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## Low Cost and Excellent Optical Properties of PEO Doped with $\text{CoFe}_2\text{O}_4$ Nanoparticles for Optoelectronics Applications

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Magnetic films of the polyethylene oxide (PEO) and cobalt ferrite nanoparticles ( $\text{CoFe}_2\text{O}_4$  NPs) nanocomposites are fabricated for magnetic, electronic, and optical applications with low cost and low weight. The structural and optical properties of PEO/ $\text{CoFe}_2\text{O}_4$  nanocomposites are investigated. The results indicate that the absorbance ( $A$ ), absorption coefficient ( $\alpha$ ), extinction coefficient ( $k$ ), refractive index ( $n$ ), real ( $\epsilon_1$ ) and imaginary ( $\epsilon_2$ ) parts of dielectric constant, and optical conductivity ( $\sigma$ ) of PEO are increased with increasing of the  $\text{CoFe}_2\text{O}_4$  NPs content, while the transmittance ( $T$ ) and energy band gap ( $E_g$ ) are decreased as  $\text{CoFe}_2\text{O}_4$  NPs concentration increases. Finally, the results show that PEO/ $\text{CoFe}_2\text{O}_4$  nanocomposites may be used for the flexible optoelectronics fields.

Магнетні плівки нанокompозитів з оксиду поліетилену (ПЕО) та наночастинок кобальтового фериту ( $\text{CoFe}_2\text{O}_4$  НЧ) виготовляються для магнетних, електронних і оптичних застосувань з низькою вартістю та низькою вагою. Досліджено структурні й оптичні властивості нанокompозитів ПЕО/ $\text{CoFe}_2\text{O}_4$ . Результати показують, що спектральна поглинальна здатність ( $A$ ), коефіцієнт поглинання ( $\alpha$ ), коефіцієнт екстинкції ( $k$ ), показник заломлення ( $n$ ), реальна ( $\epsilon_1$ ) й уявна ( $\epsilon_2$ ) частини діелектричної константи, а також оптична провідність ( $\sigma$ ) ПЕО збільшуються зі збільшенням вмісту  $\text{CoFe}_2\text{O}_4$  НЧ, тоді як коефіцієнт пропускання ( $T$ ) та ширина забороненої енергетичної зони ( $E_g$ ) зменшуються у міру збільшення концентрації  $\text{CoFe}_2\text{O}_4$  НЧ. Нарешті, результати показують, що нанокompозити ПЕО/ $\text{CoFe}_2\text{O}_4$  можуть використовуватися для областей трансформовної (гнучкої) оптоелектроніки.

**Key words:** polyethylene oxide, ferrite, nanocomposites, absorbance, energy gap, optoelectronics.

**Ключові слова:** оксид поліетилену, ферит, нанокompозити, спектральна поглинальна здатність, енергетична щілина, оптоелектроніка.

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## 1. INTRODUCTION

Nanocomposites are a relatively new class of materials with ultrafine phase dimensions, typically of the order of a few nanometres. The objectives for preparation of enhanced performance nanomaterials are to obtain a homogeneous distribution of the nanoparticles within the polymer matrix, and to promote a strong interfacial adhesion between the matrix and the nanofiller. Nanocomposites could dramatically induce improvements in mechanical and electrical properties, heat resistance, radiation resistance and other ones because of the nanometre-size dispersion of the inorganic fillers in the organic matrix. An immense amount of research and development has been devoted to characterizing and understanding the mechanical and physical properties of such nanocomposites. In recent years, studies on the optical, thermal and electrical properties of polymer nanocomposites have attracted much attention in view of their important applications in optical devices. The optical properties of polymers can be enormously modified by addition of nanoparticles, which react effectively with the host matrix due to their very large surface areas with respect to macro- and microparticles [1].

Organic polymers show ample evidence of optical, electronic and optoelectronic properties and are at length used in optical devices like lenses, optical waveguides, optical switches, light emitting diodes and nonlinear optical applications extended use of optical polymers; therefore, it is advantageous to have polymers with a property, like refractive index, within a certain range [2].

Polyethylene oxide (PEO) is a linear and semi-crystalline polymer. Because PEO is a linear polymer, the regularity of structure unit permits a high crystallinity degree. The chemical structure of PEO contains of polar group  $-O-$  that can interact/associate with the cations of metal salt. Thus, PEO can solvate different types of salts. However, the reactivity is very low because of its structural unit has C-H, C-C, C-O bonds. Due to this, it is stabilized chemically and electrochemically. However, a high concentration of crystalline phase within PEO polymer confines the conductivity [3].

Recently, attention in nanosize spinel ferrites has significantly increased due to their importance in understanding the fundamentals in nanomagnetism. Ferrite with remarkable magnetic and microwave absorbing properties has been widely used in the fields of data storage devices, magnetic sensors, actuators, biotechnology, and audio tapes. Ferrite properties strongly depend on the chemical composition, cation distribution, sintering temperature and time, additive amount of the cations and methods of preparation [4].

$\text{CoFe}_2\text{O}_4$  has received special attention because of its chemical stability, large magnet astrictive coefficient, mechanical hardness high coercivity, moderate saturation magnetization, and large magnetocrystalline anisotropy. The magnetic properties are dependent to the particle size. The energy of a magnetic particle was overall associated on the uniaxial anisotropy, magnetization direction, and easy axis aligned with the direction of external field.  $\text{CoFe}_2\text{O}_4$  is a hard magnetic material with high coercivity and suitable magnetization. These characteristics, along with their tremendous physical and chemical stability, make  $\text{CoFe}_2\text{O}_4$  nanoparticles suitable for applications such as high-density digital recording disks and lithium batteries [5]. This paper aims to investigate a new type of nanocomposites to use it for semiconductors and optoelectronics applications.

## 2. MATERIALS AND METHODS

Magnetic nanocomposites samples of polyethylene oxide (PEO) and cobalt ferrite nanoparticles ( $\text{CoFe}_2\text{O}_4$  NPs) nanocomposites were fabricated by using casting technique. The PEO solution was prepared by dissolving 0.4 gm in 50 ml of distilled water by using magnetic stirrer. The  $\text{CoFe}_2\text{O}_4$  NPs were added to the PEO solution with different weight percentages: 1.5, 3 and 4.5 wt.%. The optical properties of PEO/ $\text{CoFe}_2\text{O}_4$  nanocomposites were measured by using the double beam spectrophotometer (Shimadzu, UV-1800Å, Japan) in wavelength 200–800 nm.

## 3. RESULTS AND DISCUSSION

The variation of optical absorbance of PEO/ $\text{CoFe}_2\text{O}_4$  nanocomposites as function of wavelength is shown in Fig. 1. The optical absorption analysis is an important tool to obtain optical band gap energy of crystalline matter, corresponds to the electron excitation from the valence band to the conduction band, and can be used to determine the nature and value of the band gap. The PEO/ $\text{CoFe}_2\text{O}_4$  nanocomposites showed high absorbance in UV region due to the behaviour of  $\text{CoFe}_2\text{O}_4$  nanoparticles, which are may be used as UV shielding and low-weight electronics applications. An amount of  $\text{CoFe}_2\text{O}_4$  nanoparticles is required to reduce the value of gap energy in nanocomposites, and it has different effect depending on type of polymer matrix. The insertion of the  $\text{CoFe}_2\text{O}_4$  nanoparticles into the PEO films has a double effect because it increases the energy of the  $\text{CoFe}_2\text{O}_4$  gap and decreases that of the polymer and increase in charge-carriers' numbers [6–15]. The absorption coefficient ( $\alpha$ ) of nanocomposites is determined by [16]:

$$\alpha = 2.303A/t, \quad (1)$$

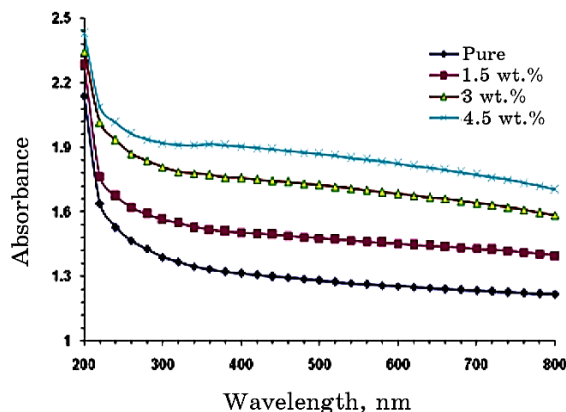


Fig. 1. Variation of optical absorbance of nanocomposites as function of wavelength.

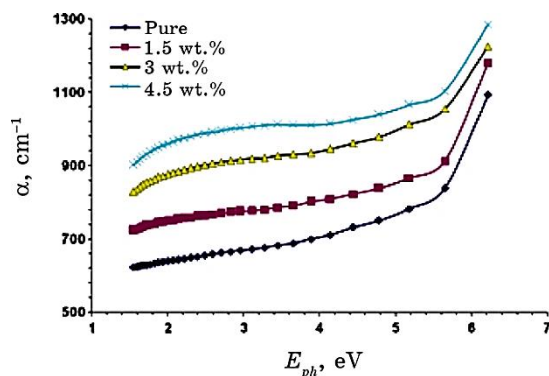


Fig. 2. Variation of absorption coefficient for nanocomposites with photon energy.

where  $A$  is the absorbance of sample, and  $t$  is the sample thickness.

Figure 2 shows the variation of absorption coefficient for PEO/CoFe<sub>2</sub>O<sub>4</sub> nanocomposites with photon energy of the incident light. As shown in this figure, the absorption coefficient of PEO/CoFe<sub>2</sub>O<sub>4</sub> nanocomposites is high at high energies. This means that the electron transition has high possibility; *i.e.*, the energy of incident photon is enough to transit the electron from the valence band to the conduction band, which due to the energy of the incident photon is greater than the energy band gap. When the values of the absorption coefficient of material are high  $\alpha > 10^4 \text{ cm}^{-1}$ , it is expected that direct transition of electron. While, when the values of the absorption coefficient of material are low ( $\alpha < 10^4 \text{ cm}^{-1}$ ), it is expected that indirect transition of electron. The values of absorption coefficient of PEO/CoFe<sub>2</sub>O<sub>4</sub> nanocomposites

are low ( $\alpha < 10^4$ )  $\text{cm}^{-1}$ ; the transition of electron is indirect. The absorption coefficient of nanocomposites increases with the increasing of the concentrations of  $\text{CoFe}_2\text{O}_4$  nanoparticles. This is attributed to increasing number of charge carriers [16], as shown in Fig. 3, and, hence, increase the absorbance and absorption coefficient.

The non-direct transition model for amorphous semi-conductors is defined as follows [17]:

$$\alpha h\nu = B(h\nu - E_g)^r ; \tag{2}$$

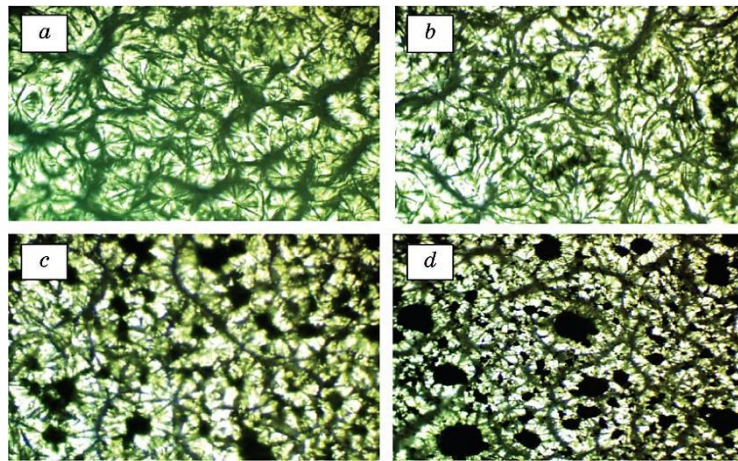


Fig. 3. Microscope images of PEO/ $\text{CoFe}_2\text{O}_4$  nanocomposites ( $\times 10$ ): *a*—for PEO; *b*—for 1.5 wt.%  $\text{CoFe}_2\text{O}_4$  NPs; *c*—for 3 wt.%  $\text{CoFe}_2\text{O}_4$  NPs; *d*—for 4.5 wt.%  $\text{CoFe}_2\text{O}_4$  NPs.

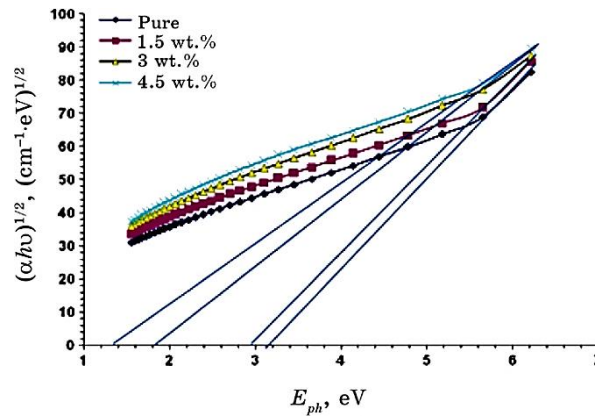


Fig. 4. Values of energy band gap for allowed indirect transition.

here,  $B$  is a constant,  $h\nu$  is the photon energy,  $E_g$  is the energy band gap, and  $r = 2$  or  $3$  for allowed and forbidden indirect transition, respectively.

Figures 4 and 5 show the values of energies band gap for allowed and forbidden indirect transition, respectively. These figures show that the values of energy gap for allowed and forbidden indirect transition decrease with increasing  $\text{CoFe}_2\text{O}_4$  nanoparticles' concentration; this decrease is due to  $\text{CoFe}_2\text{O}_4$  nanoparticles' content, which is responsible for the formation of some defects in the films. These defects produce the localized states in the optical band gap and overlap. These overlaps give an evidence for decreasing energy band gap, when the  $\text{CoFe}_2\text{O}_4$  nanoparticles' content is increased in the polymeric matrix. In other words, the decreased optical gap reflects the increase in the degree of disorder in the films [17, 18]. The extinction coefficient  $k$  is given by

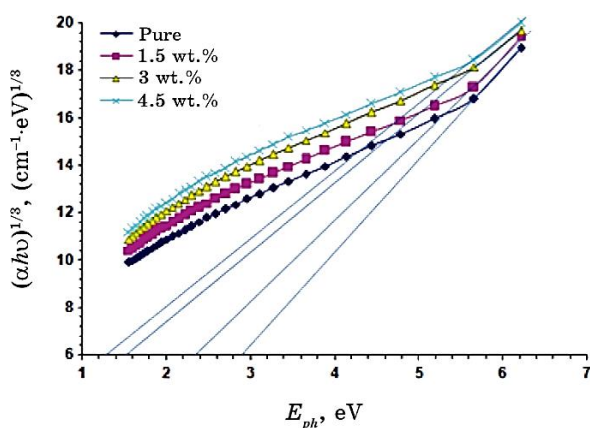


Fig. 5. Values of energy band gap for forbidden indirect transition.

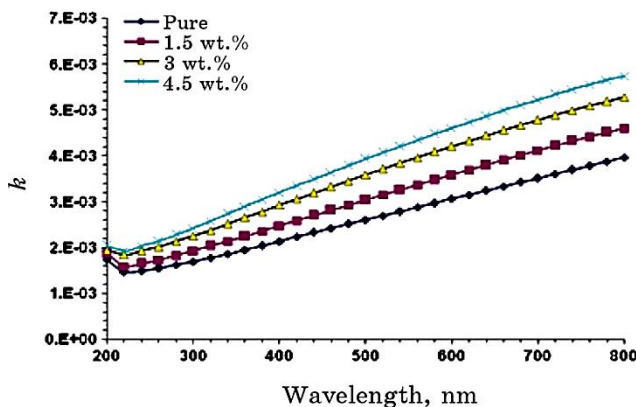


Fig. 6. Variation of extinction coefficient for nanocomposites with wavelength.

using the equation [18]:

$$k = \alpha\lambda/(4\pi). \quad (3)$$

The refractive index  $n$  can be calculated by using the equation [19]:

$$n = (1 + R^{1/2})/(1 - R^{1/2}). \quad (4)$$

Figure 6 shows the variation of extinction coefficient for PEO/ $\text{CoFe}_2\text{O}_4$  nanocomposites as a function of wavelength. This figure shows that the extinction coefficient of PEO increases with the increasing of the  $\text{CoFe}_2\text{O}_4$  nanoparticles' concentration; this is due to the increase in optical absorption and photon dispersion in the polymer matrix [19].

The refractive index of PEO/ $\text{CoFe}_2\text{O}_4$  nanocomposites as a function of wavelength is shown in Fig. 7. As shown in this figure, the refractive index of PEO increases with the increasing of the  $\text{CoFe}_2\text{O}_4$  nanoparticles concentrations. It is decreased with the increase of the wavelength. This behaviour is attributed to the increase of the density of nanocomposites.

When the incident light interacts with a sample, it has high refractivity at UV-region; hence, the values of refractive index will be increased [19].

The real ( $\epsilon_1$ ) and imaginary ( $\epsilon_2$ ) parts of dielectric constant of PEO/ $\text{CoFe}_2\text{O}_4$  nanocomposites are given by the following equations [20]:

$$\epsilon_1 = n^2 - k^2, \quad (5)$$

$$\epsilon_2 = 2nk. \quad (6)$$

The dielectric constant (with real and imaginary parts) of PEO/ $\text{CoFe}_2\text{O}_4$  nanocomposites is shown in Figs. 8 and 9. From these figures, it is clear that the increase in  $\text{CoFe}_2\text{O}_4$  concentration leads to increase of absorption coefficient and refractive index and subsequently leads to increase of the real and imaginary parts of dielectric constant of PEO [20].

The optical conductivity of PEO/ $\text{CoFe}_2\text{O}_4$  nanocomposites is determined by the equation [21]:

$$\sigma = \alpha nc/(4\pi). \quad (7)$$

Figure 10 shows the variation of optical conductivity with the wavelength for the PEO/ $\text{CoFe}_2\text{O}_4$  nanocomposites. This figure shows that the optical conductivity of PEO/ $\text{CoFe}_2\text{O}_4$  nanocomposites is decreased with the increase of the wavelength; this behaviour attributed to the optical conductivity depends strongly on the wavelength of the radiation incident on the samples of nanocomposites; the increased optical

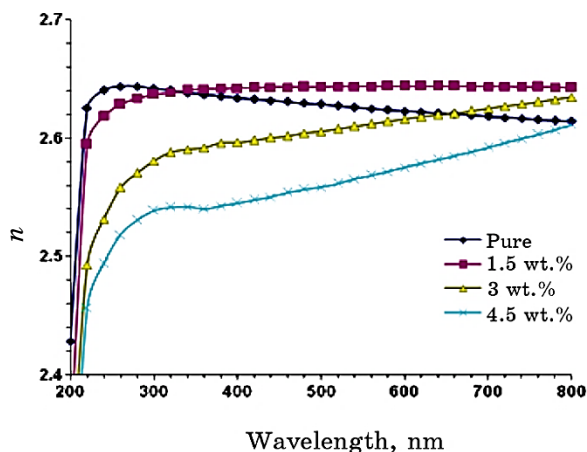


Fig. 7. Refractive index of PEO/CoFe<sub>2</sub>O<sub>4</sub> nanocomposites as a function of wavelength.

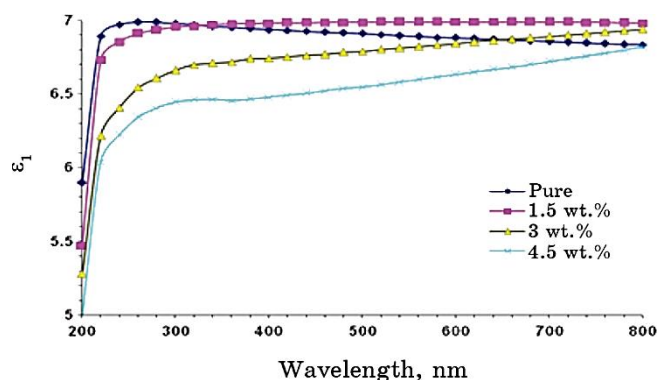


Fig. 8. Real dielectric constant of PEO/CoFe<sub>2</sub>O<sub>4</sub> nanocomposites.

conductivity at low wavelength of photon is due to high absorbance of nanocomposites in that region and, hence, increase of the charge transfer excitations.

The optical conductivity spectra indicate that the samples are transparent within the visible and near infrared regions. In addition, the optical conductivity of PEO is increased with the increase of CoFe<sub>2</sub>O<sub>4</sub> nanoparticles' concentration. This behaviour is related to the creation of localized levels in the energy gap; the increase of CoFe<sub>2</sub>O<sub>4</sub> nanoparticles' concentration increase the density of localized stages in the band structure. Hence, increase of the absorption coefficient consequently increases the optical conductivity of PEO/CoFe<sub>2</sub>O<sub>4</sub> nanocomposites [21–24].



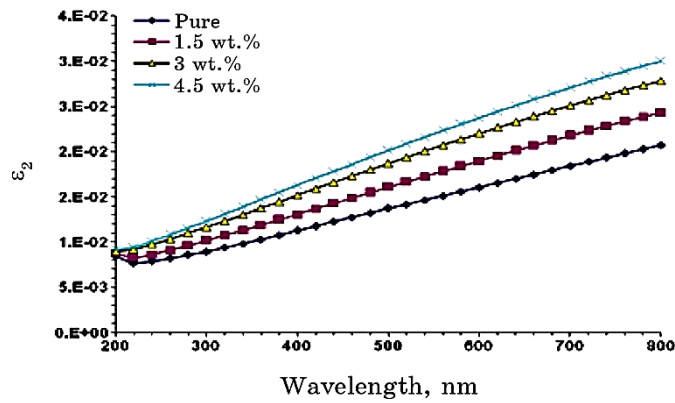


Fig. 9. Imaginary dielectric constant of PEO/ $\text{CoFe}_2\text{O}_4$  nanocomposites.

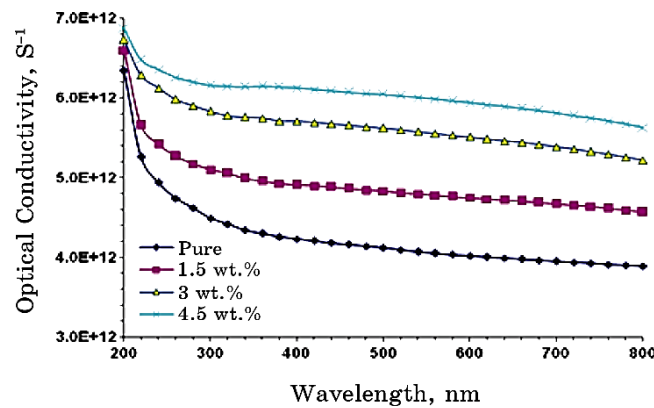


Fig. 10. Variation of optical conductivity with the wavelength of nanocomposites.

#### 4. CONCLUSIONS

In this work, the structural and optical properties of PEO/ $\text{CoFe}_2\text{O}_4$  nanocomposites have been investigated to use in optoelectronics applications such as sensors, solar cells, capacitors, transistors, diodes, *etc.*

The results indicated to the absorbance, absorption coefficient, extinction coefficient, refractive index, dielectric constant parts and optical conductivity of PEO, which are increased with the increase in  $\text{CoFe}_2\text{O}_4$  nanoparticles concentration, while the transmittance and energy band gap are decreased with the increase in  $\text{CoFe}_2\text{O}_4$  nanoparticles' concentration.

The PEO/ $\text{CoFe}_2\text{O}_4$  nanocomposites have higher absorbance in the UV-region.

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