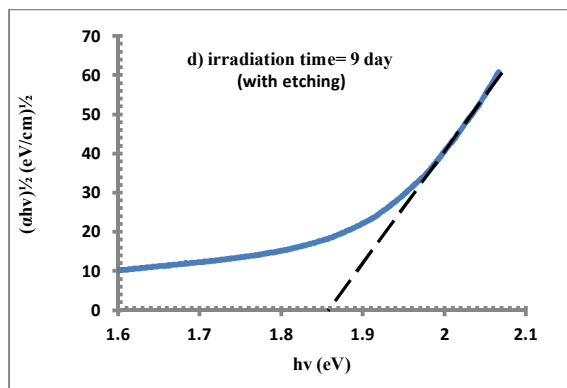


Fig. (8): The optical energy band gap of LR115 films with etching after irradiation with α - particles for different times a) not irradiation b) 3 days c) 6 days d) 9 days e) 12 days f) 15 days.

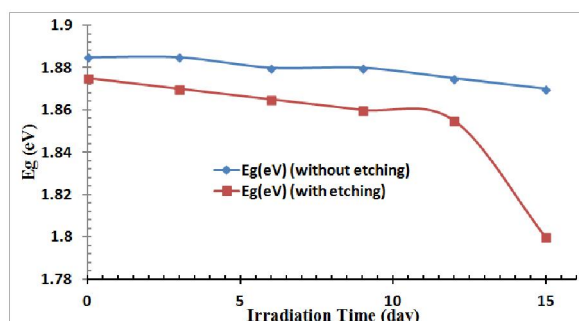


Fig. (9): The relation between optical energy band gap (E_g) and irradiation time by α -particles for (LR115) films before and after etching.

Table (1): The values of optical energy band gap (E_g) and number of carbon atoms M, N for LR115 films pristine and irradiated with α -particles for different times (before and after etching).

Irradiation Time (day)		0	3	6	9	12	15
parameter	etching						
	without etching	1.885	1.885	1.880	1.880	1.875	1.870
E_g (eV)	with etching	1.875	1.870	1.865	1.860	1.855	1.800
	without etching	331	331	333	333	335	336
M	with etching	335	336	338	340	342	363
	without etching	9.66	9.66	9.69	9.69	9.71	9.74
N	with etching	9.71	9.74	9.77	9.79	9.82	10.12

N and M values are calculated using optical energy band gap values which obtained by Tauc's equation (equation 2) and listed in table (1). It is clear that N and M values for the case of no etching LR115 films lower than that for etching films, and their values increase with increasing the irradiated α - dose.

This probably may attributed to cleavages of C-H bonds during the irradiation and, as a consequence, to the release of hydrogen, as hydrogen molecules cluster are supposed to be rich with charge carriers that enhances the optical properties in radiation bombarded

polymers and consequently they also influence the electrical conductivity of such materials [23].

4. Conclusions

In this work, the influence of the optical properties of LR115 have been investigated. The absorbance, transmittance and reflectance of LR115 films (with and without etching) for pristine and α -irradiation are measured. It is observed that the absorbance and reflectance increase with increasing dose (irradiation time) of α -particle. 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. Etching LR115 sample with 2.5N NaOH for 1hr. decreases energy band gap from 1.885 to 1.875 eV (for pristine sample). For the irradiated samples with α -particles for (0,3,6,9,12,15) days, the optical energy band gap E_g decrease from 1.885 to 1.870 eV before etching, while after etching the optical energy band gap decrease from (1.875 to 1.800)eV. This modification may be attributed to irregularities, concentration of weak bond in valence band tail, formation of defect and the formation of carbon clusters in the polymer due to the irradiation by alpha rays. The number of carbon atoms per conjugate length N and the number of carbon atoms per clusters M are found to be increase, with increasing α -irradiation dose.

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