EG0700556
Gamma Irradiation Induced Effect on the Optical Parameters of Cu_{10}Se_{90} Thin Films

A. Abu EL-Fadla, M. M. Hafiza, M. M. Wakaadb and A. S. Aashoura

a- Physics Department, Faculty of Science, Assiut University, Assiut 71516, Egypt
b- Physics Department, Sohag Faculty of Science, South Valley University, Sohag, Egypt
E-mail: abulfadl@acc.aun.edu.eg

ABSTRACT

The optical constants of Cu_{10}Se_{90} Chalcogenide films successfully deposited by evaporation coating technique have been measured. The absorption coefficient ($\alpha$) for the as-deposited or after being $\gamma$-irradiation at various doses have been computed in the spectral wavelength range 400–900 nm from the transmittance (T) and reflectance (R) measurements of normally-incident light. Both irradiated and as-prepared films showed direct transition. The direct optical band gaps of the films were found to decrease from 2.017 for as prepared to 1.941 eV for $\gamma$-irradiation at 190 krad doses. The width of the tails of localized states $E_e$ were calculated and found to be increasing after $\gamma$-irradiation. The effects of the $\gamma$-irradiation on the refractive index $n$ and extinction coefficient $k$ were studied. Other optical parameters ($\varepsilon_1$, $\varepsilon_2$) were calculated at different $\gamma$-irradiation doses the obtained values of both $\varepsilon_1$ and $\varepsilon_2$ were found to be incident light and $\gamma$-doses dependent. The effect of $\gamma$-irradiation on the high-frequency dielectric constant ($\varepsilon_\infty$) and carrier concentration (N/m$^3$) is also studied. The change on the degree of disorder as well as the radiation-induced defect changes applied to explain the radiation effects on nature of optical properties Cu_{10}Se_{90} glasses.

Keywords: thin films, chalcogenide glasses, optical constants, $\gamma$-irradiation

INTRODUCTION

Thin films of Chalcogenide glasses having a semiconductor nature have been extensively studied during the past few years for their technical interest in the field of electronics and electro-optical devices. Attempts have been made to produce stable glasses, which have good photosensitive properties so that they may be used in various solid-state devices (1-3). The interest for copper selenides semiconducting thin films is motivated by their application in optical filters and in solar cell technology. In recent years, there has been considerable interest in the study of Cu-Se semiconductor metal compounds, due to their wide applications in various photoelectric and optical filters, solar cell technology and in other kinds of devices (4-6). Selenides of copper with different compositions, stoichiometric ($\alpha$-Cu$_2$Se, Cu$_3$Se$_2$, CuSe and CuSe$_2$) and non stoichiometric (Cu$_2$Se) are well reported (7). Current research efforts are directed towards a precursor material from which solar cell grade CuInSe$_2$ can be produced. It was reported that Cu-In-Ga-Se mixture prepared by electrodoposition technique produced solar cells with conversion coefficients of 13.7% (8).

Amorphous chalcogenide films are interesting first of all due to irradiation induced changes of their optical properties that occur under $\gamma$-irradiation and can be used for optical recording and for fabrication of optoelectronic elements. In well irradiation films these changes are known to be reversible with irradiation reversible optical changes were found in these materials under irradiation.
by fast electrons and γ-rays\(^{(9,10)}\). In the case of γ-irradiation significant recovery of optical properties occurs even at room temperature.

It is well-known that the exposure of solid materials to γ-rays induces structural defects known as colour centres. The presence of such colour centres in a thin film gives rise to changes in both the optical and electrical properties of the material, which can be utilized to assess the radiation dose absorbed\(^{(11,12)}\).

The aim of the present work is to investigate the effects of γ-irradiation on some of the optical parameters of Cu\(_{10}\)Se\(_{90}\) films by means of the spectral dependence of both transmittance (T) and reflectance (R).

**EXPERIMENTAL PROCEDURE**

Bulk glasses of Cu\(_{10}\)Se\(_{90}\) were prepared by the well-established melt-quench technique. For a particular composition, the constituent elements Cu and Se of high purity (99.999\%) were weighed according to their atomic percentages and sealed in an evacuated silica ampoule (10\(^{-3}\) Torr). The sealed ampoule was heated at temperature \(T = 1373\) K in an electric furnace for about 15 h under continuous rocking. After that, the ampoule was quenched into ice-cooled water. The thin films were thermally evaporated, onto ultrasonically cleaned glass substrates; using an Edwards E306 coating unit operated at 2x10\(^{-5}\) Torr. The film thickness was accurately measured using a quartz crystal monitor (Edward model FTM5). The earthed face of the crystal monitor was facing the source and was placed at the same height as the substrate. The evaporation rate was controlled using the same FTM5 quartz crystal monitor.

The elemental compositions of Cu\(_{10}\)Se\(_{90}\) films were determined by the energy-dispersive X-ray spectrometry (using a JOEL type JSM-5400 LV). It was found that the composition of the evaporated film is 90.853 at.% Se and 8.2 at.% Cu. X-ray diffraction patterns are carried out using the X-ray diffractometer (Philips Type PW1070) with CuK\(_\alpha\) (\(\lambda = 1.5418\) Å) radiation and Ni filter operated at 40 kV and 30 mA.

Cu\(_{10}\)Se\(_{90}\) films were irradiated at room temperature with \(^{60}\)Co gamma cell (Alcyon II CGR, France). The films were exposed for different duration to achieve a series of different integrated absorbed doses from 10 krad to 190 krad at a rate of 2 krad h\(^{-1}\). After irradiation the samples were kept in a refrigerator to prevent thermal decay and to be ready for measurements.

The optical transmittance (T) and reflectance (R) of the as-deposited and irradiated Cu\(_{10}\)Se\(_{90}\) films were measured at normal incidence at room temperature by using a double-beam (ultraviolet visible) scanning spectrophotometer (SHIMADZU UV-2101) combined with a personal computer in the wave-length range 400–900 nm.

**RESULTS AND DISCUSSION**

**X-ray diffraction analysis:**

The X-ray diffraction patterns of as-prepared Cu\(_{10}\)Se\(_{90}\) films are shown in Fig. (1-I). It appeared that the film structure is amorphous and this is confirmed by the existence of low-intensity broad peak (hump) in the pattern. Cu\(_{10}\)Se\(_{90}\) films were heated in a furnace at 333 K and 353 K for 1 h in nitrogen gas and the XRD pattern in Fig. (1-II & III) shows the identified crystalline phases. The crystalline phases were Se, CuSe\(_2\) and Cu\(_3\)Se\(_2\). It noticed that the intensities of the parasite phases were enhanced.
with an increase in post-heating temperature, which may be due to the sufficient increase in the thermal energy for recrystallization and the grain growth with temperature.

---

**Fig. 1: X-ray diffraction for Cu$_{10}$Se$_{90}$ films (I) as-prepa(II) annealed films at 353 K(III) annealed films at 333 K**

**Absorption coefficient**

The measured reflectance (R) and transmittance (T) spectra as a function of wavelength in the range of 400–900 nm, for one selected film with thickness 100 nm, of Cu$_{10}$Se$_{90}$ films deposited on glass substrates at different $\gamma$-doses are shown in Figs. (2&3). Generally, the film transmittance increases with increasing the $\gamma$-doses but reflectance shows behavior opposite those in the transmission spectrum. It is obvious from Fig. (3) an increasing of the $\gamma$-dose results in a decrease in reflectance until it reaches a minimum value and then increasing with increasing $\gamma$-dose. A shift in the position of the highest peak, centered at nm to the longer wavelength, also is induced with increasing $\gamma$-dose.

The optical absorption coefficient ($\alpha$) before and after $\gamma$-ray irradiation could be calculated from the transmittance, ($T$), and reflectance ($R$) by using the formula $^{(11)}$:

$$T = \frac{(1-R)^2 e^{-(\alpha d)}}{1-R^2 e^{-(2\alpha d)}}$$

(1)
Where \( d \) is the film thickness

The dependence of the absorption coefficient on the photon energy for as-prepared and irradiated Cu\(_{10}\)Se\(_{90}\) films for different \( \gamma \)-doses is illustrated in Fig. (4). The optical absorption in the films is interpreted in terms of free carrier absorption in the near infrared and band-to-band transition in the visible-ultraviolet region. Figure (4) indicates that the absorption coefficient increases with the increasing of \( \gamma \)-ray doses and \( \alpha \) shows a steeper increase and the highest peak shifted to lower photon energies with increasing \( \gamma \)-ray dose. Similar behaviour was also observed by A. Abu El-Fadl et al.\(^{(15)}\) on Sb\(\text{NbO}_4\) films prepared by DC magnetron sputtering and irradiated with ultraviolet \( \gamma \)-radiation. And also observed by O.I. Shpotyuk et al.\(^{(16)}\) on Ge\(_{x}\)As\(_{40-x}\)\(\text{S}_60\) Chalcogenide glasses and H. El-Zahed et al.\(^{(17)}\) on AgInSe\(_2\) films and A. Abu El-Fadl et al.\(^{(18)}\) on ZnO thin films.

**Optical band gap:**

In amorphous semiconductors the optical absorption spectrum is found to have three distinct regions\(^{(11)}\). Of these, the high-absorption region bleach, bleaching region is strongly related to structural randomness of the system. In contrast, the weak absorption originates from defects and impurities. The low absorption (\( \alpha > 1 \text{ cm}^{-1} \)). The obtained values for the absorption coefficient (\( \alpha \)) as a function of the photon energy \( h\nu \) for as-prepared and irradiated Cu\(_{10}\)Se\(_{90}\) films is shown in Fig. 4. Shows that the absorption edge can be divided into two regions. For higher values of the absorption coefficient (\( \alpha > 10^4 \text{ cm}^{-1} \)) the absorption takes from relation of the form\(^{(18, 20)}\)

\[
(\alpha h\nu) = B(h\nu - E_g)^r
\]

where \( B \) is a constant, \( E_g \) the optical band gap and \( r \) a number that characterizes the transition process (\( r=1/2; r=2 \)) for direct and indirect allowed transitions, respectively. The present results were found to obey Eq. (2) with \( r=1/2 \) indicating that direct photon transitions are involved. The plot of \((\alpha h\nu)^2\) versus \( h\nu \) in the range (1.5-3.5) eV for as-prepared and irradiated Cu\(_{10}\)Se\(_{90}\) thin films are shown in Fig. 5 and summarized in Table 1. It clear that the direct energy gap \( E_g \) decreases from 3.695 eV to 2.476 eV when \( \gamma \)-irradiation doses were increased from 0 to 190 krad. This decrease of energy gaps with \( \gamma \)-ray doses can be explained.
Fig. 2. The spectral distribution of transmittance for as-prepared and irradiated with different $\gamma$-doses Cu$_{10}$Se$_{90}$ films.

![Graph showing the spectral distribution of transmittance for Cu$_{10}$Se$_{90}$ films with different $\gamma$-doses.]

Fig. 3. The spectral distribution of reflectance for as-prepared and irradiated with different $\gamma$-doses Cu$_{10}$Se$_{90}$ films.

![Graph showing the spectral distribution of reflectance for Cu$_{10}$Se$_{90}$ films with different $\gamma$-doses.]

\begin{align*}
\alpha \times 10^4 & \text{ [cm}^{-1} \text{]} \\
\hbar \nu & \text{ [eV]} \\
\end{align*}
to as due the variation of disorder and defects present in amorphous materials (21). It is known that the unsaturated bonds together with some saturated bonds are produced as a result of an insufficient number of atoms in Cu$_{10}$Se$_{90}$ thin films deposited on glass substrates. The unsaturated bonds are responsible for the formation of some defects in the film which produce localized states in the band gap. The presence of high concentration of localized states in the band structure is responsible for low values of $E_g$ in the low $\gamma$-doses. In the presence of high $\gamma$-doses, the unsaturated defects produce large number of saturated bonds. The reduction of the large number of unsaturated defects decrease the density of localized states in the band structure, consequently remain the value of the optical gap constant with increasing $\gamma$-doses (22, 23).

Bearing in mind that the value of the band gap energy is affected by the deposition technique and deposition conditions. The obtained band gap are close to that Copper selenide thin films prepared by chemical bath deposition technique using sodium selenosulfate as a source of selenide ions by Al-Mamun and A.B.M.O. Islam (24). The crystallinity of the obtained films is very low in as-deposited samples, but improves on annealing in air at 523 K. The grain size of the as-deposited was very small and to be increase to about 30% owing to anneal in air at 523 K. They observed that the direct band gap varies in the range 1.9-2.3 eV and the direct band gap is in the range 1.2-1.7 eV from as deposited to all annealed samples up to 523 K. They attributed the larger band gap values in the as-deposited samples compared with that of the annealed samples to the smaller grain size in the former.

BilJana Pejova and Ivan Grozdanov (25) used the chemical deposition method for fabrication of CuSe and Cu$_3$Se$_2$ thin films. CuSe films are characterized with two direct band gap energies of 2.0 and 2.37 eV. Their first value of the optical band gap agreed with the previously reported one for copper (II) selenide thin films. In$_x$Se$_{100-x}$ thin films with ($x=10$ and 24) were deposited on glass substrates by thermal evaporation by S.A. Fayek (26). They found that the optical band gap decreases from 1.85 eV to 1.27 eV with $x$ increase from $x=10$ to $x=24$. This shift of $E_g$ was attributed to the formation of In-Se bonds and the decrease in concentrations of other bonds, which exit in the glass. This may result in a perturbation in the system that will broaden the valence and conduction band edges in the mobility gap also increasing In content leads to the generation of excess delocalized electronic states.

Cu$_{2-x}$Se and Cu$_3$Se$_2$ thin films chemically prepared M. Lakshmi et al. (27) found to undergo cyclic inter phase conversion. When exposed to ambient conditions, the Cu$_{2-x}$Se phase converted to Cu$_3$Se$_2$ phase along with the formation of Cu$_2$O phase. The Cu$_3$Se$_2$ phase converts to Cu$_{2-x}$Se phase when annealed in air at a temperature above 140 C. Direct band gap of these phases were calculated from the absorption spectrum. The phase transformation of Cu$_{2-x}$Se to Cu$_3$Se$_2$ could be confirmed from the absorption edge shift from $2.03 \pm 0.03$ eV to $2.73 \pm 0.03$ eV. They attributed the slight shift of band gap of Cu$_3$Se$_2$ phase from the earlier reported value due to the formation of copper oxide due to oxygen incorporation. The band gap calculated for the phase transformation of Cu$_3$Se$_2$ to Cu$_{2-x}$Se are $2.84 \pm 0.03$ eV and $2.27 \pm 0.03$ eV, respectively.

The optical absorption and particularly the absorption band edge is a good method for studying optically induced transition and gives information about the structure and optical energy gap in thin films. The absorption edge in many materials follows the Urbach rule (28).

$$\alpha (h\nu) = \alpha_o \exp(h\nu/E_g)$$

(3)
where $\alpha_0$ is a constant, $h\nu$ the incident photon and $E_e$ is calculated from the slopes of the straight lines. $E_e$ is interpreted as the width of the tails due to localized states in the forbidden gap, associated with the amorphous state.

The exponential dependence of the optical absorption coefficient with photon energy may arise from the electronic transitions between the localized states, which have tailed odd in the band gap. The density of these states falls off exponentially with energy, which is consistent with the theory of Tauc (29). However, Dow and Redfield (30) believed that the exponential dependence of the optical absorption coefficient on energy might arise from the random fluctuations of the internal fields associated with the structural disorder in many materials. The width of the localized states (band tail energy or Urbach energy) $E_e$ is estimated from the slopes of $\ln(\alpha) \text{ vs } h\nu$ plots, Fig. 6 represents such dependence. The energy width of the tail $E_e$ could be obtained by extrapolating the linear portions of these curves. The dependence of $\ln(\alpha)$ on $h\nu$ in the range 3.3-3.7 eV and from the gradients of the lines, and using the least squares method, the energy width of the tail for each film has been estimated and plotted in Fig. (7), $E_e$ graph was added to the plot for sake of comparison.

Comparing the values of $E_e$, which characterizes the disorder in the film material, The changes in $E_e$ is most likely due to the creation of point defects due to irradiation. A lower value of $E_e$ implies a lower incorporation of point defects in films substrates as compared with ones grown on quartz substrates. $\alpha_0$, the value of the exponential absorption coefficient extrapolated to the fundamental gap and is assumed to be a constant for the material.

It is known that unsaturated bonds are produced as a result of an insufficient number of atoms deposited in the amorphous films (31). The unsaturated bonds are responsible for the formation of some defects in the films. Such defects produce localized states in the amorphous solids. The presence of high concentration of localized states in the band structure is responsible for low values of optical energy gap $E_g$ in the case of as-deposited amorphous films (32). In the process of $\gamma$- irradiation, the unsaturated defects produce a large number of unsaturated bonds.

![Graph](image)

Fig. 5. $(\alpha h\nu)^2$ as a function of the photon energy $(h\nu)$ for as-prepared and irradiated with different $\gamma$-doses Cu$_{10}$Se$_{90}$ films
Fig. 6. \((\ln \alpha)\) as a function of the photon energy \((h\nu)\) for as-prepared and irradiated with different \(\gamma\)-doses Cu\(_{10}\) Se\(_{90}\) films.

Fig. 7. \(E_g\) and \(E_e\) as a function of \(\gamma\)-irradiated doses for Cu\(_{10}\) Se\(_{90}\) films.
The increase in the number of unsaturated defects increases the density of localized states in the band structure and consequently decreases the optical energy gap $E_g$.

Figure 7 presents optical energy gap $E_g$ and $E_e$ of the Cu$_{10}$Se$_{90}$ thin films, irradiated with different $\gamma$-ray doses. Figure 7 also shows an increase of the density of localized states ($E_e$) when increasing the $\gamma$-ray doses. An increase in the values of Urbach’s energy $E_e$ was observed with the increase in radiation dose. The values of the optical band gap for as-deposited and $\gamma$-irradiated samples were estimated using the Mott and Davis’ model ($^{33}$). It was found that the optical band gap values were decreased as the radiation dose was increased.

The variation in the optical energy gap with $\gamma$-irradiation doses can be explained by the change in the degree of disorder. From the density-of-state model, it is known that $E_g$ decreases with an increasing degree of disorder of the amorphous phase ($^{34}$).

**Effect of $\gamma$-irradiation on the refractive index (n) and extinction coefficient ($k_{ex}$):**

The values of refractive index (n) and extinction coefficient (k) have calculated using the following relations ($^{35}$) given by:

$$R = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2_{ex.}}$$  \hspace{1cm} (4)

$$a = \frac{4\pi k_{ex.}}{\lambda}$$ \hspace{1cm} (5)

where $R$ is reflectance $k$ is extinction coefficient, n is the refractive index and $\lambda$ is the wavelength of the incident light.

The spectral dependence of refractive index (n) and extinction coefficient ($k_{ex}$) of as-prepared and $\gamma$-irradiated Cu$_{10}$Se$_{90}$ films in the wavelength range of (550–650) nm, as calculated by the method proposed by Manifacier et al. ($^{36}$) are shown in Fig. 8. The refractive index of the as-deposited film gradually increases with increasing wavelength. The extinction coefficient of the as-deposited film decreases with increasing wavelength, but the change in extinction coefficient is very small when the wavelength is greater than 550 nm. The values of n and $k_{ex.}$ for deferent $\gamma$-irradiation doses are shown in Table 1.

It can be seen that in the case of the as-deposited film $k_{ex.}$ is greater than that for the irradiated films except for highest dosed( krad). This is attributed to the defects, which are present in the film due to the high dose of $\gamma$-irradiation. Refractive indices may be attributed to the factors, which are related to the crystalline of the thin film, density, electronic structure and the defects.

Thus, the high value of refractive index (n) is an indication of high density of the film and low value of extinction coefficient illustrates nature of high quality transparent films. The observed increase in (n) for a constant value of $\lambda$ with increasing $\gamma$-doses might be caused by the increase of the material compactness as a consequence in the grain size with increasing $\gamma$-doses.

The real ($\varepsilon_1$) and imaginary ($\varepsilon_2$) parts of the dielectric constant for a- Se$_{90}$Cu$_{10}$ films has also been calculated by using the relations

$$\varepsilon_1 = n^2 - k^2$$ \hspace{1cm} (6)

$$\varepsilon_2 = 2nk_{ex.}$$ \hspace{1cm} (7)
The variation of these two parameters with wavelength is shown in Fig. (9). The values of real part ($\varepsilon_1$) and imaginary part ($\varepsilon_2$) of the dielectric constant decreases The values of real part ($\varepsilon_1$) increases with wavelength but imaginary part ($\varepsilon_2$) of the dielectric constant decreases with wavelength in all irradiation samples of Cu$_{10}$Se$_{90}$ films.

Effect of $\gamma$-irradiation on high-frequency dielectric ($\varepsilon_\infty$) and ($N/m^*$):

For a better understanding of the optical properties of the investigated film, it is necessary to determine some optical constants such as high-frequency dielectric constant ($\varepsilon_\infty$) and carrier concentration ($N/m^*$). According (37,38), the real component of the relative permittivity ($\varepsilon_1$) and the square of wavelength ($\lambda^2$) are related by the following equation:

$$\varepsilon_1 \approx n^2 = \varepsilon_\infty - \left( \frac{e^2}{\pi c} \right) \left( \frac{N}{m^*} \right) \lambda^2$$

(8)

where $c$ is the velocity of light, $e$ the electronic charge, and $m$ the electron effective mass. For a linear plot of $\varepsilon_1$ versus ($\lambda^2$) the high-frequency dielectric constant ($\varepsilon_\infty$) and the ratio ($N/m^*$) decrease with increasing $\gamma$-irradiation.

It is observed that the dependence of ($\varepsilon_1$) on ($\lambda^2$) is linear at longer wavelengths, as shown in Fig. (10). Extrapolating the linear part of this dependence to zero wavelength gives the value of ($\varepsilon_\infty$) and from the slopes of these lines we can calculate the values of ($N/m^*$) for the investigated compositions. Values of ($\varepsilon_\infty$) and ($N/m^*$) are plotted in Fig. (11) against the $\gamma$-doses and Table 2 includes the obtained values of ($\varepsilon_\infty$) and ($N/m^*$). It could be noticed that, the high-frequency dielectric constant ($\varepsilon_\infty$) and the ratio ($N/m^*$) decrease with increasing $\gamma$-irradiation.

In general, it can be concluded that both the high frequency dielectric constant and the ratio ($N/m^*$) are related to the internal microstructure, as can be emphasized considering the results in Table 2 with those in Fig. (9), most of the changes in the ($N/m^*$) ratio are regarded as corresponding to the change in N.

Analysis of our experimental results shows that the measured optical parameters of Cu$_{10}$Se$_{90}$ films are affected by $\gamma$-irradiation. The response is dependent on film substrate. This finding is expected to be useful for monitoring $\gamma$-radiation by Cu$_{10}$Se$_{90}$ films, good response can be obtained around 50 krad radiation dose. To monitor a wide range of $\gamma$-radiation, more efforts Cu$_{10}$Se$_{90}$ thin films, e.g. electrical conductivity and dielectric permittivity and irradiated at higher dose experiments are in progress.
Table 1: Optical parameters of Cu$_{10}$Se$_{90}$ thin films at 580, 600 and 620 nm

<table>
<thead>
<tr>
<th>$\lambda$ (nm)</th>
<th>$\gamma$-doses (krad)</th>
<th>T %</th>
<th>R %</th>
<th>$n$</th>
<th>$K_{ex}$</th>
<th>$\varepsilon_1$</th>
<th>$\varepsilon_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>580</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>000</td>
<td>14.65</td>
<td>36.53</td>
<td>3.995</td>
<td>0.474</td>
<td>15.738</td>
<td>3.794</td>
<td></td>
</tr>
<tr>
<td>010</td>
<td>15.56</td>
<td>36.64</td>
<td>4.014</td>
<td>0.446</td>
<td>15.915</td>
<td>3.584</td>
<td></td>
</tr>
<tr>
<td>020</td>
<td>16.20</td>
<td>40.86</td>
<td>4.511</td>
<td>0.370</td>
<td>20.215</td>
<td>3.345</td>
<td></td>
</tr>
<tr>
<td>040</td>
<td>15.43</td>
<td>42.07</td>
<td>4.660</td>
<td>0.374</td>
<td>21.576</td>
<td>3.493</td>
<td></td>
</tr>
<tr>
<td>060</td>
<td>15.83</td>
<td>35.39</td>
<td>3.879</td>
<td>0.455</td>
<td>14.844</td>
<td>3.535</td>
<td></td>
</tr>
<tr>
<td>080</td>
<td>19.33</td>
<td>34.93</td>
<td>3.851</td>
<td>0.373</td>
<td>14.694</td>
<td>2.874</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>21.05</td>
<td>26.45</td>
<td>3.046</td>
<td>0.440</td>
<td>9.087</td>
<td>2.683</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>22.66</td>
<td>33.98</td>
<td>3.766</td>
<td>0.315</td>
<td>14.089</td>
<td>2.377</td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>25.70</td>
<td>34.86</td>
<td>3.865</td>
<td>0.249</td>
<td>14.882</td>
<td>1.929</td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>25.09</td>
<td>28.75</td>
<td>3.274</td>
<td>0.334</td>
<td>10.610</td>
<td>2.189</td>
<td></td>
</tr>
<tr>
<td>190</td>
<td>31.44</td>
<td>32.68</td>
<td>3.658</td>
<td>0.190</td>
<td>13.348</td>
<td>1.395</td>
<td></td>
</tr>
<tr>
<td>600</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>000</td>
<td>18.96</td>
<td>36.04</td>
<td>3.965</td>
<td>0.380</td>
<td>15.580</td>
<td>3.013</td>
<td></td>
</tr>
<tr>
<td>010</td>
<td>20.21</td>
<td>37.54</td>
<td>4.136</td>
<td>0.331</td>
<td>16.995</td>
<td>2.739</td>
<td></td>
</tr>
<tr>
<td>020</td>
<td>21.28</td>
<td>41.54</td>
<td>4.611</td>
<td>0.255</td>
<td>21.199</td>
<td>2.354</td>
<td></td>
</tr>
<tr>
<td>040</td>
<td>20.21</td>
<td>44.18</td>
<td>4.952</td>
<td>0.242</td>
<td>24.465</td>
<td>2.395</td>
<td></td>
</tr>
<tr>
<td>060</td>
<td>20.59</td>
<td>33.93</td>
<td>3.751</td>
<td>0.370</td>
<td>13.933</td>
<td>2.779</td>
<td></td>
</tr>
<tr>
<td>080</td>
<td>25.57</td>
<td>35.16</td>
<td>3.895</td>
<td>0.258</td>
<td>15.106</td>
<td>2.008</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>28.04</td>
<td>24.92</td>
<td>2.950</td>
<td>0.341</td>
<td>8.582</td>
<td>2.008</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>30.49</td>
<td>30.68</td>
<td>3.466</td>
<td>0.234</td>
<td>11.958</td>
<td>1.623</td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>34.09</td>
<td>31.16</td>
<td>3.517</td>
<td>0.179</td>
<td>12.338</td>
<td>1.262</td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>33.95</td>
<td>23.73</td>
<td>2.872</td>
<td>0.266</td>
<td>8.175</td>
<td>1.527</td>
<td></td>
</tr>
<tr>
<td>190</td>
<td>42.06</td>
<td>27.57</td>
<td>3.205</td>
<td>0.127</td>
<td>10.259</td>
<td>0.816</td>
<td></td>
</tr>
<tr>
<td>620</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>000</td>
<td>25.03</td>
<td>33.50</td>
<td>3.722</td>
<td>0.297</td>
<td>13.769</td>
<td>2.215</td>
<td></td>
</tr>
<tr>
<td>010</td>
<td>26.70</td>
<td>36.85</td>
<td>4.076</td>
<td>0.225</td>
<td>16.565</td>
<td>1.837</td>
<td></td>
</tr>
<tr>
<td>020</td>
<td>28.25</td>
<td>40.02</td>
<td>4.473</td>
<td>0.162</td>
<td>19.666</td>
<td>1.437</td>
<td></td>
</tr>
<tr>
<td>040</td>
<td>27.16</td>
<td>44.95</td>
<td>5.065</td>
<td>0.1166</td>
<td>25.649</td>
<td>1.210</td>
<td></td>
</tr>
<tr>
<td>060</td>
<td>27.57</td>
<td>30.06</td>
<td>3.399</td>
<td>0.296</td>
<td>11.466</td>
<td>2.015</td>
<td></td>
</tr>
<tr>
<td>080</td>
<td>34.64</td>
<td>33.61</td>
<td>3.752</td>
<td>0.150</td>
<td>14.058</td>
<td>1.126</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>38.09</td>
<td>21.47</td>
<td>2.700</td>
<td>0.246</td>
<td>7.234</td>
<td>1.329</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>41.58</td>
<td>25.02</td>
<td>2.991</td>
<td>0.164</td>
<td>8.921</td>
<td>0.986</td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>45.60</td>
<td>24.55</td>
<td>2.958</td>
<td>0.127</td>
<td>8.733</td>
<td>0.751</td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>46.59</td>
<td>16.66</td>
<td>2.358</td>
<td>0.202</td>
<td>5.519</td>
<td>0.957</td>
<td></td>
</tr>
<tr>
<td>190</td>
<td>56.10</td>
<td>19.64</td>
<td>2.588</td>
<td>0.083</td>
<td>6.694</td>
<td>0.430</td>
<td></td>
</tr>
</tbody>
</table>
Fig.(8-a): Refractive index (n) versus wavelength (\(\lambda\)) for Cu\textsubscript{10}Se\textsubscript{90} films irradiated with different \(\gamma\)-doses

Fig.(8-b): Extinction coefficient (\(k_{ex}\)) versus wavelength (\(\lambda\)) for Cu\textsubscript{10}Se\textsubscript{90} films irradiated with different \(\gamma\)-doses
Fig. (9-a): Real part ($\varepsilon_1$) of the dielectric constant versus wavelength ($\lambda$) at different $\gamma$-doses for Cu$_{10}$Se$_{90}$ films

Fig. (9-b): Imaginary part ($\varepsilon_2$) of the dielectric constant versus wavelength ($\lambda$) at different $\gamma$-doses for Cu$_{10}$Se$_{90}$ films
Fig. 10. Relative permittivity ($\varepsilon_1$) versus ($n^2$) for Cu$_{10}$Se$_{90}$ films irradiated with different $\gamma$-doses.

Fig. 11. The ratio ($N/m^*$) as a function of $\gamma$-irradiated doses for Cu$_{10}$Se$_{90}$ films.
CONCLUSIONS

The work presents results of the optical measurements on as-deposited and irradiated films with different γ-doses. Key results of this work are summarized as follows:

* X-ray diffraction patterns for Cu$_{10}$Se$_{90}$ thin films show that, no well defined peak was found in the case of as-deposited films, which suggests that the as-deposited films were disorder. A tendency of growing well-defined peaks is found after film annealing at 353 K or 373 K suggesting the formation of polycrystalline film.

* The optical gap of as-deposited and irradiated films with different doses showed direct transition. An allowed direct transition near the fundamental absorption edge was calculated to be $E_g = 2.017$ eV for as-deposited films which then to decrease to 1.941 eV for irradiation with a 190 krad dose. This variation can be discussed in terms of unsecured bonds present in the composition. These bonds are responsible for the formation of some defects in the film. Such defects produce a localized state in the band gap of the films. The decrease in the band gap can be explained in terms of the appearance of more localized states as the dose increases which reduce the value of the band gap. For highest doses more localized states are produced, so the defects increase in the film composition with unirradiated film. As a result, the optical gap decreased to a value lower than that of unirradiated films.

* The optical constants (n, k) decrease with increasing γ-doses.

REFERENCES

York;(1988).
USA (1955).
(13) T. Horkawa, N. Mikami, T. Makita, J. T. Amimura, M. Kataoka, K. Sato, M. Nunoshita,
103.
(15) A. Abu El-Fadl, G. A. Mohmad and T. Yamazaki, Materials Chemistry and Physics; 80
,239(2003).
143(2004).
(21) O. I. Shpotyuk, A. O. Matkovsky, A. P. Kovalsky and M. M. Vakiv, Rad. Effects Defects in
Holland, Amsterdam, 277 (1972).
(31) M. L. Theye, Proc. 5th Int. Conf. on Amorphous and Liquid Semiconductors,
Garmisch-Partenkichen;1,479(1973).
(33) M. V. Kurik, Physica Status Solidi (a); 8, 9(1971).
(34) N. F. Mott and E. A. Davis, Electronic Processes in Non-crystalline Materials, 2nd ed.,