Optical characterization of aluminum doped Cadmium selenide thin film irradiated by IR-laser

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Abstract: The optical properties of a cadmium selenide (CdSe) film doped with aluminum (Al) at a rate of (3%) have been studied. It was deposited on glass substrates at 250 K with a thickness of 0.15 μm and a deposition rate of 2± 0.1 m.sec^{-1} using a thermal evaporation technique to create the compound. The optical characteristics of the produced film were investigated after being subjected to irradiation by 50 mW, 1064 nm IR laser for 15 minutes at a distance of 0.5 m. Through monitoring the absorbance and transmission spectra of prepared thin film across the wavelength range (190-1100 nm), the optical energy gap value for the permitted direct electronic transitions was determined, and the absorption and reflectivity coefficients were computed and investigated. The optical experiments included computing the optical constants, and result explained that the optical energy gap decreased from (1.76 eV) to (1.64 eV) following irradiation (extinction coefficient, refractive index, and absorption coefficient).

***Keywords*:** CdSe, thin film, energy band gap, absorbance.

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1. Introduction

Thin film technology is one of the most important technologies that has aided the advancement of semiconductor research [1], as it is considered a suitable means to reach the physical and chemical properties of materials whose properties are difficult to study while they are in their mass form [2]. This technology has made significant and remarkable progress since the last century, especially in the field of electronics. It has been used in the production of many important devices in the field of practical and technological progress. For example, many parts of electronic circuits have been replaced with thin films that give similar characteristics with more efficiency, such as electrical resistors, capacitors, filters, detectors, transistors, micro-electrical connections, and others. It also entered into many important industrial applications that effectively contributed to scientific progress, such as solar cells [3]. The effect of infrared laser (IR-laser) on these properties has been studied due to the importance of the optical properties of the thin films through which the optimal field of use can be determined.

This type of laser, which was discovered in 1961, is considered one of the most important solid-state lasers. Semiconductor lasers differ from ordinary solid-state lasers in the method of energy pumping, and they contain broad bands of energy levels instead of single levels between which transitions occur that participate in the laser emission process. Each band contains a large number of close energy levels, whose presence is not associated with certain atoms but rather the crystalline substance that participates in them, and the increase in the value of the optical gain factor is related to the amount of current that passes through the interface of the semiconductor. With semiconductor lasers (laser diodes), the intensity of the laser beam is modulable by adjusting the electric pumping current, and the devices are compact, inexpensive, and highly efficient [4].

The compound (CdSe) is one of the semiconducting compounds of group (II-VI)[5], as it belongs to the group of chalcogenides. These compounds, which are semiconductors of the donor type (n-type), have a direct energy gap suitable for optical absorption, and this means that the photon energy is directly transformed into creating electron - hole pairs. Additionally, their high optical absorption coefficients are associated with the rate of pair production deep inside the semiconductor, making them a unique type of material. [6]. CdSe compounds can be used in the manufacture of solar cells, light-emitting diodes (LED), and lasers [7]. Doping conductive or semiconductor materials with tiny quantities of aluminum to increase their physical and chemical characteristics is one example of aluminum's usefulness in the modern world. The study of the laser beam effect on thin films gives a clear idea of the changes caused by the irradiation process in the different physical properties of the films. In this paper, the effect of irradiation by (IR-Laser) on the optical properties of the Al-doped (CdSe) composite film deposited by thermal evaporation was studied.

2. Methodology (Experimental Procedure)

Pure (CdSe) films are prepared by placing an amount of powder material that gave the required thickness (2 ± 0.1) μm in a basin made of molybdenum (Mo). The basin has a perforated cover of the same material to prevent volatilization of the film material during the deposition process, according to the eq. [11]:

$$t = \frac{m}{4\pi\rho r_0^2} \ldots\ldots\ldots\ldots\ldots (1)$$

Where:

m: the required material weight in (gm) units, t: film thickness (cm), ρ: material density (g/cm^3), r_o: the distance from the basin to the base (cm).

The deposition process begins by passing an electric current through the basin when the pressure reaches its maximum value (5x10^{-5} mbar). The increase in the current amount must be gradual and slow in order to achieve thermal equilibrium. The pressure gauge must be monitored because a rapid rise in temperature leads to a significant increase in pressure inside the vacuum chamber. Material deposition on glass bases at a temperature of (250 K) and a rate of (2 m/sec^{-1}) results in a pure (CdSe) film. In order to ensure the completion of the crystallization process and to prevent oxidation of the prepared film or the occurrence of cracks in it, the samples are left in the evaporation chamber until their temperature reaches room temperature after the completion of the deposition process on the glass bases. The pure film was doped with aluminum using another basin of molybdenum (Mo), where the aluminum material that achieves the required weight ratio for doping (3%) of the weight of (CdSe) is placed. To assure the success of the diffusion process, the doped aluminum sample was placed in an electric vacuum oven at a temperature of (473 K) for two hours. By measuring the change in weight of the glass substrate before and after film deposition, the gravimetric approach was utilized to determine the produced film thickness. A sensitive balance whose sensitivity reaches four decimal places of the type (Sartorius BP 3015, Max 303 gm) was used. The thickness of the prepared film was (0.15 μm).

The CdSe:Al film was exposed by 50 mW operating at 1064 nm for about 15 min . the distance between the CdSe:Al film and laser source was 0.5 m.

3. Results and Discussion

As shown in Figure (1), the absorbance spectrum (A) of a (CdSe:Al) film doped with 3% aluminum was calculated using a UV-V is Spectrophotometer within the wavelength range (190-1100) nm before and after IR-Laser irradiation.

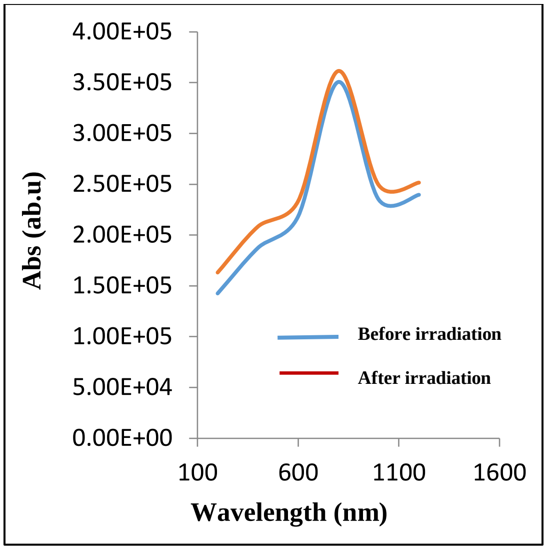


Fig (1): The relation between absorbance and wavelength

It is observed in Figure (1) that the absorbance values increase in terms of the wavelengths associated with the photons before and after irradiation. The absorbance increases with irradiation, especially in the range of wavelengths located within the visible and near-infrared regions of the spectrum of electromagnetic radiation (500-800) nm. This is due to the density of local levels formed by the excited material atoms as a result of irradiation. These levels act as auxiliary levels for the transfer of electrons that absorb photons with energies less than the value of the optical energy gap of the prepared film.

Figure (2) shows the transmittance spectrum as a function of wavelength of (CdSe:Al) film before and after irradiation. The above-mentioned figure shows that the transmittance values decrease in general as the wavelength of the incident electromagnetic radiation increases.

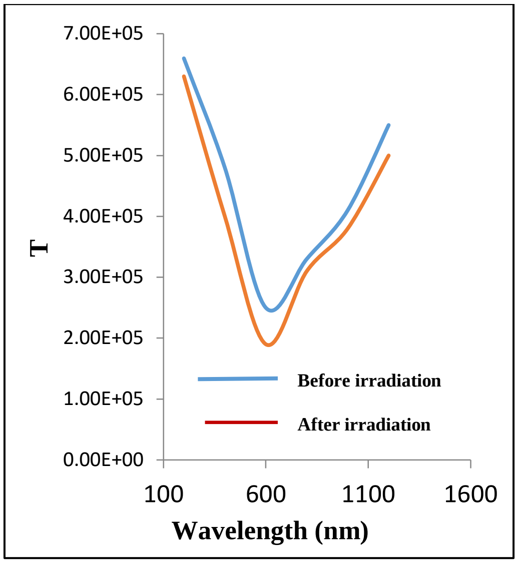


Fig (2): The relation between transmittance and wavelength

The reflectivity (R) was calculated from the absorption and transmittance spectra according to the following equation:

$$A+R+T=1 \quad \ldots\ldots\ldots\ldots\ldots\ (2)$$

Figure (3) shows that reflectivity increases with increasing wavelength before and after irradiation, and that its value increases after irradiation when compared to pre-irradiation values.

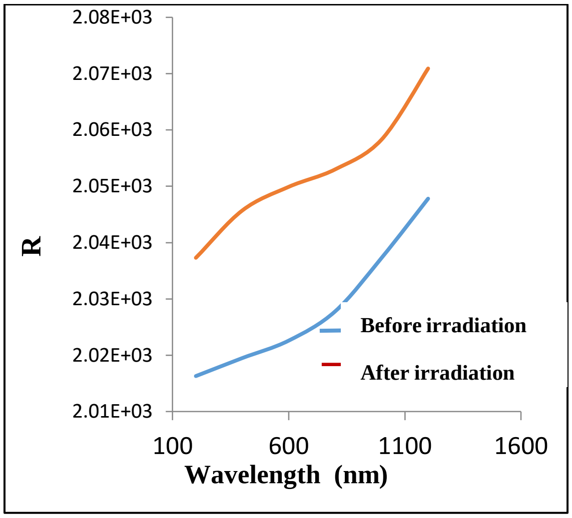


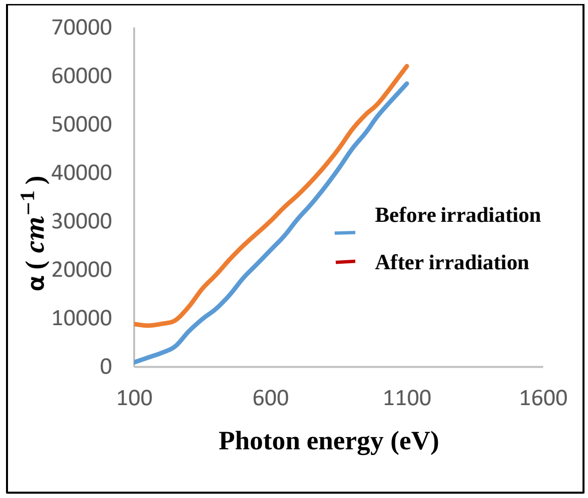
Fig (3): Reflectivity as a function of wavelength of (CdSe:Al) film before and after irradiation.

The optical absorption coefficient (α) was calculated from the absorption spectrum (A) of the prepared film using the following equation [8]:

$$\alpha = 2.303 \frac{A}{t} \text{..........(3)}$$

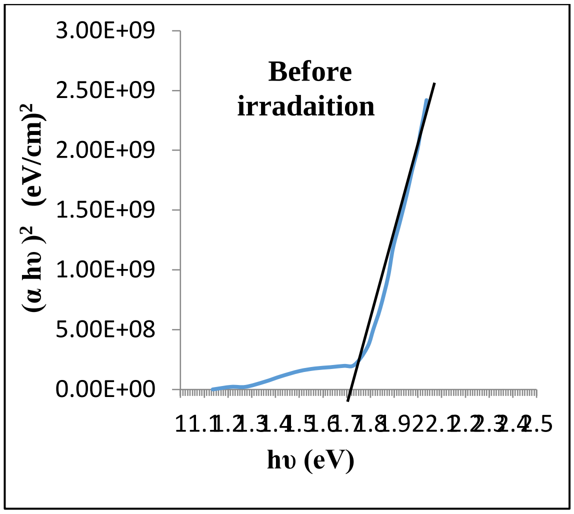
when A represents the absorbance, and t is the thickness of the film.

From Figure (4), the similarity of the curved behavior of the membrane was observed in the two cases before and after irradiation, and all values of the absorption coefficient (α) were greater than (10^4 cm^{-1}), meaning that all transitions are direct. As it is noticed that the values of (α) gradually begin to increase with the increase in the energies of the photons and that (α) increases significantly after the irradiation process and reaches its maximum values, this leads to a high probability of direct electronic transitions.



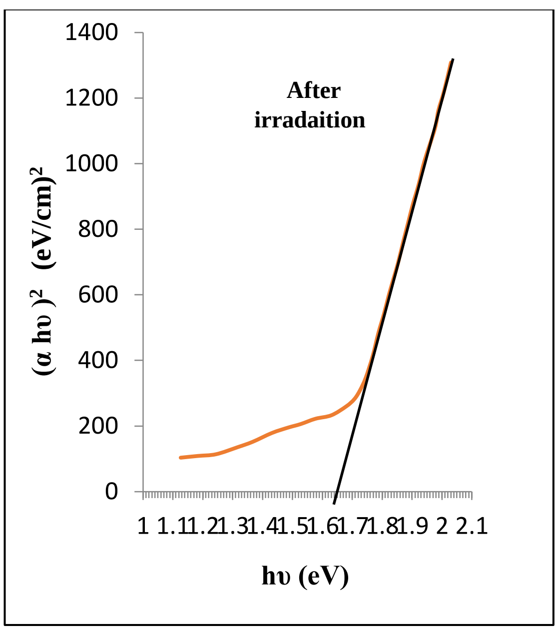
Fig(4): Absorption coefficient as a function of Photon Energy.

The direct optical energy gap of the CdSe:Al film before irradiation was calculated from Figure (5-a), and its value was (1.76 eV) [9].



Fig(5-a): (α hυ)^2 versus Photon Energy before irradiation

Figure (5-b) shows the reduced direct optical energy gap (1.64 eV) of the CdSe:Al film after the irradiation process.



Fig(5-b): (α hυ)^2 versus Photon Energy after irradiation

Figure (6) shows the change in the values of the extinction coefficient (K) for the CdSe:Al film as a function of the wavelength (λ) before and after irradiation. It was observed that the values of (K) increase rapidly for the two cases before and after the irradiation, and this rapid increase results from the occurrence of direct transitions between the valence and conduction bands due to the density of the levels of the substance at those energies. It was also noticed that the values of (K) begin to gradually increase after the irradiation process, because of these values are directly dependent on the values of (α), according to the relation [10]:

$$K=\frac{\alpha\lambda}{4\pi} \text{ ....(4)}$$

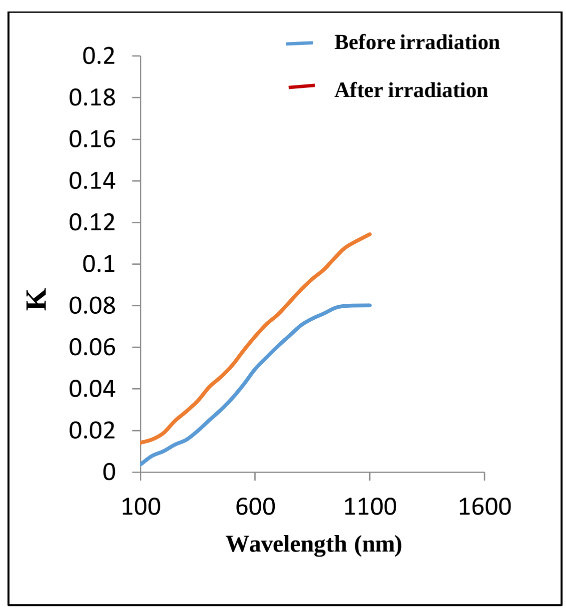


Fig (6): Extinction coefficient (K)

as a function of wavelength for CdSe:Al

Figure (7) shows the change in the refractive index (n) values of the CdSe:Al film as a function of the wavelength before and after irradiation. It was noticed that the higher value of the refractive index of the film prepared before irradiation is equal to (2.4) at (750 nm), then it decreases after the irradiation process to become (2.28) at the wavelength (700 nm), meaning that the refractive index of the film after the irradiation process has decreased toward short wavelengths.

The decrease in the values of (n) after the irradiation process may be due to the fact that the refractive index depends on the polarity of the material. As the polarity of the material increases, the process of delaying the rays inside it becomes greater. In fact, the polarity depends on the degree of crystallinity and the granular size of the prepared film [11]. As a result, it is possible that the laser beams and the associated thermal effect increased the size of the granules that comprise the film, causing its refractive index to decrease [10].

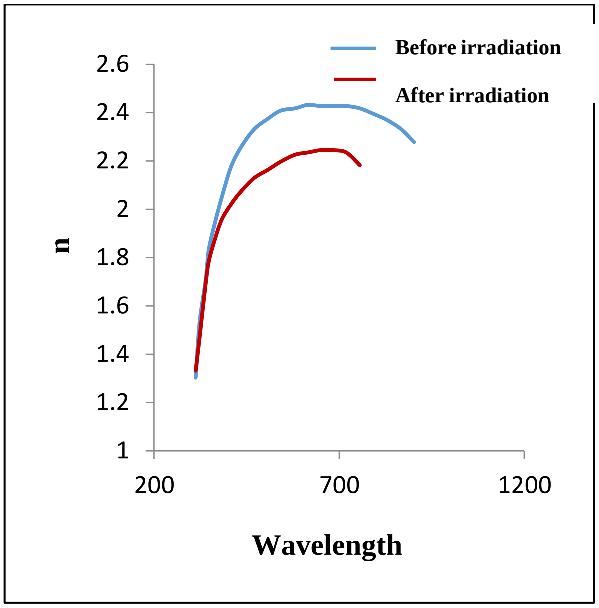


Fig (7): Refractive index as a function of wavelength for CdSe:Al

4. Conclusion

This study showed that the irradiation process by IR-Laser of a CdSe:Al film for a period of 15 min, led to a change in the optical properties of the film. The irradiation process clearly resulted in a decrease in the optical energy gap value, an increase in the values absorption coefficient and extinction coefficient, and a decrease in the refractive index for all wavelength values.

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References

[1] Prashanth, P., 2010, Presentation of Thermal Evaporator, Indian Institute of Science Publication.

[2] Singh, R. S., Bhushan, S., Singh, A. K. Deo, S. R., 2011, Characterization and Optical Properties of CdSe Nano-Crystalline Thin Films, Digest J. Nanomater. Biostructures, 6(2), 403-412.

[3] Whitten, K.W., Davis, R.E., Davis, R.E., Chemistry, 2014, M. Larry Peck, George G. Stanley 10th Edition.

[4] Gnatenko, Yu.P., Bukivskij, P.M., Faryna, I.O., Opanasyuk, A.S., Ivashchenko, M.M., 2014, Photoluminescence of high optical quality CdSe thin films deposited by close-spaced vacuum sublimation, J. Lumin. 146, 174–177.

[6] Abdulmunem, O. M., Mohammed, A., Mohammed, J., Hassan, E.S., 2020, Optical and structural characterization of aluminum doped zinc oxide thin films prepared by thermal evaporation system, Opt. Mater.J. 109 , DOI: 10.1016/j.optmat.2020.110374.

[7] Sarmah, K., Sarma, R., Das, H. L., 2008, Structural Characterization of Thermally Evaporated CdSe Thin Films, Chalcogenide Letters, 5 (8) 153 –163.

[8] Betkar, M.M., Bagde, G.D., 2012, Structural and optical properties of spray deposited CdSe thin films, Materials physics and mechanics, 14, 74 -77.

[9] Ibrahim, W.N., 2012, Opticelectronic Properties Of CdSe/Si Heterojunction, Eng.&Tech.Journal, 30, (12) 2138-2149.

[10] Hatch, J.E., Aluminum Properties and Physical Metallurgy, 2005, American society for metals, 10th edition.

[11] Kittel, Ch., Introduction Solid State Physics, 2005, John Wiley & Sons, 8th edition.

[12] Dimitrijev, S., Understanding Semiconductors Devices, 2000, Oxford university press, 2nd edition.