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Optical Properties of PMMA/PS/$CoFe_2O_4$ Magnetic Nanostructures for Low-Cost Optoelectronics Applications

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This work aims to prepare the PMMA/PS/$CoFe_2O_4$ magnetic nanostructures to employ in low-cost magnetic, optic and electronic applications (PMMA—polymethyl methacrylate, PS—polystyrene). The optical properties of PMMA/PS/$CoFe_2O_4$ magnetic nanostructures are examined. The results show that the absorbance and absorption coefficient of PMMA/PS blend are increased with an increase in the $CoFe_2O_4$-nanoparticles' content, while the transmittance and energy band gap are decreased with increasing the $CoFe_2O_4$-nanoparticles' content. Finally, the results demonstrate that PMMA/PS/$CoFe_2O_4$ magnetic nanostructures may be suitable for various optoelectronics fields.

Цю роботу було спрямовано на підготовку магнетних наноструктур ПММА/ПС/$CoFe_2O_4$ (ПММА — поліметилметакрилат, ПС — полістирол) для використання в недорогих магнетних, оптичних та електронних застосуваннях. Досліджено оптичні властивості магнетних наноструктур ПММА/ПС/$CoFe_2O_4$. Результати показують, що абсорбція та коефіцієнт вбирання суміші ПММА/ПС збільшується зі збільшенням вмісту наночастинок $CoFe_2O_4$, тоді як пропускання та енергетична заборонена зона зменшуються зі збільшенням вмісту наночастинок $CoFe_2O_4$. Нарешті, результати демонструють, що магнетні наноструктури ПММА/ПС/$CoFe_2O_4$ можуть бути придатними для різних галузей оптоелектроніки.

Key words: PMMA/PS/$CoFe_2O_4$ nanocomposites, absorbance, energy gap.

Ключові слова: нанокомпозити поліметилметакрилат/полістирол/$CoFe_2O_4$, вбирання, енергетична щілина.

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1. INTRODUCTION

Polymer matrix nanocomposites, which exhibit distinct physico-chemical characteristics by incorporating inorganic fillers into polymer networks, have received much attention due to their various industrial applications in drug delivery, water treatment, food industry, aeronautical and aerospace structures [1].

Combining two or more polymers has become an effective strategy to produce advanced polymeric materials with improved physical and chemical properties compared to the original polymers. The final product properties depend on factors such as the method of mixing, the mixed polymer proportions, the temperature, at which mixing is done, and the degree of mixing of individual polymeric components. The rheological as well as the mechanical properties of the material are strongly affected by the immiscible polymer phase because of its morphology and internal framework, which are controlled by the degree of dispersion of polymers. The interfacial interactions between polymer functional groups in the mixture govern the final physical and chemical properties of the material. In addition, the incorporation of nanoparticles (NPs) into the polymer mixture enhances their properties due to the interaction between them and the functional groups of the mixture [2, 3].

On account of polymeric materials, polymethyl methacrylate (PMMA) is one of the polymers that have garnered a lot of interest due to its transparent and colourless properties. It has a long life span, excellent mechanical and chemical stability, and high wettability. However, it has a few drawbacks, including low thermal stability, restricted electrochemical stability, and low cyclic rate efficiency. For that reason, there has been a lot of research over the past few decades showing that incorporating even trace amounts of nanofillers into polymers can improve their properties without negatively influencing their processability. Therefore, when the nanofiller is incorporated, embeds, or decorates itself across a polymer matrix, the structure of the resulting nanocomposite can produce promising properties [4].

Polystyrene (PS) is an inexpensive, environmentally friendly polymer it is among the most popular materials, which has many applications in industry, building and construction, domestic appliances and food packaging. In food packaging, polystyrene can be used in many shapes as monolayer plastic film, plastic sheet, or injection moulded and foamed [5].

Among various spinel ferrites, $CoFe_2O_4$ has received special attraction due to the unique physical properties such as high Curie temperature, large magnetocrystalline anisotropy, high coercivity, moderate saturation magnetization, large magnetostrictive coefficient, excellent chemical stability and mechanical hardness [6].

The nanocomposites of nanoparticles'-doped polymers have many applications for different electronics, optical and electronics fields [7–18]. The present work deals with preparation of PMMA/PS/$CoFe_2O_4$ magnetic nanostructures and studying the optical properties to use them in various optical devices.

2. MATERIALS AND METHODS

Films of magnetic nanostructures were prepared from PMMA/PS blend doped with $CoFe_2O_4$ nanoparticles by using casting technique. The PMMA/PS/$CoFe_2O_4$ magnetic nanostructures films were fabricated by dissolving of 1 gm of PMMA 50% and PS 50% in 30 ml of chloroform using magnetic stirrer to mix the polymers for 1 hour to obtain solution that is more homogeneous. Then, $CoFe_2O_4$ nanoparticles were added to PMMA/PS blend with contents of 2.1%, 4.2% and 6.3%. The optical properties of PMMA/PS/$CoFe_2O_4$ magnetic nanostructures films were tested by using the double beam spectrophotometer (Shimadzu, UV-1800) in wavelength 240–840 nm.

Coefficient of absorption (α) is found by [19]:

$$\alpha = 2.303A/t, \tag{1}$$

where A is the absorbance and t is the sample thickness.

The energy gap is given by [20]:

$$ah\nu = B\left(h\nu - E_g\right)^r, \tag{2}$$

where B is the constant, $h\nu$ is the photon energy, E_g is the energy gap, and $r = 2$ and 3 for allowed and forbidden indirect transitions.

3. RESULTS AND DISCUSSION

The absorbance and transmittance behaviours of PMMA/PS/$CoFe_2O_4$ magnetic nanostructures with photon wavelength are shown in Figs. 1 and 2. As demonstrated in these figures, the PMMA/PS/$CoFe_2O_4$ magnetic nanostructures included high absorbance with low transmittance at UV spectrum because the high energies at UV spectra and have broad absorbance spectra in the UV and VIS areas, which makes the PMMA/PS/$CoFe_2O_4$ magnetic nanostructures can be useful in the optical applications. The absorption of PMMA/PS rises, while the transmission reduces with rising of the $CoFe_2O_4$ NPs content, which is, due to rise in the density of charge carriers, lead to

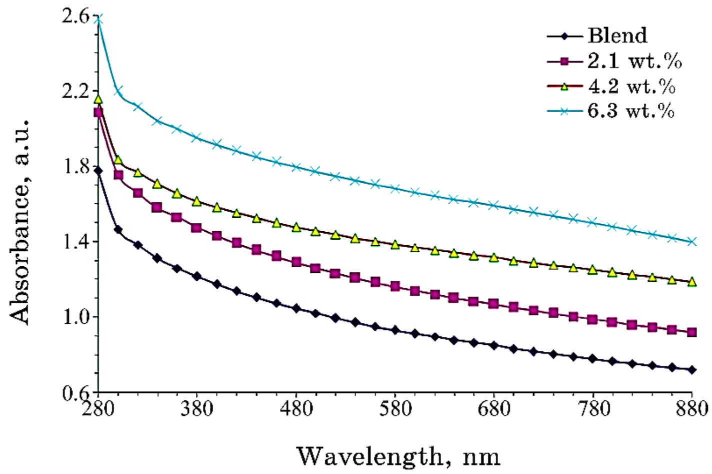

Fig. 1. Absorbance behaviour of $PMMA/PS/CoFe_2O_4$ magnetic nanostructures with photon wavelength.

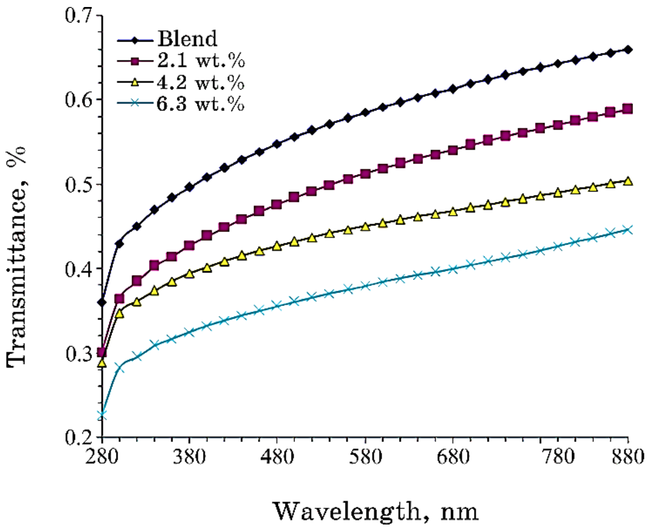

Fig. 2. Performance of transmittance for $PMMA/PS/CoFe_2O_4$ magnetic nanostructures with photon wavelength.

absorb or scat the photons [21–30].

The absorption coefficient performance for $PMMA/PS/CoFe_2O_4$ magnetic nanostructures with photon energy is represents in Fig. 3. The values of $\alpha < 10^4$ cm^{-1} and indicate to indirect transition. The increase in the α values might be due to the significant decrease in the transitions of interband [31–34].

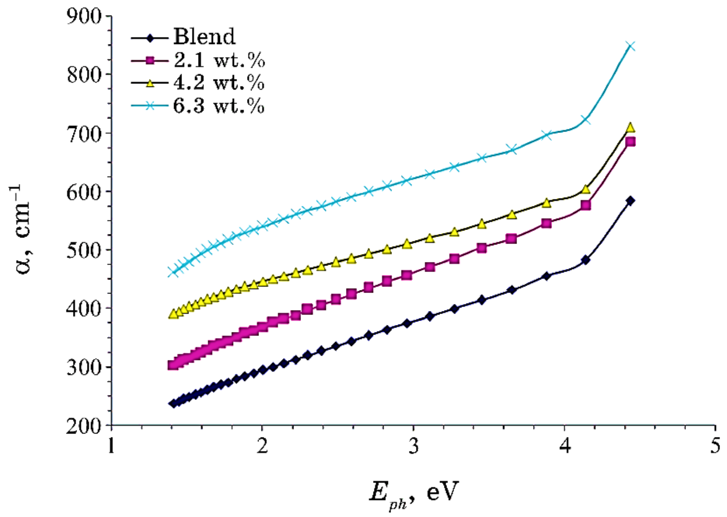

Fig. 3. Performance of absorption coefficient for PMMA/PS/$CoFe_2O_4$ magnetic nanostructures with photon energy.

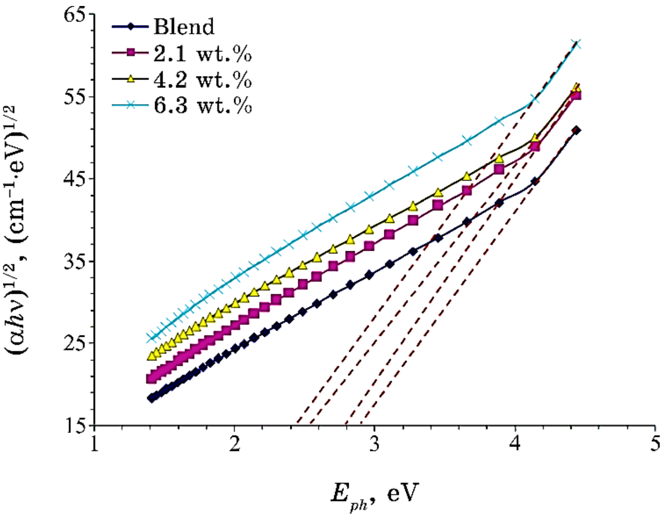

Fig. 4. Energy gaps of allowed indirect transition for PMMA/PS/$CoFe_2O_4$ magnetic nanostructures.

Figures 4 and 5 demonstrate the energies gaps for magnetic PMMA/PS/$CoFe_2O_4$ nanostructures of allowed and forbidden indirect transitions respectively.

The energy gaps of PMMA/PS/$CoFe_2O_4$ magnetic nanostructures reduced with rise in the $CoFe_2O_4$ NPs content; this is related to the

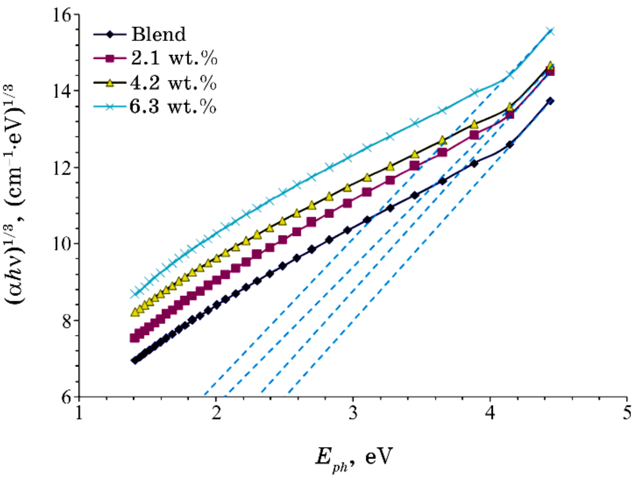

Fig. 5. Energy gaps of forbidden indirect transition for magnetic PMMA/PS/$CoFe_2O_4$ nanostructures.

formation of charge-transfer complexes in the polymeric medium. These charge-transfer complexes increase the electric conduction by generating extra charges; this effect is in a decrease of the energy gap. As the $CoFe_2O_4$ NPs content increases, the dopant molecules begin bridging the gap separating the two localized stages and reduce the potential barrier between them, thereby create easily the charge carrier transfer between localized levels [35–40].

4. CONCLUSIONS

The present work includes fabrication of PMMA/PS/$CoFe_2O_4$ magnetic nanostructures to employ in low cost magnetic, optic and electronic applications. The results show that the absorbance, absorption coefficient, extinction coefficient, refractive index, real and imaginary parts of dielectric constants and optical conductivity of PMMA/PS blend increased with an increase in the $CoFe_2O_4$ NPs content while the transmittance and energy band gap were decreased with increasing the $CoFe_2O_4$ NPs content. Finally, the results demonstrated that PMMA/PS/$CoFe_2O_4$ magnetic nanostructures might be appropriate for different optoelectronics fields.

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