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RESEARCH ARTICLE OPEN ACCESS

Preparation and Optical Characterization of PAAm/TiO_2 Nanocomposites for Optoelectronic Applications

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Abstract:

The synthesis and optical characterization of PAAm/TiO_2 nanocomposites made using the solution casting method for optoelectronic applications are the main objectives of this work. Improved light-matter interaction inside the polymer matrix is indicated by the optical research, which shows a discernible increase in ultraviolet (UV) absorption with increasing TiO_2 nanoparticle loading. Additionally, when the concentration of TiO_2 nanoparticles increases, the optical constants of the nanocomposite films, such as the refractive index and extinction coefficient, show a consistent rise. On the other hand, when nanoparticle loading increases, the PAAm/TiO_2 nanocomposites' optical transmittance and optical energy band gap diminishes. This can be explained by the creation of localized states and enhanced charge carrier interactions. These results demonstrate that the incorporation of TiO_2 nanoparticles effectively tailors the optical properties of PAAm, highlighting the potential of PAAm/TiO_2 nanocomposites for optoelectronic device applications.

Keyword: PAAm, TiO_2 NPs, Optical properties, optoelectronic device

1. INTRODUCTION

Polymer nanocomposites (PNCs) are an advanced class of functional materials in which nanoscale fillers are introduced into polymer matrices to improve performance above ordinary composites. Nanoparticles improve optical, electrical, mechanical, and thermal properties significantly because of their high surface-to-volume ratio and strong interfacial interactions with polymer chains [1, 2]. Such materials have received a lot of attention in optoelectronic technologies, which need precise control over light absorption, transmission, and electrical band structure [3, 4].

Polyacrylamide (PAAm) is a hydrophilic polymer that is widely utilized in scientific and industrial applications due to its outstanding film-forming ability, chemical stability, and strong interaction with inorganic fillers via its amide functional groups. These properties enable PAAm to serve as an excellent host matrix for metal oxide nanoparticles, allowing for uniform dispersion and stable nanocomposite formation [5, 6]. Furthermore, PAAm-based nanocomposites display tunable optical characteristics, making them intriguing candidates for optoelectronic and photonic applications [7, 8].

Titanium dioxide (TiO_2) is a widely studied metal oxide semiconductor with a wide band gap, high refractive index, significant UV absorption, and great chemical and thermal durability. TiO_2 is mostly found in anatase and rutile crystalline phases, which are ideal for optoelectronic applications such UV detectors, photovoltaic devices, and optical coatings [9]. Nanoscale TiO_2 exhibits size-dependent optical characteristics, including band gap alteration and improved light absorption, which are particularly useful when introduced into polymer matrices [10].

Integrating TiO_2 nanoparticles into polymer matrices alters optical behavior, resulting in increased absorbance, reduced band gap, and improved refractive index. These alterations are the result of nanoparticle-induced localized

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states and enhanced charge transfer at the polymer-nanoparticle interface [11]. Increasing nanoparticle concentration in polymer/TiO_2 nanocomposites enhances light-matter interaction, improving optoelectronic device performance [12].

While polymer/TiO_2 nanocomposites have been studied extensively, there has been less focus on analyzing the optical properties of PAAm/TiO_2 systems for optoelectronic applications. Understanding the link between nanoparticle concentration, structural traits, and optical properties such absorbance spectra, optical band gap, and refractive index is critical for optimizing these materials for device integration [13]. To assess their potential in future optoelectronic technologies, PAAm/TiO_2 nanocomposites must be synthesized and optically characterized. This study aims to synthesis PAAm/TiO_2 nanocomposite films with different TiO_2 nanoparticle concentrations using casting process and analyze the applicability of PAAm/TiO_2 nanocomposites for optoelectronic applications by observing optical improvements relative to virgin PAAm.

2. MATERIALS AND METHOD

The casting procedure was utilized to create PAAm/TiO2 films with varying amounts of PAAm and TiO2 nano powder. The PAAm films were created by dissolving 1 g of PAAm in 50 mL of distilled water and mixing the polymers with a magnetic stirrer to obtain a more homogeneous solution. TiO2 NPs were introduced to PAAm solution at concentrations of 1.3%, 2.6%, and 3.9%, resulting in a 130 µm thickness. The UV-1800 0A-Shimadzu was used to test optical qualities.

The absorption coefficient (α) is given as [14]:

$$\alpha = 2.303 \; \frac{A}{t} \tag{1}$$

The energy gap is calculated by [15]:

$$(\alpha \mathrm{h}v)^{1/m} \; = \; B\,(\mathrm{h}v - Eg) \tag{2}$$

The refractive index (n) can be determined using [16]:

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

The reflectance is denoted by R. This describes the extinction coefficient (k) [17]:

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

Real (ε_1) and imaginary (ε_2) components of the insulator continuous are provided by [18]:

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

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

The optical conductivity (σ_{op}) is calculated by [19]:

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

2. RESULTS AND DISCUSSION

The data in Figure 1 show that absorbance values vary significantly with wavelength. It is interesting to note that, despite its narrower range compared to the visible wavelength, UV absorption is higher. This supports the presence of perfumed mixes with protracted π-electron schemes, recognized to absorb UV light, rather than protracted conjugate groups in the resulting precipitate, which absorb visible light. TiO_2 exhibits unusual behavior in terms of light absorption. This absorption can be determined using UV-visible (UV-vis) spectroscopy. As a result, the absorbance increases while the conduction reductions, as seen in Figure 2. The results match [20].

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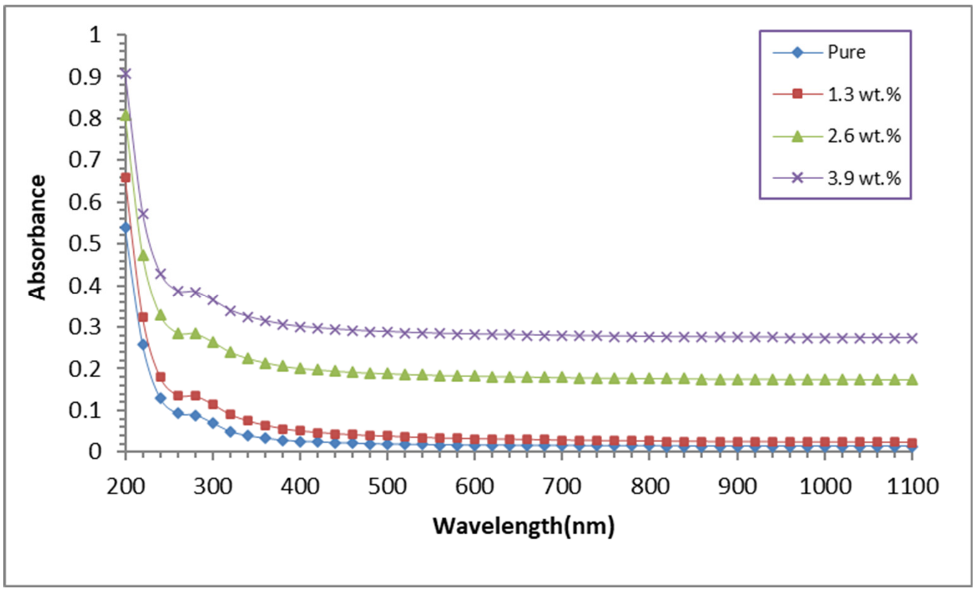

FIGURE 1. Absorbance scales of PAAm/TiO_2 NCPs.

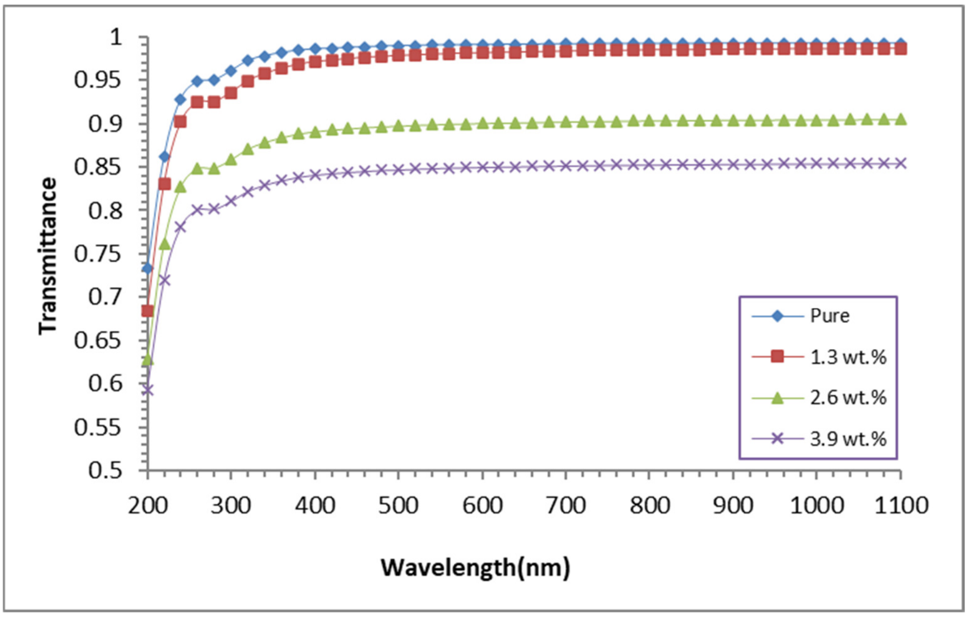

FIGURE 2. Transmittance of (PAAm/TiO_2) PNCs

The (α) for PAAm/TiO_2 with light energy is shown in Figure 3. With their inclined posture, TiO2 NPs showed an increase in α. An indirect transition is indicated by $\alpha < 10^4$ cm^{-1}. The rise in values may be related to the notable drop in inter-bond changes [22, 23]. Over a broad range of wavelengths, PAAm/TiO_2 alloys show enhanced UV spectra uptake. This characteristic makes nanostructures suitable for optoelectronic nanodevices.

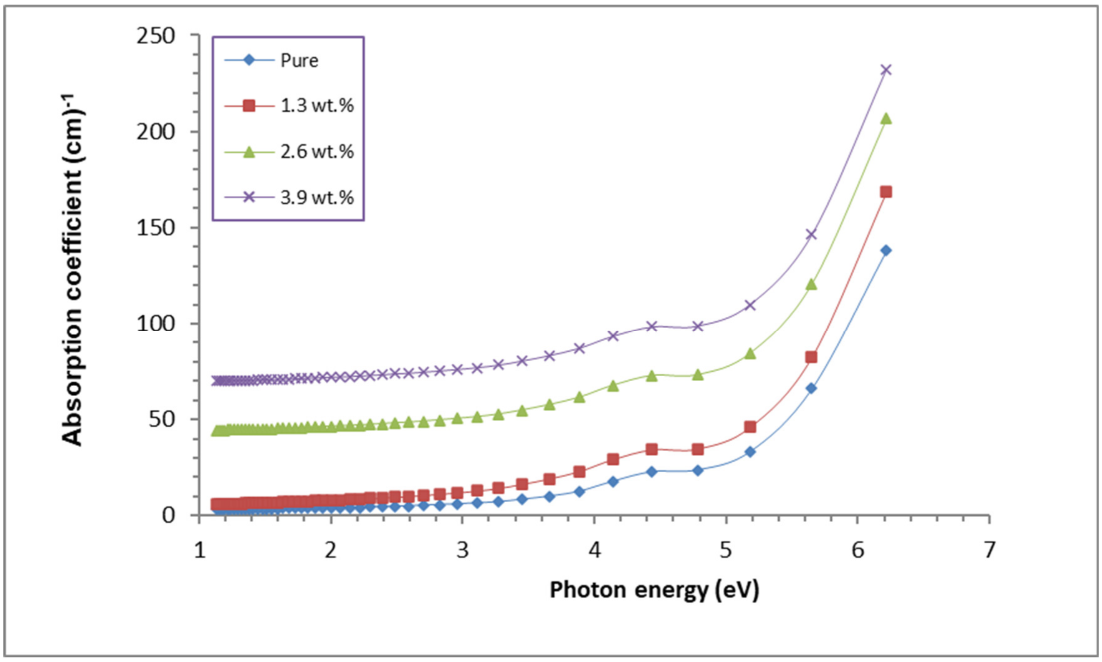

FIGURE 5. α of the ($PAAm/TiO_2$) PNCs

Figures 6 and 7 show the wavelength-dependent fluctuations in the (n) and (k) of $PAAm/TiO_2$ nanocomposites. The n values of $PAAm/TiO_2$ NCs increase as the TiO_2 NP content increases. This phenomenon is caused by the aggregation of nanoparticles within the PAAm matrix. The k values of $PAAm/TiO_2$ nanocomposites increase as the concentration of TiO_2 NPs increases. Because of TiO_2 NP dispersion and absorption, the k values of $PAAm/TiO_2$ NCs increase, demonstrating momentous light indulgence. Strong interaction between PAAm and TiO_2 NPs causes crystallinity alterations, which result in modifications in band structure and absorbance percentage [24].

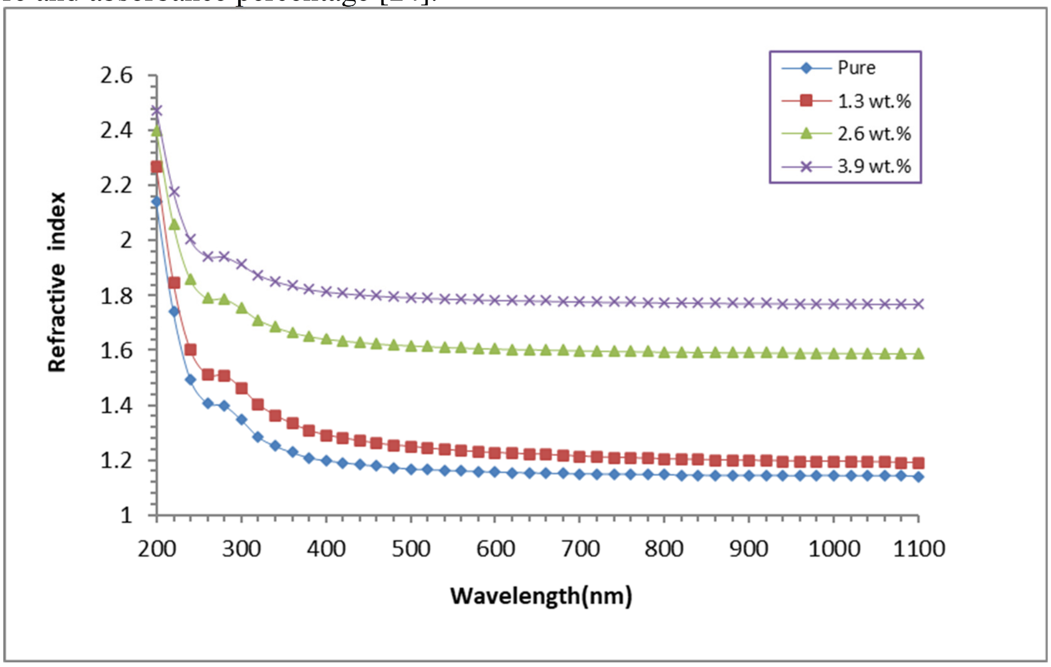

FIGURE 6. The n of ($PAAm/TiO_2$) PNCs

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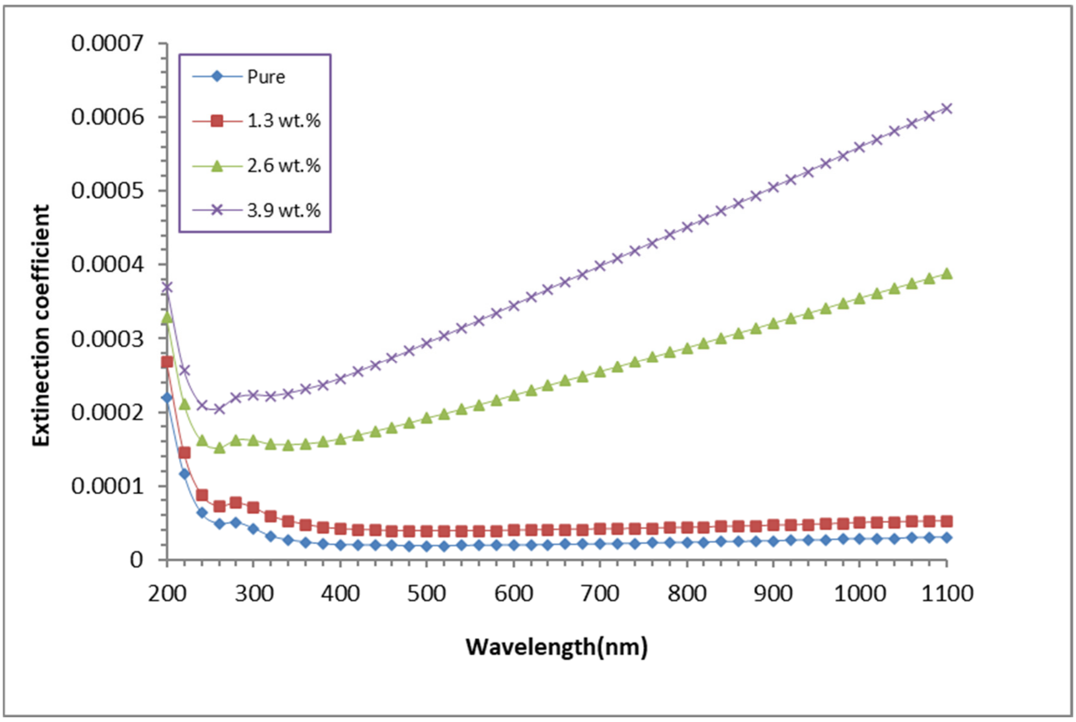

FIGURE 7. The K of (PAAm/TiO_2) PNCs

The energy difference in permitted and prohibited unintended changes for PAAm/TiO_2 is displayed in Figures 8 and 9. As the ratio of TiO_2 NPs rises, the values of Eg for PAAm diminution due to the creation of custody program complexes between the atoms of TiO_2 NPs and the practical gatherings of PAAm. By generating an interior band inside the PAAm structure, the injected TiO_2 NPs lower the nanocomposites' Eg. In order to generate a local level in the nanocomposites' edifices that led to the reduction in Eg values, the drop in Eg values is permitted to increase with a specific degree of disruption [25].

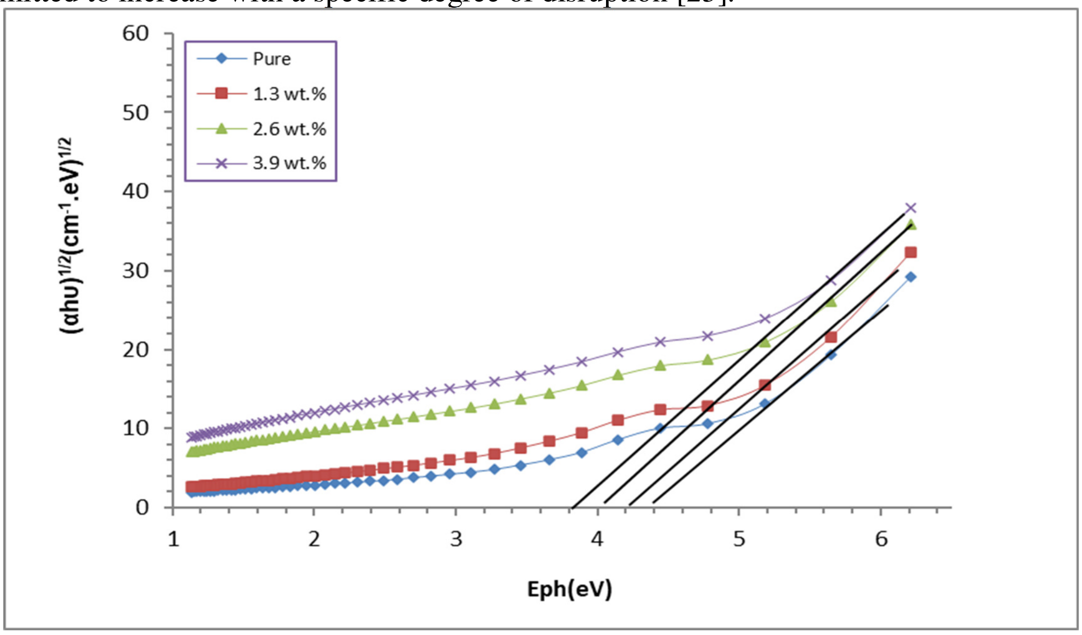

FIGURE 8. The $(\alpha h\nu)^{1/2}$ for $(PAAm/TiO_2)$ PNCs

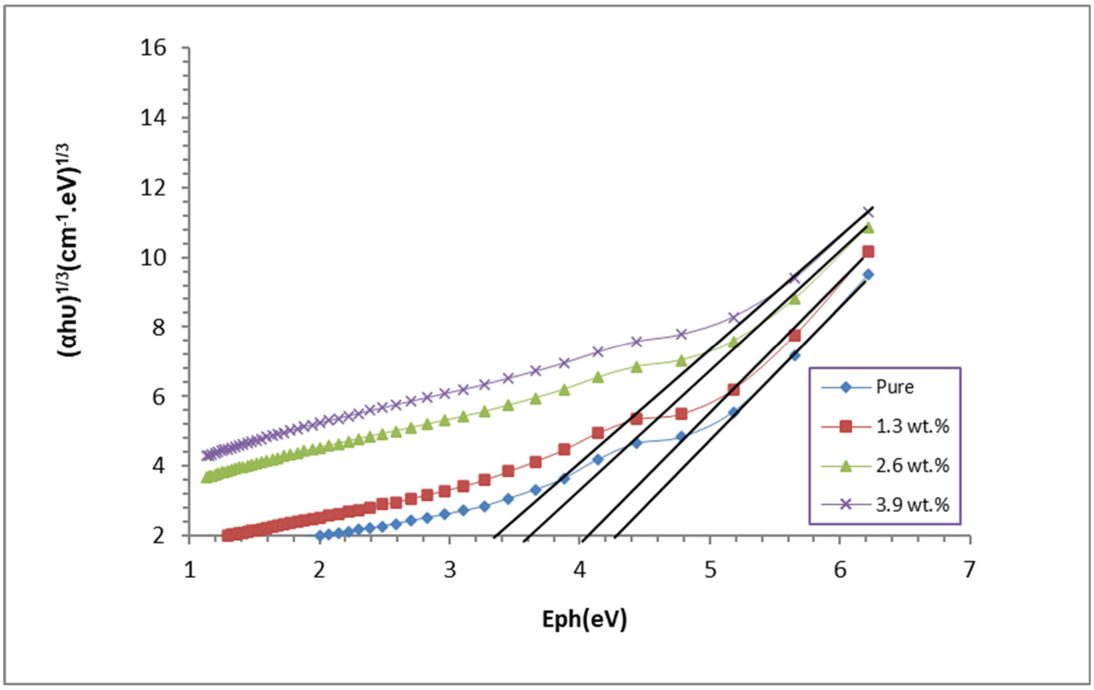

FIGURE 9. The $(\alpha h\nu)^{1/3}$ for $(PAAm/TiO_2)$ PNCs

TABLE 1. standards for the Eg of $PAAm/TiO_2$ PNCs

wt.% of TiO_2	Allowed Eg (eV)	Forbidden Eg (eV)
0	4.4	4.24
1.3	4.2	4
2.6	4	3.8
3.9	3.8	3.4

Figures 10–11 show the actual and fantasy sections of the insulator continuous behaviors for $PAAm/TiO_2$ films with wavelength. Increased TiO_2 NP content leads to higher ε_1 and ε_2 dielectric constants. Vagaries in the motion of charge carriers and local charged particles impacted the dielectric dispersion properties, affecting the performance of ε_1. Defects that cause charge transference between polymer manacles and dopants in nanoparticles lead to an increase in ε_2 [26].

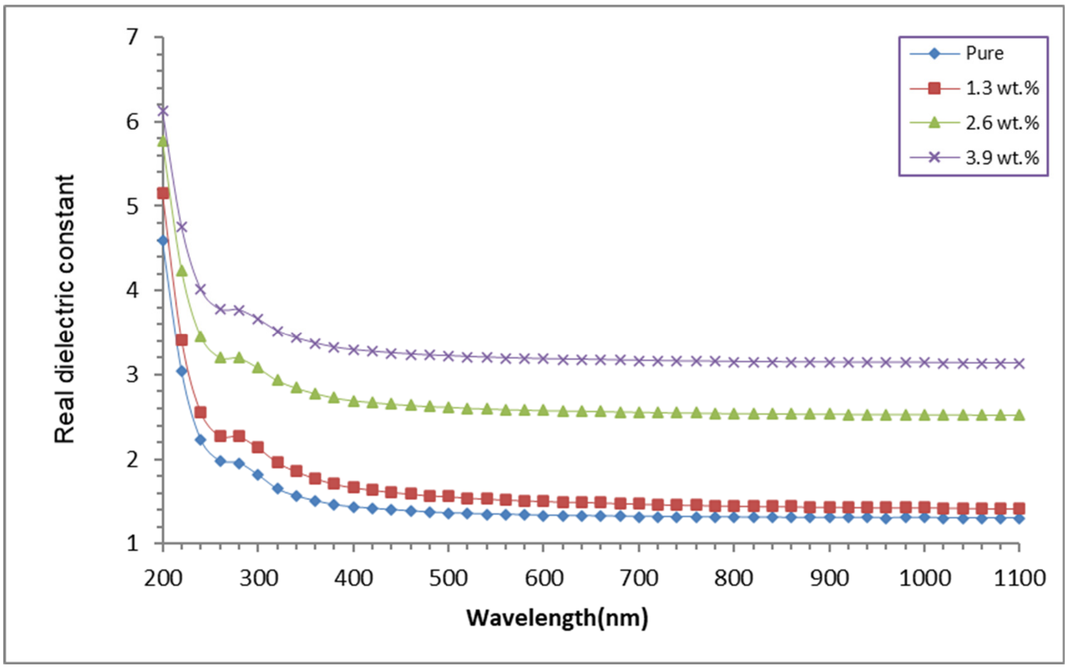

FIGURE 10. The ε_1 for ($PAAm/TiO_2$) PNCs

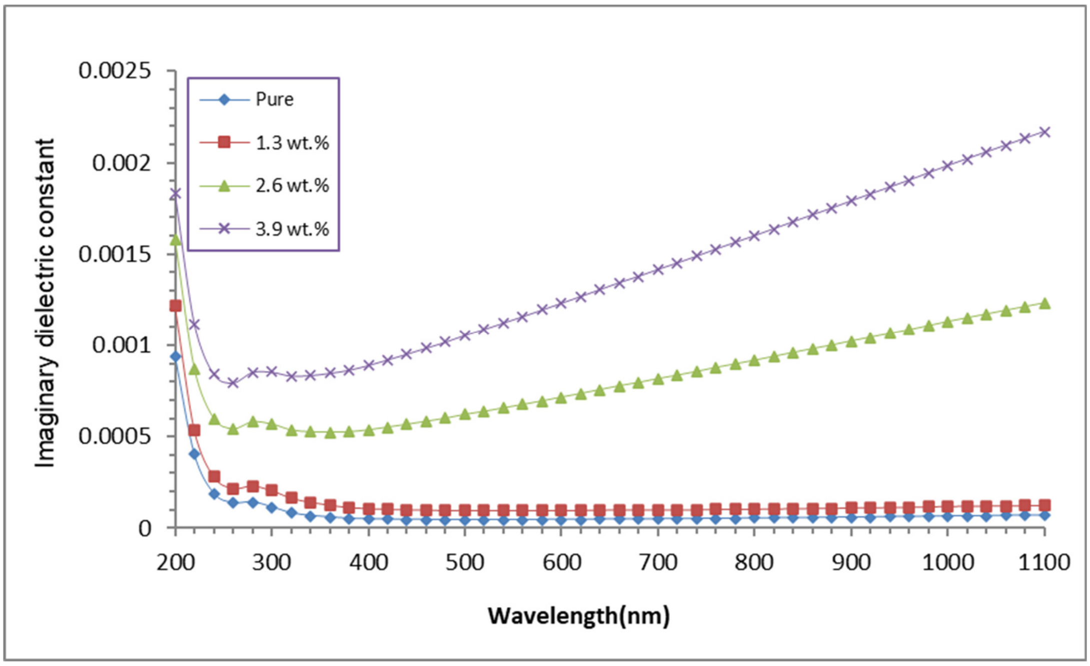

FIGURE 11. The ε_2 of ($PAAm/TiO_2$) PNCs

Figure 12 illustrates how $PAAm/TiO_2$ nanostructures' optical conductivity changes with wavelength. Because the absorption value encourages charge transference excitations, $PAAm/TiO_2$ nanostructures show higher optical conductivity at in-height photon energies. Increased optical conductivity in the presence of TiO_2 nanoparticles is correlated with higher restricted level concentrations in the gang construction. The optical conductivity of PAAm rises with the concentration of TiO_2 NPs; this phenomenon can be explained by either an growth in density and preoccupation factor or a reduction in the optical band gap [27].

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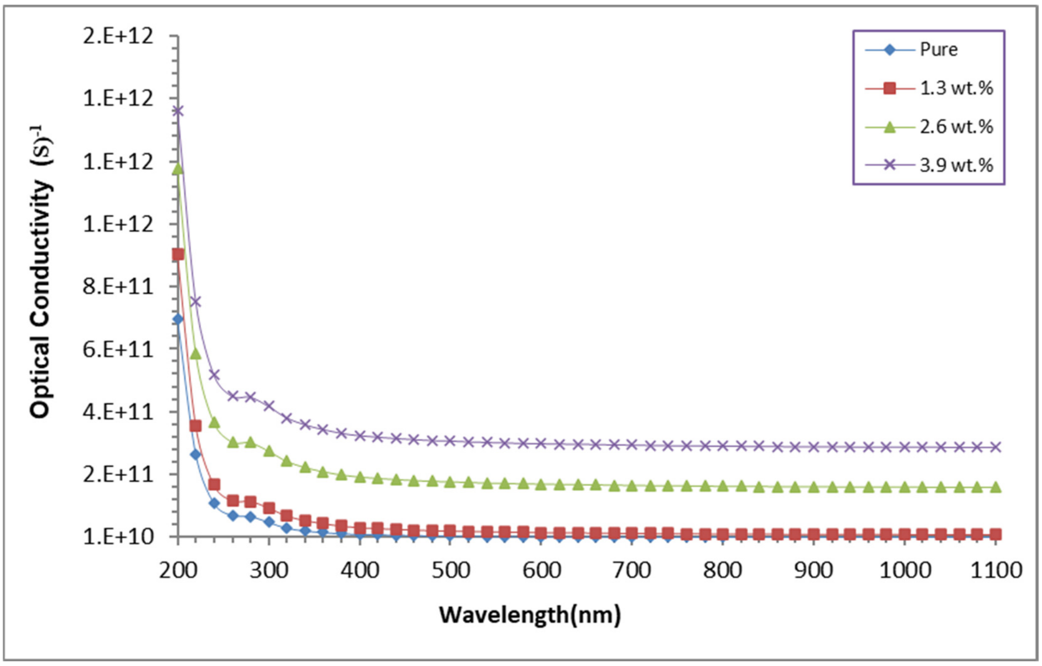

FIGURE 12. Optical conductivity for ($PAAm/TiO_2$) PNCs

4. CONCLUSION

$PAAm/TiO_2$ nanocomposites were made using the solution casting process, and their optical characteristics were thoroughly studied. Adding TiO_2 nanoparticles to the polymer matrix improves UV absorption, indicating stronger light-matter interaction. Increasing the concentration of TiO_2 nanoparticles leads to a rise in optical constants including refractive index and extinction coefficient, indicating greater interfacial polarization and nanoparticle-polymer interactions. Higher TiO_2 loading resulted in a reduction in optical transmittance and energy band gap. This conduct is linked to the creation of localized energy states and increased charge carrier interactions in the nanocomposite structure. The study found that adding TiO_2 nanoparticles improves the optical characteristics of PAAm, making it suitable for use in optoelectronic devices such UV sensors and optical components.

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