

## Effect of UV–radiation on physical properties for CR-39 detector

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Received  
22 / 03 / 2010

Accepted  
14 / 09 / 2010

### المخلص

تم في هذا البحث دراسة تأثير الأشعة فوق البنفسجية على الخواص الفيزيائية (الامتصاص البصري) للكاشف CR-39 لآزمان تشعيع مختلفة من 2hr الى 11hr بواسطة مطياف الأشعة فوق البنفسجية. العينات المشععة بواسطة هذه الاشعة لها طيف امتصاص البصري طول هالموجي ما بين (190-1110) nm. بالقرب من 314-316 nm كان هنالك اعلى حالة امتصاص. من خلال طيف الأشعة فوق البنفسجية تم ملاحظة تغير في حافة الامتصاص عند الأطوال الموجية العالية، وكذلك تباين فجوة الطاقة ( $E_g$ ) باستخدام معادلة ايرياج. من الجدير بالاهتمام فجوة الطاقة غير المباشرة اقل من قيمة فجوة الطاقة المباشرة وإن كلاهما تزداد بزيادة جرعة الأشعة فوق البنفسجية. كما تم حساب عدد ذرات الكاربون (N) بالاعتماد على كل من فجوتي الطاقة المباشرة وغير المباشرة حسب المعادلة (٤). طاقة التنشيط للالكترونون، ( $E_u$ ) طاقة ايرياج، تتناقص مع زيادة جرعة الاشعة فوق البنفسجية.

### Abstract

In this work, several pieces of CR-39 detector were irradiated by UV radiation in order to study their physical characteristics. A UV spectrometer was utilized to read radiation coming out of the CR-39 detectors., and obtain their optical absorption. It was realized that the optical absorption wave length range was between 190-1110 nm. Near 314-316 nm at the absorption peak, a UV spectrum change was observed in which there was an energy gap ( $E_g$ ) variation which was confirmed by the Urbach equation. It was interesting to notice that the indirect energy gap value was less than that of

the direct gap value. Both direct and indirect energy gaps do increase with increasing dose of UV radiation. The number of carbon atoms (N) was calculated depending on direct and indirect energy gaps return to the equation (4). It was also observed that the excitation electron, Urbach energy ( $E_u$ ), do actually decrease when UV radiation dose is increased.

## **1. Intruduction**

The absorption coefficient near the band edge for non-crystalline materials shows an exponential dependence on the photon energy (Urbach, 1953). The different batches of CR-39 were irradiated with various Ultraviolet (UV) sources and an excimer laser ( $\lambda=308$ ) and the visible change of color of defects under heavy dose appeared in both case studied by (Aburjared *et al*, 2000). The optical absorption coefficient ( $\alpha$ ) was calculated from the absorbance (A) Studied by (Mark, 2001). (Bozhko *et al*, 2002) found Urbach energy depend on the temperature which was generated from the band and the type material. The origin of  $E_u$  is considered as thermal vibrations in the lattice (Migahed & Zidan, 2006). The effect of annealing in the optical absorbance of PM-355 nuclear track detector radiated by alpha particale studied from (Sulaiman, 2006). (Shamra *et at*, 2007) found the effect of gamma radiation on optical properties of CR-39 polymer with various dose (20-800 kGray) and determined the values of indirect and direct for band energy gap. (Zaki, 2008) used gamma radiation to irradiate CR-39 and he found the optical band gap (direct and indirect) decreased with photon energy. The number of carbon atom and Urbach energy was determined. (Tse *et al*, 2008) studied the effect of UVC exposure on alpha- particle track parameter in CR-39 and find the track diameters and depths were used to drive a V function for CR-39 detector with and with out UV-radiation (Ramola *et al*, 2008) modified the optical band gap, carbonaious cluster and structure in CR-39 and PET polymers irradiated by 100 MeV  $O_{7+}$  ions and found the UV-visible show the shift in the absorption edge towards the higher wave length indicating the change in band gap (Kumar *et al*, 2009) studied the effect of neutron radiation with optical properties of CR-39. He found the band energy gap for two case direct and indirect which was decreased with increased the fluences of neutron radiation and determined the Urbach energy, number of carbon atom. (Prasher *et al*, 2009) deals with the changes induced to CR-39 and PET polymers by IR irradiation. The modifications induced in the polymers due to IR irradiation have been analyzed with the help of XRD and UV-visible spectra of the pristine and IR irradiated polymers.

In the present work, we report the effect of UV- radiations on the UV-VIS spectra of CR-39 plastic track detector as the spectroscopic studies. Also we investigated the behaviours of band gap and Urbach energy with

increasing UV dose. The simultaneous existence of indirect and direct band gap in CR-39 polymer and the number of carbon atoms (N) in a cluster are also reported.

## 2. Experimental Procedure

CR-39 samples of thickness 250  $\mu\text{m}$ , type TASTRAK (Track Analysis System Ltd., UK) (composition  $\text{C}_{12}\text{H}_{18}\text{O}_7$ , molecular weight 274 a.m.u., density 1.32  $\text{g}/\text{cm}^3$ ), were irradiated with different UV – radiation doses at 4 cm from the UV source has wave length 254 nm.

The nature of the optical modifications of the UV- irradiated CR-39 polymer samples were subjected to spectral studies in the Ultraviolet and Visible region. These studies were carried out by using TECHCOMP Double beam Double monochromator UV-Visible Spectrophotometer (UV–VIS 8500) in the wavelength range of 190–1110 nm having resolution of 0.1 nm (Zaki, 2008). All the spectra were recorded by mounting the samples in the Integrating Sphere Assembly attached with the Spectrophotometer, keeping air as the reference.

## 3. Results and Discussion

From these spectra, displayed in Fig. 1, it is clear that a shift of absorption edge towards longer wavelength with increasing UV- absorbed dose can be readily observed. The absorption peak with increasing dose 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 the  $\pi$ – $\pi^*$  electronic transitions. This type of transitions occurs in the unsaturated centers of the molecules i.e. in compounds containing double or triple bonds and also in aromatics. The excitation of  $\pi$  electron requires smaller energy and hence, transition of this type occurs at longer wavelengths. (Zaki, 2008).

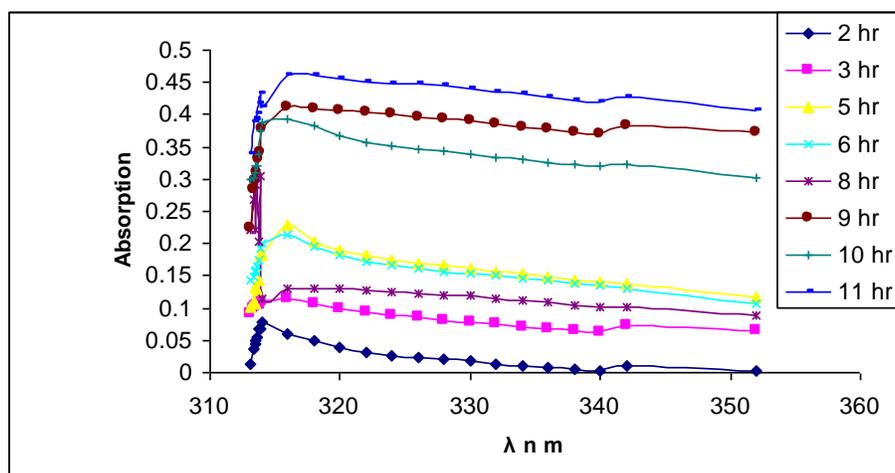


Fig. 1: UV–visible spectra of the UV -irradiated CR-39

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The optical absorption coefficient ( $\alpha$ ) was calculated from the absorbance, (A). After correction for reflection losses, may be obtained using the following equation (Mark,2001)

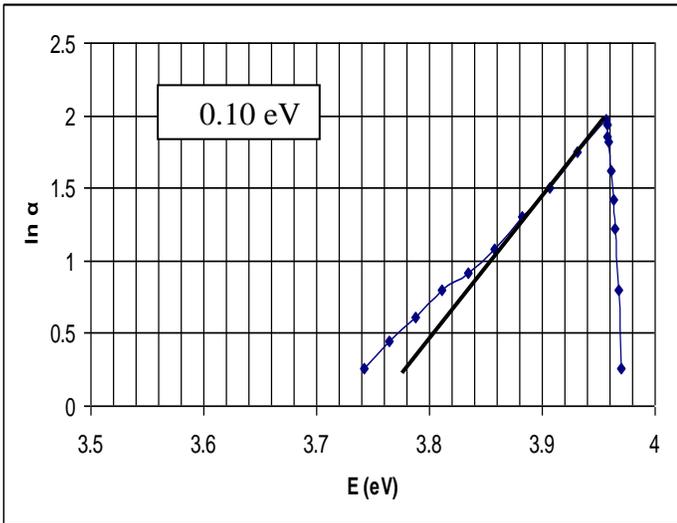
$$\alpha(\nu) = 2.303A/t \dots\dots\dots (1)$$

where  $t$  is the sample thickness in cm and  $A$  is defined by  $A = \log(I_0/I)$  where  $I_0$  and  $I$  are the intensity of the incident and transmitted beams, respectively. The absorption coefficient near the band edge for non-crystalline materials shows an exponential dependence on the photon energy ( $h\nu$ ) which follows the Urbach formula (Urbach,1953)

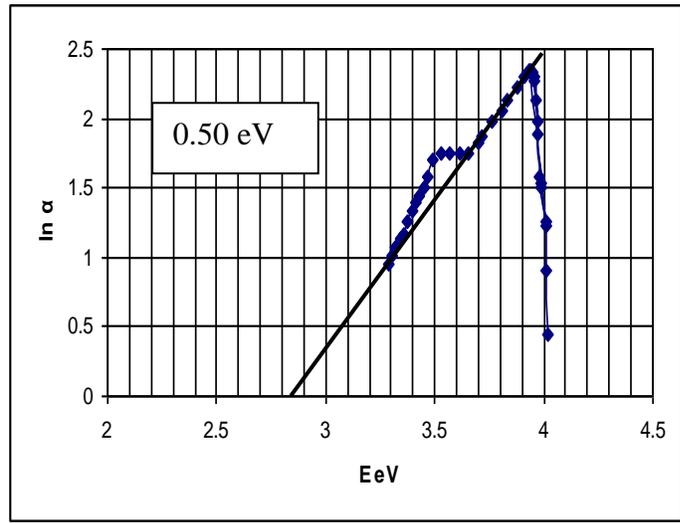
$$\alpha(\nu) = \alpha_o \exp(h\nu/E_u) \dots\dots\dots(2)$$

where  $\alpha_o$  is a constant,  $E_u$  is called Urbach energy which is interpreted as the width of the tail of localized states in the forbidden band gap,  $\nu$  is the frequency of radiation and  $h$  is Planck's constant.(Migahed & Zidan,2006)The logarithm of the absorption coefficient  $\alpha(\nu)$  was plotted as a function of the ( $h\nu$ ) for CR-39 irradiated with different doses of UV – radiation as in Fig.(2 : a,b,c,d,e,f,g,h).

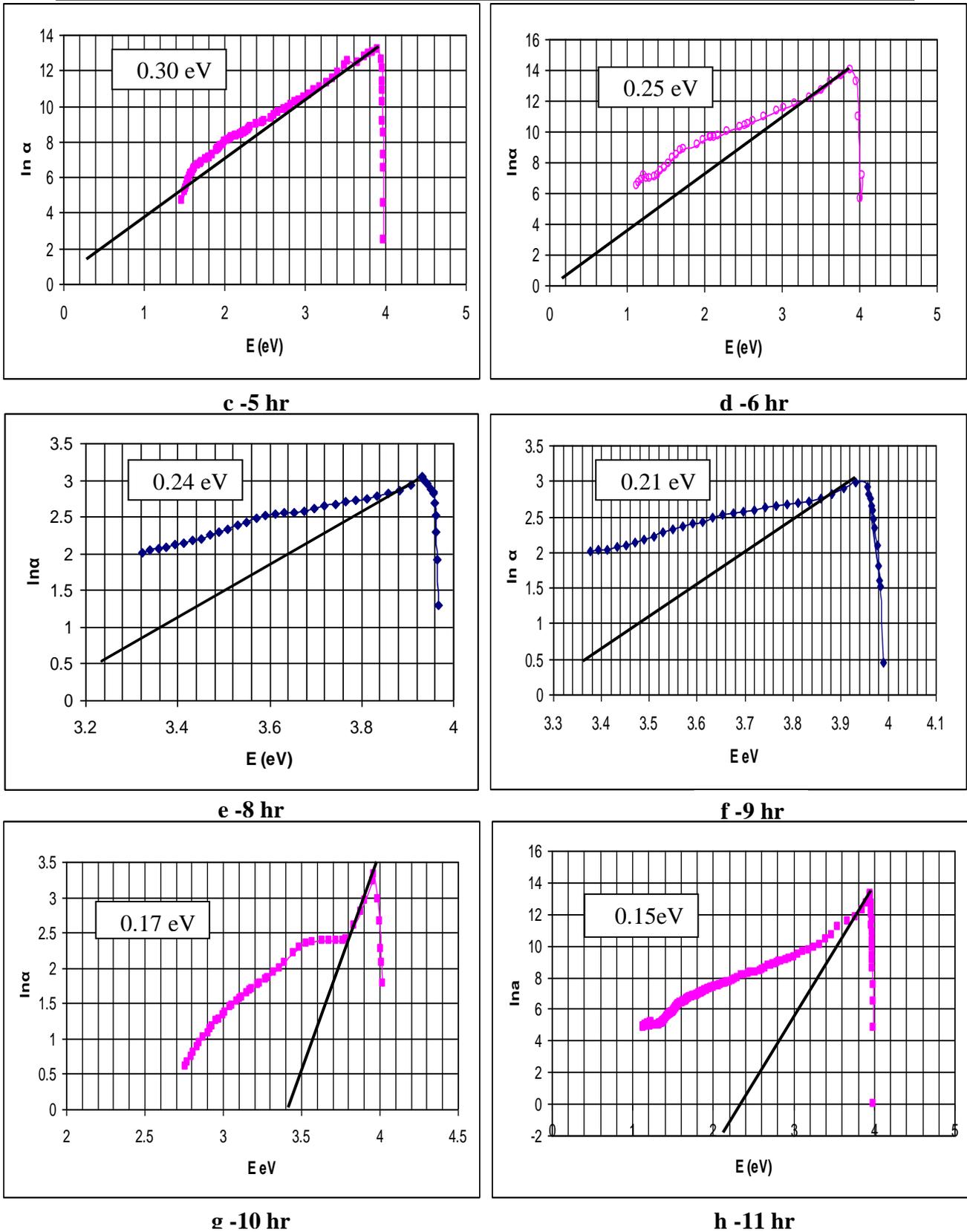
The values of the energy ( $E_u$ ) were calculated by taking the reciprocal of the slopes of the linear portion in the lower photon energy region of these curves and listed in Table 1. The decrease in the Urbach's energy in case of CR-39 may be due to the decrease in the crystalline nature of the polymer (Kumar *et al*,2009).



**a -2 hr**



**b -3 hr**



**Fig. 2: Urbach energy for CR-39 which was irradiated with UV-radiation for a- 2 hr, b-3 hr, c 5 hr, d- 6 hr, e – 8 hr, f- 9 hr g, -10 hr, h- 11 hr**

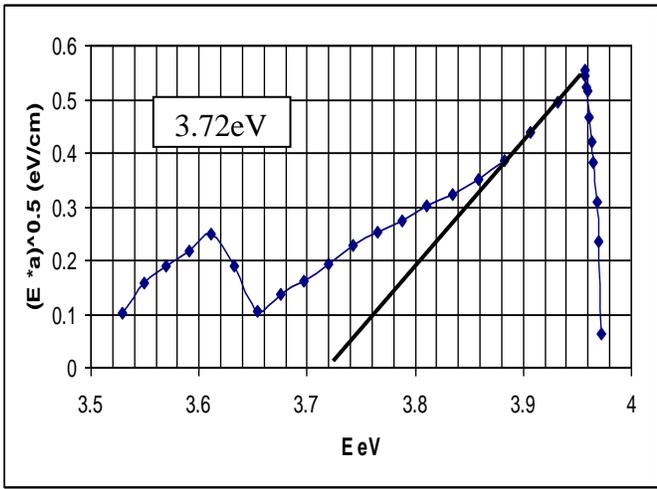
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The above relation was first proposed by Urbach (Urbach,1953) to describe the absorption edge in alkali halide crystals. Also, this relation has been found to hold for many amorphous materials. Eq. (2) has been modified to a more general form by (Sulaiman,2006)

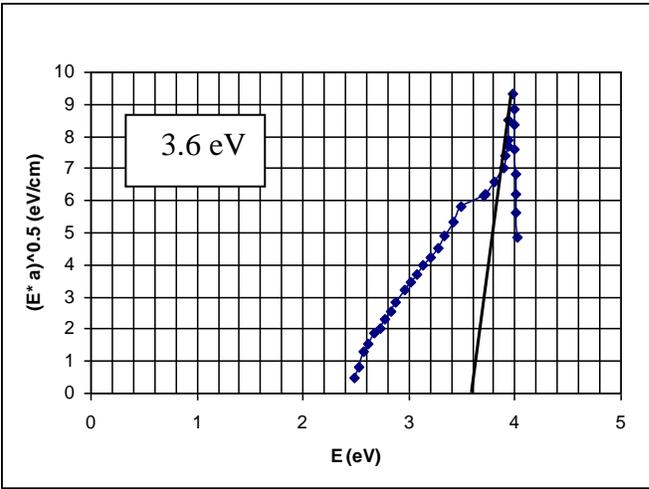
$$\alpha \cdot hv = B (hv - E_g)^n \dots\dots\dots (3)$$

where  $hv$  is the energy of the incident photons, energy gap ( $E_g$ ) is the value of the optical energy gap between the valence band and the conduction band, and  $n$  is the power, which characterizes the electronic transition, whether it is direct or indirect during the absorption process in the K-space. Specially,  $n$  is 1/2, 3/2, 2 and 3 for direct allowed, direct forbidden, indirect allowed and indirect forbidden transitions, respectively

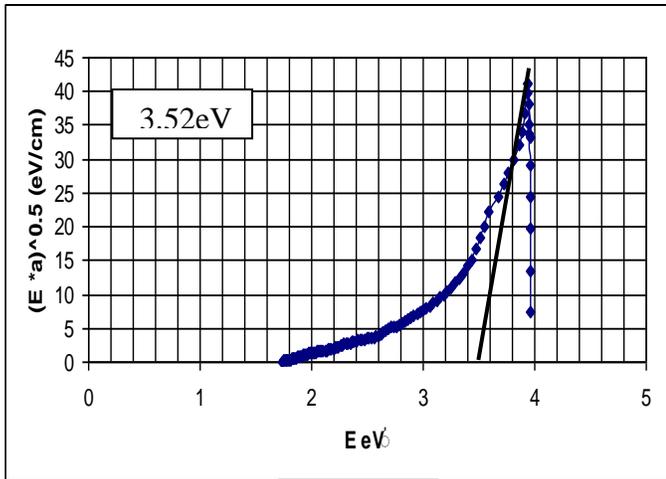
The factor  $B$  depends on the transition probability and can be assumed to be constant within the optical frequency range. The usual method for the determination of the value of  $E_g$  involves plotting  $(\alpha hv)^{1/n}$  against  $(hv)$ . Indirect transitions in many amorphous materials fit the case for  $n = 2$ ; for a direct transition a reasonable fit with  $n = 1/2$  is achieved. In the present study the most satisfactory results were obtained by plotting  $(\alpha hv)^{1/2}$  and  $(\alpha hv)^2$  as a function of photon energy ( $hv$ ) respectively, taking into account the linear portion of the fundamental absorption edge of the UV-Visible spectra (shown in Fig. 1). Such plots have been presented in Figs. (3:a,b,c,d,e,f,g,h) and (4:a-b-c-d-e-f-g-h), respectively. From extrapolating the straight parts of these relations to the  $hv$  axis, indirect and direct band gaps have been determined for UV irradiated (different doses) CR-39 polymer and these different transition energies are displayed in Figs (3:a,b,c,d,e,f,g,h,4:a,b,c,d,e,f,g,h) and depicted in Table 1. This, in turn, clearly indicates the simultaneous existence of indirect and direct band gap in CR-39 polymer with decreasing tendency at higher UV-radiation dose. This result confirms that the irradiation produces faults in CR-39 polymer 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 (Zaki,2008).



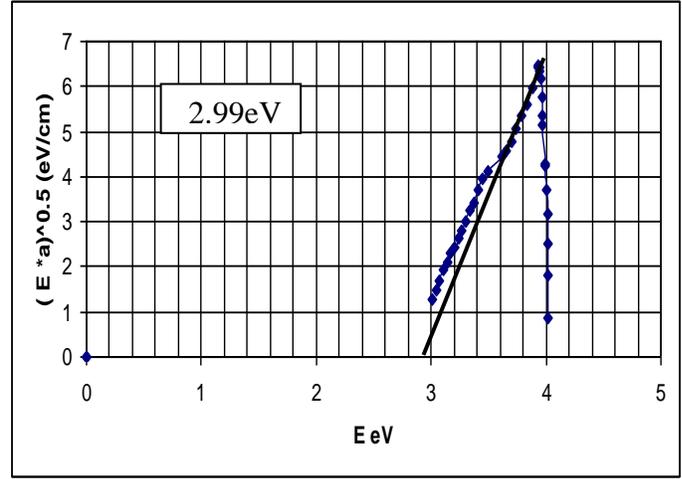
**a -2 hr**



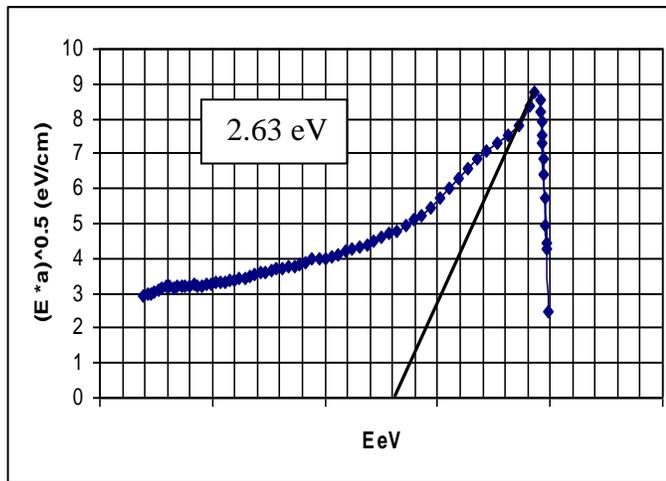
**b -3 hr**



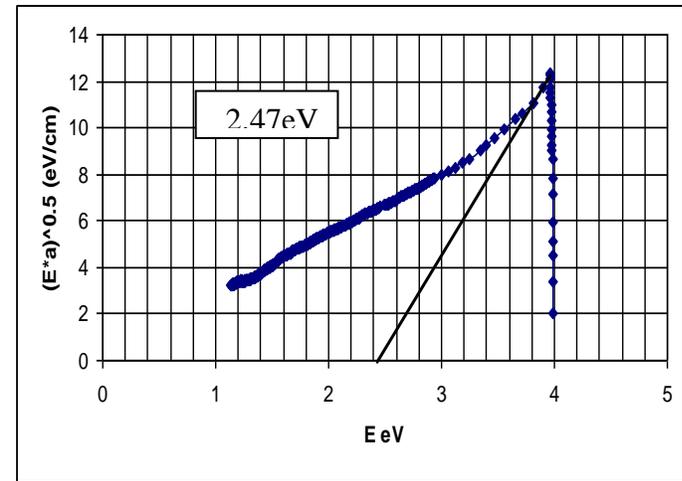
c -5 hr



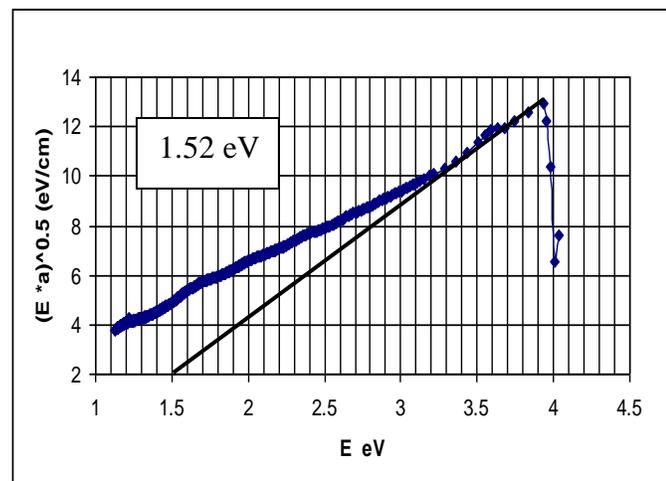
d -6 hr



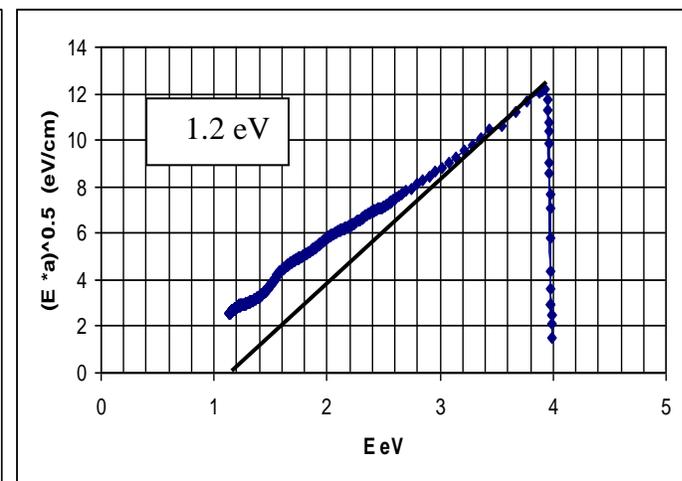
e - 8 hr



f - 9 hr



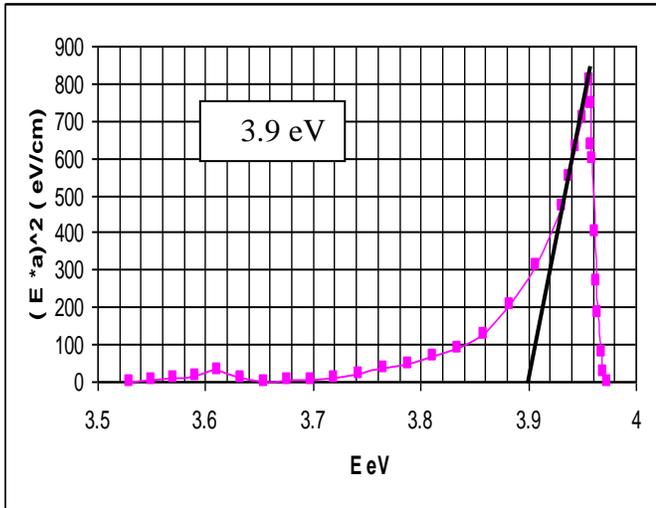
g- 10 hr



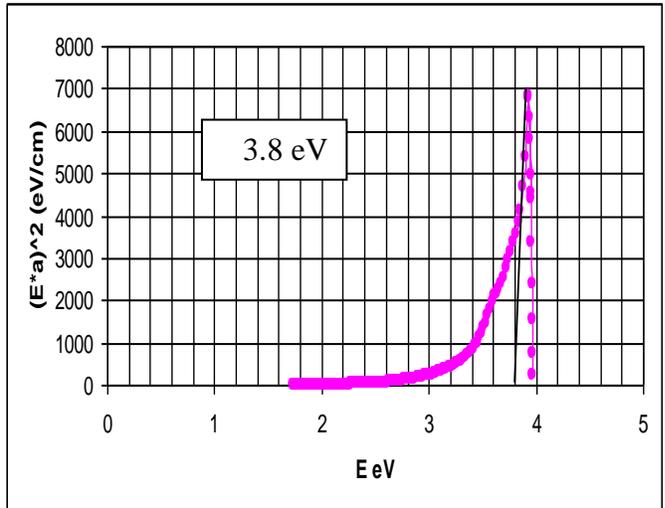
h- 11 hr

Fig.3: indirect energy gap for CR-39 which was irradiated with UV-radiation for a- 2 hr, b- 3 hr, c- 5 hr, d -6 hr, e- 8 hr, f- 9 hr, g- 10 hr, h-11 hr

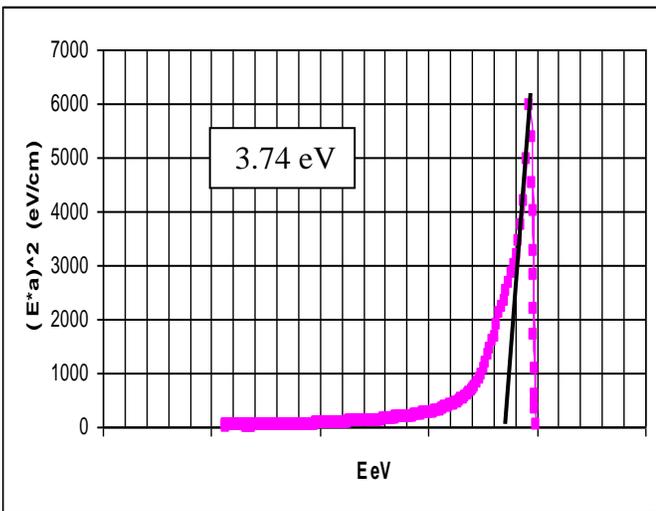
**Effect of UV-radiation on physical properties for CR-39 detector.**



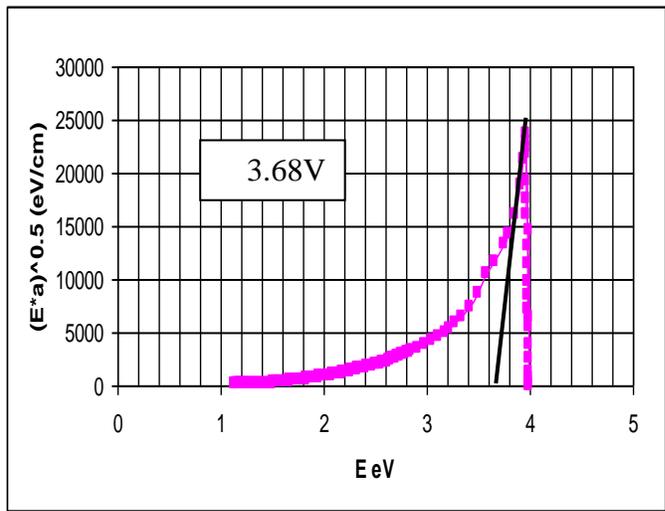
**a -2 hr**



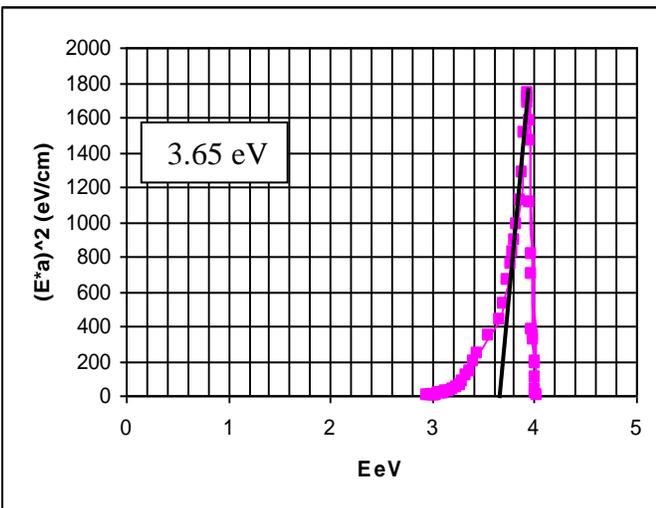
**b -3 hr**



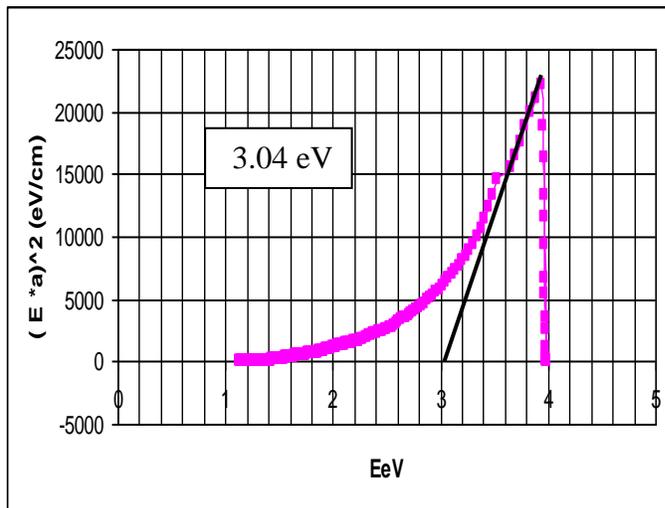
**c -5 hr**



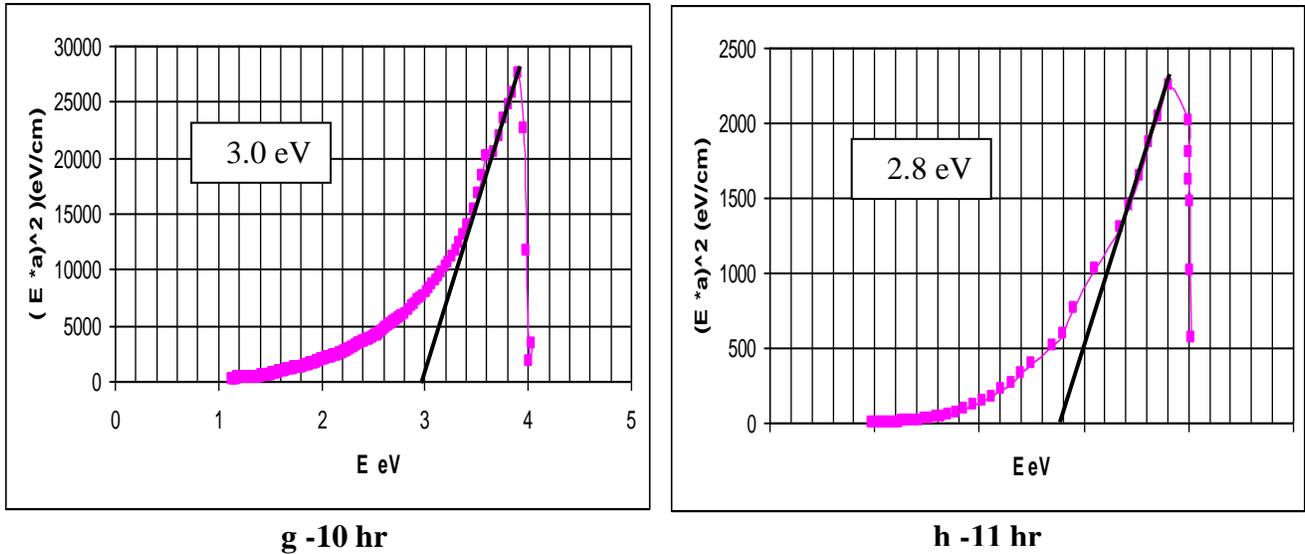
**d -6 hr**



**e -8 hr**



**f -9 hr**



**Fig.4: direct energy gap for CR-39 which was irradiated with UV-radiation for a-2 hr, b- 3 hr, c- 5 hr, d-6 hr, e- 8 hr, f- 9 hr, g- 10 hr, h-11 hr**

Furthermore, the values of indirect band gap have been found to be lower than the corresponding values for the direct band gap as shown in Figs(3,4). The simultaneous existence of indirect as well as direct band gap in CR-39 polymer has rarely been reported (Migahed & Zidan,2006), although such a coexistence of direct and indirect band gap have been observed in some other materials (Tanu *et al*,2007)

The number of carbon atoms per conjugation length  $N$  is given by (Zaki,2008) (Kumar et al,2009)

$$N = 2\beta \pi / E_g \dots\dots\dots (4)$$

Here  $2\beta$  gives the band structure energy of a pair of adjacent  $\pi$  sites. The value of  $\beta$  is taken to be  $\sim 2.9$  eV as it is associated with  $\pi \rightarrow \pi^*$  optical transitions in  $-C = C-$  structure. As the shift of the absorption edge can be attributed to an increase of the conjugation length without formation of new lengthy linear conjugated structures, Eq. (4) is applied in the present study.

Finally the exposure time of CR-39 irradiated with UV-radiation has converted to radiation dose by multiplying with converter factor (9.524  $\text{erq/mm}^2.\text{sec}$ ) which was used from (AL-Jomaily,2009) for the same wave length of UV-radiation in this work. and fixed in Table 1.

When the UV- radiation was striking CR-39 detector, the heat generated from this processing more than heat generated if IR radiation passed from the same detector for the same case because high absorption edge obtained at wave length of UV-radiation (254 nm) which was corresponding to the band structure energy of band pair of carbon  $-c=c-$  ~

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2.9 eV, Thus the Urbach energy was determined in this work near to the Urbach energy computed in previous study spically (Prasher *et al*,2009 ((Zaki,2008) as shwn in (Table.2) because the Urbach energy depend on the heat generated from the band and the type of impure material in base material (Bozhko *et al*,2002).

**Table 1. Computing UV-radiation dose, Band energy gap (eV), Urbach energy (eV) and N (number of carbon atom)**

UV exposure time/hr	UV-radiation dose (erq/mm <sup>2</sup> )	Band energy gap (eV)		Urbach energy (eV)	N (number of carbon atom per conjugation length)	
		indirect	direct		indirect	direct
2	68572.8	3.72	3.9	0.10	~ 5	~ 5
3	102859.2	3.6	3.8	0.50	~ 6	~ 5
5	171432	3.52	3.74	0.30	~ 6	~ 5
6	205718.4	2.99	3.68	0.25	~ 7	~ 5
8	274291.2	2.63	3.65	0.24	~ 8	~ 6
9	308577.6	2.47	3.04	0.21	~ 8	~ 6
10	342864	1.52	3.0	0.17	~ 12	~ 7
11	377150.4	1.2	2.8	0.15	~ 16	~ 7

**Table 2. Comparative present work with previous studies.**

Researcher	Detector	Radiation	Urbach energy eV	Band energy gap eV		N(number of carbon atom)	
				direct	indirect	direct	indirect
Singh& Samra,2007	CR-39	Proton	.....	4.36-3.15	.....	5	.....
Ramola <i>et al</i> ,2008	CR-39	Neutron	0.74-0.29	3.42-1.35	4.90-2.30	4-8	5-13
Prasher <i>et al</i> ,2009	CR-39	IR	0.42-0.27	5.2-2.30	.....		.....
Zaki,2008	CR-39	Gamma- ray	0.61-0.53	4.2-2.7	3.6-1.9	4-7	5-9
Present (Work,2010)	CR-39	UV - radiation	0.5- 0.10	3.9 – 2.8	3.72 – 1.2	5-7	5-16

The Urbach’s energy sharply decreasing with increasing UV-radiation dose as Fig. 5.This sharp decrease indicates the irregularization of the band gap energy level; furthermore this is due to amorphous nature of CR-39 polymer. The decrease in band gap energy attributes to the decrease in the resistivity of CR-39. This means that there is change in the structural characteristics of CR-39 as a result of UV- irradiation (Kumar *et al*,2009). It may accounts for the scission of the polymer chain and formation of free radicals.

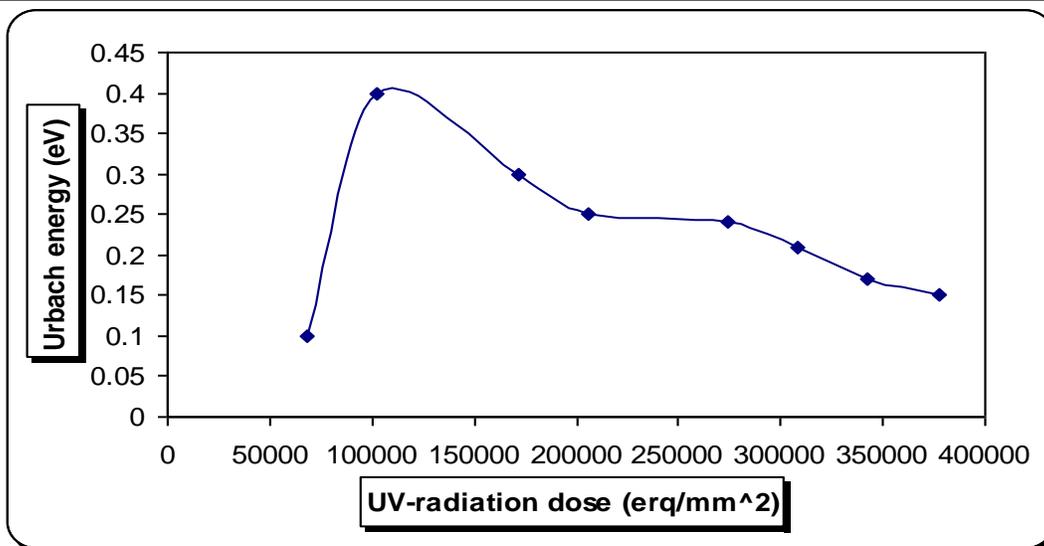


Fig. 5 :Calibration curve between Urbach energy (eV) with UV-radiation dose (erq/mm<sup>2</sup>)

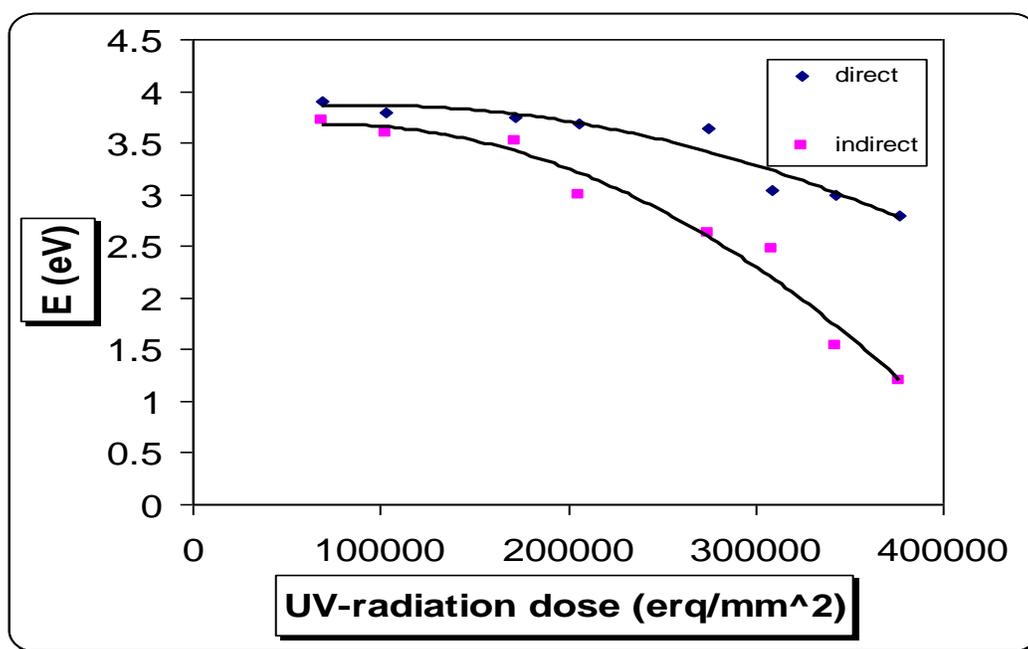


Fig. 6: Calibration curve between band energy (eV) with UV-radiation dose (erq/mm<sup>2</sup>)

It is observed that there is a decreasing trend of energy gap with increasing UV-radiation dose Fig.6.

This is due to the carbon enriched domains created in polymers during irradiation. In the studied range of wavelength the absorption bands are associated with  $\pi \rightarrow \pi^*$  electronic transition. The excitation of  $\pi$  electron requires smaller energy and hence, transition of this type occurs at longer

wavelength. In the high absorption region where absorption is associated with interband transition (Zaki,2008) (Kumar *et al*,2009).

### **Conclusion**

- 1- increasing UV-radiation dose lead to decreasing the direct and indirect of energy gap for CR-39 detector, Thus the electrical conductivity ( $\sigma$ ) increase.
- 2- The atomic number (N) for CR-39 increase with increasing UV-radiation dose.
- 3- The crystalline structure of CR-39 detector was changing with increasing UV-radiation dose because to the physical and chemical properties had changed.
- 4- The Urbach's energy ( $E_u$ ), excitation energy of electron, sharply decreasing with increasing UV-radiation dose.

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