



# Essential tips for enhancing the opto-electrical performance of CdSe (NPs)/ Epoxy resin

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## ABSTRACT

The current paper presents the advantages of the addition of CdSe nanoparticles (NPs) with different ratio (0, 0.25, 0.5, 0.75, 1.0, 1.25 and 1.5%) on opto-electrical properties of Epoxy resin [ER]. The organometallic method was used for preparing CdSe (NPs) in epoxy matrix solution. The morphology of the obtained nanocomposites (NCs) was characterized in terms of X-Ray diffraction, scanning electron microscope (SEM), Energy-dispersive X-ray spectroscopy (EDX), optical and dielectric properties. The UV-Visible absorption spectra for (NCs) were collected in the wavelength range (250–700 nm) and were analyzed. The absorption coefficient ( $\alpha$ ), optical energy gap ( $E_g$ ), and refractive index ( $n$ ) showed a clear dependence on the CdSe NPs concentration. Increasing the ratio of CdSe NPs led to the increase of the values of the absorption coefficient ( $\alpha$ ). Moreover, the results also demonstrate that the value of the direct optical band energy for [ER] was decreased from 3.40 eV to 2.69 eV with increasing the CdSe (NPs) concentration from 0.25% to 1.50% in the [ER]. It was also observed that the optical energy gap ( $E_g$ ) is correlated with the optical electronegativity ( $\Delta\chi_{opt}$ ) and is affected by the increase of CdSe NPs ratio as well. The refractive index ( $n$ ), the dielectric constant ( $\epsilon$ ) and optical dielectric constants ( $\epsilon_{opt}$ ) increased with the increase in CdSe NPs content. Furthermore, the optical conductivity ( $\sigma_{opt}$ ), increases with the increase CdSe NPs content. Finally, the variation of the electronic polarizability ( $\alpha_e$ ), the dielectric susceptibility ( $\chi_e$ ), transmission coefficient (T) and reflection loss ( $R_L$ ) with the increase of CdSe NPs ratio in [ER] were analyzed. In this work we highlight the significance of the interrelations between the above defined parameters, which were successfully predicting their effect on the performance of [ER] upon the addition of CdSe NPs.

## 1. Introduction

A great attention has been given in recent years, to the development of polymer-semiconductor nanocomposite (NCs) as they exhibit a new generation of semiconductor nanoparticles (NPs) with a unique physical and chemical properties [1–4]. Among various types of polymeric matrices Epoxy resin is the most polymer matrix used for advanced nanocomposite. Epoxy resin [ER] exhibit high stiffness and is widely used as an insulation in aggressive environmental conditions. Corrosion and service life of the structure of [ER] is often can be delayed by providing some protection layers [5,6].

Optical or unfilled epoxy adhesives are commonly used for providing protective coating in several optical applications [7,8]. Optical epoxy provides structural integrity while resisting many types of environmental factors such as, humidity, temperature and sterilization [9,10].

Understanding the protective ability of coating offers one avenue to monitor the statue of coating in order to achieve prediction. The coating protective are efficient for enhancing the [ER] durability performance [11].

Polymer-semiconductor nanocomposites are new generation of materials that exhibit enhanced properties, which forward with increasing the content of nanoparticles. They offer more advantages and attracting scientific and industrial interest due to their unique characteristics and their remarkable changes in their optical and electrical properties. The CdSe NPs is a representative material with a wide range of applications in various electronic devices. Transparent [ER] have been employed as a packing material because of their low-water absorption and high-glass transition temperature [12].

The addition of CdSe NPs to pure [ER] can improve the stability, dispersion strength of the material. On the other hand, the surface of

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CdSe NPs could be modified by the polymeric matrix via the interaction between the CdSe NPs with [ER] [13,14].

In this work, CdSe/Epoxy nanocomposites (NCs) were prepared by incorporating different percent of CdSe NPs into [ER]. The effect of CdSe NPs addition was characterized by X-Ray diffraction, Scanning electron microscope (SEM), Energy-dispersive X-ray spectroscopy (EDX) and the UV-Visible absorption spectra.

## 2. Methods and materials

### 2.1. Materials

The type of epoxy resin [ER] used as a matrix material in the present work is from (CMB) company Egypt, while Cadmium oxide (CdO 99.99%), trioctylphosphine oxide (TOPO 99.99%), Selenium (Se 99%), Hexadecylamine (HDA 98%), Oleic acid ( $\geq 99\%$ ), Mercapto propionic acid (MPA  $\geq 98\%$ ) were obtained from Sigma-Aldrich. Trioctylphosphine (TOP 97%) was purchased from Fluka.

### 2.2. The devices used for measurements

The particle size was identified by Transmission Electron microscope (HRTEM, JEOL JEM-2100 operated at 200KV with high resolution Gatan CCD bottom camera, Orius SC200). The X-ray diffraction patterns of the pure Epoxy resin [ER] and CdSe/Epoxy resin NCs were recorded in reflection mode using (Rigaku, Miniflix 600). The elemental composition of Epoxy resin and CdSe/Epoxy resin NCs were investigated by the scanning electron microscope (SEM) (JOEL-JSM Model 5600) and Energy-dispersive X-ray spectroscopy (EDX) (Shim ADZU diffractometer type XRD 6000). The optical absorbance was measured using a V-670 Jasco double-beam from 190 to 2700 nm. Spectrophotometer, which utilizes a unique, single monochromator design covering a wavelength range.

### 2.3. Preparation of CdSe nanoparticles with MPA capping

CdSe NPs were prepared according to the organometallic method

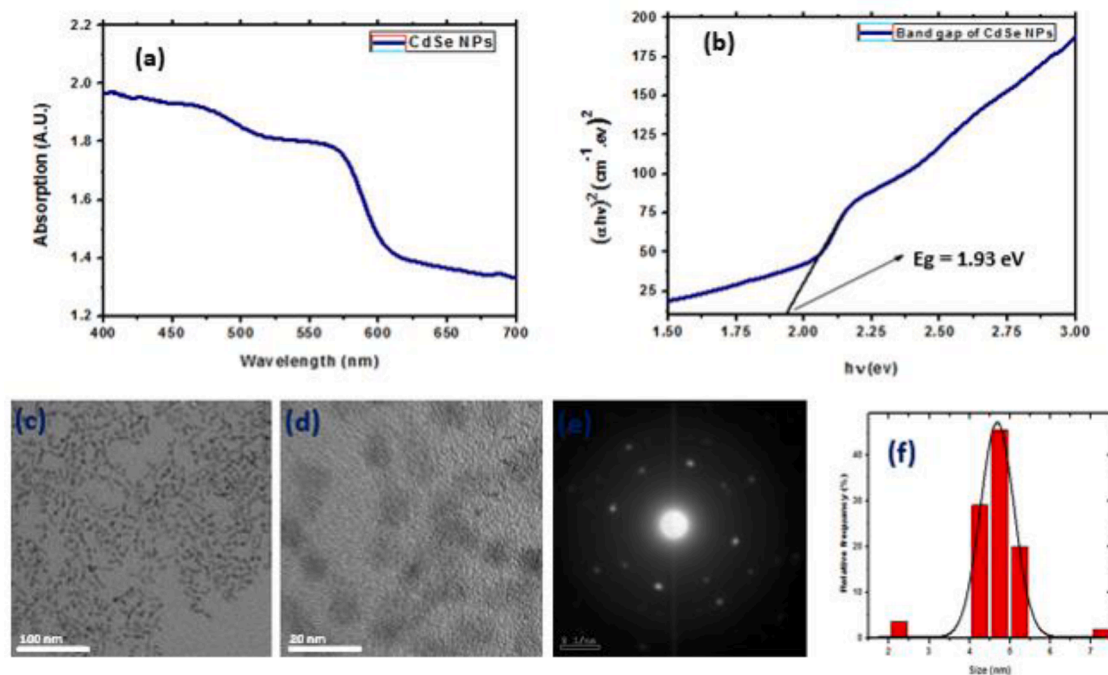
[15], in which we used 0.3 g (2.34 mmol) of CdO in 2 g (0.701 mol) Oleic acid at 170 °C. A mixture of 2 g (4.77 mmol) of TOPO and 2 g (8 mmol) of HDA is added to the solution and held at 180 °C for nearly 5 min. Meanwhile, the selenium was synthesized by dissolving a 0.3 g (3.79 mmol) of selenium in 4 mL (8.8 mmol) of TOP. The Cadmium solution is loaded to a tri-neck flask and heated to 130 °C, followed by the injection of the selenium solution dropwise to the reaction mixture and heating to 220 °C for 15 min, during this time CdSe *in-situ* indicated by the change in color in the reaction mixture. The heating mantle is removed to allow cooling of the three-neck flask to 100 °C then reinstalled to keep the bottle flask at 100 °C for approximately 5 min. The reaction is then rapidly quenched by cooling the solution in a water bath. CdSe NPs are washed via dispersion in hexane and ethanol, followed by centrifugation. We repeated the washing steps three times, and upon completion, all solid residues are re-dispersed in hexane. To obtain the MPA coated nanocrystals, CdSe NPs (about 50 mg/ml) coated with TOPO, HDA and Oleic acid was added in 37 mg/ml of MPA and heated at 70 °C for 24 h until the nanocrystals were totally dispersed in MPA to get a clear solution. A copious number of hexanes was added to precipitate the nanocrystals, and the CdSe NPs were collected by using centrifugation. After two repetitions of dissolution/precipitation with MPA/hexanes, the surface capping ligands were replaced by MPA [16].

The UV-vis absorption spectrum of CdSe NPs is shown in Fig. 1(a). From the spectra, it is observed that the absorption peak at 550 nm for CdSe NPs. Using Tauc's equation the direct/indirect optical energy gap could be deduced by plotting  $(\alpha h\nu)^2$  of CdSe NPs versus  $h\nu$  [17,18], as shown in Fig. 1(b).

$$\alpha h\nu = A(h\nu - E_g)^r \quad (1)$$

where  $A$  is constant,  $\alpha$  is the optical absorption coefficient,  $h\nu$  is the energy of the incident photons,  $h$  is Planck's constant and  $r$  value depends on being either direct or indirect optical transition. In case of CdSe NPs, the transition is direct allowed semiconductor and  $r$  value is chosen to be 2 [18].

The bandgap ( $E_g$ ) value of CdSe NPs can be determined from the extension intercept of the linear part of the plotted  $(\alpha h\nu)^2$  versus  $(h\nu)$  plot to the x-axis, as indicated in Fig. 1(b). The resultant value of ( $E_g$ ) for



**Fig. 1.** (a) UV-vis absorption of CdSe NPs, (b) Presents  $(\alpha h\nu)^2$  versus  $(h\nu)$  plot for CdSe NPs, (c,d) TEM analysis of particle size for CdSe NPs with low and high magnification respectively. (e) SAED pattern of CdSe NPs and (f) histogram distributions of CdSe NPs.

CdSe NPs is found to be equal (1.93 eV).

The transmission electron microscope (TEM) was used to determine the morphological structure of CdSe NPs as seen in Fig. 1(c–f). A spherical morphology can be observed as gray color in the image of CdSe NPs as shown in Fig. 1(c and d). The Selected Area of Electron Diffraction (SAED) pattern for the CdSe NPs in the HR-TEM image was shown and the SAED pattern of the CdSe NPs indicated ring patterns with intense spots showing that the CdSe NPs are polycrystalline as shown in Fig. 1(e). The particle size histogram Fig. 1(f) shows that the average particle size of CdSe NPs was found to be 4.72 nm, which is in a good agreement with several literature reported studies on CdSe NPs [19]. The effective mass approximation (EMA) model is used for calculating the particle size of the CdSe NPs, according to the equation [20].

$$E_{gn} = E_{gb} + \frac{h^2}{8R^2} \left[ \frac{1}{m_e} + \frac{1}{m_h} \right] - \frac{1.8e^2}{4\pi\epsilon\epsilon_0R} \quad (2)$$

where,  $E_{gn}$  is the electronic bandgap for CdSe NPs,  $E_{gb}$  is the bandgap of bulk CdSe (1.74 eV),  $R$  is the average radius of nanoparticles.  $m_e$  is the electron effective mass (0.13  $m_0$ ),  $m_h$  is the hole effective mass (0.45  $m_0$ ),  $m_0 = 9.11 \times 10^{-31}$  Kg and  $\epsilon$  is the dielectric constant for CdSe NPs [19]. The average particle size of CdSe NPs by this method was 4.70 nm. The results obtained from TEM images are in consistent with the calculated values of the average particle size estimated via (EMA).

#### 2.4. Synthesis of CdSe/Epoxy resin nanocomposites

For the preparation of CdSe/Epoxy resin nanocomposites (NPs) we used the following technique: Firstly the epoxy resin with a certain weight percent of CdSe NPs were mixed together in plastic mold, and stirred mechanically using SUPERMIX homogenizer (model DEPOSE) at 1000 r.p.m for twenty minutes in room temperature; Secondly the hardener was added to the mixture by ratio 1:2 by weights and then stirred mechanically again for five minutes; Then the CdSe /Epoxy (NCs) slurry was poured in silicon dies; Finally the mixture was allowed to fully hardened at room temperature. Nanocomposites were prepared by dispersing (0, 0.25, 0.50, 0.75, 1.00, 1.25 and 1.50 vol.%) of CdSe nanoparticles (NPs). The experimental set-up of the CdSe/ Epoxy resin (NCs) technique is shown schematically in Fig. 2.

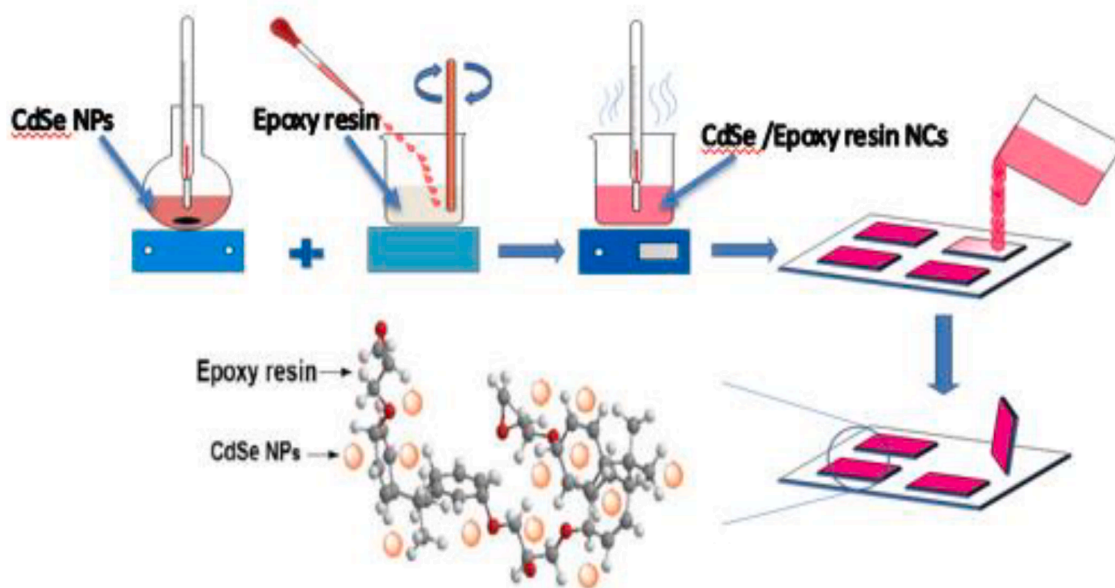


Fig. 2. Schematic diagram for the experimental steps for the preparation steps of CdSe/Epoxy resin nanocomposite (NCs).

### 3. Results and discussion

#### 3.1. Structural and morphological properties

##### 3.1.a. X-ray diffraction measurements

The XRD pattern for the Epoxy and the CdSe/Epoxy resin NCs (0, 0.25, 0.5, 0.75, 0.10, 1.25, and 1.5% CdSe ratio) are given in Fig. 3. There is an obvious broad peak focused around  $2\theta = 20^\circ$ . This confirms the amorphous nature of the materials under investigation. No significant difference between the pure Epoxy film with all the other films of CdSe/Epoxy resin NCs. The observe results suggest that the Epoxy is largely amorphous, so the CdSe NPs diffraction peaks disappear due to the small particle size of CdSe NPs. This is in coincides with the results given by [20].

##### 3.1.b. SEM micrographs and EDX analysis

The (SEM) image has been used to explore the surface morphology and the structure of the studied samples. SEM image of Epoxy resin pure, (0.75%) CdSe /Epoxy resin NCs and (1.5%) CdSe /Epoxy resin NCs is presented in Fig. 4(a,b,c) respectively. As observed a smooth fracture

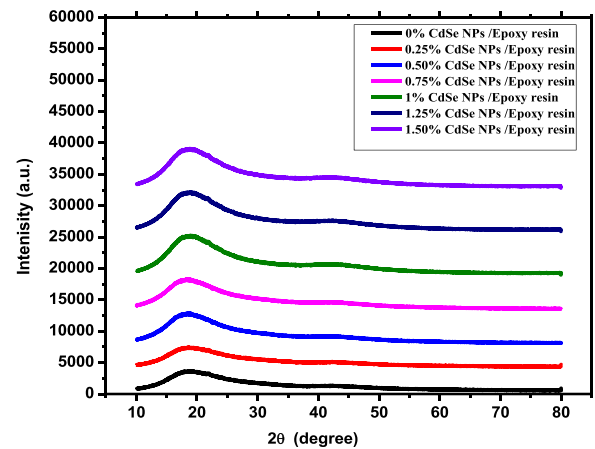


Fig. 3. X-ray pattern of the Epoxy and the CdSe/Epoxy resin nanocomposite (NCs) samples.

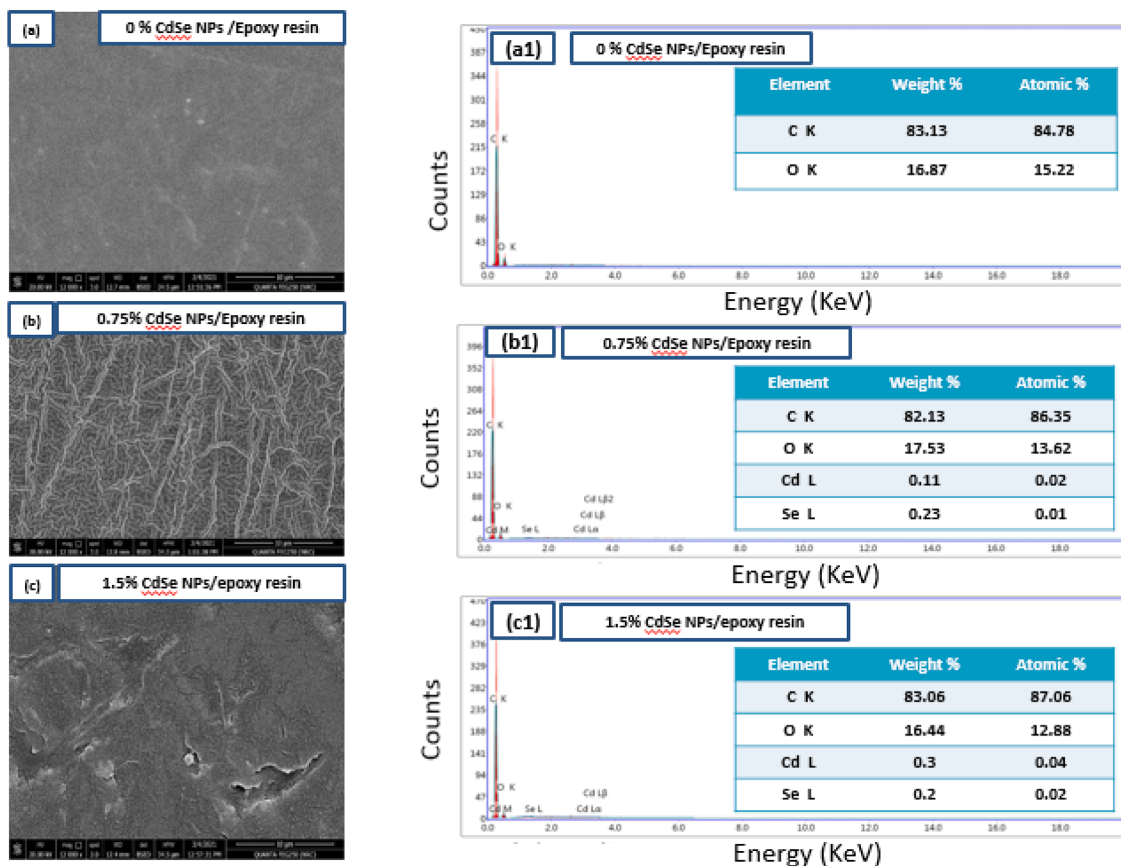


Fig. 4. (a,b,c) and (a1,b1,c1) presents the SEM fracture surface samples and EDX for pure epoxy resin, 0.75% CdSe / Epoxy resin NCs, and 1.5% CdSe / Epoxy resin NCs respectively, as a representative example.

surface is seen in Fig. 4(a) for pure Epoxy, while Fig. 4(b) while increasing the CdSe to (0.75%) the fracture surface became cloud-like and rough, and by increasing the CdSe NPs content to (1.5%) as seen in Fig. 4(c), more roughness in the fracture of the surface is observed. The dispersed cracks, indicate that CdSe NPs has a high specific surface area and acts as an obstacle to crack propagation Thus the addition of CdSe NPs enhances the strength of pure Epoxy.

On the other hand, an energy-dispersive X-ray (EDX) spectroscopy connected to the FE-SEM was used to the elemental analysis of the samples as shown in Fig. 4(a1, b1, c1). Energy lines are clearly observed for the elements C, O, Cd and Se in the EDX spectra. The peaks percentages and the weight of each element are listed in the inset of Fig. 4 (a1, b1, c1). This finding confirms the successful synthesis of CdSe / Epoxy resin NCs.

### 3.2. Absorption performance of CdSe / Epoxy resin NCs

Optical properties of materials are essential for the advancement of optical technology and several applications. Absorption spectra is useful in chemical analysis because of its specificity and its quantitative nature. Moreover, based on absorption the compounds are allowed to be distinguish from one another in a mixture, making absorption useful in wide variety of application. Fig. 5(a) shows the absorption spectra for pure [ER] and CdSe (NPs)/[ER] NCs with different concentration. The experimental results show that the absorption is obviously affected by the addition of CdSe NPs. Increasing the concentration of CdSe NPs led to increase the values of absorption. The second derivative in the range (250 nm to 500 nm) chosen from the accurate position of the peaks given from Fig. 5(b) was used for determining the accurate peak position of pure [ER] and CdSe/[ER] NCs as seen in Fig. 3(c). As seen a shift in the absorption peak from 275 nm to 330 nm is observed with increasing the

concentration ratio of CdSe NPs.

The absorption coefficient ( $\alpha$ ) was calculated using the equation given in details in [21–23].

$$\alpha = 2.303A/t \quad (3)$$

where  $A$  is the absorbance and  $t$  are the thickness of the samples.

The addition of CdSe NPs with different concentration to Epoxy resin, increases the absorption coefficient as seen in Fig. 6. The optical band gap values were obtained by extrapolating the linear part of the curve at  $(\alpha h\nu)^2 = 0$ , given in Fig. 7, for Pure Epoxy and Epoxy with different concentration of CdSe NPs and are given in Table 1. The inset graph in Fig. 7 shows that the optical energy gap is highly dependent on the concentration of CdSe (NPs) in Epoxy resin.

The values of the energy gap  $E_g$  decreased from 3.60 to 2.69 eV with increasing the concentration of CdSe NPs from 0.25% for the lowest concentration to 1.50% for the highest one. The shrinkage in the optical band gap can be attributed to the created localized energetic states due to the increase of the CdSe (NPs) filling between energetic bands of the Epoxy resin. Our results are in agreement with the reported ones [7–23].

The optical electronegativity  $\Delta\chi_{opt}$  indicates the nature of bonding in solids and it represents the utility of an atom's capability to attract an electron for bonding. There is hardly any information in the literature on the evaluation of optical electronegativity basing on the optical energy gap. The correlation between  $E_g$  and  $\Delta\chi_{opt}$  is given by using the empirical formula [24].

$$E_g = 3.72(\Delta\chi_{opt}) \quad (4)$$

As observed the values  $\Delta\chi_{opt}$  listed in Table 1 decreases with the decrease of  $E_g$ , and demonstrate that both parameters decreases increasing the CdSe NPs% in pure Epoxy. The value of the refractive



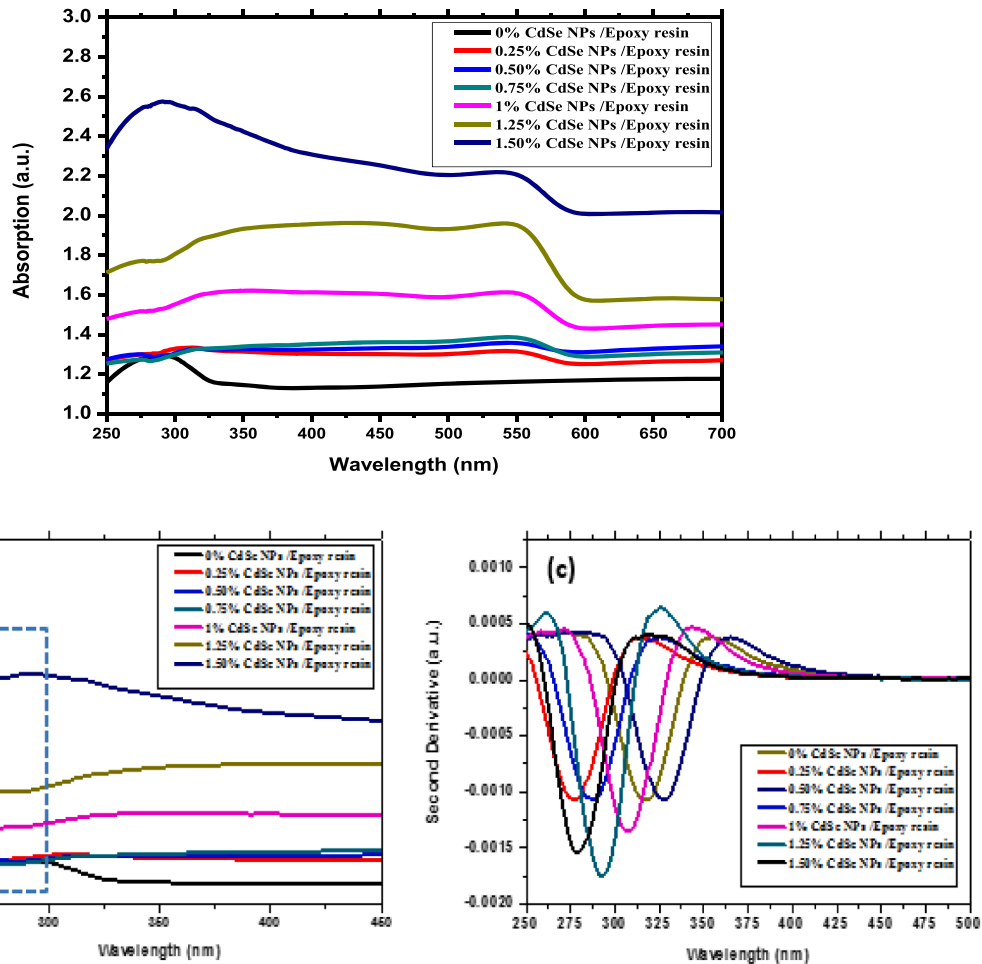


Fig. 5. (a,b) shows the absorption spectra with different scale, (c) the second derivative of different concentration of CdSe NPs from 0 to 1.5%.

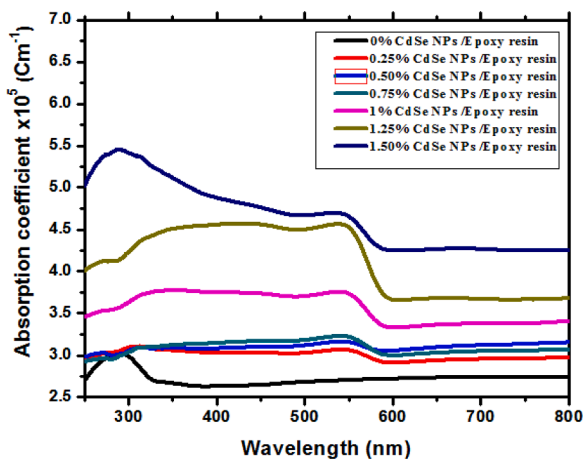


Fig. 6. Variation of absorption coefficient for Epoxy resin pure with different concentration of CdSe NPs versus wavelength.

index (n) was calculated by using the  $E_g$  value based on the following equation [25].

$$n = k [E_g]^C \quad (5)$$

where  $K = 3.3668$  and  $C = 0.32234$ . According to the above relation the refractive index n was determined for pure Epoxy resin and with the addition of CdSe NPs with different ratio into pure Epoxy and are

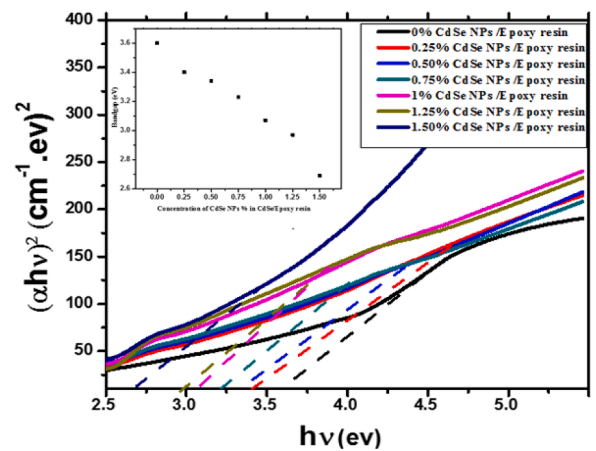


Fig. 7. Dependence of  $(\alpha hv)^2$  on the photon energy  $h\nu$ , and the inset of figure is the relation between concentration of CdSe NPs in CdSe/Epoxy resin with bandgap ( $E_g$ ).

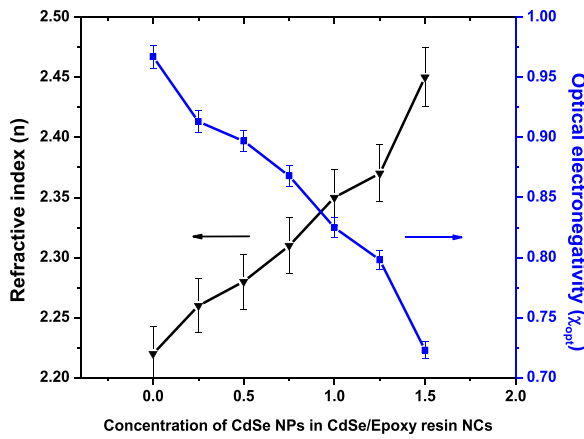
presented in Table 1.

An interesting correlation between optical electronegativity and refractive index can be observed as seen in Fig. 8. It can be observed that as the optical electronegativity decreases the refractive index increases with the concentration increase of the CdSe (NPs) in pure Epoxy. The trend highlights the significance of the interrelation between the energy gap, optical electronegativity and refractive index. Furthermore, the

**Table 1**

Optical energy gap (Eg), optical electronegativity ( $\Delta\chi_{opt}$ ), refractive index (n), dielectric constant ( $\epsilon$ ) and optical dielectric constant ( $\epsilon_{opt}$ ) for different ratio of CdSe NPs on Epoxy resin NCs.

Samples	Energy gap (eV)	$(\Delta\chi)_{opt} \pm 0.02$	n $\pm 0.04$	$\epsilon \pm 0.1$	$\epsilon_{opt} \pm 0.1$
0%CdSe NPs / Epoxy resin	3.60	0.967	2.22	4.92	3.92
0.25% CdSe NPs / Epoxy resin	3.40	0.913	2.26	5.10	4.10
0.50% CdSe NPs / Epoxy resin	3.34	0.897	2.28	5.19	4.19
0.75% CdSe NPs / Epoxy resin	3.23	0.868	2.31	5.33	4.33
1% CdSe NPs / Epoxy resin	3.07	0.825	2.35	5.52	4.52
1.25% CdSe NPs / Epoxy resin	2.97	0.798	2.37	5.61	4.61
1.50% CdSe NPs / Epoxy resin	2.69	0.723	2.45	6.00	5.00



**Fig. 8.** Dependence of refractive index, and optical electronegativity on CdSe (NPs) concentration.

increases of (n) as the concentration of CdSe (NPs) increases up to 1.5 in Epoxy resin, is obviously appears since the CdSe NPs play the role of scattering and reflecting centers in Epoxy resin matrix. Our results are in agreement with further reported ones [7–22].

The dielectric constant ( $\epsilon$ ) and the optical dielectric constant ( $\epsilon_{opt}$ ) were calculated using the determined value of the refractive index (n) as mentioned in the below expressions:

$$\epsilon = n^2 \tag{6}$$

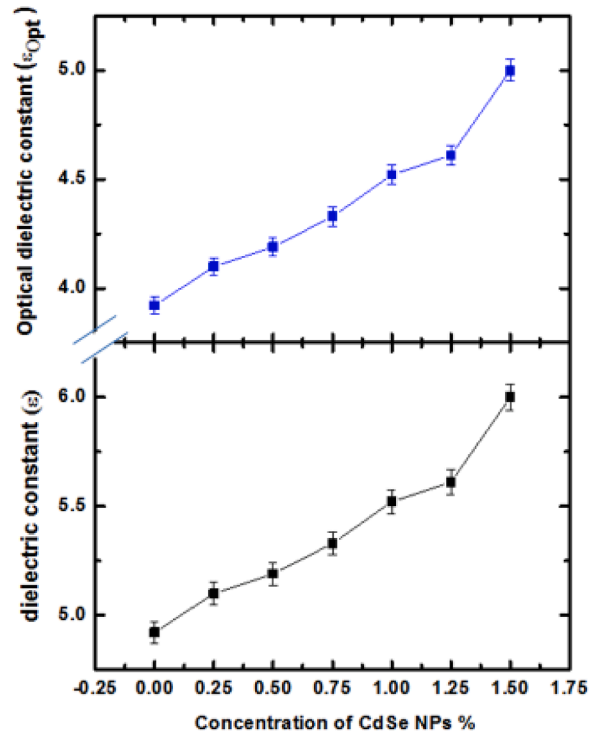
$$\epsilon_{opt} = \epsilon - 1 = n^2 - 1 \tag{7}$$

The dielectric and optical dielectric constants as presented in Table 1, increased from 4.92 to 6.00 and from 3.92 to 5.00 with the increase of CdSe NPs ratio in pure Epoxy. The Dielectric and optical dielectric constants variations with CdSe NPs ratio are given in Fig. 9.

Materials with high dielectric constants can store more energy compared with those with low dielectric constants. The linear electric or dielectric susceptibility ( $\chi_e$ ) is a dimensionless proportionality constant which is responsible for indicating the degree of polarization of a dielectric material. It measures the ability of a material to become completely polarized. The electrical susceptibility was calculated from the dielectric constant using the relation given by [26].

$$\chi_e = \frac{\epsilon - 1}{4\pi} \tag{8}$$

The average electronic polarizability ( $\alpha_e$ ) of ions is considered to be



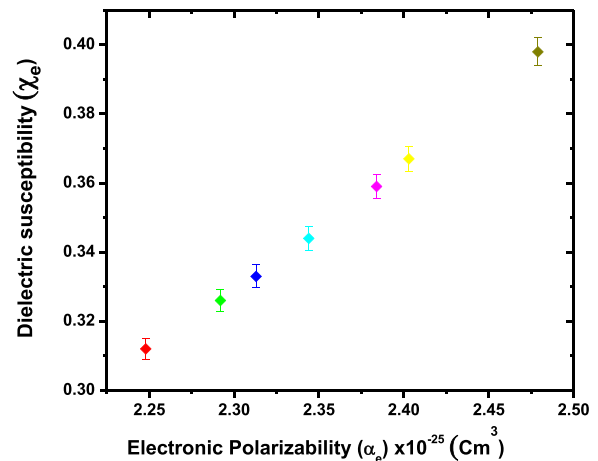
**Fig. 9.** (Dielectric and optical dielectric) constants at different concentration of CdSe NPs.

one of the most significant characteristics of any material. It is closely related to the applicability in the field of optics and electronics. It was found that, optical non-linearity is caused by the electronic polarization of the material as its exposure to intense light beams. Hence, the nonlinear response of the material is governed by the electronic polarizability [27–30]

The electronic polarizability ( $\alpha_e$ ) can be evaluated by substituting the obtained value of (n) into this equation [31]:

$$\alpha_e = \frac{3(n^2 - 1)}{4\pi N_A (n^2 + 2)} \tag{9}$$

Where (n) is the refractive index and ( $N_A$ ) is Avogadro’s number =  $6.023 \times 10^{23} \text{ mol}^{-1}$ . Fig. 10 presents the relationship between the dielectric susceptibility and the electronic polarizability with the variation of the ratio of CdSe NPs in pure epoxy resin, while Table 2 presents



**Fig. 10.** Electric susceptibility against the electronic polarizability for CdSe / Epoxy resin NCs.

**Table 2**

Dielectric susceptibility ( $\chi_e$ ), electronic polarizability ( $\alpha_e$ ), Reflection loss (RL) and transmission coefficient (T) for different ratio of CdSe NPs on epoxy resin NCs.

Samples	$\chi_e$ $\pm 0.01$	$\alpha_e \times 10^{-25}$ (Cm <sup>3</sup> )	R <sub>L</sub> $\pm 0.01$	T $\pm 0.01$
0% CdSe NPs/Epoxy resin	0.312	2.248	0.142	0.748
0.25% CdSe NPs / Epoxy resin	0.326	2.292	0.149	0.740
0.50% CdSe NPs / Epoxy resin	0.333	2.313	0.152	0.735
0.75% CdSe NPs / Epoxy resin	0.344	2.344	0.156	0.729
1% CdSe NPs / Epoxy resin	0.359	2.384	0.162	0.720
1.25% CdSe NPs / Epoxy resin	0.367	2.403	0.165	0.716
1.50% CdSe NPs / Epoxy resin	0.398	2.479	0.176	0.699

the values for pure epoxy resin and different concentration of CdSe NPs in pure epoxy resin. The relationship showed partially a linear proportionality between the polarizability with the refractive index.

The variation of the optical conductivity with the incident photon energy for pure Epoxy and CdSe/Epoxy NCs with different content of CdSe NPs is presented in Fig. 11. The optical conductivity ( $\sigma_{opt}$ ) is an important property that measures the electronic state in material and depends on the refractive index ( $n$ ) and absorption coefficient ( $\alpha$ ) parameters of the investigated samples. The optical conductivity ( $\sigma_{opt}$ ) can be determined by using the obtained value of the average refractive index and the velocity of light  $c$  from this equation [32]:

$$\sigma_{opt} = \frac{\alpha n c}{4\pi} \quad (10)$$

Where ( $\alpha$ ) is the absorption coefficient, ( $n$ ) is the refractive index and ( $c$ ) is the speed of light in air ( $3 \times 10^8$  m/sec). The optical conductivity ( $\sigma_{opt}$ ) involves the dielectric constants, and can be calculated for Pure Epoxy resin and CdSe /Epoxy resin NCs with different CdSe NPs ratio according to the expression given in [32,33].

As seen the optical conductivity increases with the increase of CdSe NPs ratio in Epoxy resin. The transmission coefficient ( $T$ ) depends on the refractive index, according to the following equation: [34].

$$T = 2n/(n^2 + 1) \quad (11)$$

Also, the reflection loss ( $R_L$ ) from the surface is given by [35,36].

$$R_L = \left( \frac{n-1}{n+1} \right)^2 \quad (12)$$

The values of ( $T$ ) and ( $R_L$ ) for different CdSe NPs concentration are tabulated in Table 2.

The relationship between the between the transmission coefficient ( $T$ ) and the reflection loss ( $R_L$ ) for CdSe/Epoxy resin NCs with different concentration of CdSe NPs is shown in Fig. 12. A partial inverse proportionality between the two quantities is observed with increasing the CdSe NPs ratio into pure Epoxy.

Reflection loss reduction caused an increase in the transmission coefficient because the relation between the reflection coefficient and the transmission coefficient is inversely proportional.

#### 4. Conclusion

The performance of Epoxy resin coating by CdSe NPs has been studied based on the measurement of optical absorption. Optical or unfilled epoxy adhesives are commonly used for providing protective coating in several optical applications. Optical analysis showed that the best allowed transition was for direct transition, and the value of the energy gap decreases with the increase of CdSe NPs in pure Epoxy resin. Two of the most important parameters to be considered in selecting an optical Epoxy are the refractive index ( $n$ ) and the dielectric constant ( $\epsilon$ ). The value of the refractive index, the dielectric constant and the optical dielectric constant ( $\epsilon_{opt}$ ) reveal their increase by increasing the CdSe

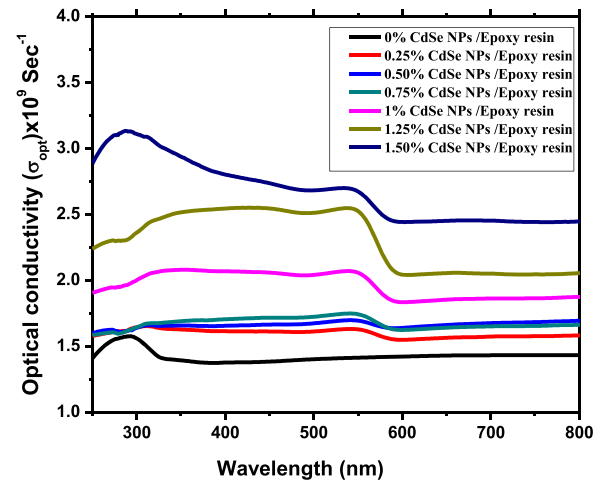


Fig. 11. Optical conductivity versus ( $h\nu$ ) plot for different concentration of CdSe NPs/Epoxy resin NCs.

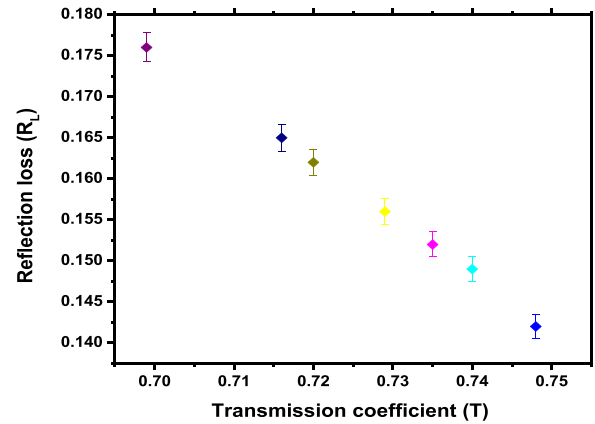


Fig. 12. Reflection loss (RL) against the Transmission coefficient (T) for CdSe /Epoxy resin NCs.

NPs percentage in pure epoxy. Moreover, we showed that the disappear of the cracks in the (SEM) images, and the increase of the dielectric constant correlate well with CdSe NPs% concentration in CdSe/Epoxy resin NCs, that enhances the strength of pure Epoxy to be a better electrical insulator in particular conditions.

#### CRediT authorship contribution statement

**S.S. Fouad:** Writing – review & editing. **K. Easawi:** Conceptualization, Writing – review & editing. **T.S. Mahmoud:** Conceptualization, Writing – review & editing. **M. Nabil:** Conceptualization, Methodology, Investigation, Writing – review & editing.

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Data availability

No data was used for the research described in the article.

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