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Investigating the Optical Properties of PVA/PEG/CeO₂ Nanocomposites for Optics Devices

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ABSTRACT

The purpose of this work is to fabricate of PVA/PEG/CeO_2 nanocomposites and examining their optical characteristics used in different optical devices. The PVA/PEG/CeO_2 nanocomposites were prepared by using casting method with different concentrations of PVA/PEG blend and CeO_2 nanoparticles. The optical properties were tested at wavelengths range from 200nm to 800nm. The analysis showed that the CeO_2 NPs content was increased, the absorption of PVA/PEG/CeO_2 nanocomposites was enhanced whereas the transmittance was reduced. Whenever the CeO_2 NPs content was increased, the band gap was reduced. With addition of CeO_2 NPs, the other optical properties of PVA/PEG/CeO_2 nanocomposites were enhanced. Lastly, the optical characteristics outcomes showed that the PVA/PEG/CeO_2 nanocomposites are being used in a variety of optical devices.

1. INTRODUCTION

Polymer nanocomposites, also known as PCs, are a recently popular class of materials that have gained attention due to their distinctive blend of nanostructures and polymeric substances. Their unique attributes arise from the interaction between the two entities, rather than being inherent in their initial properties [1-5]. The proliferation of polymer materials and their widespread use in technology have resulted in the development of polymeric composites. The relevance of polymers mostly stems from their reputation as cost-effective and readily manufacturable materials. The extensive utilization of polymer materials in various applications has resulted in the creation of composite materials designed for specific purposes. Recently, there has been growing interest in polymer matrix-ceramic additive composites because of their intriguing electrical and electronic properties. These composites have potential applications in various fields, including integrated decoupling capacitors, angular acceleration accelerometers, acoustic emission sensors, and electronic packaging. Organic polymers are known for their advantageous properties such as flexibility, toughness, formability, and low density. On the other hand, ceramics exhibit exceptional mechanical, thermal, and optical properties. Composite materials have emerged as one of the primary categories of high-performance engineering materials, alongside metals and alloys, ceramics, and polymers. The ultimate features of a composite material are determined by the distribution of reinforcement or filler in the medium and the adhesion phenomena between the filler and the medium. [6, 7]. Polyvinyl alcohol (PVA) is regarded as a water-soluble polymer material that is biocompatible, biodegradable, and non-toxic. This polymer substance is an exceptional adhesive, displaying remarkable resistance to organic solvents and greater resistance to the passage of oxygen compared to any other acknowledged polymer. It is a rare type of polymer that can dissolve in water and has exceptional properties at the boundary between different materials. It is widely utilized in the textile industry, packaging sector, and biomedical applications including contact lenses, pharmaceuticals, orthopedic materials, tissue engineering, and the production of artificial organs [8-10]. Polyvinyl alcohol is a polymer that is capable of undergoing biodegradation and is environmentally friendly [11]. PVA is a water-soluble polymer that exhibits favorable thermal and mechanical properties [12]. Producing thin films with oxide may occur spontaneously and serve a practical purpose [13]. The properties of polymers can be improved by combining two or more polymers and/or adding organic or inorganic additives for use in various industries such as marine, aviation, aerospace, etc. [14, 15]. Cerium oxide nanoparticles (CeO_2NPs) are becoming increasingly popular due to their advantageous features such as a large surface area, high porosity volume, excellent stability, conductivity, and dielectric properties. These traits make them suitable for a wide range of applications [16-21]. Hybrid optical compounds composed of both organic and inorganic materials are exceedingly costly from a technical perspective. Combinations of hybrid materials with exceptional properties can be developed after the relationships between the properties of inorganic components and polymeric matrices are clarified. Nanocomposites consisting of polymeric matrices are a significant group within the field of applied materials science and technology due to their appealing properties. Polymeric composites (PC) possess several appealing optical properties, including a high/low refractive index, altered emission/absorption spectra, and enhanced optical nonlinearities. Hybrid compounds possess unique features that make them suitable for functional optoelectronic applications [22]. The nanocomposites have extensive applications in numerous fields, including piezoelectricity and sensors [23-29], energy storage [30-33], antimicrobial properties [34-36], and electronics [37, 38]. This study involves the fabrication of PVA/PEG/CeO_2 films and the examination of their optical properties for potential usage in various optical applications.

2. MATERIALS AND METHODS

Films of PVA/PEG/CeO_2filmshave prepared with various ratios of cerium oxide nanoparticles (CeO_2 NPs) and polymer blend. The polymer blend was prepared by dissolving 1gm of polymers in (30 ml) of distilled water with ratio (81%PVA/19%PEG). The CeO_2 NPs were added to polymer blend with ratios (1.5%, 3% and 4.5%). using the casting method to prepare nanocomposites. The (UV-18000A-Shimadzu) spectrophotometer was used to test the optical characters of blend/CeO_2 nanocomposites. Utilizing the given relation to get the absorption coefficient (α) [39]:

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

wherever: d is the thickness, A is the absorbance.

The energy gap (E_g) is assumed by [40]:

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

where, B is a constant, hυ represents the energy of a photon, Eg represents the band gap, and m can take the values 2 and 3 for allowed and forbidden transitions, respectively. The refractive index (n) is provided [41]:

$$n = \frac{1+R^{\frac{1}{2}}}{1-R^{\frac{1}{2}}} \tag{3}$$

where, R is reflectance. The extinction coefficient (k) is defined by the relation [41]:

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

wherever λ is wavelength. Dielectric constant of the real (ε_1) and imaginary (ε_2) is given by [42]:

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

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

The optical conductivity (σ_{op}) defines [43].

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

3. RESULTS AND DISCUSSION

Utilizing the refractive index, which is indicated by the symbol n, enables one to calculate the speed at which an electromagnetic wave traveling through a medium is moving. The real part of the refractive index, which is indicated as n, stands for the actual velocity, while the complex part of the refractive index, which is denoted ask, is known as the extinction coefficient. The refractive index may be broken down into these two components. The extinction coefficient is a measure of how the oscillatory amplitude of the electric field decreases or is absorbed as a wave passes through a substance [44]. The refractive index, represented as n*, is controlled by the interaction between the electric field of the electromagnetic wave and the medium it is traversing [45]. The refractive index of a substance is an essential property that determines its optical characteristics. This statement describes the measurement of the change in the speed of light when it moves from a vacuum to a different material. The refractive index measures the extent of light bending or refraction that takes place when moving from one substance to another [46]. The deceleration of light occurs as it moves from a vacuum to another substance due to the interplay between the electromagnetic fields of light and the properties of the new medium. The refractive index of a vacuum is 1 because the speed of light is highest in a vacuum. Consequently, it serves as the standard for evaluating the refractive indices of other substances [47]. Because of their ability to hold electrical charge, dielectric materials can generate an electric field with little to no energy loss. Polymers are not only useful as insulators for cables and other electrical components, but they also exhibit dielectric properties. Mica and silicon dioxide are two examples of common inorganic components found in dielectric materials [48]. However, polymers are rapidly gaining ground as viable dielectric alternatives. As a result of their versatility, low production costs, and the ability to be molded into a variety of shapes and sizes, polymers can be used in a wide variety of settings. Their dielectric properties, in particular, make them highly resistant to chemical attack. A substance's dielectric constant is a dimensionless metric that assesses its polarization in response to an applied electric field. To get the dielectric constant, divide the electric field E_0 from outside the dielectric by the electric field E [49].

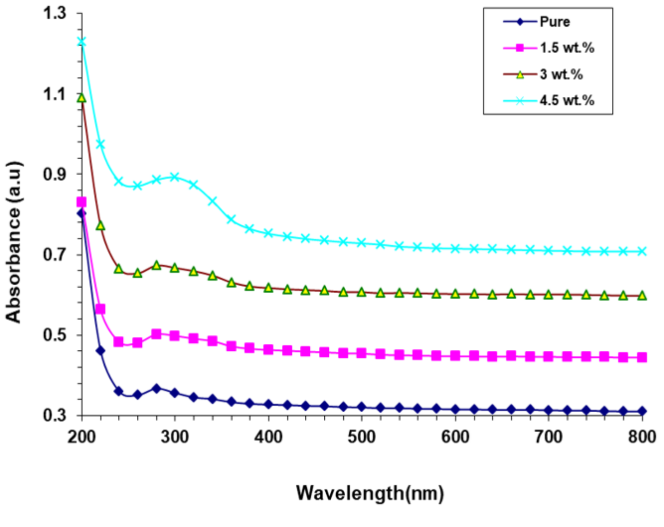

Figure 1. Variation absorbance of PVA/PEG/CeO_2 nanocomposites

Figure 1 shows the absorbance spectra of PVA/PEG/CeO_2 films. It is show that the absorption spectra increases when the added CeO_2 NPs content. This result because the rise charge carrier's density which lead to improve the absorbance [50-52] hence the transmittance will decrease for all sample prepared as shown in Figure 2. As shown in Figures 1 and 2, the absorbance reduces and transmittance increases with increase in wavelength of photons. The PVA/PEG/CeO_2 films included high value of absorbance at UV-spectra while the transmittance of PVA/PEG/CeO_2 films included lower values at UV-spectra then increases with rising wavelength of photons.

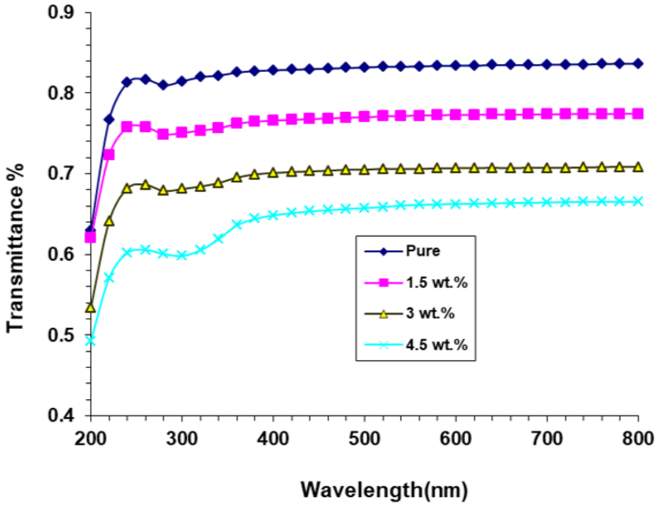

Figure 2. Transmission varieties of PVA/PEG/CeO_2 nanocomposites

Figure 3 obtain the absorption coefficient of PVA/PEG/CeO_2 nanocomposite. The α give the information on the nature of the transition. It is observed that the $\alpha<10^4\ cm^{-1}$ therefore the happened indirect transition. The polymeric blend exhibited a low absorption coefficient, maybe attributed to its poor crystallinity [53, 54].

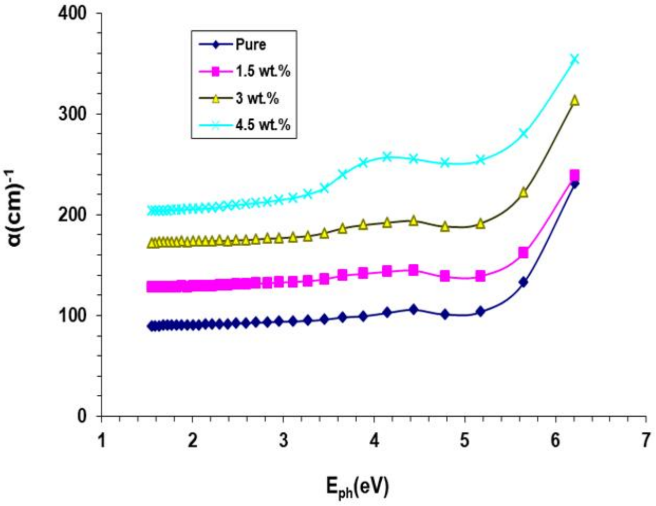

Figure 3. Absorption coefficient of PVA/PEG/CeO_2 nanocomposites

The value of allowed &forbidden energy gap of blend/CeO_2 films is illustrate in Figures 4 and 5 respectively. Because formation of levels inside band gap and the local cross-linking thattake place inside the composites noncrystallinephase [55-62], the value of E_g reduce with increase of CeO_2 NPs.

Figures 6 and 7 show the performances of n and k of blend/CeO_2 nanocomposites. The n values reduce with rising photon wavelength. The k values reduce, then rise with rising photon wavelength. It is observed that the n and k of PVA/PEG/CeO_2 nanocomposite reduce when additive CeO_2 NPs ratio, which related to the increase density of films and α value [63-68].

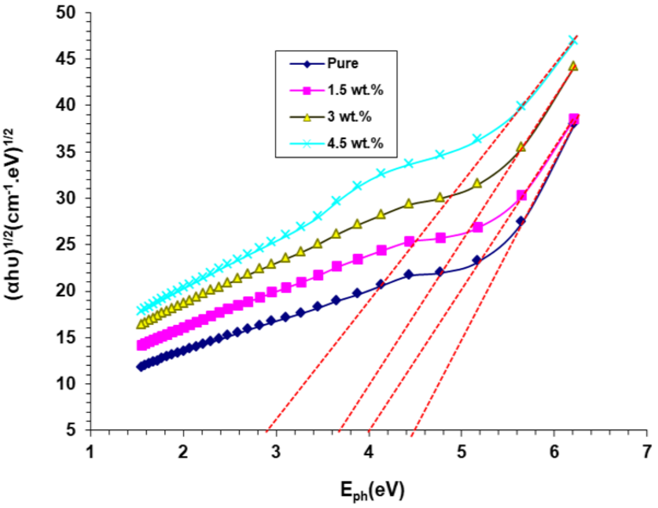

Figure 4. E_g values of blend/CeO_2 nanocomposites for allowed transition

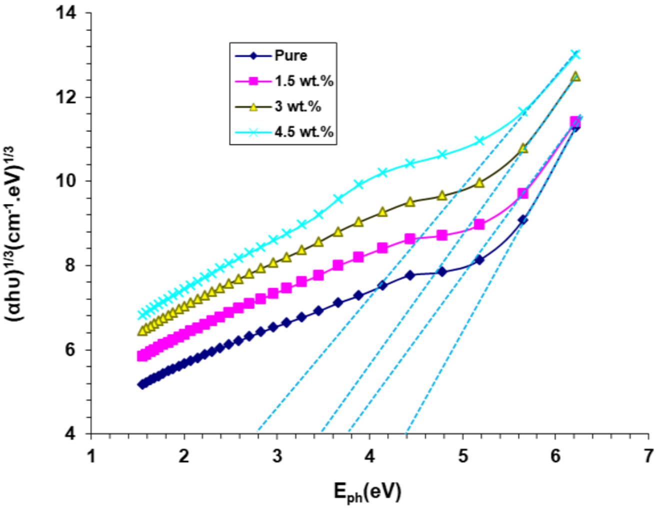

Figure 5. E_g values of blend/CeO_2 nanocomposites for forbidden transition

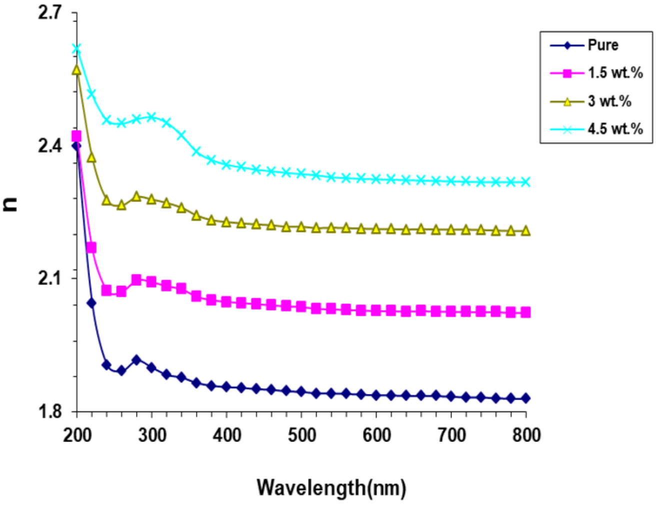

Figure 6. Performanceof n for PVA/PEG/CeO_2 nanocomposites

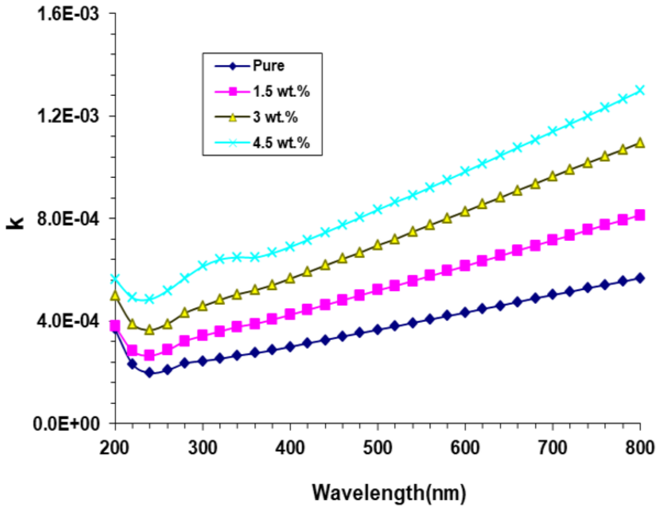

Figure 7. Extinction coefficient of PVA/PEG/CeO_2 nanocomposites

The real and imaginary dielectrics constants of PVA/PEG/CeO_2 films are shown in Figures 8 and 9. The real dielectric constant decrease with rising photon wavelength. The ε_2 values reduce, then rise with rising photon wavelength. These figures obtain that the ε_1 and ε_2 reduce when increase in the CeO_2 NPs which attribute to the increase in n and k [69-73].

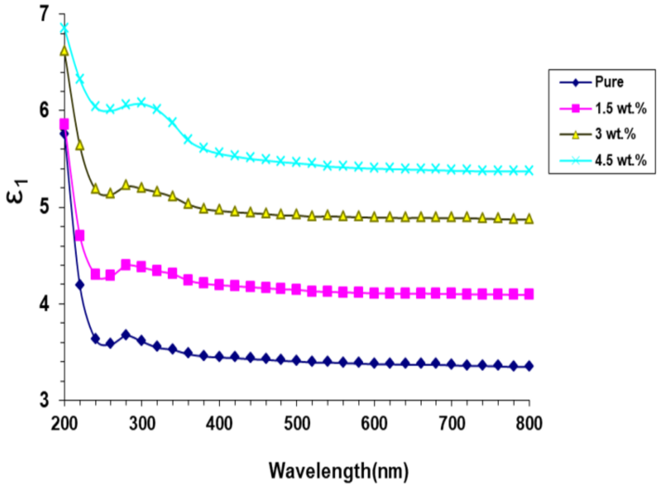

Figure 8. ε_1 of blend/CeO_2 nanocomposites

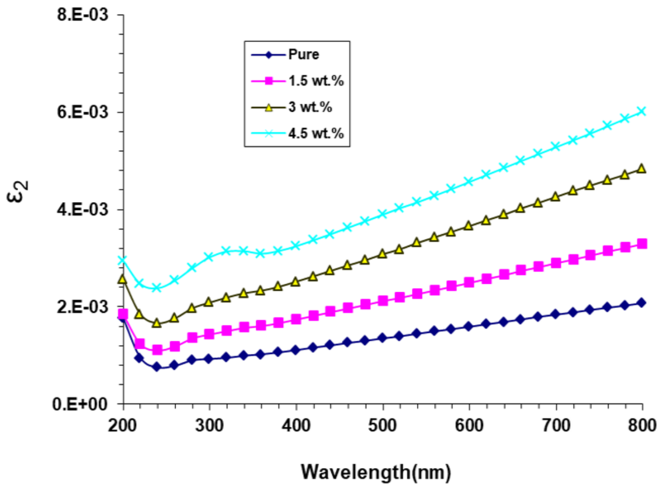

Figure 9. ε_2 of blend/CeO_2 nanocomposites

Figure 10 shows that the effect of the optical conductivity of blend CeO_2 films. The σ_{op}values decrease with rising photon wavelength. Through rise in content in CeO_2 NPs, the σ_{op} value will rises which due to the increase in absorbance and reduce the energy gap [74-80].

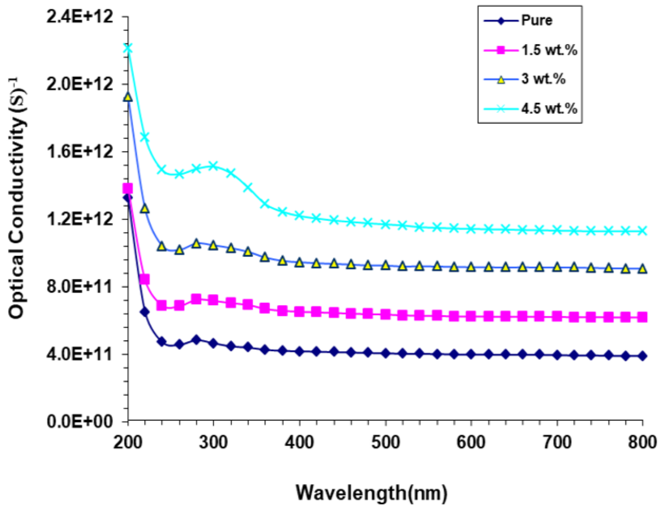

Figure 10. The σ_{op} of blend/CeO_2 nanocomposites

4. CONCLUSIONS

This research explores the manufacturing of blend/CeO_2nanocomposites and their optical characteristics used in different optical devices. The optical characterizations of PVA/PEG/CeO_2 nanocomposites were examined at wavelengths range from 200 nm to 800nm. The analysis indicated that the rise in the CeO_2NPs concentration causes to rise in the absorption of PVA/PEG while a transmittance is reduced. When the CeO_2 NPs content is increased, the bandgap reduces. The adding of CeO_2 NPs enhances the optical characteristics of PVA/PEG/CeO_2 nanocomposites. The optical characters showed that the blend CeO_2 films can be used in different optical devices.

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