



Fabrication and exploring the structural, dielectric and optical features of PVA/SnO₂/Cr₂O₃ nanostructures for optoelectronic applications

Majeed Ali Habeeb¹ · Nawras Karim Al-Sharifi¹ · Alaa Abass Mohammed¹

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Abstract

The present study investigates the characteristics of nanocomposites comprising polyvinyl alcohol (PVA), tin dioxide (SnO₂), and chromium trioxide (Cr₂O₃) with respect to their synthesis, structural, electrical, and optical properties. Nanocomposite samples with flexibility were expeditiously synthesized using the cast method. Optical microscope (OM) images elucidated that an increase in the concentration of nanoparticles results in the formation of network pathways within the polymeric matrix, which function as charge carriers. FTIR analysis has demonstrated the existence of physical interactions between the (PVA) and the nanoparticles. The AC electrical characteristics of nanocomposites, specifically the dielectric constant and dielectric loss, exhibit a decrease as the frequency of the applied electric field increases. Conversely, an increase in concentration of SnO₂/Cr₂O₃ nanoparticles results in an increase in these properties. AC electrical conductivity of the nanocomposites increases with both increasing frequency and concentration of SnO₂/Cr₂O₃ NPs. Based on the analysis of its structural and electrical properties, it can be inferred that the PVA/SnO₂/Cr₂O₃ nanocomposite exhibits potential for application in diverse electronic devices. The optical characteristics of PVA/SnO₂/Cr₂O₃ nanocomposites indicated that these materials exhibit greater absorbance in the ultraviolet region. This behavior suggests that the nanocomposites have potential for utilization in optoelectronics applications. The optical properties including absorbance, absorption coefficient, extinction coefficient, refractive index, real and imaginary dielectric constant, and optical conductivity, exhibit an upward trend with increasing concentrations of SnO₂/Cr₂O₃ nanoparticles. At a concentration of 6 wt.%, the allowed and forbidden indirect transitions exhibit a reduction in their optical energy gap from 4.38 to 2.53 eV and from 3.67 to 1.4 eV, respectively. This nanostructured composition tested the first time for the optoelectrical applications. The results showed that the PVA/SnO₂/Cr₂O₃ nanostructures can be considered as promising nanostructures for optics, photonics and electronics nanodevices.

Keywords PVA · SnO₂ · Cr₂O₃ NPs · Optical properties · Dielectric properties · Nanodevices

1 Introduction

Polymer nanocomposites were suggested as a viable option for a wide range of applications, including but not limited to car protection and developed optoelectronic devices. Comprehending the influence of the nanofillers on the physical characteristics of composites is imperative for the triumph of aforementioned applications (Naeimirad et al. 2016). As a result, numerous research teams are currently dedicated to formulating a comprehensive framework for forecasting, or at the very least, comprehending the interplay between the chemistry and morphological concepts of the matrix of polymers and the surface chemistry, size, and shape of a nanoscale filler in order to establish mechanical properties. The fundamental mechanisms underlying this framework are situated at the intersection of various disciplines, including chemistry, physics, materials science, and continuous mechanics. Hence, the scientists engaged in this crucial field of study exhibit a diverse range of backgrounds and methodologies (Habeeb 2011; Kim et al. 2006). Nanomaterials exhibit distinct physical characteristics in the field of nanotechnology as compared to conventional chemicals. Examples of such nanomaterials include silver Nano, carbon nanotubes, fullerenes, and carbon Nanos (Mahdi and Habeeb 2023; Hayder et al. 2020). Polyvinyl alcohol (PVA) exhibits promising characteristics such as elevated dielectric strength, favorable charge storage capacity, and electrical and optical properties that are contingent upon the dopant utilized. The molecule possesses a carbon chain as its backbone that is accompanied by hydroxyl groups that are affixed to the methane carbons. These hydroxyl groups have the potential to serve as a source of hydrogen bonding, thereby facilitating the creation of polymer complexes (Lee et al. 2004; Jebur et al. 2020). Poly(vinyl alcohol) (PVA) has garnered attention due to its favorable characteristics and diverse applications. The extensive practical applications of PVA resins, including their use in clothing and industrial fibers, adhesives and binders, films, membranes, drug delivery systems, and cancer cell-killing embolic materials, can be attributed to their exceptional chemical resistance, physical properties, and biocompatibility (Makhlouf et al. 2013; Habeeb et al. 2020a). The semiconductor Cr_2O_3 is considered intrinsic and exhibits conductance that remains unaffected by oxygen partial pressure when subjected to high temperatures (> 1273 K). However, at lower temperatures, the oxide behaves as an extrinsic p-type semiconductor. The utilization of nanoparticles of chromium oxide (Cr_2O_3) has garnered attention in various fields such as green pigments, thermal protection, wear resistance, chemical catalysts, and digital recording systems (Parthibavarman et al. 2010). Nanometric particles of SnO_2 are a significant group of materials with technological relevance, exhibiting a diverse array of applications in gas sensors, transparent conducting electrodes, and transistors. The optical conductivity of SnO_2 films has led to the expansion of its utilization in solar cells. Semiconductors in the form of nano crystals, such as SnO_2 , have been studied extensively (Habeeb and Mahdi 2019). In recent times, significant attention has been directed towards the synthesis of thin films or particles of SnO_2 and the investigation of their unique properties. Several techniques, including chemical vapor deposition (CVD), magnetron sputtering, and thermal evaporation, have been employed (Gu et al. 2003). The technological advancements in stretchable and flexible-type organ electronic, optoelectronic, and energy harvesting storage devices have led to the establishment of polymer nanocomposites (PNCs) as multifunctional materials. The concentration of nanofillers has been found to have an impact on the structural, dielectric, and optical properties of PNCs, making them a smart choice for such technological applications (Habeeb and Hamza 2018). Wei, et al. (Wei and jinliang He et al. 2011) studied the influence of Cr_2O_3 on the microstructure, nonlinear $J-E$ characteristics and surge current of SnO_2 -based varistor. They obtained the residual voltage ratio is 1.68, when the content of

Cr_2O_3 is 0.03 mol%. Hu, et al. (Guangliang et al. xxxx) studied effect of Cr_2O_3 addition on the microstructure and electrical properties of SnO_2 . They found the highest nonlinear coefficient value of 27 and lowest leakage current density of $9 \mu\text{A}/\text{cm}^2$. Zang, et al. (Zang et al. 2014) studied dielectric properties of Cr_2O_3 doped $\text{SnO}_2\text{-Zn}_2\text{SnO}_4$ composite. They obtained the dielectric properties increase with increasing of Cr_2O_3 content. Prashanth, et al. (Prashanth et al. xxxx) They found the addition of Cr_2O_3 nanoparticles creates the interfacial interaction between the surface of nanoparticles and PVA. Gao, et al. (Xin Gao et al. 2019) They found improvement the gas sensing performances for the Cr_2O_3 nanoparticles coated SnO_2 nanofibers. The efficiency of composites' production is significantly impacted by the usage of these nanoparticles, which enhance the chemical processes inside them. There have not been many researches, nevertheless, on how nanomaterials affect the performance characteristics of an enhanced composite. To our knowledge, no attempt has been made to synthesize PVA/ SnO_2 / Cr_2O_3 nanocomposites.

2 Experimental part

(PVA/ SnO_2 / Cr_2O_3) nanocomposites were created by dissolving 1gm of PVA in 30 ml of distilled water for 30 min under continuous stirring using a magnetic stirrer at 70°C to achieve a more homogeneous solution. SnO_2 / Cr_2O_3 nanoparticles were added to the PVA in various ratio (0, 2, 4 and 6) wt.%. The structural characteristics of (PVA/ SnO_2 / Cr_2O_3) nanocomposites tested by the optical microscope (OM) provided by Olympus (Top View, type Nikon-73346) and Fourier transformation infrared ray (FTIR) (Bruker company type vertex-70, German origin) with range wavenumber ($500\text{--}4000$) cm^{-1} . The dielectric characteristics were studied in the range ($f=100$ Hz to 5×10^6 Hz) by LCR meter (HIOKI 3532–50 LCR HI TESTER). The optical characteristics of (PVA/ SnO_2 / Cr_2O_3) nanocomposites were tested using spectrophotometer (UV-1800⁰A-Shimadzu).

The dielectric constant (ϵ') of (PVA/ SnO_2 / Cr_2O_3) nanocomposites is given by the following equation (Mohammed and Habeeb 2023a)

$$\epsilon' = \frac{C_p}{C_o} \quad (1)$$

where, C_p is capacitance and C_o is a vacuum capacitance.

The dielectric loss (ϵ'') of (PVA/ SnO_2 / Cr_2O_3) nanocomposites is given by following equation (Al-Sharifi and Habeeb 2023a)

$$\epsilon'' = \epsilon' D \quad (2)$$

where, D is the displacement.

The A.C electrical conductivity is determined by Mahdi and Habeeb (2022)

$$\sigma_{AC} = \omega \epsilon' \epsilon_o \quad (3)$$

where, ω is the angular frequency.

The absorption coefficient (α) is given as (Du et al. 2002)

$$\alpha = 2.303 * A/t \quad (4)$$

where t: thickness of the samples, A: represent the optical absorbance. The energy gap is given by Habeeb and Abdul Hamza (2018)

$$(\alpha h\nu)1/m = B(h\nu - E_g) \quad (5)$$

where B is constant, $h\nu$ is the photon energy, E_g is the energy gap, $m=2$ and 3 to indirect transition of allowed and forbidden.

The index of refractive (n) is defined by Habeeb et al. (2023)

$$n = (1 + R^{\frac{1}{2}})/(1 - R^{\frac{1}{2}}) \quad (6)$$

Which R is the reflection, the coefficient of extinction (k) is determined by Chen et al. (2021)

$$k = \frac{\alpha \lambda}{4\pi} \quad (7)$$

Which λ is the wavelength. The dielectric constant parts: real (ϵ_1), and imaginary (ϵ_2) are given by Habeeb et al. 2020b

$$\epsilon_1 = n^2 - k^2 \quad (8)$$

$$k\epsilon_2 = 2nk \quad (9)$$

The optical conductivity (σ_{op}) is defined by Hadi (2021)

$$\sigma_{opt.} = \frac{\alpha n c}{4\pi} \quad (10)$$

where c is velocity of light.

3 Results and discussion

The optical microscopy images presented in Fig. 1 depicts PVA/SnO₂/Cr₂O₃ nanocomposites with various ratio of SnO₂/Cr₂O₃ NPs, observed at a magnification power of 10x. Image A (PVA) exhibits remarkable miscibility, as evidenced by its refined structure and uniform, seamless surface. Conversely, images B, C, D, and E demonstrate that SnO₂/Cr₂O₃ nanoparticles are evenly dispersed on the polymer's surface. The images reveal that the SnO₂/Cr₂O₃ nanoparticles have formed clusters in the shape of chains that extend along the surface of the films. This unique property of the SnO₂/Cr₂O₃ nanoparticles (Rezvanpour et al. 2018), enhances not only charge transport within polymer matrices but also the percentage of SnO₂/Cr₂O₃ nanoparticles.

FTIR was employed to examine the atomic or ionic interactions within nanocomposites consisting of polyvinyl alcohol (PVA), tin dioxide (SnO₂), and chromium trioxide (Cr₂O₃). The aforementioned interactions may entail alterations in the vibrational patterns exhibited by the nanocomposites. Figure 2 displays the transmission spectra of nanocomposite films composed of PVA, SnO₂, and Cr₂O₃ nanoparticles, as measured by FTIR. The spectra correspond to films with varying ratios of SnO₂/Cr₂O₃ nanoparticles, denoted as A, B, C, and D. (FTIR) technique provides insight into the nature of functional groups present in (PVA/SnO₂/Cr₂O) nanocomposites. The nanocomposites exhibit OH group frequencies at approximately 3259 cm⁻¹. The nanocomposites composed of PVA, SnO₂, and Cr₂O₃ exhibit spectral peaks at 1084, 1416, 2908, and 3259 cm⁻¹, which are associated with the C–O, C=C, and C–H functional groups present in the nanocomposites (Mahdi and M. A. Habeeb, 2022a; Habeeb 2014).

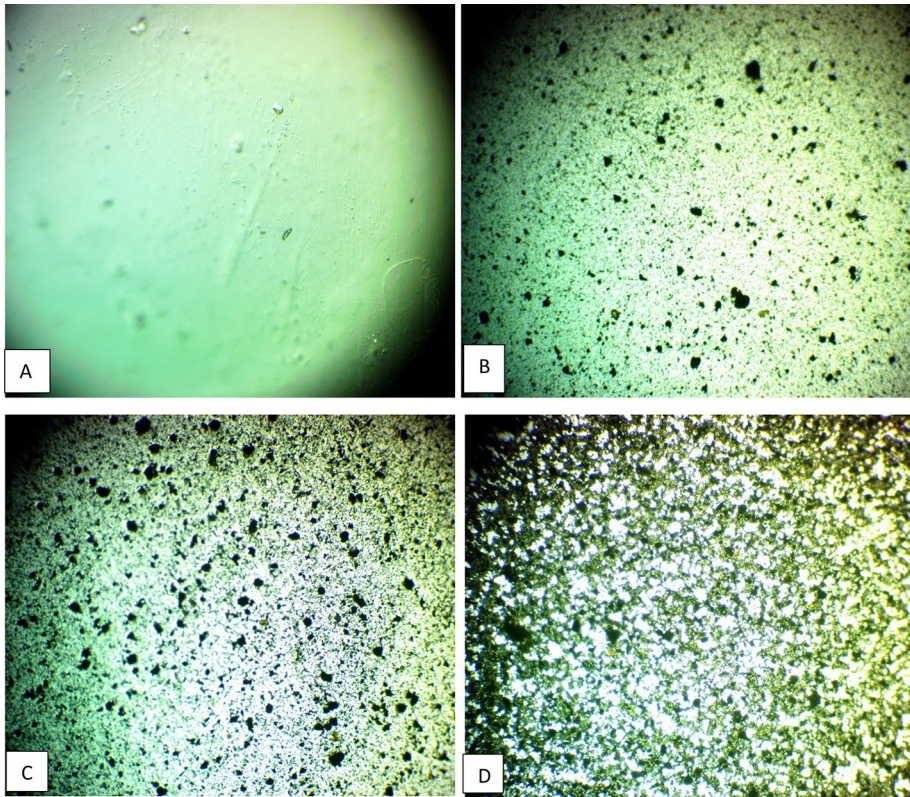


Fig. 1 Photomicrographs (10x) for (PVA/SnO₂/Cr₂O₃) nanocomposites (A) for (PVA) (B) for 2wt. % (SnO₂/Cr₂O₃) NPs, (C) 4wt.%(SnO₂/Cr₂O₃) NPs, (D) for 6wt.%(SnO₂/Cr₂O₃) NPs

The dielectric constant (ϵ') of (PVA/SnO₂/Cr₂O₃) nanocomposites was determined using Eq. (1). The variation of dielectric constant with frequency for nanocomposites consisting of PVA, SnO₂, and Cr₂O₃ is depicted in Fig. 3. The presented figure illustrates a negative correlation between frequency and dielectric constant values. As frequency increases, the polarization of space charge decreases, eventually leading to complete polarization. The primary form of polarization, as indicated is the polarization of the space charge at low frequencies (Bigg 1979).

The plot in Fig. 4 illustrates the relationship between the dielectric constant and the concentration of SnO₂/Cr₂O₃ nanoparticles in the (PVA/SnO₂/Cr₂O₃) nanocomposites, specifically at a frequency of 100 Hz. The augmentation of SnO₂/Cr₂O₃ nanoparticles results in an associated rise in the dielectric constant of (PVA/ SnO₂/Cr₂O₃) nanocomposites. The observed phenomenon can be attributed not only to the effects of atomic, ionic, and electronic influences, but also to the influence of space charge (Mahdi and M. A. Habeeb", 2022b).

The calculation of the dielectric loss (ϵ'') of nanocomposites was performed using Eq. (2). The frequency-dependent dielectric loss of nanocomposites consisting of (PVA/ SnO₂/Cr₂O₃) is illustrated in Fig. 5. The figure illustrates that the dielectric loss exhibits a notable increase at lower applied frequencies, while it exhibits a decrease as the

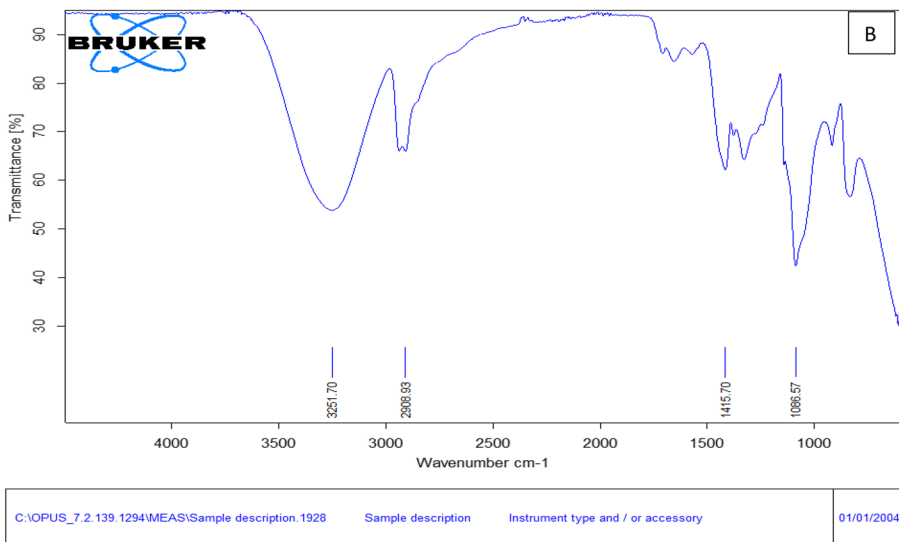
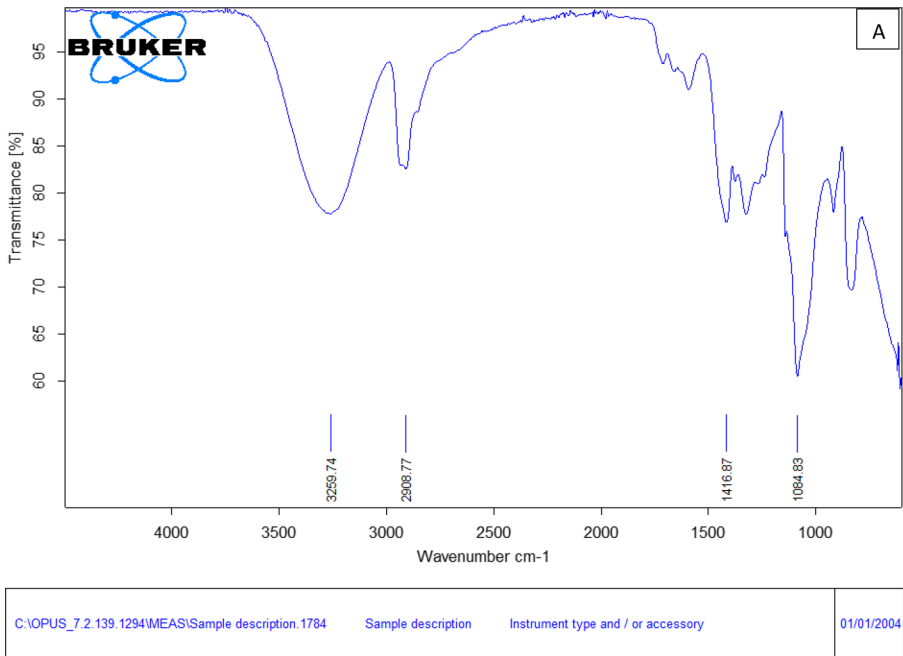
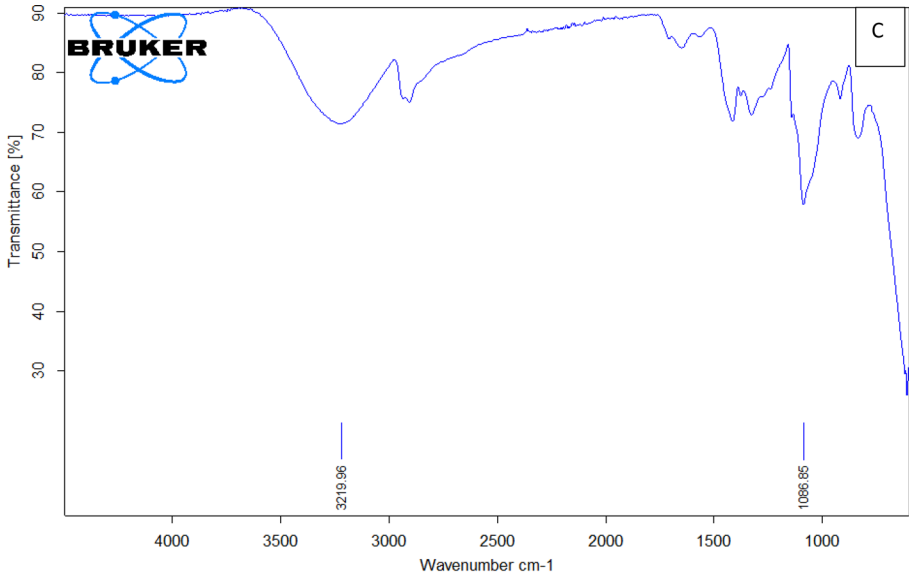
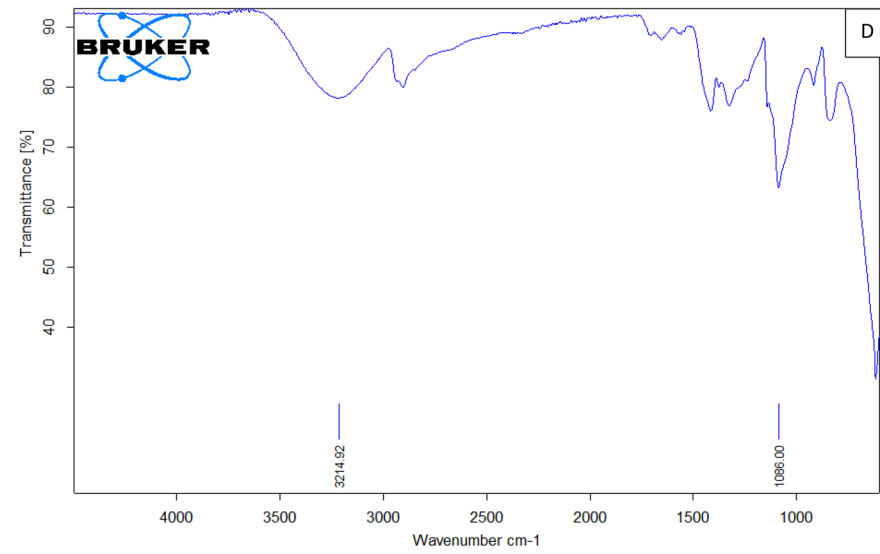


Fig. 2 FTIR spectra for (PVA/ $\text{SnO}_2/\text{Cr}_2\text{O}_3$) nanocomposites: (A) for (PVA), (B) 2 wt.% of $\text{SnO}_2/\text{Cr}_2\text{O}_3$, (C) 4wt.% of $\text{SnO}_2/\text{Cr}_2\text{O}_3$, (D) 6 wt.% of $\text{SnO}_2/\text{Cr}_2\text{O}_3$

applied frequencies increase. The aforementioned phenomenon can be ascribed to the fact that with an increase in frequency, the extent of the space charge polarization component diminishes, as stated in reference (Hadi and M. A. Habeeb, 2021; Vidyalyaya 2009).



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Fig. 2 (continued)

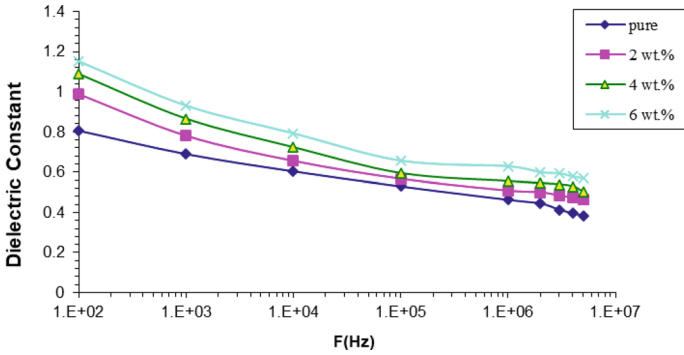


Fig. 3 Difference of dielectric constant with the frequency for PVA/SnO₂/Cr₂O₃ nanocomposites

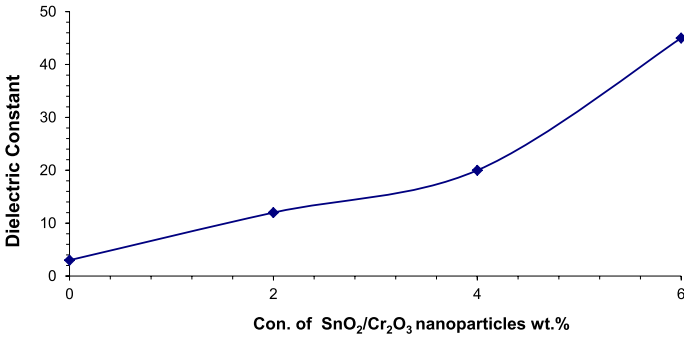


Fig. 4 Difference of dielectric constant for (PVA/SnO₂/Cr₂O₃) NCs with different concentrations of SnO₂/Cr₂O₃ NPs at 100 Hz

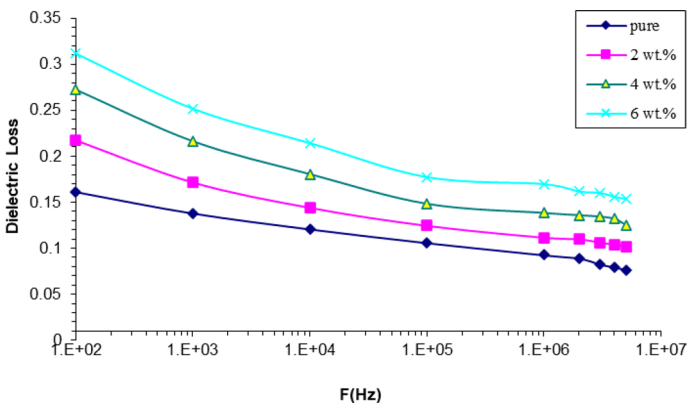


Fig. 5 Variation of dielectric loss with the frequency for PVA/SnO₂/Cr₂O₃ nanocomposites

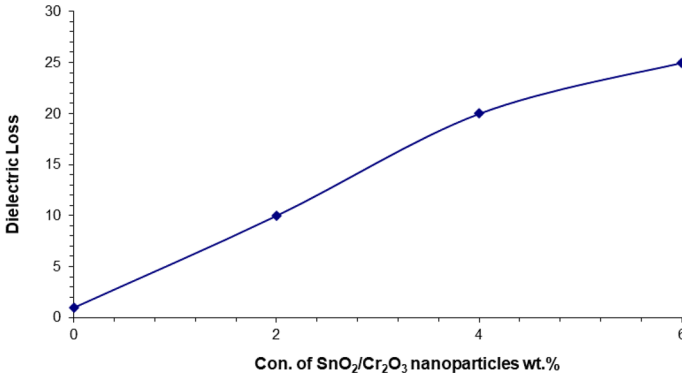


Fig. 6 Difference of dielectric loss for (PVA/ SnO₂/Cr₂O₃) NCs with different concentrations of SnO₂/Cr₂O₃ NPs at 100 Hz

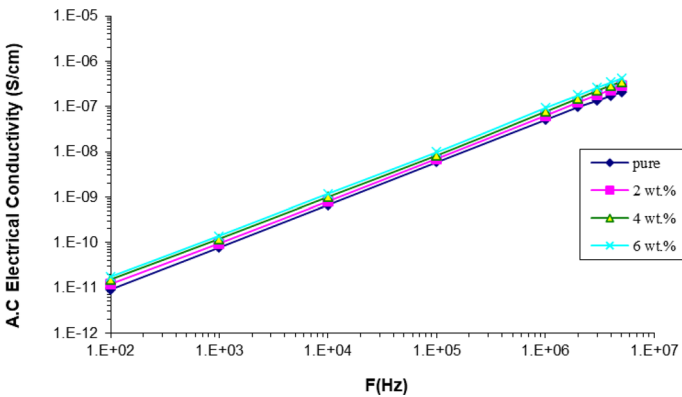


Fig. 7 Difference of A.C electrical conductivity with frequency for (PVA/SnO₂/Cr₂O₃) NCs

The impact of SnO₂/Cr₂O₃ nanoparticles ratio on the dielectric loss of PVA/ SnO₂/Cr₂O₃ nanocomposites at a frequency of 100 Hz is illustrated in Fig. 6. The concentration in SnO₂/Cr₂O₃ nanoparticles has a direct correlation with the dielectric loss of (PVA/SnO₂/Cr₂O₃) nanocomposites, indicating a rise in the dielectric loss as the ratio of nanoparticles increases. The aforementioned increments are attributed to the rise in the quantity of charge carriers. In the case of (PVA/SnO₂/Cr₂O₃) nanocomposites, it has been observed that at low ratio, the SnO₂/Cr₂O₃ nanoparticles tend to aggregate and form clusters. The aforementioned study indicates that at a nanoparticle concentration of 6 wt. %, a path network is formed within the (PVA/SnO₂/Cr₂O₃) nanocomposite (Abdul Hamza and Habeeb, 2023).

The electrical conductivity in alternating current (A.C) was computed using Eq. (3). Figure 7 illustrates the frequency-dependent alteration of A.C electrical conductivity in (PVA/SnO₂/Cr₂O₃) nanocomposites at ambient temperature. The electrical conductivity under alternating current conditions exhibits a positive correlation with the frequency of the applied electric field. The observed phenomenon can be rationalized by the polarization effect and hopping mechanism. Specifically, the polarization effect arises due to the limited

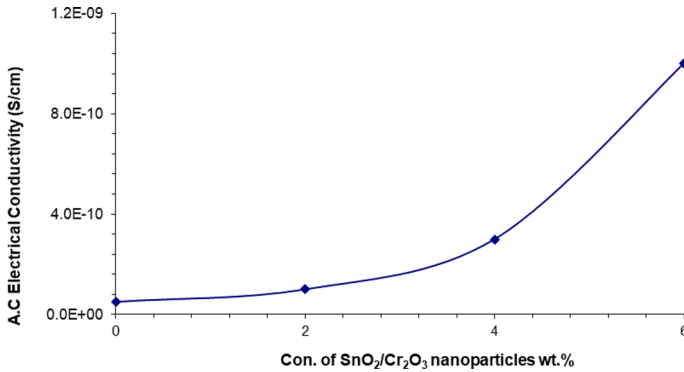


Fig. 8 Difference of A.C electrical conductivity with (SnO₂/Cr₂O₃) NPs for (PVA/ SnO₂/Cr₂O₃) NCs

Table 1 Values of dielectric constant, dielectric loss and A.C. electrical conductivity for (PVA/ SnO₂/Cr₂O₃) NCs at 100 Hz

Con. (wt.%)	Dielectric constant	Dielectric loss	A.C electric conductivity S/cm
0	3	1	5.00 × 10 ⁻¹¹
2	12	10	1.00 × 10 ⁻¹⁰
4	20	20	3.00 × 10 ⁻¹⁰
6	45	25	1.00 × 10 ⁻⁹

concentration of SnO₂/Cr₂O₃, which is inadequate to establish an extensive network. Consequently, there is a polarization effect between these finite networks or clusters, and the electron hopping occurs between adjacent states that are randomly distributed within these finite networks (Hadi and M. A. Habeeb²⁰²¹).

The graphical representation depicted in Fig. 8 illustrates the fluctuation in A.C electrical conductivity of (PVA/SnO₂/Cr₂O₃) nanocomposites in relation to the varying concentrations of SnO₂/Cr₂O₃ nanoparticles, specifically at a frequency of 100 Hz. It can be observed from the figure that the alternating current electrical conductivity of the nanocomposites exhibits an increase with an increase in the concentrations of SnO₂/Cr₂O₃ nanoparticles. The observed increase in conductivity can be attributed to the rise in the number of charge carriers resulting from the presence of dopant nanoparticles in the composition of the nanocomposite. This, in turn, leads to a gradual reduction in resistance and a subsequent increase in A.C electrical conductivity. Moreover, it has been observed that the SnO₂/Cr₂O₃ nanoparticles establish a network of pathways within the nanocomposites, particularly when the nanoparticle concentration is at 6 wt.%, in the case of (PVA/SnO₂/Cr₂O₃) nanocomposites (Hashim et al. 2020). The dielectric constant, dielectric loss, and A.C. electrical conductivity values of (PVA/SnO₂/Cr₂O₃) nanocomposites at 100 Hz are presented in Table 1.

The graphical representation depicted in Fig. 9 illustrates the correlation between absorption and wavelength in (PVA/SnO₂/Cr₂O₃) nanocomposites. The observed high absorption of all samples in the ultraviolet region can be due to the sufficient energy of photons to interact with atoms, leading to the excitation of electrons from lower to higher energy levels. The nanocomposite exhibits low absorption in the near-infrared region, which can be attributed to the limited energy of the incident photons that are insufficient

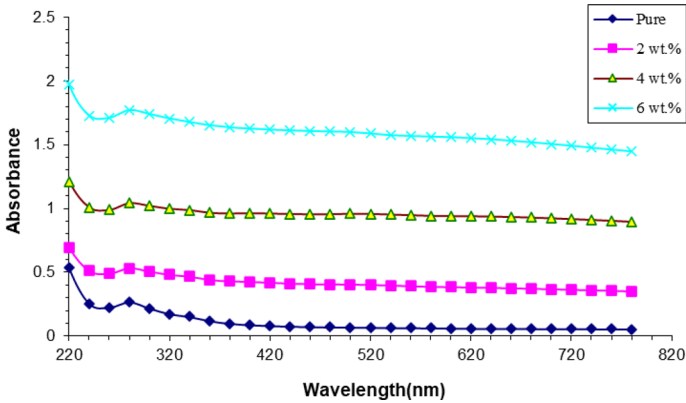


Fig. 9 Variation of absorbance for (PVA/SnO₂/Cr₂O₃) nanocomposites with wavelength

for contact with the atoms (Habeeb and Kadhim 2014). The phenomenon of film absorbing exhibits a higher magnitude at shorter wavelengths, followed by a gradual decline as the wavelength increases. The phenomenon of absorption is observed to exhibit a positive correlation with the concentration of SnO₂ and Cr₂O₃ nanoparticles, as well as with the corresponding increase in charge carriers. The observed phenomenon can be attributed to the density of the positional levels that arise from the presence of impurity atoms situated between the conduction and valence band. The absorption process takes place when electrons, which receive photons with an energy level lower than the optical energy gap of the incident photons, are transferred to auxiliary levels (Yagci et al. 2001).

The transmittance spectrum of films comprising (PVA/SnO₂/Cr₂O₃) has been depicted in Fig. 10, as a function of the wavelength of incident light. The spectrum has been plotted for varying concentrations of (SnO₂/Cr₂O₃) nanoparticles. As depicted in the graph, the increase in concentration of SnO₂/Cr₂O₃ leads to a decrease in transmittance. The observed phenomenon can be attributed to the capacity of SnO₂/Cr₂O₃ electrons in their valence shells to assimilate the electromagnetic energy of the incoming light and transition to greater energy states (Habeeb and Jaber, 2022). As a consequence of the occupied energy

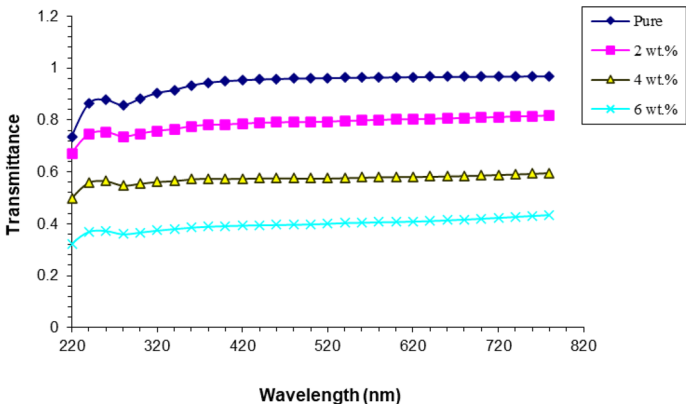


Fig. 10 Transmittance spectra of (PVA/SnO₂/Cr₂O₃) nanocomposites as a function of wavelength

locations within each band by the travelling electron, the substance is capable of absorbing any incoming light, thereby precluding its transmission (Mahdi1 and Habeeb 2023).

Formula (4) is employed for the computation of the absorption coefficient. The difference of the absorption coefficient of (PVA/SnO₂/Cr₂O₃) nanocomposites with respect to photon energy is illustrated in Fig. 11. The absorption coefficients exhibit a decrease at higher wavelengths and lower energies, as visually discernible. This suggests that the probability of electron displacement due to low energy photons ($h\nu < E_{\text{gap}}$) is minimal, as stated in reference (Yu et al. 2001). Due to the pronounced absorption at elevated energies, there exists a greater probability for electron migration. The incident photon possesses adequate energy to facilitate the transition from the valence bands to the conduction bands, indicating that the energy gap is less than that of the photon. The present study demonstrates the impact of the absorption coefficient on the electron transition mechanism. Specifically, it is observed that at high energies, the absorption coefficient is expected to be significantly high, exceeding 10^4 cm^{-1} . This indicates that direct electron transitions take place, with both electrons and photons conserving their energy and momentum. On the other hand, at low energies, the absorption coefficient is approximately 10^4 cm^{-1} , indicating the occurrence of indirect transitions, where the electric momentum is strengthened by the phonons (Dwech et al. 2022). The nanocomposites comprising of PVA, SnO₂, and Cr₂O₃ exhibit a coefficient of absorption that is less than 10^4 cm^{-1} . This observation, along with other findings, indicates the occurrence of an indirect electron transition.

The extinction coefficient pertains to the degree of reduction in the intensity of an electromagnetic wave as it traverses a medium. The similarity between the attenuation coefficient curves and the absorption coefficient curves can be attributed to their inherent relationship in Eq. (7). The graphical representation in Fig. 12 illustrates the relationship between the extinction coefficient and the wavelength. It was observed from the figure that there is a positive correlation between the concentrations of SnO₂/Cr₂O₃ nanoparticles and the values of extinction coefficient. The heightened absorbance of the prepared films can be attributed to the density of levels generated by the impurities present within the energy gap. The nanocomposites exhibit high extinction coefficients in the ultraviolet region owing to their significant absorbance characteristics. The extinction coefficient of nanocomposites exhibits an increase as the wavelength increases within the visible and near-infrared regions. This phenomenon can be attributed to the nearly constant absorption

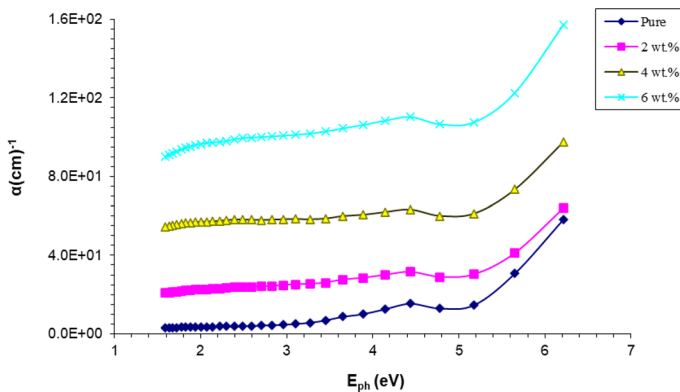


Fig. 11 The absorption coefficient of (PVA/SnO₂/Cr₂O₃) nanocomposites with energy of photon

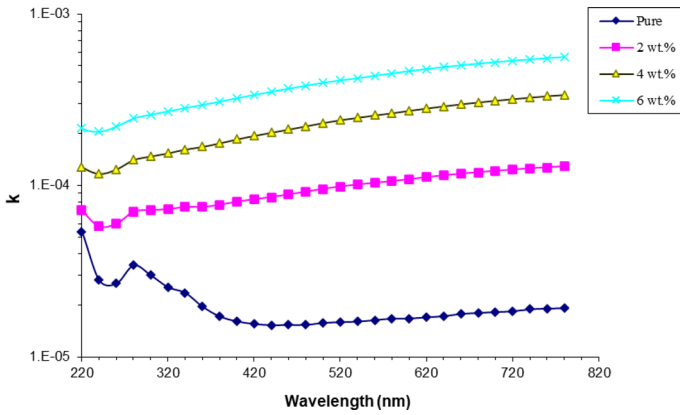


Fig. 12 Difference of extinction coefficient for (PVA/SnO₂/Cr₂O₃) nanocomposites with wavelength

coefficient of the nanocomposites within these regions, as reported in reference (Mohammed and Habeeb 2023b).

The calculation of refractive index (n) is performed through the utilization of Eq. (6). The refractive index as a function of the wavelength is depicted in Fig. 13. The figure demonstrates a positive correlation between the SnO₂/Cr₂O₃ nanoparticles and the refractive index. The rationale behind this phenomenon is that the introduction of doping agents results in the creation of additional energy levels through the inversion of the incident rays by a greater magnitude. This, in turn, leads to an augmentation in the intensity of the reflected rays, thereby elevating the refractive index. High values of the refractive index are observed in the ultraviolet (U.V) region owing to the limited transmittance (T) in this spectral range. Conversely, in the visible and near-infrared (IR) regions, the refractive index values are low due to the high transmittance (T) in these regions, as reported in reference (Al-Sharifi and Habeeb 2023b).

The calculation of the energy gap of nanocomposites is performed through the utilization of Eq. (5). It has been observed that the energy gap exhibited by nanocomposites is

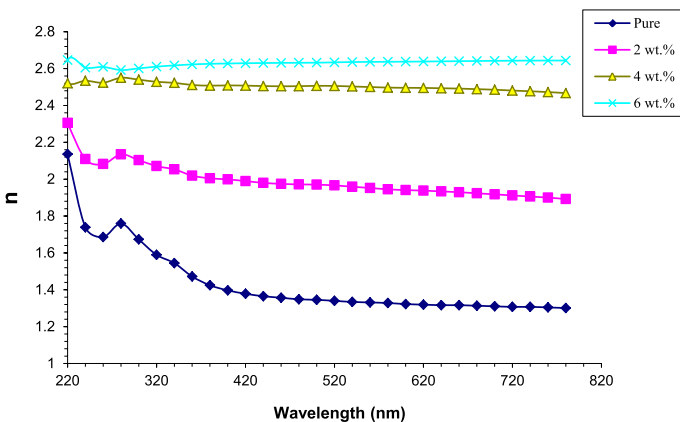


Fig. 13 Variation of refractive index for (PVA/SnO₂/Cr₂O₃) nanocomposites with wavelength

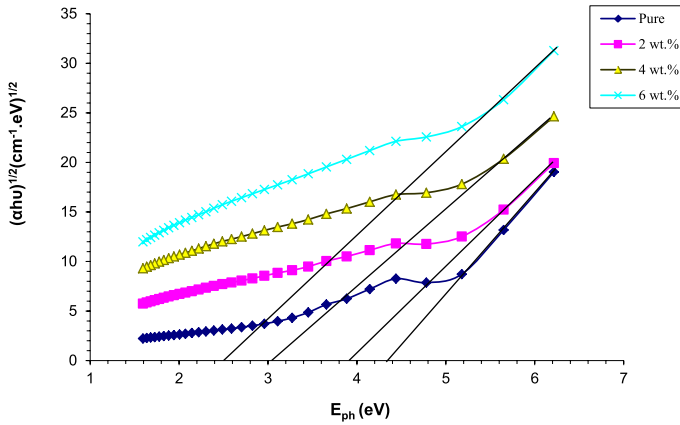


Fig. 14 Variation of $(\alpha h\nu)^{1/2}$ for (PVA/SnO₂/Cr₂O₃) nanocomposites with photon energy

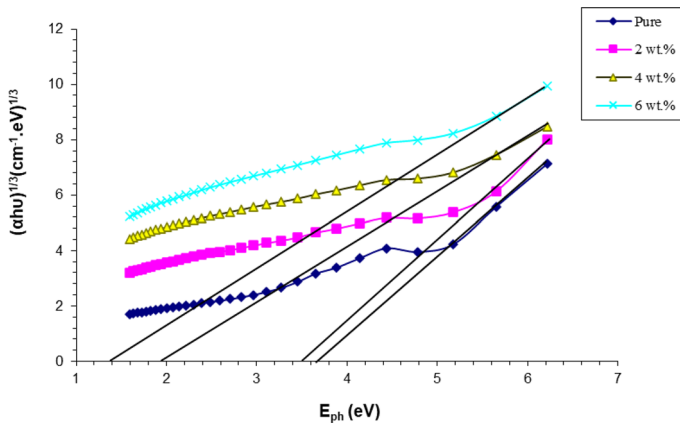


Fig. 15 Variation of $(\alpha h\nu)^{1/3}$ for (PVA/SnO₂/Cr₂O₃) nanocomposites with photon energy

comparatively lower than that of pure polymers. Specifically, an increase in doping levels has been found to correspond with a decrease in energy gap. Figures 14, 15 depict the energy gaps pertaining to permissible and impermissible indirect transitions, respectively, as a function of the energy of the incident photon. The allowed energy gap can be obtained by drawing a straight line from the highest point of the curve towards the x-axis at $(\alpha h\nu)^{1/2}=0$. On the other hand, the forbidden energy gap can be determined when the value $(\alpha h\nu)^{1/3}=0$ is reached. The concentration of SnO₂/Cr₂O₃ nanoparticles has been observed to have a decreasing effect on the energy gap values. This decrease is attributed to the doping process, which creates levels within the energy gap. The transition of electrons occurs in two stages, namely from the valence band to the local levels within the energy gap, and subsequently to the conduction band (Manhas et al. 2019). These results are agree with other researchers results (Mondal et al. 2023; Habeeb and Mohammed 2023).

The dielectric constant is a measure of a material's polarizability in response to electromagnetic radiation. It is typically characterized by two distinct components: the real

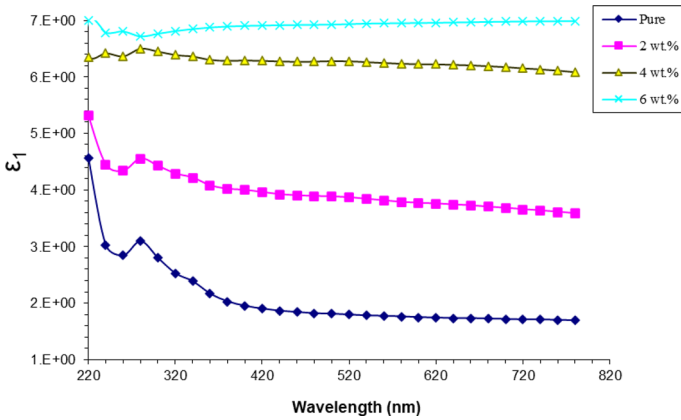


Fig. 16 Performance of real part of dielectric constant for (PVA/SnO₂/Cr₂O₃) nanocomposites with wavelength

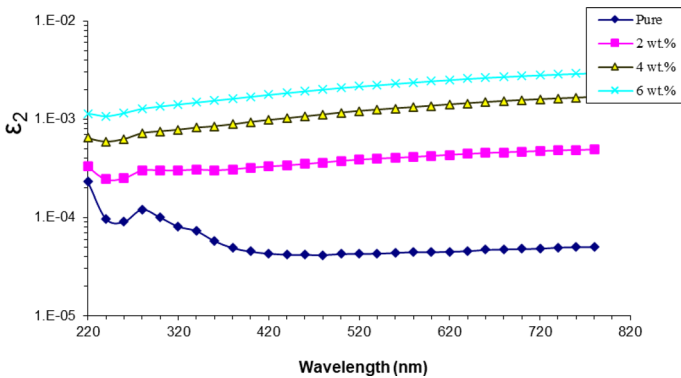


Fig. 17 Performance of imaginary part of dielectric constant for (PVA/SnO₂/Cr₂O₃) nanocomposites with wavelength

dielectric constant (ϵ_1) and the imaginary dielectric constant (ϵ_2). The aforementioned categories were determined through the utilization of Eqs. (8) and (9), correspondingly. The real and imaginary dielectric constant variations with wavelength for (PVA/SnO₂/Cr₂O₃) nanocomposites are depicted in Figs. 16, 17, respectively. The presented data illustrates that the actual and imaginary dielectric constants exhibit an upward trend as the ratio of SnO₂/Cr₂O₃ nanoparticles increases. This phenomenon can be due to the heightened electric polarization induced by the nanoparticles. The rise in electric polarization results in a higher density of dipoles, which in turn leads to an increase in the dielectric constant. The curves of the real dielectric constant depicted in Fig. 16 exhibit comparable behavior to the refractive index curves, owing to their interconnectedness. This similarity can be attributed to the fact that the real dielectric constant is contingent upon the values of (n) to a greater extent than the value of (k), given that the values of (k) are considerably smaller in comparison to the refractive index, particularly after being squared (Atta et al. 2021). The graph depicted in Fig. 17 demonstrates the variation of the imaginary dielectric constant with wavelength. It is observed that the imaginary component of the dielectric constant is

influenced by the damping coefficient, particularly in the infrared and visible regions. In these regions, the refractive index remains relatively constant, while the extinction coefficients exhibit an increasing trend with increasing wavelength, as reported in reference (Habeeb and Rahdi 2023).

The formula (10) was utilized to compute the optical conductivity. The optical conductivity of the (PVA/SnO₂/Cr₂O₃) nanocomposites is depicted in Fig. 18, exhibiting a wavelength-dependent trend. The presented figure illustrates a decline in optical conductivity as the wavelength raises across all nanocomposite specimens, while exhibiting an increase at lower wavelengths. The heightened optical conductivity observed at shorter photon wavelengths can be attributed to the heightened absorption of all nanocomposite samples in this spectral range. This, in turn, leads to a rise in charge transfer excitations. The spectra indicate a notable degree of transmittance in the visible and near-infrared regions. Additionally, it was observed that the optical conductivity escalates in tandem with the concentration of SnO₂/Cr₂O₃ nanoparticles. This phenomenon can be attributed to the emergence of localized levels of energy inside the energy gap (Kumar et al. 2022).

4 Conclusion

In this work, the solution casting technique was used to prepare (PVA/SnO₂/Cr₂O₃) NCs films. The optical microscope images revealed a uniform dispersion of the nanoparticles inside the polymeric matrix, and the emergence of network pathways as the concentration of SnO₂/Cr₂O₃ nanoparticles increases. FTIR measures indicate a physical superposition between the polymer and the nanoparticles upon their mixture. The frequency-dependent behavior of (PVA/SnO₂/Cr₂O₃) NCs is characterized by a decrease in the dielectric constant and dielectric loss, and an increase in A.C electrical conductivity. The concentration of SnO₂/Cr₂O₃ nanoparticles has been observed to have a significant impact on the dielectric constant, dielectric loss, and A.C electrical conductivity of (PVA/SnO₂/Cr₂O₃) NCs. Specifically, an increase in concentration results in a raise in the aforementioned properties. The dielectric constant increasing from 3 to 45, the dielectric loss increasing from 1 to 25, and the A.C electrical conductivity increasing from 5×10^{-11} to 1×10^{-9} S/cm. These characteristics can be applied to films in a variety of electrical applications. The optical

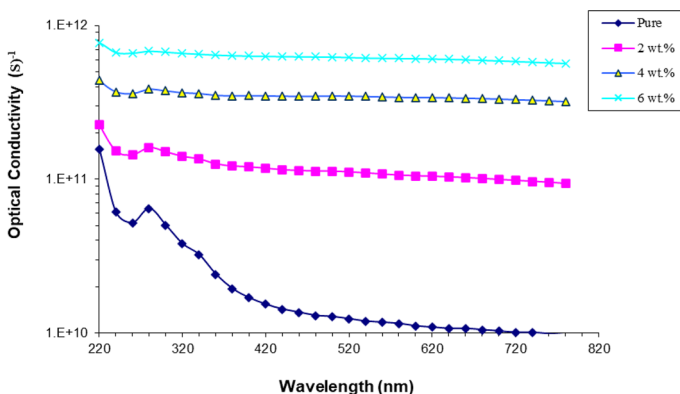


Fig. 18 Variation of optical conductivity for (PVA/SnO₂/Cr₂O₃) nanocomposites with wavelength

properties of the (PVA/SnO₂/Cr₂O₃) nanocomposite, including absorbance, absorption coefficient, extinction coefficient, refractive index, real and imaginary dielectric constants, and optical conductivity, exhibit an upward trend with an increase in the concentration of SnO₂/Cr₂O₃ nanoparticles. Conversely, transmittance demonstrates a decreasing trend. At 8 wt.% concentration, the permitted and forbidden indirect transitions experienced a reduction in their optical energy gap, decreasing from 4.19 eV to 2.69 eV and from 3.5 eV to 1.45 eV, respectively. The decrease in the energy gap is observed with an increase in the concentrations of SnO₂/Cr₂O₃ nanoparticles. The decrease in optical energy gap and increase in refractive index brought on by the inclusion of PVA/SnO₂/Cr₂O₃ NCs point to the possibility of their usage in optoelectronic devices.

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Declarations

Conflict of interest No conflict of interest.

Consent to participate Consent.

Consent for publication Consent.

Ethical approval The Research is not involving the studies on human or their data.

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Authors and Affiliations

Majeed Ali Habeeb¹ · Nawras Karim Al-Sharifi¹ · Alaa Abass Mohammed¹

✉ Majeed Ali Habeeb
pure.majeed.ali@uobabylon.edu.iq

Nawras Karim Al-Sharifi
Nkareem769@gmail.com

Alaa Abass Mohammed
alaa.mohammed.pure405@student.uobabylon.edu.iq

¹ Department of Physics, College of Education for Pure Sciences, University of Babylon, Hilla, Iraq