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Enhancement of Optical Properties in In_2O_3-Doped PVA/PEG Nanostructured Films for Optoelectronic Applications

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ABSTRACT

In this investigation, nanostructured films comprising polyvinyl alcohol (PVA)/polyethylene glycol (PEG) blended with indium oxide (In_2O_3) nanoparticles were fabricated using a casting technique. The study focused on examining the impact of varying the ratios of PVA/PEG blend and In_2O_3 nanoparticle content on the optical properties of these nanostructures. Optical assessments were conducted across a spectrum ranging from 220 nm to 820 nm. It was observed that an increase in In_2O_3 nanoparticle concentration resulted in elevated absorbance levels in the PVA/PEG matrix, particularly within the ultraviolet spectrum, while simultaneously causing a decrease in transmittance. This effect was attributed to the interaction between the polymer matrix and the In_2O_3 nanoparticles, leading to altered electronic and photonic interactions within the material. A notable reduction in the energy band gap was also recorded with increasing In_2O_3 content, suggesting enhanced electron mobility and photon interaction within the nanostructures. These findings underscore the potential of In_2O_3-doped PVA/PEG films in optoelectronic applications, particularly in fields requiring controlled optical properties such as photonics and advanced optical systems. The improved optical parameters, specifically in terms of absorbance and band gap manipulation, highlight the versatility of these nanostructures in various optoelectronic applications.

1. INTRODUCTION

Nanocomposite films, characterized by a polymer matrix, have emerged as materials of significant interest across various scientific disciplines. Their notable properties encompass a range of attributes including optical, magnetic, thermal, electrical, and mechanical aspects. Recent advancements have focused on the development and properties of these nanocomposite-based polymer films, particularly for their application in light-stable color filters, solar cells, and optical sensors [1]. The composite materials, especially those incorporating a polymer matrix, have been extensively explored for electrical applications due to their flexible nature and ease of fabrication [2, 3].

Recent advancements in the field of material science have witnessed a significant surge in the development of polymer-based composites. These materials have been extensively explored due to their versatility, cost-effectiveness, and ease of fabrication. Polymers, traditionally seen as inexpensive and easily malleable materials, have found widespread applications, particularly in the realm of composites. The integration of polymer matrices with ceramic additives has led to composites that exhibit enhanced reflectivity, proving beneficial in various electrical and electronic applications. Such composites have been employed in diverse domains, including the manufacturing of angular acceleration accelerometers, integrated decoupling capacitors, acoustic emission sensors, and electronic packaging. Organic polymers are prized for their ease of shaping, flexibility, durability, and lightweight nature. In contrast, ceramics are renowned for their exceptional optical, mechanical, and thermal resistance properties. In recent years, alongside metals and alloys, ceramic-polymer composites have emerged as a prominent class of high-performance engineering materials. The characteristics of these composites, such as the distribution of reinforcement or filler within the matrix and the adhesion phenomena between the filler and the matrix, are crucial in determining the final properties of the composite [4, 5].

Organic polymers are typically insulating, yet capable of accumulating electronic charge. Composites have become pivotal in contemporary material science due to their combination of desirable characteristics: lightweight, corrosion resistance, high fatigue strength, and ease of assembly. These materials find applications in the construction

of aircraft, medical devices, spacecraft, and domestic buildings, providing extraordinary combinations of material properties [6]. PVA is recognized for its biocompatibility, biodegradability, and excellent barrier properties. Its versatility has led to its use in industries ranging from food to textiles, and as a carrier for drug delivery systems. PVA is known for its good physical properties, non-toxicity, and biodegradability [7-9]. PEG is similarly valued for its solubility in water and low toxicity, making it a preferred material in biotechnical applications [10]. Indium oxide (In_2O_3), a widely used n-type semiconductor with an energy gap of 3.6 eV, has garnered attention due to its unique optical, chemical, and electrical properties [11]. Nanocomposites have found applications across a broad spectrum of fields, including antibacterial [12-14], energy storage [15-18], electronics [19, 20], and as components in piezoelectric and sensor technologies [21-24]. This study delves into the fabrication of blend/In_2O_3 nanostructures and examines their optical characteristics for potential use in various optical fields.

2. MATERIALS AND METHODS

The casting procedure was used to create nanostructure films of PVA/PEG in varied ratios of In_2O_3 nanostructures. 1 g of polymers dissolved in distilled water (30 ml) yields a blend solution of PVA and PEG in a ratio of 70% PVA and 30% PEG. The In_2O_3 NPs were added to the mix solution (PVA/PEG) at 1%, 2%, and 3% concentrations. The optical properties of blend/In_2O_3 nanostructures films were evaluated using a Shimadzu UV-18000A spectrophotometer. Absorption coefficient, α is defined by the study [25]:

$$\alpha = 2.303(A / d) \tag{1}$$

where, A denotes to absorbance and d denotes to thickness.

The energy gap is determined by the study [26]:

$$(\alpha h\upsilon) = G\left(h\upsilon - E_g\right)^m \tag{2}$$

where, G represents a constant, $h\upsilon$ represents the energy of photon, E_g denotes to band gap, m = 2 and 3 to transitions of allowed and forbidden. Refractive index(n) is given by the study [27]:

$$n = \frac{1+\sqrt{R}}{1-\sqrt{R}} \tag{3}$$

where, R is the reflectance.

The extinction coefficient (k) is determined by the study [28]:

$$k = \frac{\alpha\lambda}{4\pi} \tag{4}$$

where, λ is the wavelength.

The dielectric constant parts: real (ε_1), and imaginary (ε_2) are given by the study [29]:

$$\varepsilon_1 = n^2 - k^2 \tag{5}$$

$$\varepsilon_2 = 2nk \tag{6}$$

The optical conductivity (σ_{op}) is defined by the study [30].

$$\sigma_{op} = \frac{\alpha nc}{4\pi} \tag{7}$$

3. RESULTS AND DISCUSSION

A material's optical and electrical characteristics are intertwined; in electromagnetic theory, for instance, the high frequency permittivity and the optical refractive index, n, are associated. The absorption of optical light occurs through electron rearrangements within molecules, particularly in the visible and ultraviolet range, as well as by the activation of bond vibrations in the infrared range. Scattering events [31] have a significant impact on optical properties. Given that the polymer materials possess microstructural features that align with the size of optical wavelengths, the phenomenon of light scattering serves as a clear manifestation of optical diffraction processes [32]. The majority of polymers lack color due to the fact that only a small fraction of pure polymers have the ability to absorb photons within the visual range, which spans from around 380 to 760 nm [33]. Their brownish appearance in reflected light is due to their significant absorption of blue light. Chromophores are organic compounds with aromatic rings or alternating double and single covalent bonds. At frequencies corresponding to the excitation energy of the bonding electrons, they absorb light. To add pigments or dyes to polymer materials in order to give them a certain hue. The hues of solid polymers can be fully identified by analyzing their spectra, either through transmission or reflection if applicable [34]. While certain polymers may not absorb light within the visible spectrum, it is widely understood that they do exhibit significant light absorption at specific infrared frequencies. Infrared spectroscopy is a highly effective technique for analyzing polymers, enabling the straightforward identification of polymer compounds with unknown composition using small samples. The molecular structure of a polymer determines its infrared spectrum, which can be characterized by either transmission or reflectance [35].

Figure 1 depicts the absorption of films made from PVA/PEG/In_2O_3 nanostructures. The absorption intensity of the PVA/PEG increases with an increase in the content of In_2O_3 NPs. This is attributed to the higher density of charge carriers, resulting in higher absorbance values [36, 37]. Consequently, the transmittance decreases, as illustrated in Figure 2. Furthermore, when the wavelength of photons rises, the absorbance falls and the transmittance increases. The PVA/PEG/In_2O_3 nanostructure films exhibit a significant level of absorption in the UV-spectrum. Understanding the absorption coefficient is helpful for determining the nature of a transition. Figure 3 illustrates the alpha (α) values of PVA/PEG/In_2O_3 nanostructure films. The Figure shows α values of 104 cm-1, which correspond to indirect transitions. The pristine sample exhibited a diminished absorbance coefficient, potentially attributable to its reduced crystallinity [38].

Figures 4 and 5 illustrate the energies gaps values of PVA/PEG/In_2O_3 nanostructures films of allowed and forbidden transitions. Because of the formation of levels in the band gap, the blend's Eg value lowers as the concentration of In_2O_3 NPs rises. Moreover, the noncrystalline phase of the composite polymer experiences local cross-linking [39-47].

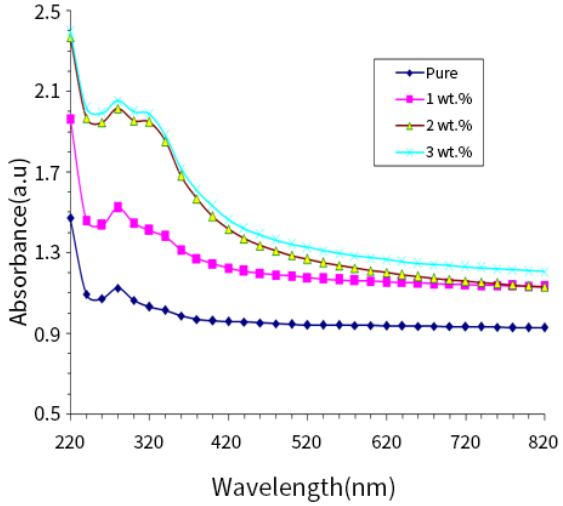

Figure 1. Absorption spectra of PVA/PEG/In_2O_3 nanostructures films

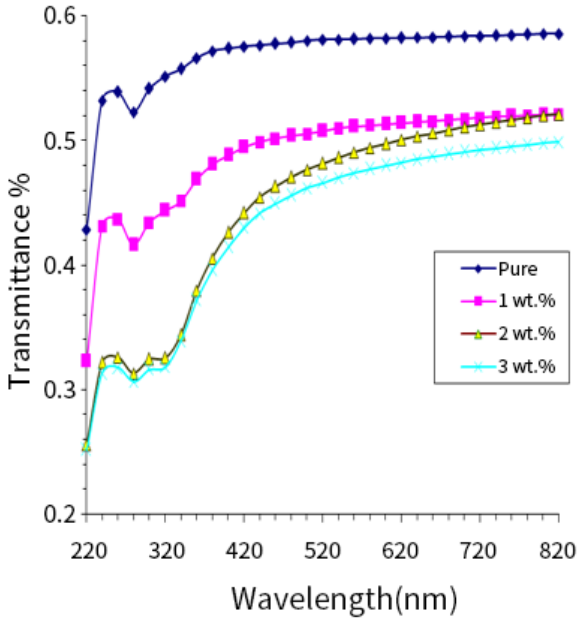

Figure 2. Transmission spectra of PVA/PEG/In_2O_3 nanostructures films

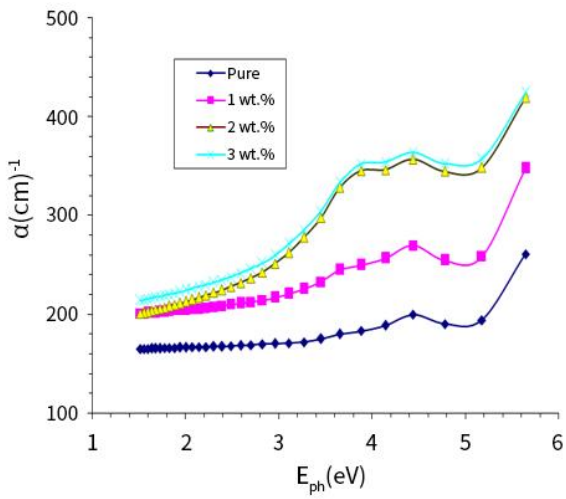

Figure 3. Values of α for PVA/PEG/In_2O_3 nanostructures films

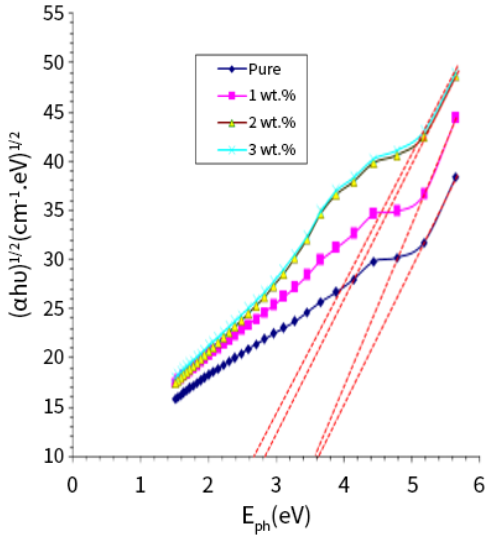

Figure 4. E_g values of PVA/PEG/In_2O_3 nanostructures of allowed transition

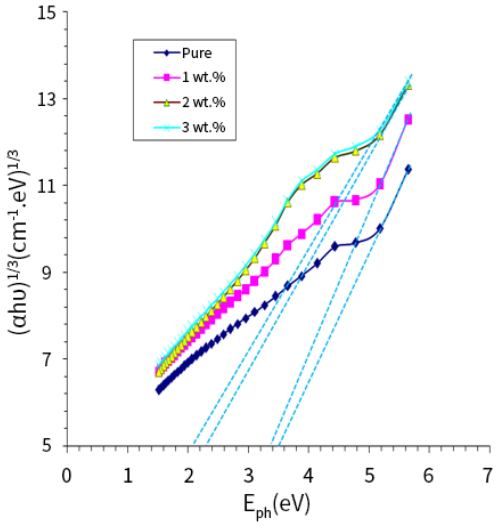

Figure 5. E_g values of PVA/PEG/In_2O_3 nanostructures of forbidden transition

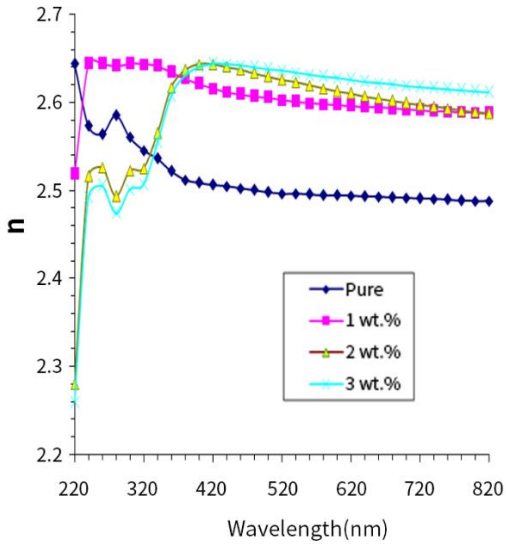

Figure 6. Refractive index performance of PVA/PEG/In_2O_3 nanostructures films

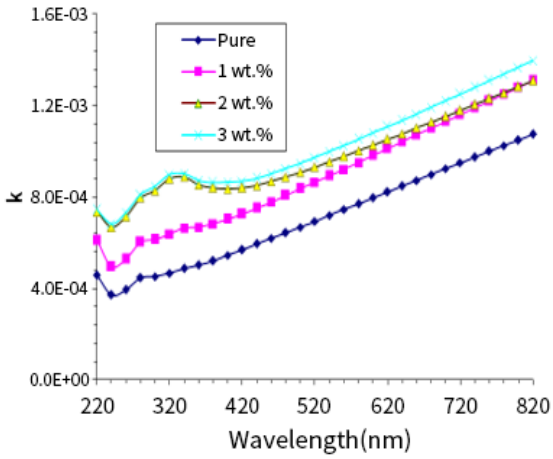

Figure 7. Extinction coefficient performance of PVA/PEG/In_2O_3 nanostructures films

The refractive index and extinction coefficient performances of blend/In_2O_3 nanostructures films are showed in Figures 6 and 7. The values of n and k of blend rise when the In_2O_3 NPs ratio increases, these behaviors due to rise in the density of films and α values [48-52].

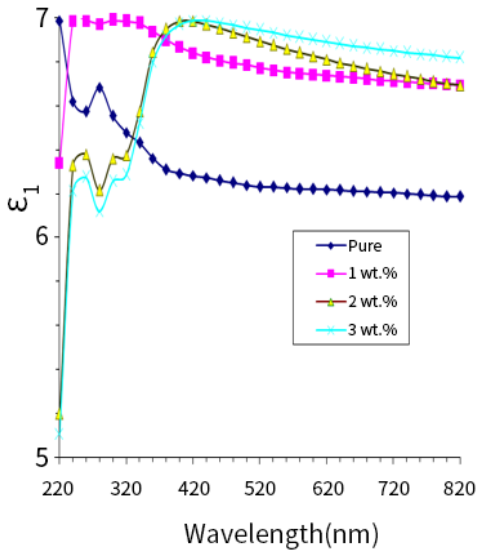

Figure 8. Variase of ε_1 of PVA/PEG/In_2O_3 nanostructures

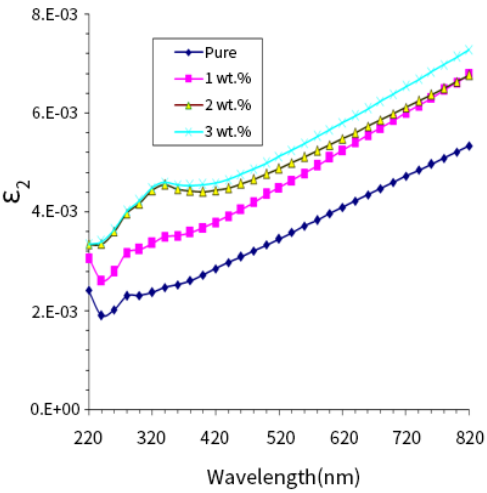

Figure 9. Behavior of ε_2 of PVA/PEG/In_2O_3 nanostructures

Figures 8 and 9 demonstrate the behaviors of real and imaginary parts of dielectric constant of PVA/PEG/In_2O_3 nanostructures films. From these figures, the values of ε_1 and ε_2 rise as the ratio of In_2O_3 NPs rises which relate to rise in the n and k values [53-58].

The influence of In_2O_3 NPs content on conductivity of blend/In_2O_3 nanostructures films is represented in Figure 10. The σ_{op} value of PVA/PEG/In_2O_3 nanostructures films rises with rise in the In_2O_3 NPs content and this behavior related to rise in the absorption and reduce in the energy gap [59-64].

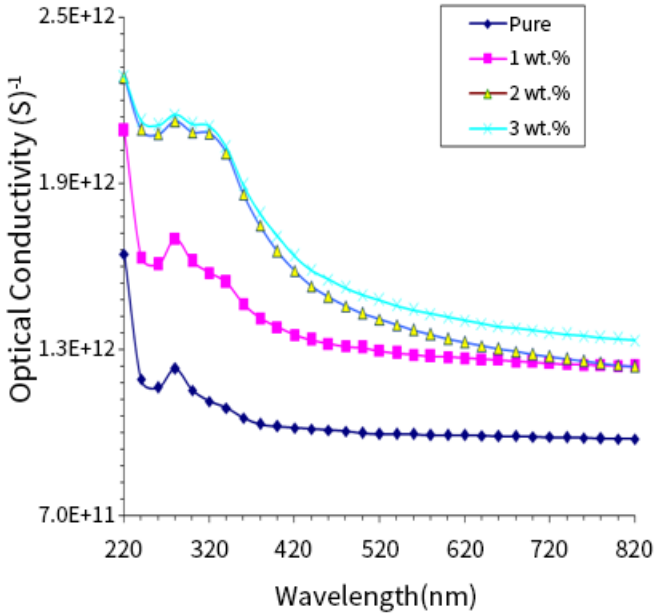

Figure 10. Influence of In_2O_3 NPs content on optical conductivity for PVA/PEG/In_2O_3 nanostructures

4. CONCLUSIONS

The goal of this research is to produce blend/In_2O_3 films and examine their optical characteristics for use in a variety of photonics and optical applications. The PVA/PEG/In_2O_3 films' optical characteristics were investigated at wavelengths between 220 and 820 nm. The findings showed that as the amount of In_2O_3 NPs increases, the transmittance decreases and the absorbance of PVA/PEG increases. With an increase in In_2O_3 NPs content, the band gap shrank. By including In_2O_3 NPs, the blend/In_2O_3 nanostructures' optical properties are enhanced. The optical character results demonstrated the potential use of blend/In_2O_3 nanostructures in many photonics and optics domains.

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