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Fabrication of PVA–PEG–Ag Nanocomposites and Improved Optical Properties for Optical Fields

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This work aims to improve the optical properties of photonic nanodevices based on nanostructures of silver (Ag), polyethylene glycol (PEG) and polyvinyl alcohol (PVA). By solution casting with varying concentrations of Ag nanoparticles (0, 2, 4, and 6 wt.%), PVA–PEG–Ag nanocomposites are fabricated. The optical properties of PVA–PEG–Ag nanocomposites are studied experimentally. The results show that the absorbance and absorption coefficient of the PVA–PEG mixture are increased, while both the permeability and energy gap (permissible and forbidden) are decreased with increasing concentration of Ag nanoparticles. The study results indicate that the inclusion of Ag nanoparticles into the PVA–PEG mixture results in improved optical properties, making PVA–PEG–Ag nanocomposites as viable materials for a variety of photonic-nanodevice applications.

Цю роботу спрямовано на поліпшення оптичних властивостей фотонних нанопристроїв на основі наноструктур (НС) срібла (Ag), поліетиленгліколю (ПЕГ) і полівінілового спирту (ПВС). Шляхом лиття з розчину з різною концентрацією наночастинок (НЧ) срібла 0, 2, 4 та 6 мас.% було одержано нанокомпозити (НК) ПВС–ПЕГ–Ag. Оптичні властивості НК ПВС–ПЕГ–Ag було досліджено експериментально. Результати показали, що вбирання та коефіцієнт вбирання суміші ПВС–ПЕГ збільшуються, тоді як проникність та енергетична щілина (допустима та заборонена) зменшуються зі збільшенням концентрації НЧ срібла. Результати дослідження показують, що включення НЧ срібла до суміші ПВС–ПЕГ приводить до поліпшення оптичних властивостей, що робить НЧ ПВС–ПЕГ–Ag життєздатними матеріялами для різноманітних застосувань фотонних нанопристроїв.

Key words: nanostructures, Ag nanoparticles, optical properties.

Ключові слова: наноструктури, наночастинки срібла, оптичні властивості.

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1. INTRODUCTION

Polymer matrix composites are utilised in a wide range of industries as sustainable materials since they have a wide range of chemical structures, features, applications, and potential reusability among other advantages in construction and economy. This materials' group saw a major increase in attention related to the growing need for very lightweight and expensive behaviour issues. Combining nanomaterials with standard polymer medium as reinforcements exhibits a wide range of extra typical characteristics related to small size, unique form, and large surface area [1, 2].

PVA was used in earlier times as a simple polymer with certain qualities such as high chemical stability, environmental stability, biodegradability, optical properties, and electric properties. The presence of both crystalline and amorphous sections, which results in the effects of crystal–amorphous interface to raise physical characteristics, is the main property of PVA [3, 4]. PVA has high mechanical and thermal properties and is soluble in water. Polyvinyl alcohol finds extensive application in fields such as electronics, construction, medicine, and other sectors [5, 6].

PEG is one of the most important polymers due to its demonstrated favourable performances and attributes, such as being affordable, non-toxic, and commercial [7, 8]. Silver (Ag) nanoparticles (NPs) find applications in several fields, including integrated circuits, biocaptures, medical imaging, medication delivery, hyperthermic therapy, chemical and electrochemical sensors, and biomarker applications. Increased attention is given to nanocomposites (NCs) made of polymers with embedded nanostructures because of their optical, electrical, mechanical, chemical, and electrical properties, which make them useful for enhancing industrial and biomedical applications [9–12].

2. MATERIALS AND METHODS

By mixing PVA–PEG with different concentrations of Ag nanoparticles 0%, 2%, 4%, and 6%, PVA–PEG–Ag NCs were generated. Using casting technique, PVA–PEG polymer was added to the samples, and until homogeneous solutions were obtained, the mixtures were stirred continuously for 40 min at 70°C. After pouring into several Petri dishes, the solutions were allowed to form films by drying at room temperature. The material was divided into 1 cm-pieces for analysis. The optical properties of PVA–PEG–Ag nanocomposites were examined by means of the UV/1800/Shimadzu spectrophotometer for their optical characteristics in the 220–820 nm spectrum measured.

To compute absorbance, the following formula is used [13, 14]:

$$A = I_A/I_0. \qquad (1)$$

The intensity of light incident on the medium is denoted by I_0, while the intensity of light absorbed by the medium is represented by I_A. To compute transmittance (T) [15, 16], the following formula is used too:

$$A = \log(1/T). \qquad (2)$$

The absorption coefficient (α) is calculated by the formula

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

(t denotes the sample thickness) [17, 18].

The energy gap is calculated based on the equation [19, 20]

$$\alpha h\nu = B\left(h\nu - E_g\right)^r. \qquad (4)$$

3. RESULTS AND DISCUSSION

3.3. The Optical Characteristics for PVA–PEG–Ag NCs

In Figure 1, various concentrations of Ag nanoparticles and their

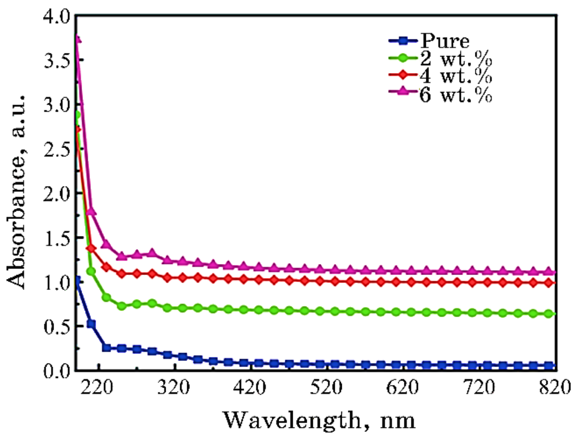

Fig. 1. Absorbance *vs*. wavelength for PVA–PEG–Ag NCs.

optical absorption spectra are shown in PVA–PEG loaded. It is evident that, when Ag concentration rises, more nanoparticles inside the polymer matrix are present that increases the films' absorption. Because of the semi-crystalline structure of PVA–PEG, each sample has two absorption borders, which slightly move towards longer wavelengths [21, 22].

Perhaps related to this, it is the fluctuating size of Ag nanoparticles in the polymer matrix: from 220 to 320 nm, the absorption border is associated with the transition between π and π^*, whereas from 320 to 420 nm, the transition is associated with the $n-\pi^*$ border [23–27]. In strengthened contact, the 'entering' and 'implanted' photons are visible through the high absorption spectrum of the polymer-matrix nanoparticles. All polymer films have a maximum transmission spectrum (about 85%) in the visible and near-infrared regions, as well as high wavelengths. These regions appear to be mostly constant. The reason is the incident-photons' low energy [28–32]. Electrons to change from a lower state to a higher state absorb enough energy included in incoming photons. As a result, absorption increases and transmission decreases [33, 34].

Figure 2 illustrates the correlation between the PVA–PEG–Ag-NCs' spectrum and the transmittance spectrum. In light of the growing concentration of the Ag NPs, which is correlated with an increase in the number of charge carriers, we may assume that transmittance declines and absorbance increases [35–37]. The transmittance in this instance rises as the wavelength increases, while the absorption falls [38].

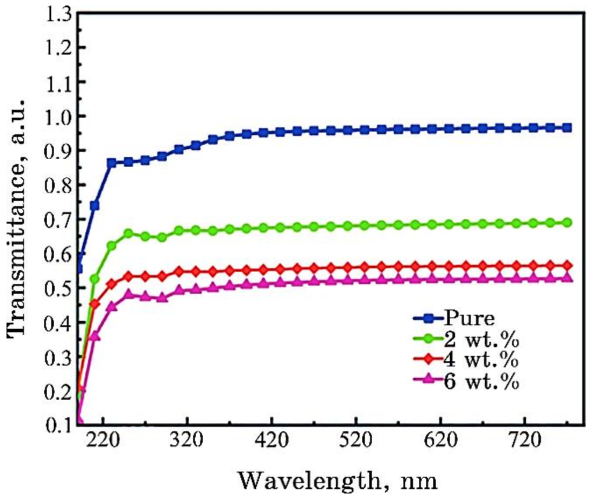

Fig. 2. Changes in transmittance for PVA–PEG–Ag NCs depending on wavelength.

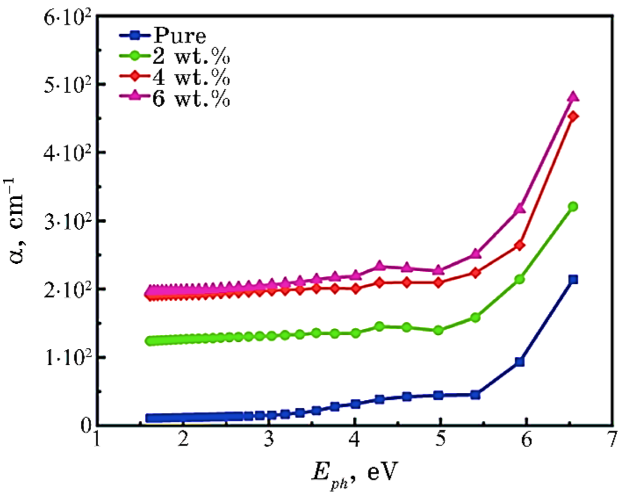

Fig. 3. Absorption coefficient variation with photon energy for the PVA–PEG–Ag NCs.

Figure 3 demonstrates how the concentration of Ag nanoparticles grows with the absorption coefficient of the PVA–PEG–Ag nanocomposite, and it was linked to an increase in the quantity of charge carriers, which raises the rate of absorption. This happens due to its wavelength-dependent rise [39–40].

Figures 4 and 5 demonstrate the absorbance edge $(\alpha h\nu)^{1/r}$ for PVA–PEG–Ag NCs varying with incoming photon energy. Thus, in

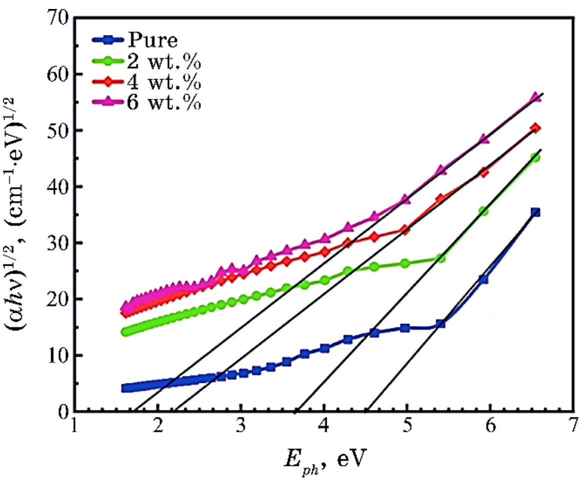

Fig. 4. Variation in $(\alpha h\nu)^{1/2}$ for PVA–PEG–Ag NCs in relation to photon energy.

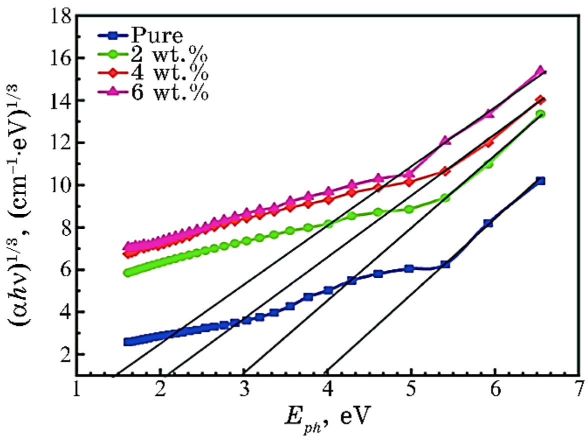

Fig. 5. Variation in $(\alpha h\nu)^{1/3}$ for PVA–PEG–Ag NCs in relation to photon energy.

TABLE. Energy gap estimated for PVA–PEG–Ag NCs in the permitted and prohibited indirect transitions.

Con. of Ag NPs, wt.%	Indirect energy gap (allowed), eV	Indirect energy gap (forbidden), eV
0	4.66	4
2	3.8	3
4	2.2	2.1
6	1.8	1.6

Figure 4, to depict an indirect energy gap transition, a straight line can be drawn from the curve apex at $(\alpha h\nu)^{1/2} = 0$ (allowed) to the X-axis. This can be used to make the adjustment. Table illustrates how the indirect energy-gap values for PVA–PEG–Ag NCs are constrained lower, when Ag NPs' concentration increases. This suggests that there is a significant gap in some locations, when it comes to restricted energy [41, 42]. The effect of the absorbance edge $(\alpha h\nu)^{1/3}$ in PVA–PEG–Ag nanostructures on photon energy is shown in Fig. 5, and table illustrates how the concentration of Ag NPs reduces the indirect energy gap (prevent) for PVA–PEG–Ag NCs. So, this property accelerates electron transport between adjacent levels and the formation of new ones [43–44].

4. CONCLUSIONS

Using the casting process, PVA–PEG–Ag NCs films were formed.

PVA–PEG–Ag NCs absorb more effectively, when the concentration of Ag NPs is increased. The UV region manifests an increase in the absorption of PVA–PEG–Ag NCs with increasing NPs' concentration, but the energy gap of the positive PVA–PEG–Ag NCs decreases from 4.66 eV to 1.8 eV (for allowed) and from 4 eV to 1.6 eV (for forbidden). As the weight percentage of Ag nanoparticles increases to 6%, the absorption coefficient α increases. The optical properties indicate potential uses of PVA–PEG–Ag nanocomposites in a variety of fields, including photonics and electronics.

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