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Fabrication and Enhancing the Features of Chitosan/SnO_2-ZnO Nanocomposites Films for Optoelectronics and Biological Applications

Saad Abbas Jasim[1], Najah M. L. Al Maimuri[2], Ahmed Hashim[1,*], Mohammed H. Abbas[1], Aseel Hadi[3] and Hamed Ibrahim[4]

[1]*Department of Physics, University of Babylon, College of Education for Pure Sciences, Babylon, Iraq*
[2]*Building and Construction Technologies Engineering Department, College of Engineering and Engineering Technologies, Al-Mustaqbal University, 51001, Babylon, Iraq*
[3]*Department of Ceramic and Building Materials, College of Materials Engineering, University of Babylon, Babylon, Iraq*
[4]*Al-Zahraa University for Women, Kerbala, Iraq*

([*]Corresponding author's e-mail: ahmed_taay@yahoo.com)

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Abstract

The present work aims to fabricate of chitosan doped with SnO_2-ZnO nanoparticles to employ in various optical and electronics applications. The study included the compact of (SnO_2/ZnO) nanocomposites on optical features of chitosan to be used in variety of optics and electronics applications. The chitosan-SnO_2/ZnO nanocomposites have been prepared by utilizing casting technique with various concentrations of (SnO_2/ZnO) nanoparticles and chitosan. The optical features have been investigated at a range of wavelengths from (320 - 920 nm). The analysis reveal that when (SnO_2/ZnO) nanoparticles ratio has been increased, absorption value of chitosan-(SnO_2/ZnO) nanocomposites was boosted whereas the transmittance value was drop down. Whenever (SnO_2/ZnO) nanocomposites ratio have been rise, the band gap was reduced from 3.33 to 2.9 eV for allowed transition and from 3.13 to 2.51 eV for forbidden transition. The other optical features of chitosan-SnO_2/ZnO nanocomposites have been boosted. Finally, the outcomes of optical features reveal that the chitosan-SnO_2/ZnO nanocomposites are being possible to be utilized in a variety of applications.

Keywords: Chitosan, SnO_2, ZnO, Nanocomposites, Optical properties, Optoelectronics, Nanoparticles

Introduction

Nanotechnology provides the ability to engineer the materials properties by controlling their size. It producing major advances in energy, including high-performance batteries and economic solar cells; electronics, with single atom transistors and ultrahigh density data storage; food and agriculture, increased screening for contaminants and offering smart delivery of nutrients. The composites have been widely used in the various fields such as military equipments, safety, protective garments, automotive, aerospace, electronics, and optical devices. However, these application areas continuously demand additional properties and functions such as high mechanical properties, flame retardation, chemical resistance, UV resistance, electric conductivity, environmental stability, water repellency, magnetic field resistance, radar absorption, etc [1-3]. Due to the widespread use of polymer materials in a variety of applications, composite materials with specialized uses have been developed [4]. Chitosan, a biopolymer derived from chitin, has garnered significant attention in various fields due to its biodegradability, biocompatibility, and antimicrobial properties. Its potential applications span across medicine, agriculture, and environmental sectors. Recent advancements have focused on enhancing chitosan's properties by integrating it with metal oxide nanoparticles, particularly tin oxide (SnO_2) and zinc oxide (ZnO). These composites leverage the

unique characteristics of both chitosan and metal oxides to create materials with superior functionalities [5,6]. Chitosan is a natural polymer obtained through the deacetylation of chitin, primarily sourced from crustacean shells. It is characterized by its positive charge, which facilitates interactions with negatively charged bacterial cell membranes, leading to antimicrobial effects. Additionally, chitosan is known for its wound-healing properties, making it suitable for biomedical applications. Its biodegradability and non-toxicity further enhance its appeal in various industrial applications, including food packaging, water treatment, and drug delivery systems [7,8]. It is a natural polysaccharide derived from chitin, the second most abundant biopolymer after cellulose. Chitin is commonly found in the exoskeletons of crustaceans such as crabs, shrimp, and lobsters, as well as in the cell walls of fungi [9]. Through a process called deacetylation, where acetyl groups are removed using alkaline treatment, chitin is converted into chitosan. The extent of this deacetylation greatly affects the physicochemical and biological properties of chitosan, particularly its solubility and bioactivity. Structurally, chitosan is composed of β-(1→4)-linked D-glucosamine and N-acetyl-D-glucosamine units. Unlike cellulose, which is insoluble in water, chitosan becomes soluble in slightly acidic solutions due to the protonation of its amine groups, allowing for its wide range of uses in aqueous environments [10,11]. Chitosan's key properties include: Biodegradability: Naturally degraded by enzymes such as lysozyme into non-toxic, environmentally friendly components. Biocompatibility: Compatible with human tissues and cells, making it a prime candidate for biomedical applications. Antimicrobial Activity: Exhibits inherent antibacterial and antifungal properties, mainly due to its polycationic nature, which disrupts microbial cell membranes. Film-Forming Ability: Chitosan can form transparent, flexible films, useful in coatings and packaging. Non-Toxicity: Safe for both pharmaceutical and food-grade applications. Its positive charge in acidic environments also enables mucoadhesion - a crucial property in drug delivery systems, especially for mucosal surfaces like the nose, mouth, and gastrointestinal tract [12,13]. Tin oxide (SnO_2) and zinc oxide (ZnO) are wide-bandgap semiconductors with distinct properties that contribute to their effectiveness in composite materials. SnO_2 is known for its high surface area and photocatalytic activity, making it suitable for environmental applications such as pollutant degradation. ZnO, on the other hand, exhibits strong antimicrobial properties and photocatalytic activity, which can be harnessed in various applications, including wound healing and water purification [13,14]. Experimental research has shown that as the mean grain size of ZnO sensors increases, their gas sensitivity reduces. In addition, Due to its high exciton binding energy, zinc oxide is also a skilled material for short-wavelength optoelectronics [15]. When integrated with chitosan, SnO_2 and ZnO nanoparticles can enhance the composite's mechanical strength, antimicrobial activity, and photocatalytic efficiency. The combination of chitosan's biopolymer matrix with the functional properties of metal oxides results in nanocomposites that are not only effective in antimicrobial applications but also in environmental remediation and energy conversion processes [16,17]. Chitosan-based nanocomposites incorporating SnO_2 and ZnO nanoparticles exhibit enhanced mechanical, antibacterial, and photocatalytic properties. The inclusion of SnO_2 improves the chemical stability of ZnO in acidic environments, while ZnO contributes to antibacterial activity and photocatalytic efficiency. These nanocomposites have applications in antifouling coatings, antimicrobial wound dressings, and environmental remediation. Studies have demonstrated their effectiveness in degrading pollutants and inhibiting bacterial growth, making them promising materials for various biomedical and environmental applications [17,18]. The addition of oxides nanostructure into polymers aims to improve their optical and dielectric properties [19-25]. This study involves the fabrication of CS/SnO_2/ZnO films and the examination of their optical and morphological properties for potential usage in various optical applications.

Materials and methods

The used materials in the present work are chitosan as host matrix and SnO_2-ZnO nanoparticles as a fillers. The CS/SnO_2/ZnO films were prepared by dissolving of 1 g of chitosan in 50 mL of deionized water with 0.2 % of acetic acid using magnetic stirrer for 3 h at room temperature. The mixing procedure was

repeated 4 times until the mixture was homogeneous. The solution was poured into a Petri dish (9 cm in diameter) and left at room temperature for a week to dry using the traditional casting method. In the method of fabrication of CS/SnO_2/ZnO nanocomposite films, different weight percentage of (0, 1.5 and 3 wt%) were added to chitosan pure films separately to the above blend for 3 h, and the mixtures were cast and dried for a week by the same previous procedure. The samples' thickness was measured using a micrometer and found to be within 30 μm. The (UV-18000AShimadzu) spectrophotometer was used to test the optical characters of CS/SnO_2/ZnO nanocomposites. The optical microscope was utilized to observe the distribution of nanoparticles inside the polymer medium at 100 X. The coefficient of absorption (α) is given by Henaish and Abouhaswa [26]:

$$A = 2.303\ (A/d) \quad (1)$$

where A is the absorbance and d is the film thickness. Energy gap is determined by Mahalakshmi *et al.* [27]:

$$(\alpha h\upsilon)^{1/r} = Y(h\upsilon - E_g) \quad (2)$$

wherever Y is a constant, hυ is the photon energy, E_g is the energy gap, r = 2 and 3 for transitions of allowed & forbidden. Index of refractive (n) is defined by Santhosh *et al.* [28]:

$$n = \frac{1+\sqrt{R}}{1-\sqrt{R}} \quad (3)$$

where R is the reflectance. The coefficient of extinction (k) is given by Peshawa *et al.* [29]:

$$k = \frac{\alpha\lambda}{4\pi} \quad (4)$$

Real (ε_1) and imaginary (ε_2) dielectric constants are calculated by Salohub *et al.* [30]:

$$\varepsilon_1 = n^2 - k^2 \quad (5)$$

$$\varepsilon_2 = 2nk \quad (6)$$

The optical conductivity (σ_{op}) is defined by Kumar *et al.* [31]:

$$\sigma_{op} = \frac{\alpha nc}{4\pi} \quad (7)$$

Results and discussion

Morphological investigations

Figure 1 shows the surface morphology images of chitosan doped with (0, 1.5 and 3 wt %) of (SnO_2:ZnO), respectively. It's clearly appear from the optical microscopy image that the polymer blend was homogeneously and perfectly dissolved in the solution, as shown in **Figure 1(a)**. **Figures 1(b)** and **1(c)** show that SnO_2 and ZnO was well distributed on the surface of chitosan with uniform density. These results indicate that the molecules of dopant material tend to form well dispersed groups and may indicate the occurrence of a homogeneous growth mechanism. With grow NPs content, the NPs propagated as a clusters structure. At high concentration, the NPs shape a network of pathways inside the matrix of polymer material [32-38].

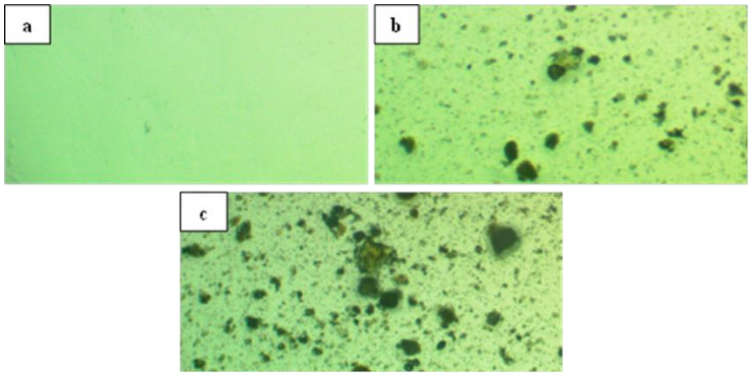

Figure 1 Optical microscopy images at 100 X: (a) pure Chitosan, (b) 1.5 wt. % and (c) 3 wt %.

Optical properties investigations

In this section, the optical properties of chitosan films were systemically examined and studied. **Figure 2** shows the variation of the optical absorbance spectra of chitosan and chitosan-SnO_2/ZnO films against photon wavelength for different concentrations of SnO_2 and ZnO nanoparticles. All the results show that films have high absorbance in the ultraviolet region and become have low values in the NIR and visible regions. This behavior can be explained by the addition of SnO_2 and ZnO nanoparticles to chitosan films enhances their absorbance by modifying the electronic structure, introducing defect states, and improving charge transfer efficiency, making them suitable for different applications [39-45].

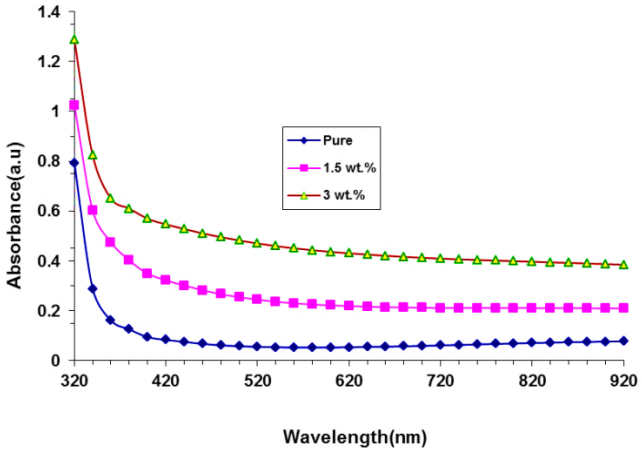

Figure 2 The absorbance versus wavelength for Chitosan-SnO_2/ZnO films.

Figure 3 shows the transmittance spectra of Chitosan (CS) and Chitosan-SnO_2/ZnO films as a function of wavelength. The transmittance increases with rising photon wavelength but its decreases with rising NPs content. The reduction in transmittance of chitosan films with the addition of SnO_2 and ZnO nanoparticles is primarily due to increased light scattering by the (SnO_2/ZnO) NPs and rising the numbers of charges carriers inside nanocomposites [46-50].

Figure 4 shows the optical conductivity as a function of the wavelength for Chitosan (CS) and chitosan-SnO_2/ZnO films. The optical conductivity increases with rising SnO_2/ZnO NPs content. It was observed from the figure that the optical conductivity at high photon energy (low wavelength) increased and vice versa at high wavelength. This may be due to enhancing free carrier density and modifying the band structure. These nanoparticles improve charge transport and light absorption through interfacial and crystallinity effects. Together, they enable more efficient photon-induced carrier excitation and mobility [51-54].

Figure 5 obtains the absorption coefficient of Chitosan (CS) and Chitosan (SnO_2/ZnO) films nanocomposite. The α give information on the nature of the transition. It is observed that the $\alpha < 10^4$ cm^{-1} therefore the happened indirect transition. Chitosan modified with SnO_2 and ZnO nanoparticles shows increased absorption coefficient due to enhanced light scattering, charge transfer, and bandgap tuning. These effects improve photon interaction and broaden spectral absorption, especially in the UV-visible range [55,56].

The value of allowed &forbidden energy gap of Chitosan (CS) and Chitosan-SnO_2/ZnO films is illustrate in **Figures 6** and **7**, respectively. The addition of SnO_2 and ZnO to chitosan introduces defect states and facilitates orbital hybridization, leading to the formation of new energy levels within the band gap. This results in a reduced energy gap from 3.33 to 2.9 eV for allowed transition &from 3.13 to 2.51 eV for forbidden transition due to easier electron transitions and modified electronic structure. the value of Eg reduce with increase of (SnO_2/ZnO) nanoparticles [57-65].

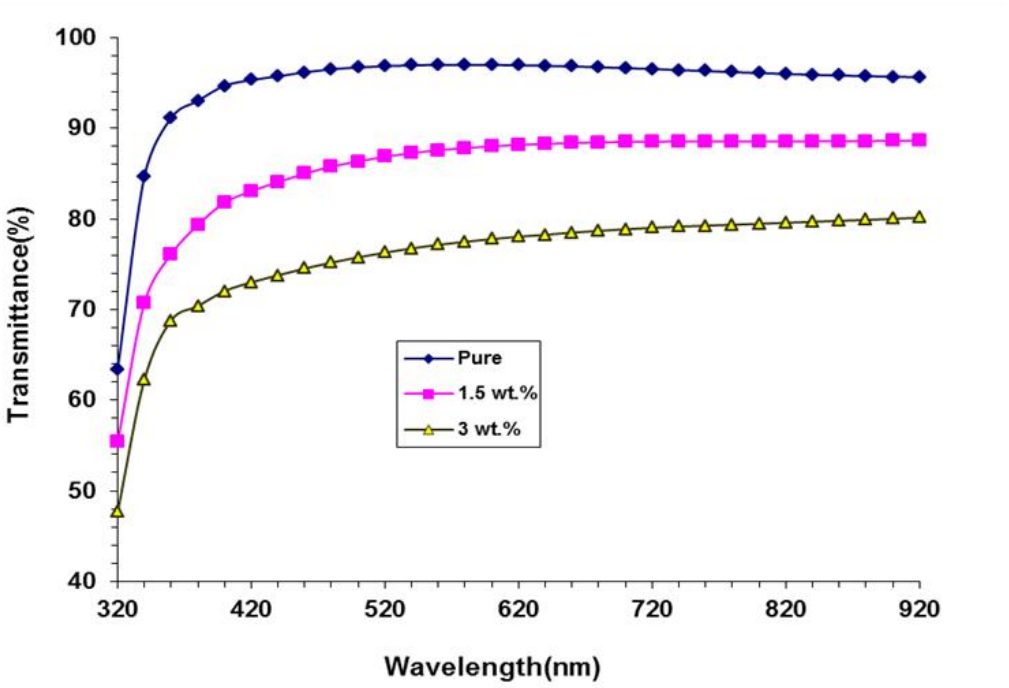

Figure 3 The transmittance versus wavelength for Chitosan-SnO_2/ZnO films.

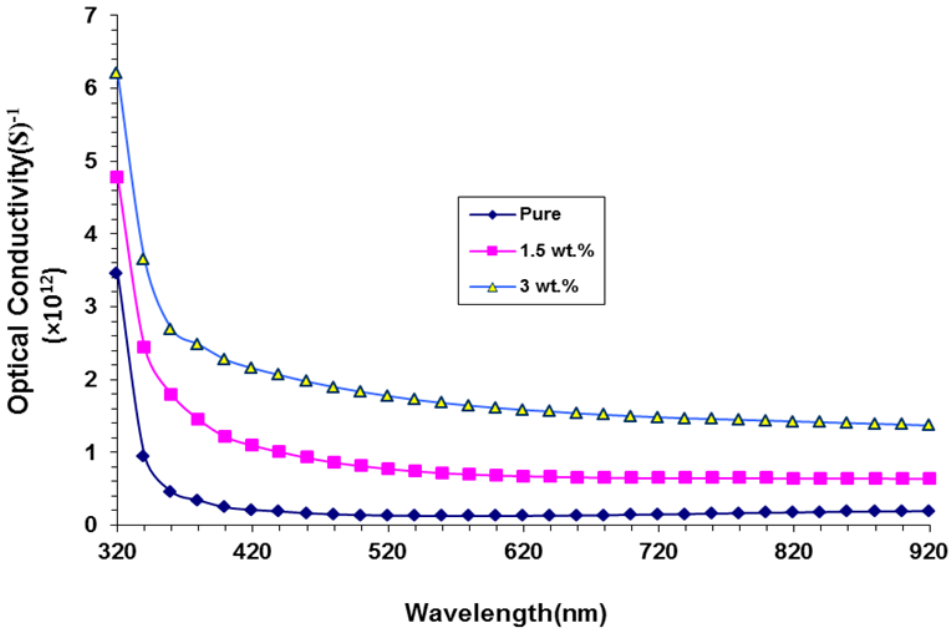

Figure 4 The optical conductivity variation with wavelength for Chitosan-SnO_2/ZnO films.

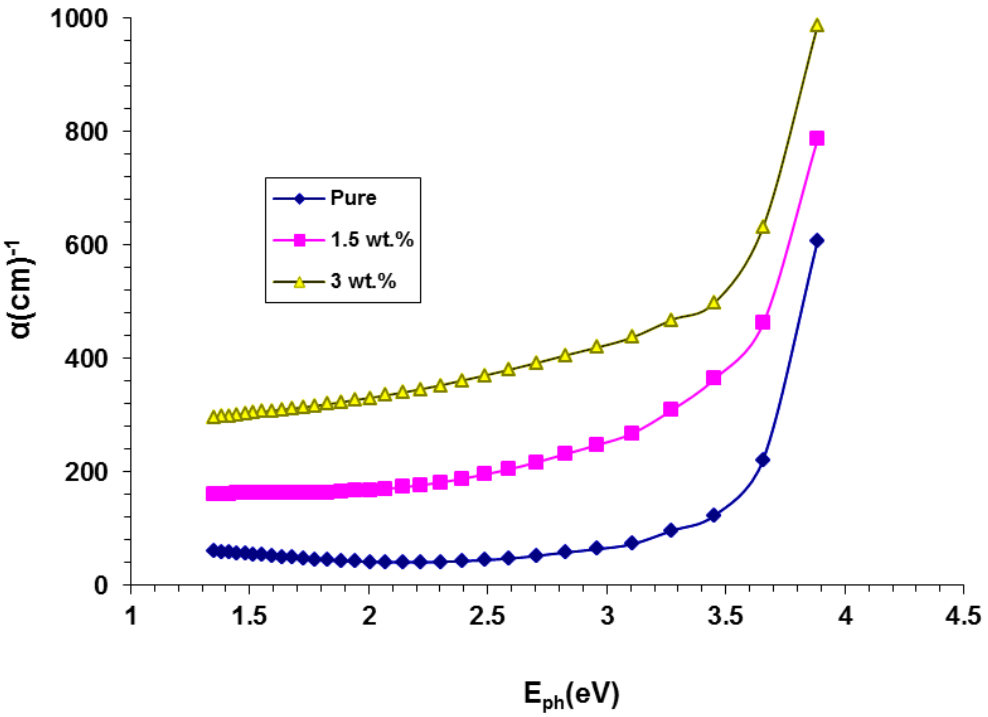

Figure 5 Absorption coefficient for Chitosan-SnO_2/ZnO films.

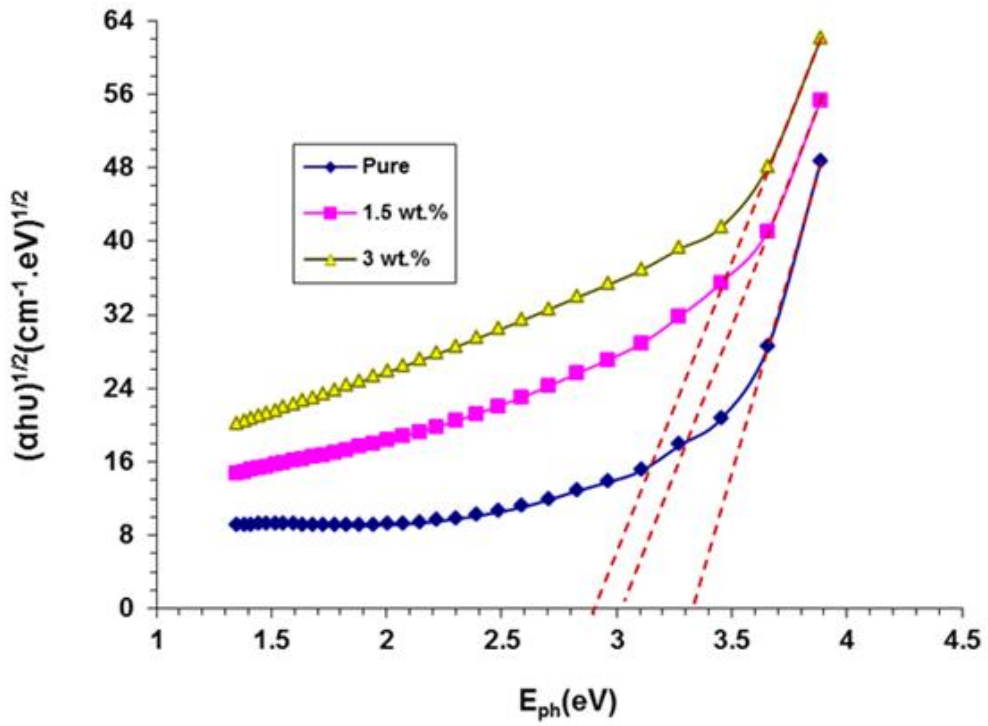

Figure 6 Allowed E_g values for Chitosan-SnO_2/ZnO films.

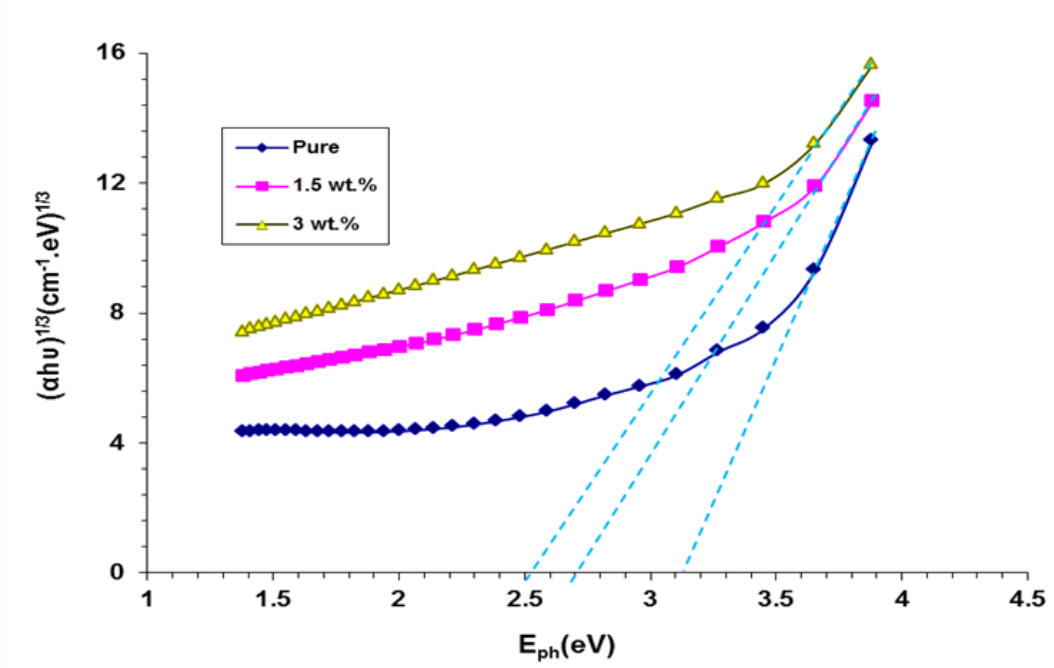

Figure 7 Forbidden E_g values for Chitosan-SnO_2/ZnO films.

Figures 8 and **9** show the performances of n and k of Chitosan (CS) and Chitosan-SnO_2/ZnO films. The n values reduce with rising photon wavelength. The k values reduce, then rise with rising photon wavelength. The refractive index (*n*) and extinction coefficient (*k*) of chitosan increase with rising SnO_2-ZnO due to the rising absorption and scattering within the composite material. Also, the rising of n values related to increase of composite density [66-71]**.**

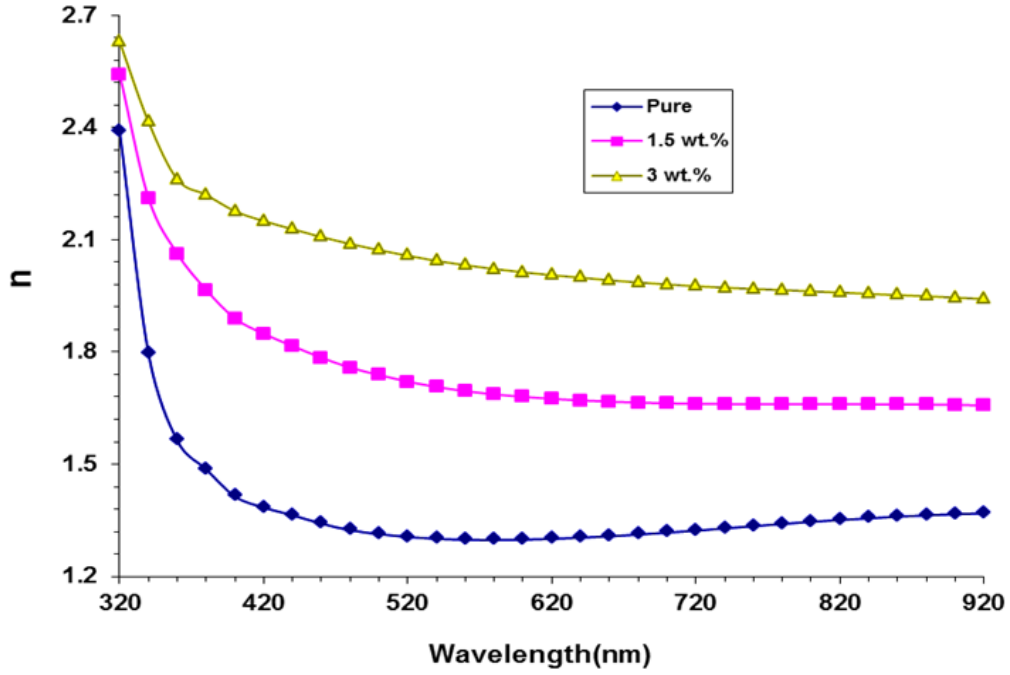

Figure 8 Performance of n with wavelength for Chitosan-SnO_2/ZnO films.

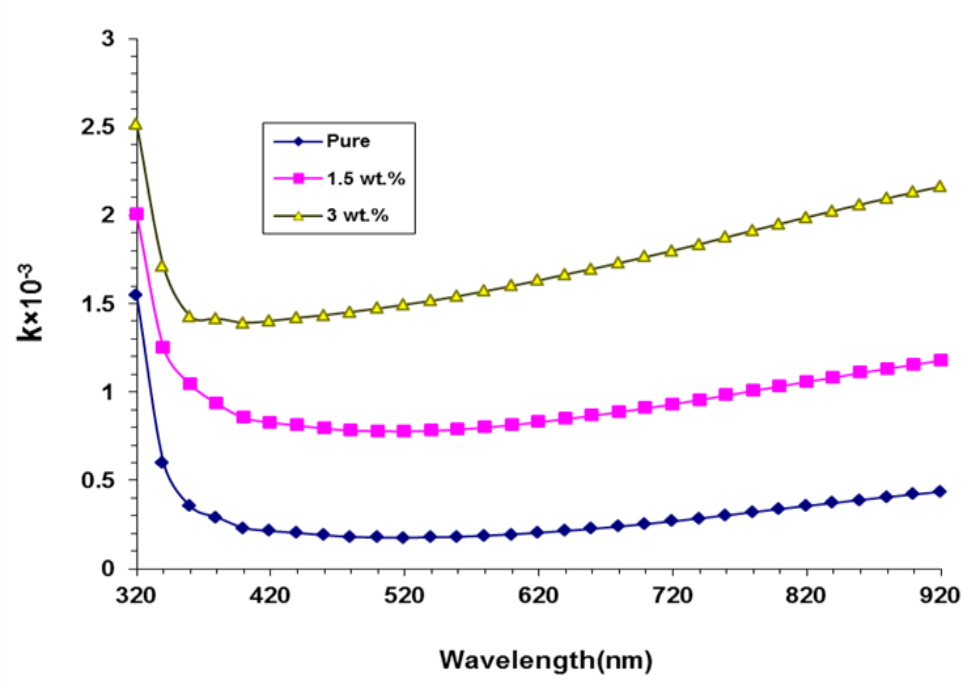

Figure 9 Extinction coefficient behavior for Chitosan-SnO_2/ZnO films**.**

The real and imaginary dielectrics constants of Chitosan (CS) and Chitosan-SnO_2/ZnO films are shown in **Figures 10** and **11**. The real dielectric constant decreases with rising photon wavelength. The ε_2 values are reduce, then rise with rising photon wavelength. The addition of SnO_2-ZnO into chitosan rises both the real (ε_1) and imaginary (ε_2) parts of the dielectric constant. It is concluded that the imaginary part (ε_2) essentially depends on the values of the (k), which are connected to the variation of coefficients of absorption, while the variation of the real part (ε_1) mainly depends on the values of the (n^2) due to small values of (k^2) [72-77].

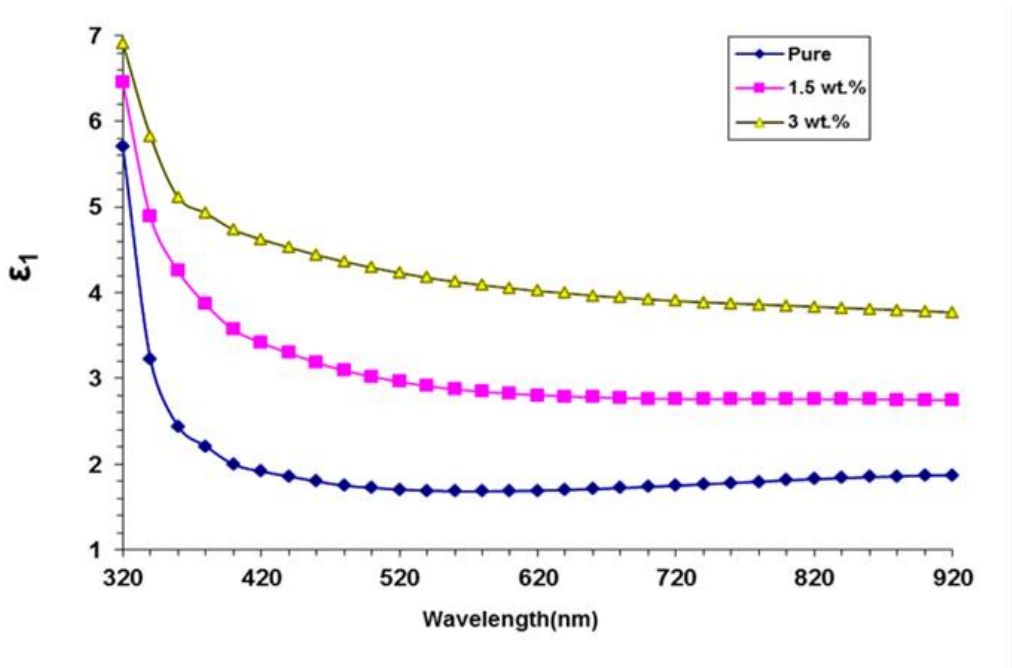

Figure 10 ε_1 behavior for Chitosan-SnO_2/ZnO films.

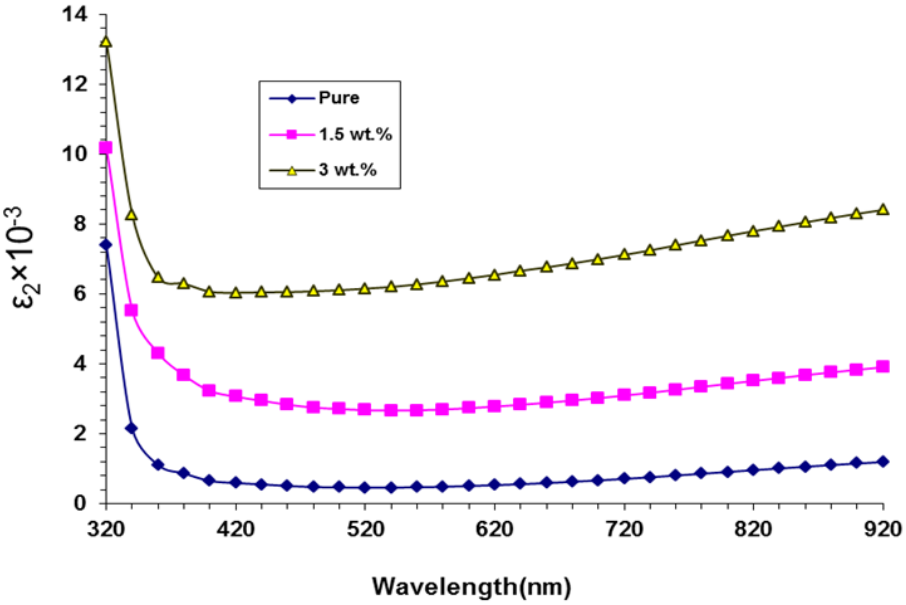

Figure 11 ε_2 variation with wavelength for Chitosan-SnO_2/ZnO films.

Conclusions

The chitosan-SnO_2/ZnO nanocomposites films were successfully prepared by the traditional casting technique. The Optical microscopy images showed that the (SnO_2/ZnO) were homogeneously diffused within the matrix of polymer. It was observed from the study of optical properties that the increase of (SnO_2/ZnO) nanocomposite lead to enhance of all optical coefficients such as absorbance, optical conductivity, refractive index, and energy gap. The energy gap decreased from 3.33 to 2.9 eV for allowed transition & from 3.13 to 2.51 eV for forbidden transition. The optical characters showed that the chitosan-SnO_2/ZnO nanocomposite can be used in different optical devices.

Acknowledgements

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