Effect of Beta Ray on the Optical Properties of CuO Thin Films

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Abstract

Thin film technology is one of the most important techniques at the present time to study the properties of its constituent materials. One of the most important thin films used is copper oxide thin film because of its different applications in all fields. These thin films have been studied in different researches and treated with different types of radiation to know their effects on them and to improve some of their properties. In this study, thin films have been deposited on glass substrates by (Sol-Gel / Spin Coating) technique and used convection oven with (600°C) for one hour and then were exposed to beta radiation for different periods of time (15, 30, 45, 60, 75 and 90) min. The optical properties of prepared thin films before and after irradiation were studied to investigate the effect of beta radiation on the prepared thin films. The results of optical test of the thin films showed that they are generally highly transmittance, especially in the visible and near infrared regions. The results showed an increase in the energy gap values of these thin films by increasing the duration of beta irradiation. Other optical characteristics which were studied in this paper included both reflective, absorbance, as well absorption, refraction and extinction parameters, in addition to both of real and imaginary dielectric constants.

Keywords: thin films, CuO, spin coating, beta irradiation, optical properties.

تأثير اشعة بيتا على الخواص البصرية لأغشية CuO الرقيقة

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الخلاصة

تعد تقنية الاغشية الرقيقة من اهم التقنيات في الوقت الحاضر لدراسة خواص المواد المكونة لها، ومن اهم الاغشية المستخدمة اغشية اوكسيد النحاس الرقيقة لما لها من تطبيقات مختلفة في كافة المجالات، وقد تم دراسة هذه الاغشية وخصائصها في عدة بحوث ومعاملتها بإشعاعات مختلفة لمعرفة تأثيرها عليها ولتحسين بعض خواصها. في هذا البحث تم ترسيب اغشية (CuO) على قواعد زجاجية بتقنية (Sol – Gel / Spin Coating) وتلدينها باستخدام الفرن الحراري بدرجة (600°C) لمدة ساعة واحدة، ثم تم تعريضها لأشعة بيتا لفترات زمنية مختلفة (15، 30، 45، 60، 75 و 90) دقيقة وتم دراسة الخواص البصرية للأغشية المحضرة قبل وبعد التشعيع لمعرفة مدى تأثير اشعة بيتا عليها، وقد اظهرت نتائج الفحوصات البصرية لهذه الاغشية بصورة عامة أنها ذات نفاذية عالية خصوصاً في منطقتي الطيف المرئية وتحت الحمراء القريبة وتزداد بزيادة مدة التشعيع، كما بينت النتائج ازدياد قيم فجوة الطاقة لهذه الاغشية بزيادة مدة التشعيع ببيتا، بالإضافة الى ذلك فقد تضمنت الخواص البصرية المدروسة في هذا البحث كلاً من الامتصاصية والانعكاسية ومعاملات الانكسار والامتصاص والخمود وثابتي العزل الكهربائي الحقيقي والخيالي .

الكلمات المفتاحية: اغشية رقيقة، اوكسيد النحاس، الطلاء الدوراني، التشعيع ببيتا، خصائص بصرية.

Introduction

Thin film technique has added a lot in the study of semiconductors and it has given an evident view about many of their physical and chemical characteristics [1], and for study their properties, they must be manufactured with thicknesses of not more than few microns [2]. Copper oxide (CuO) is a semiconductor material which its scientific names are (tenorite, cupric). It is stable oxide, brown – black powder, odorless [3], not soluble in water or bases [4], low cost of production, non-toxic nature [5, 6], high quality in optical and electrical properties [6], known as (TCO) which is used in optoelectronic applications [5], has many applications in the field of photoelectric appliances [3], used in diodes link (p-n junction) and energy sources, etc. [7].

Beta rays are electrons with a negative charge emitted from the unstable nucleus as a result of the conversion of neutrons into protons, and they travel with a speed of about the speed of light. Beta particles are emitted with different energies with speed which is a special characteristic of the radioactive element. This radiation loses most of its energy as it passes through the material due to the inelastic collisions of the electrons. Its absorption depends on its energy, and it has the ability to ionize the air [8].

In this study, we prepared (CuO) thin films by (Sol-Gel / Spin Coating) technique and have annealed these thin films by convection oven at (600 °C), and then irradiated by beta radiation to study the effect of beta rays on the optical characteristics of these thin films.

Experimental

In this study, (CuO) thin films were deposited by (Sol-Gel / Spin Coating) technique on glass substrates. At first glass substrates were cleaned by washing with tap water and were placed in diluted nitric acid and then they were placed in filtered water, after that these substrates were placed in acetone, then in ethanol and then they were dried. To prepare (CuO) thin films; a solution was prepared at (0.2 M) concentration by dissolving copper acetate dehydrate (high purity) in ethanol, and to complete the solution process; the solution was mixed by magnetic stirrer for an hour at (60˚C), after that it was covered and left for a whole day to get a "homogeneous solution", then it is deposited on glass substrates by placing the samples on spin coating base at rotational speed of (3000 rpm) for (30 s), then they were placed in the convection oven at (100˚C) temperature for drying with a time period of (10 min), and then the temperature was raised to (150˚C) with a time period of (10 min), then (CuO) thin films were annealed by thermal oven at temperature (600˚C) for one hour.

After completion of the annealing process, the thin films were irradiated by beta ray for time periods of (15, 30, 45, 60, 75 and 90) min. The optical properties of prepared (CuO) thin films were analyzed using (UV – Visible Spectrophotometer) which gave the transmittance spectrum at (300 – 1100) nm range of wavelength.

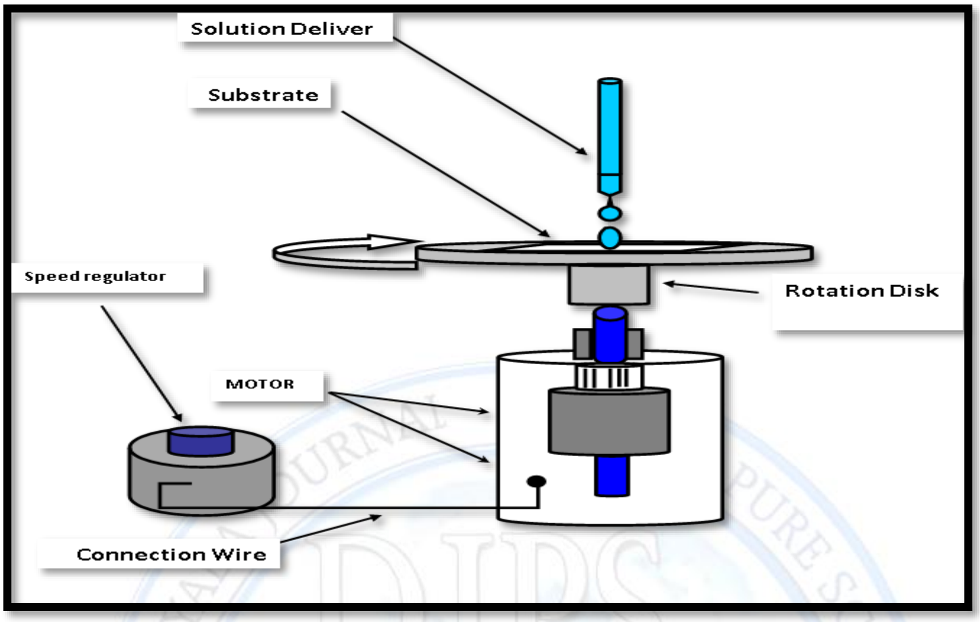

Figure 1: Spin coating system [9]

Results and Discussion

The outcome of this paper is obtained from optical tests of prepared thin films, which were conducted with the (UV – Visible Spectrophotometer), which showed the effect of beta radiation on the optical properties of these thin films.

- **Absorbance, Transmittance and Reflectivity:**

Beta irradiation led to a decrease in the absorbance values (A) when increasing period of time of exposure of the thin films to this radiation. In contrast, the transmittance values (T) showed an increase when increasing the time period of exposure as it begins to increase in the visible area of the spectrum to reach the highest values in the red region of spectrum to be up to (98%) and so that in the infrared region. The behavior of the thin films exposed to irradiation for (30 min) is different, where the value of absorption spectrum showed more than its value before irradiation and the range of transmittance is less than that before irradiation, and this behavior is the same for those thin films which were exposed to irradiation at period of (75 min) where its absorbance is higher than those irradiated at (60 min) and (45 min), and its transmittance is less than them, that may be due to structural defects just in these thin films, as shown in absorbance and transmittance spectra in figures (2 and 3) respectively. We find that the best exposure time of beta irradiation which was used to irradiate these thin films in this research to get a high transmittance, is (90 min).

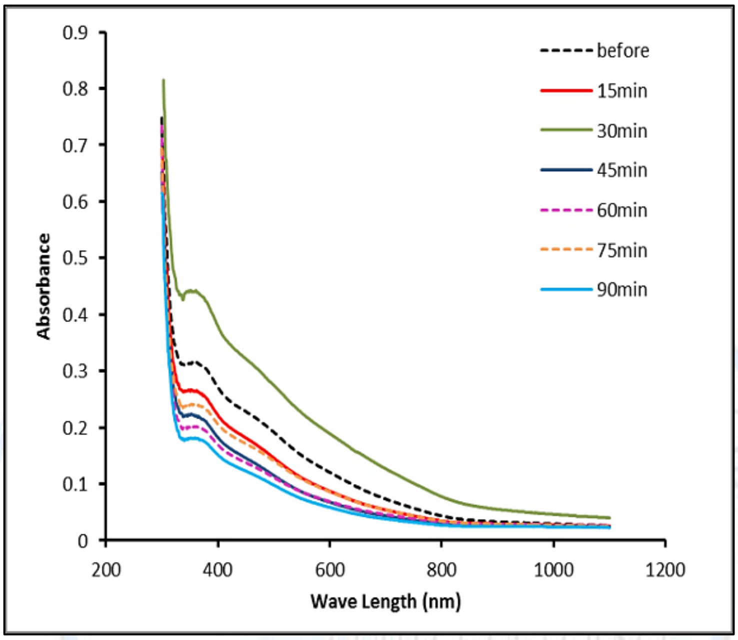

Figure 2: Absorbance spectra of CuO thin films

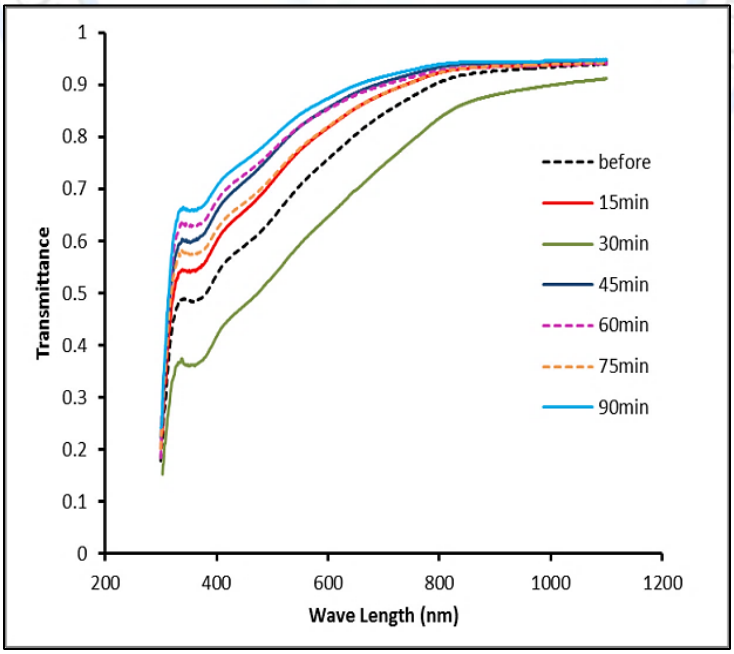

Figure 3: Transmittance spectra of CuO thin films

The reflectivity (R) spectrum showed that the reflectivity values were almost equal for all thin films before and after the irradiation with beta rays at the low wavelength region of the spectrum, till reaching the visible region, when the values gradually decrease until they reach their lowest values in the infrared region of the spectrum, and it is clear that the decrease is faster when time of exposure to the radiation was longer, but it showed a difference in the case of those exposed to radiation at (30 min) of time period, as in the absorbance and transmittance spectra, where the decrease in reflectivity values is less than that before beta irradiation, and this is shown in figure (4). From this we find that these thin films can be used in applications which depend on reflectivity especially in the violet and UV wavelengths regions, where we observe the highest values of reflectivity at these areas. In general, the reflectivity curve showed less values at the low energies regions of spectrum, and the absorption values are very little at the energies below the value of the energy gap (E_g), where the peak at the curve of reflectivity represents the value corresponding to the energy gap.

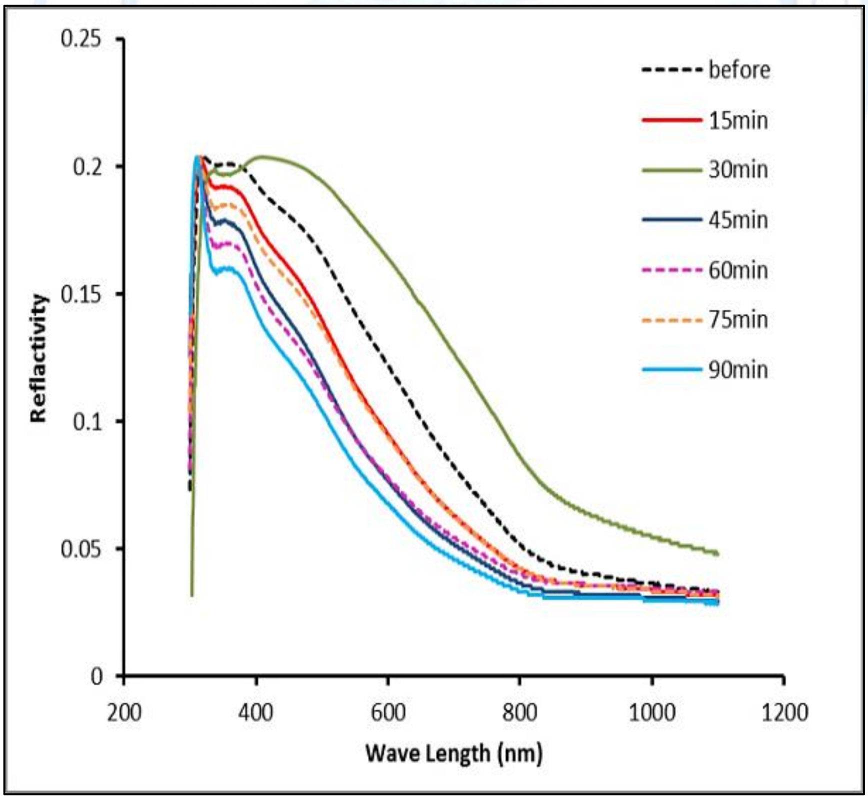

Figure 4: Reflectivity spectra of CuO thin films

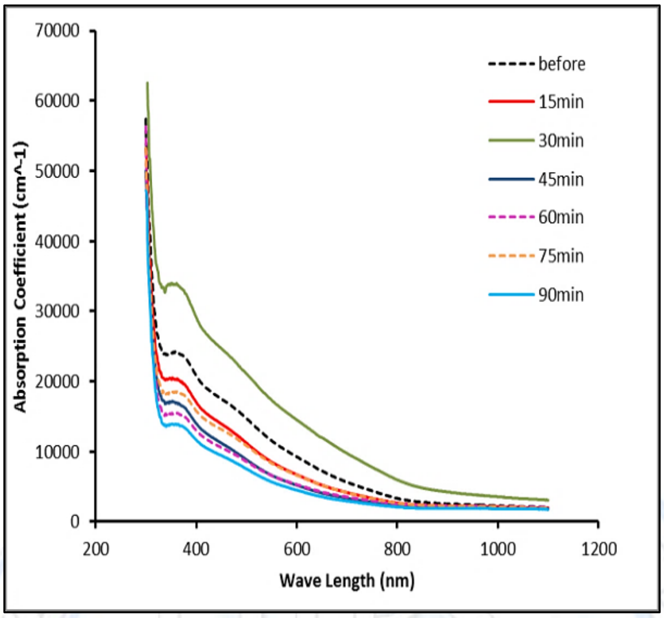

Figure 5: Absorption coefficient of CuO thin films

- **Optical Constants:**

Figure (5) shows the change in the absorption coefficient values (α) of copper oxide thin films with wavelength change. The figure shows a similar behavior to the absorbance spectra, the absorption coefficient was obtained by the following [1]:

$\alpha = 2.303\,\frac{A}{t}$ ………………………. (1)

Where (t) is the thickness of thin films. From the figure we find that (α) decreases rapidly with increasing wavelength and then decreases slowly at high wavelengths, note that the highest value of (α) is at the beginning of the curve at the low wavelengths (high photons energies) where the value is ($\alpha > 10^4$ cm^{-1}), which indicates the occurrence of directly electronic transitions.

The refractive index (n) values were obtained for CuO thin films from equation (2), which is defined as the ratio between the speed of light in the vacuum and its velocity in the medium [10]:

$$n = \left(\frac{1+R}{1-R}\right) + \sqrt{\frac{(1+R)^2}{(1-R)^2} - (k^2+1)}$$ ………….…. (2)

Where (k) is extinction coefficient, it represents attenuation of the electromagnetic beam within the material, and it can be calculated according to the following relationship [11]:

$$k = \frac{\alpha \lambda}{4\pi} \quad \text{.......................... (3)}$$

It is noted that the coefficient of extinction depends mainly on the wavelength (λ) and absorption coefficient (α) which depends on the quality of the material. Figures 6 and 7 showed the changes of (n) and (k) with wavelength respectively, and it is clear from equations (2 and 3) that they have the similar changes of the reflectivity and absorption coefficient respectively. The value of (n) is high at high energies (low wavelengths), and it has the highest value when the energy reaches a value which is equal to (E_g), so (k) rapidly decreases at low wavelengths and then gradually decreases at the absorption edge due to electronic transitions between the equivalent and conduction bands, we note that beta irradiation generally led to decrease (n) and (k) values compared to their values before irradiation.

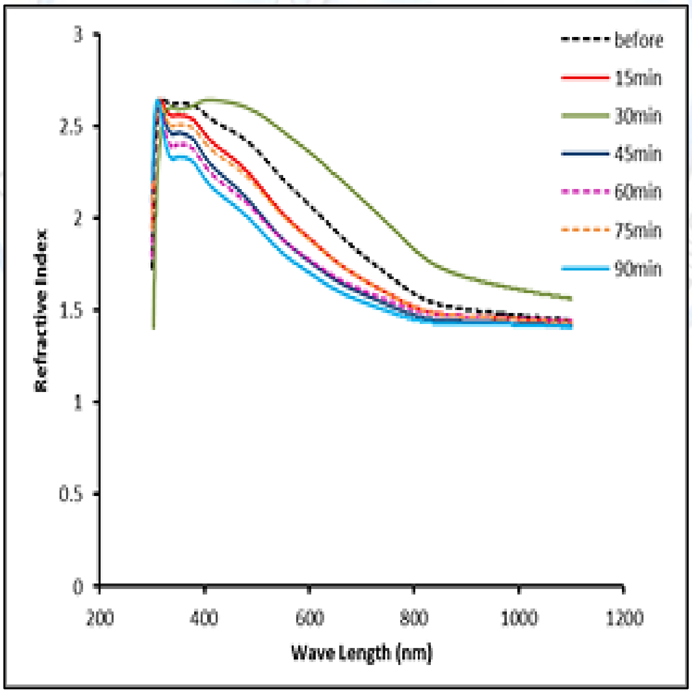

Figure 6: Refractive index of CuO thin films

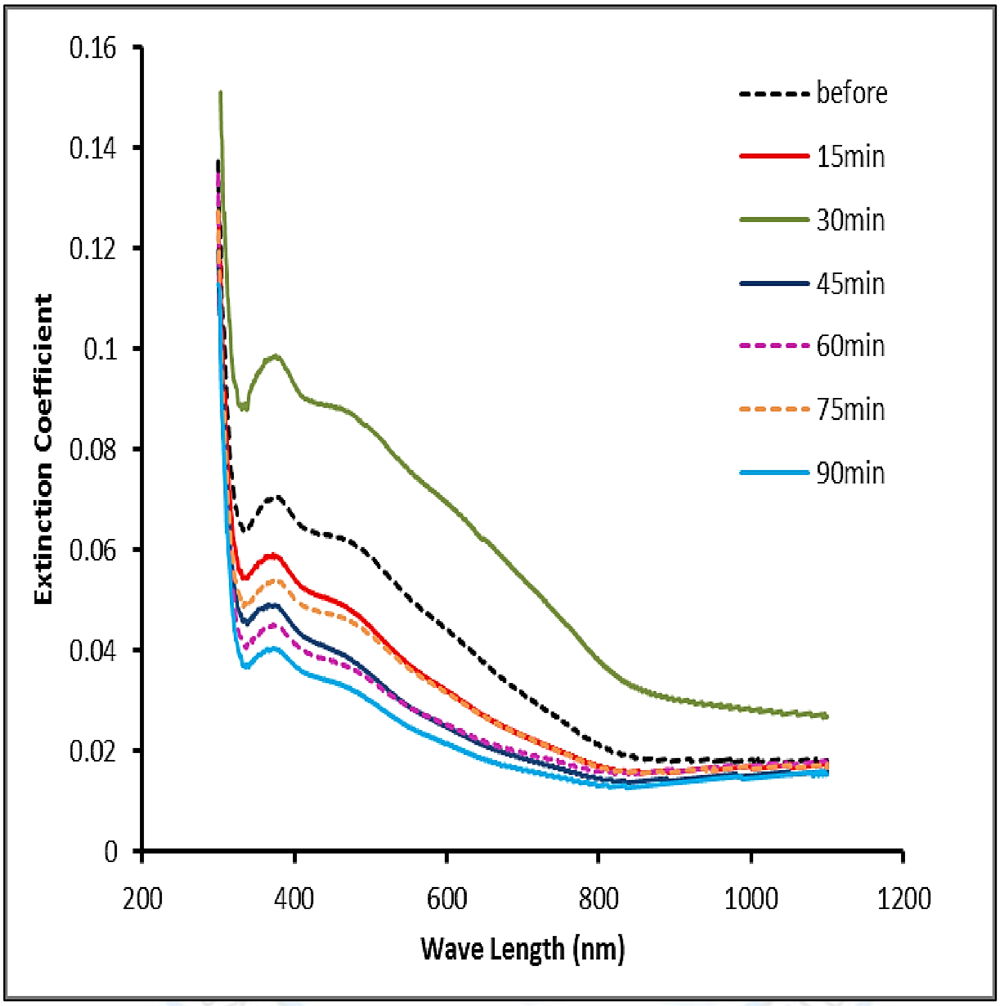

Figure 7: Extinction coefficient of CuO thin films

The real and imaginary dielectric constants (shown in figures 8 and 9 respectively) are calculated by calculating the refractive index. Dielectric constant represents the material's polarization, which is the material's response to different frequencies with complex behavior. The following equations represent real dielectric constant ($\boldsymbol{\varepsilon_r}$) and imaginary dielectric constant ($\boldsymbol{\varepsilon_i}$) [1]:

$\varepsilon_r = n^2 - k^2$ …………………….. (4)

$\varepsilon_i = 2n\,k$ …………………..……. (5)

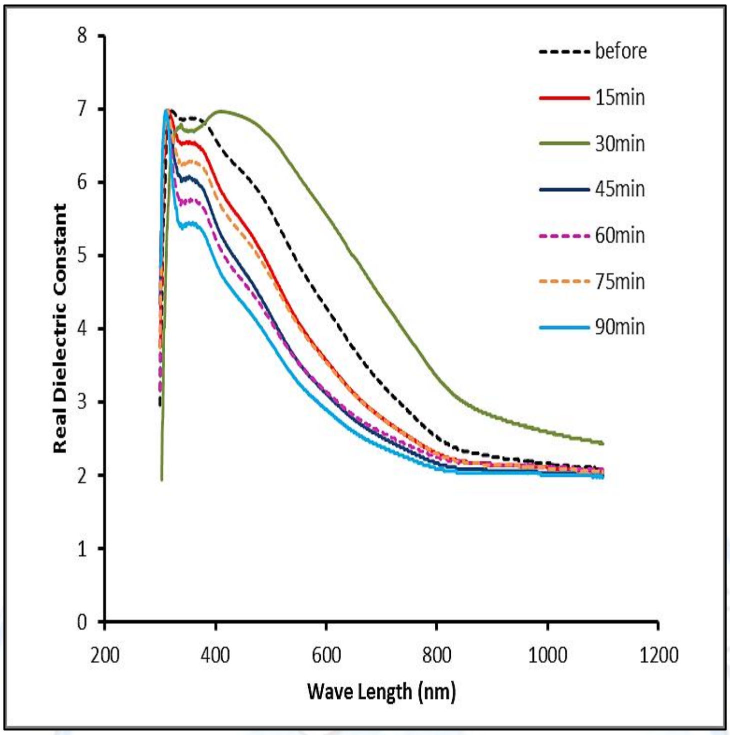

Figure 8: Real dielectric constant of CuO thin films

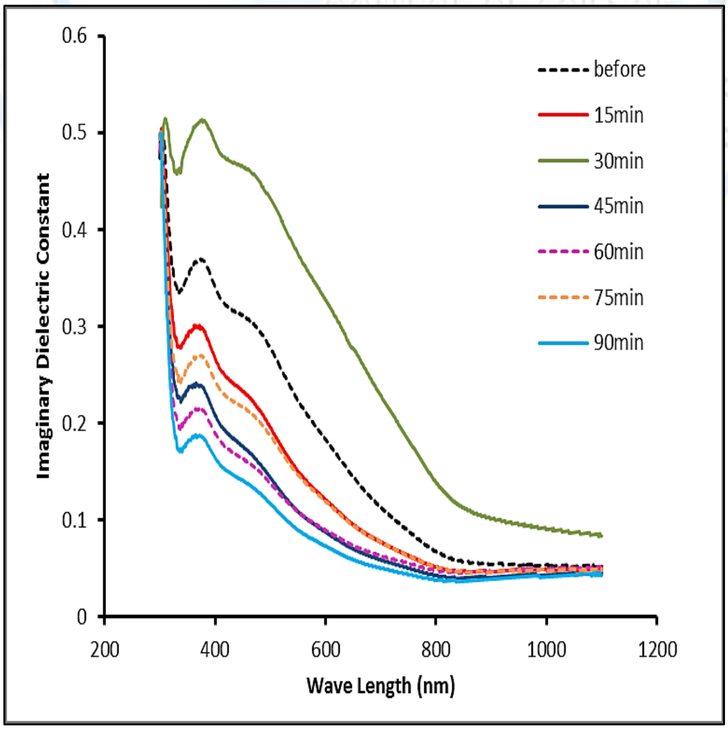

Figure 9: Imaginary dielectric constant of CuO thin films

Figure (10) represents $(\alpha h\upsilon)^2$ curve as a function of energy of photon to calculate the direct energy gap of the CuO thin films, where (h) is Plank constant and (υ) is frequency. It is clear from the figure that values of energy gap of the thin films have exceeded their value before the beta irradiation and the increase in the irradiation time has increased the values of the energy gap except for those thin films which were irradiated at the time periods (30 and 75 min). The difference in the values of energy gaps may be due to the local levels of some of the thin films prepared.

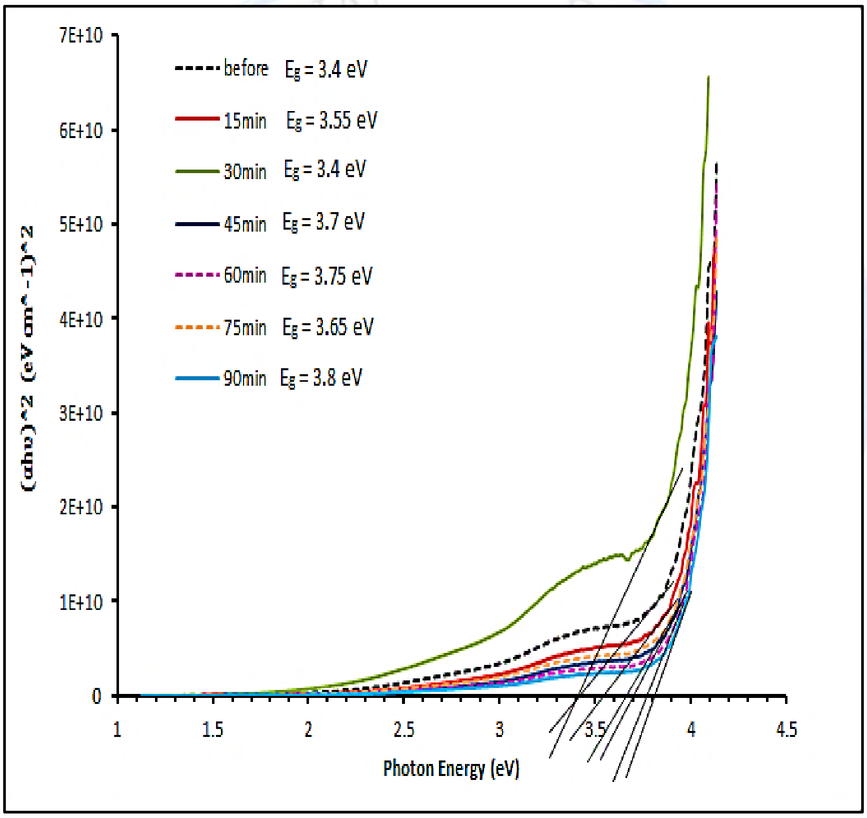

Figure 10: Energy gap values of CuO thin films

Conclusion

1. We can use beta rays to irradiate CuO thin films with different periods of time to improve the optical properties of thin films for various industrial applications.
2. The curves of all the properties and optical constants of CuO thin films irradiated at different time periods show a regular behavior of change with wavelength change except

for those irradiated at (30 and 75) min, this may be due to structural defects in these thin films.

3. Optical outcomes showed that thin films at the preparation conditions of this study have a direct electronic transmission; they have allowed direct energy gaps, and the values of energy gap increase by the increase of periods of irradiation time.

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