

# Synthesis and Ameliorating the Morphological, Microstructure and Optical Features of PMMA-PEG/BaTiO<sub>3</sub> Nanostructures for Flexible Photonics and Optics Devices

Ahmed Hashim<sup>1,\*</sup>, Ghaith Ahmed<sup>2</sup>, Najah M. L. Al Maimuri<sup>3</sup>,  
Hamed Ibrahim<sup>4</sup>, Aseel Hadi<sup>5</sup> and Dinesh Uthra<sup>6</sup>

<sup>1</sup>Department of Physics, University of Babylon, College of Education for Pure Sciences, Babylon, Iraq

<sup>2</sup>Department of Anesthesia Techniques, Hilla University College, Babylon, Iraq

<sup>3</sup>Building and Construction Department, College of Engineering & Engineering Techniques, Al-Mustaqbal University, 51001, Babylon, Iraq

<sup>4</sup>Al-Zahraa University for Women, Kerbala, Iraq

<sup>5</sup>Department of Ceramic and Building Materials, College of Materials Engineering, University of Babylon, Babylon, Iraq

<sup>6</sup>Department of Pure & Applied Physics, Guru Ghsaidas Vishwavidyalaya, Biaspur-Chhattisgarh, India

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

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## Abstract

The polymer nanocomposites are important materials for many optical and electronic applications. This research aims to fabricate of barium titanate (BaTiO<sub>3</sub>) NPs doped polyethylene glycol (PEG)-polymethyl methacrylate (PMMA) to apply in various photonics and optical approaches. The (PEG-PMMA/BaTiO<sub>3</sub>) films were prepared using the casting method. The microstructure and optical characteristics of (PEG-PMMA/BaTiO<sub>3</sub>) films were investigated. The optical features results showed when the BaTiO<sub>3</sub> NPs content reached 5 wt.%, the transmission(T) was reduced whereas the absorption(A) was augmented. The energy gap (E<sub>g</sub>) of the (PEG-PMMA) blend decreased from 2.5 to 1.9 eV with increasing BaTiO<sub>3</sub> NPs concentration to reach of 5 wt.% making the (PEG-PMMA/BaTiO<sub>3</sub>) nanostructures are suitable for optical and optoelectronic nanodevices. The refractive index, real and imaginary dielectric constants, absorption coefficient, optical conductivity and extinction coefficient were improved with increasing BaTiO<sub>3</sub> NPs concentration. Finally, the obtained findings indicated that the (PEG-PMMA/BaTiO<sub>3</sub>) nanostructures might be employed in a range of optical applications.

**Keywords:** Absorbance, BaTiO<sub>3</sub>, Energy gap, Optoelectronics, PMMA, PEG

## Introduction

In recent years, nanocomposites composed of practically all polymer systems have been used to improve one or more properties, with varying degrees of success. Polymers have inspired substantial interest in device manufacture due to their remarkable inherent properties such as ease of processing, flexibility, extraordinary strength, and so on. It is widely known that the optical and electrical features of polymers

could be enhanced to a favorite boundary with appropriate

doping [1]. Polymers and organic substances have attracted a lot of consideration for their exceptional properties, which promise to build lightweight, flexible, friendly for ecologically, and cost-effective electrical gadgets [2-4]. Nanotechnology delivers an appropriate platform to adjust the physicochemical features of varied substances in an evaluation to their

bulk equivalents, which could be utilized for bioapplications [5]. Nanotechnology is thus a very promising issue, and it is anticipated to radically reconstruct the technical applications in semiconductors, inorganic and organic materials, energy storage, and biology [6-8]. Polyethylene glycol is commonly used for solid dispersions due to its short melting point, quick rate for solidification, ability to produce solid medication solutions, few toxicity, and few cost [9]. As a result, it is employed in a variety of fields, including clothing, textiles, rubber, wood, metal, medicines, coatings, and cosmetics [10]. PEG is also available in a variety of geometric shapes [11]. PMMA (polymethylmethacrylate) is a linear thermoplastic polymer. The glass transition temperature is 85 °C, whereas the melting point is 160 °C. PMMA provides outstanding mechanical strength, hardness, stiffness, transparency, and insulation [12]. Its refractive index ranges between 1.3 and 1.7, making it an excellent optical material. PMMA is a common organic optical material because to its lightweight, high strength under pressure, and shatter-resistant qualities. A replacement for inorganic glass [13]. PMMA was utilized as a matrix of various nanocomposites to apply in many applications [14-19]. The piezoelectric materials were employed in several applications [20-23]. The ecologically friendly synthesis of BaTiO<sub>3</sub> at the nanoscale level remains a major concern. BaTiO<sub>3</sub> is widely used in electrical devices because of its ferroelectric, and piezoelectric features in a tetragonal construction. Its optical features, predominantly the luminescence of the nanostructured substance, include attracted substantial interest. BaTiO<sub>3</sub> material is widely used in various approaches, including piezoelectric devices, extraordinary density optical data storage, and capacitors, [24-26]. BaTiO<sub>3</sub> was added into polymers to improve their optical and electrical properties [27-29]. The casting method was used to fabricate of nanocomposites [30-34]. The novelty of current work comprises production of (PEG-PMMA/BaTiO<sub>3</sub>) nanostructures films have best optical characteristics with few cost and excellent flexibility compared with other nanostructures types.

## Materials and methods

A casting procedure was used to create nanostructured films of barium titanate (BaTiO<sub>3</sub>) doped polyethylene glycol (PEG), and polymethyl methacrylate (PMMA). The casting method is straightforward, cost-effective, and easy to fabricate. BaTiO<sub>3</sub> (50 nm, high purity (99.99%)) was obtained as nanopowder form US Research Nanomaterials, Inc. To create a PEG-PMMA polymeric film, 1 g of PMMA and PEG were dissolving in the chloroform of 30 mL with 50 wt.% PMMA + 50 wt.% PEG by employing the magnetic stirrer for 1 h at room temperature. BaTiO<sub>3</sub> NPs were added to a PEG/PMMA solution at concentrations of 2.5% and 5%. Nanostructured films of BaTiO<sub>3</sub>/PEG-PMMA made with thickness of 90 μm which was measured using digital micrometer. An optical microscope was used to analyze the distribution of BaTiO<sub>3</sub> NPs in the PEG/PMMA matrix. FTIR analysis for PEG-PMMA/BaTiO<sub>3</sub> films verified by FTIR (Bruker). The optical properties of BaTiO<sub>3</sub>/PEG-PMMA nanostructured films were evaluated via a spectrophotometer (Shimadzu). The optical characteristics of BaTiO<sub>3</sub>/PEG-PMMA nanostructures were investigated at wavelengths ranging from 280 - 880 nm. **Figure 1** displays the experimental part diagram. The extinction coefficient (k) is defined by [35]:

$$k = \alpha\lambda/4\pi \quad (1)$$

where  $\lambda$  refers to the wavelength and ( $\alpha$ ) indicates to the coefficient of absorption. Coefficient of absorption is defined by [36]:

$$\alpha = 2.303 A/t \quad (2)$$

where A is absorbance and t is thickness. The refractive index(n) is given by[37]:

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

where R is the reflectance. The following formula is used to calculate the real ( $\epsilon_1$ ) and imaginary ( $\epsilon_2$ ) components of the dielectric constant [38]:

$$\epsilon_1 = n^2 - k^2 \quad (4)$$

$$\epsilon_2 = 2nk \quad (5)$$

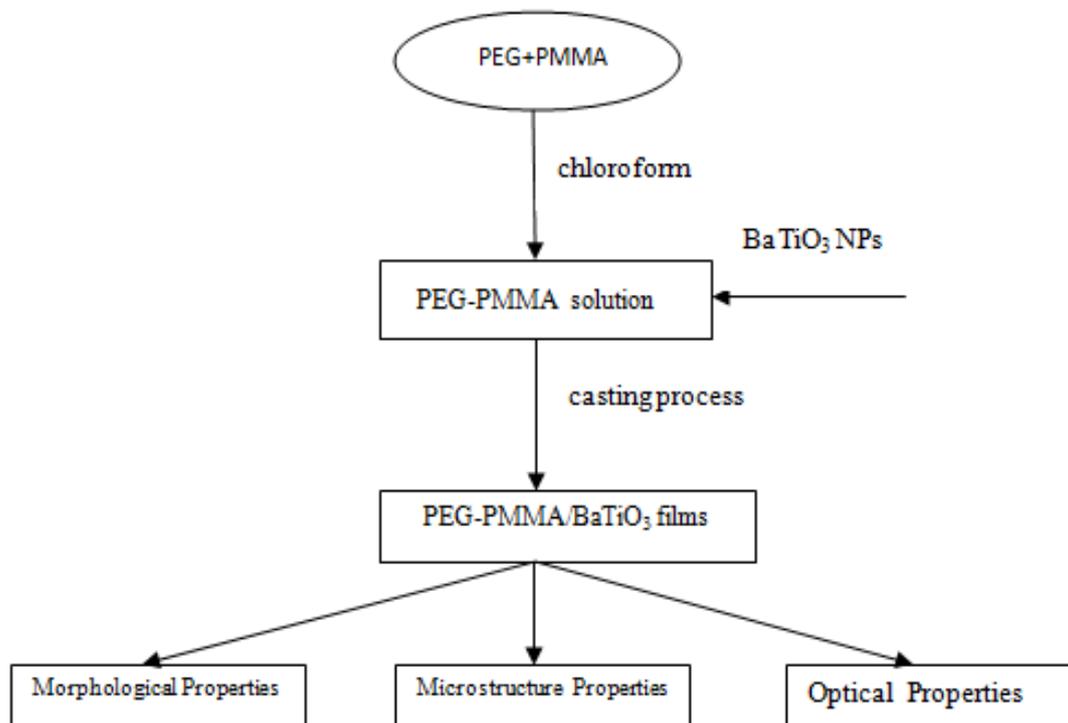
The band gap( $E_g$ ) is given by [39]:

$$\alpha h\nu = B(h\nu - E_g) \quad (6)$$

where B represents a constant. The optical conductivity( $\sigma_{op}$ ) is calculated by [40]:

$$\sigma_{op} = \alpha n c / 4\pi \quad (7)$$

Wherever c refers to the light veloci

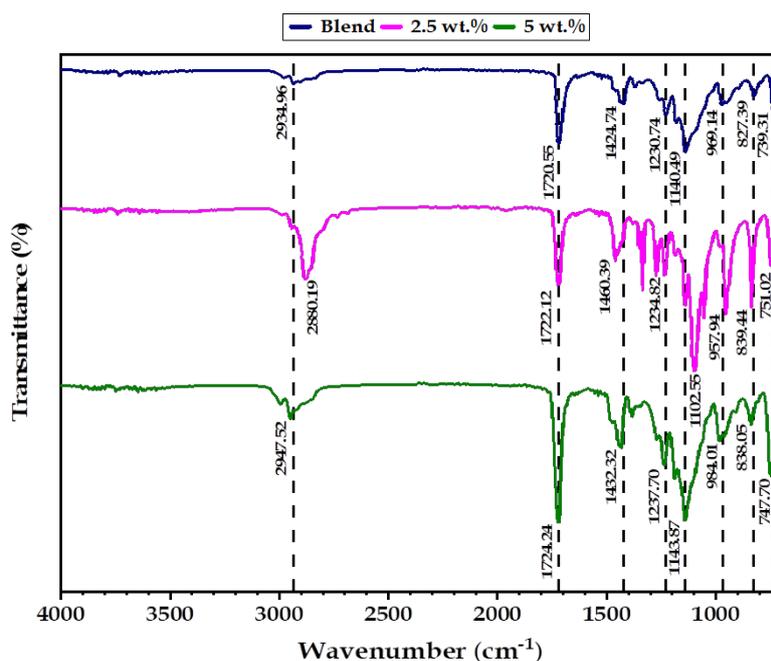


**Figure 1** Diagram of experimental part.

## Results and discussion

**Figure 2** displays the analysis of FTIR for PEG-PMMA/BaTiO<sub>3</sub> films. PEG-PMMA spectra revealed peaks about (2934.96) cm<sup>-1</sup>, showing stretching of asymmetric of the CH<sub>2</sub> set linked with PMMA. Peak at (1722.55) cm<sup>-1</sup> from the carbonyl C=O stretching vibration demonstrates the overlap of PMMA and PEG. The peaks at (1424.74) cm<sup>-1</sup> represent the C-O sets in the blend matrix. Peaks at (1230.74)

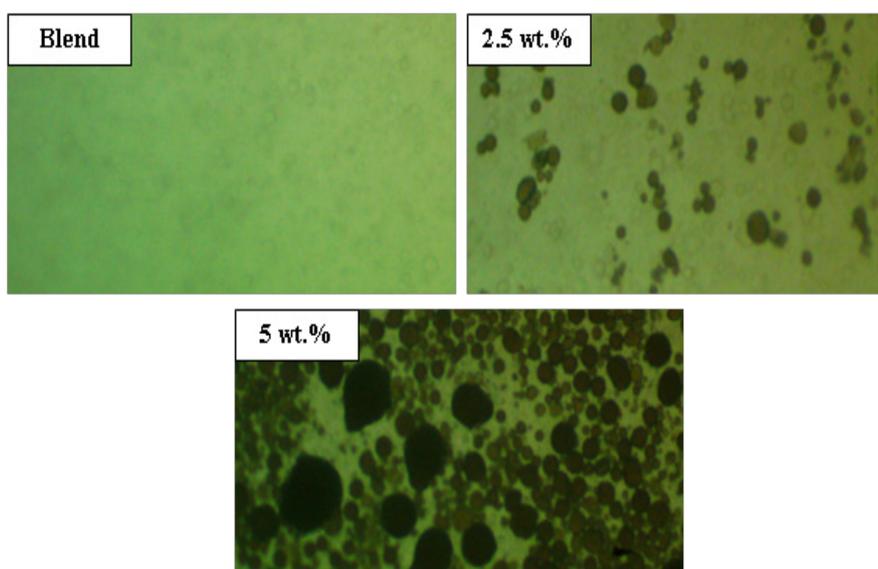
cm<sup>-1</sup> represent to the stretching of C-C-O in the set of ester. The CH<sub>2</sub> sets at 1140.49 and 969.14 cm<sup>-1</sup> denote the bending and stretching modes of CH<sub>2</sub>. The FTIR curves of BaTiO<sub>3</sub> complexes reveal unique absorption peaks at (827.39 and 739.31) cm<sup>-1</sup>, which indicate the existence of BaTiO<sub>3</sub> nanoparticles. Increased concentrations of BaTiO<sub>3</sub> NPs resulted in a modest decrease in transmittance, most likely due to the rise density of films [41-43].



**Figure 2** FT-IR spectra (PEG-PMMA/BaTiO<sub>3</sub>) nanocomposites.

**Figure 3** displays the optical microscope image for (PEG-PMMA/BaTiO<sub>3</sub>) films at (100x) for all films. This Figure depicts the dispersion of BaTiO<sub>3</sub> nanostructures inside a PEG-PMMA matrix. At low concentration, the nanoparticles form a clusters inside

polymer matrix. With increasing the content of NPs provides a link of pathways inside the plastic matrix, permitting carriers of charges to travel across the nanocomposites films, resulting in a change in material characteristics [44-51].



**Figure 3** Microscope images (10x) for (PEG-PMMA/BaTiO<sub>3</sub>) nanocomposites.

**Figure 4** demonstrates the absorption spectra of PEG-PMMA/BaTiO<sub>3</sub> films with photon wavelengths. The addition of BaTiO<sub>3</sub> to the (PEG-PMMA) blend shifted the edge of absorption to greater wavelengths. The absorption of the PEG-PMMA mix rises with

increased BaTiO<sub>3</sub> NP content. Doping PEG-PMMA with BaTiO<sub>3</sub> NPs improved its absorption and increased molecular interactions between cations and anions, producing defects during the polymer. The shift in UV absorption revealed exchange interactions inside

the host polymeric blend matrix. Furthermore, a slight shift in the absorption edge toward the great wavelength region indicates a narrowing of the optical band gap. The absence of an absorption band in the visible spectrum also indicates that the samples are transparent. PEG-PMMA/BaTiO<sub>3</sub> nanocomposites

exhibit high absorptivity at high photon energies, as these energies are sufficient to transfer electrons to high levels. The rise of absorbance with growing BaTiO<sub>3</sub> NPs ratio may be due to increase the charges carriers numbers [52-60].

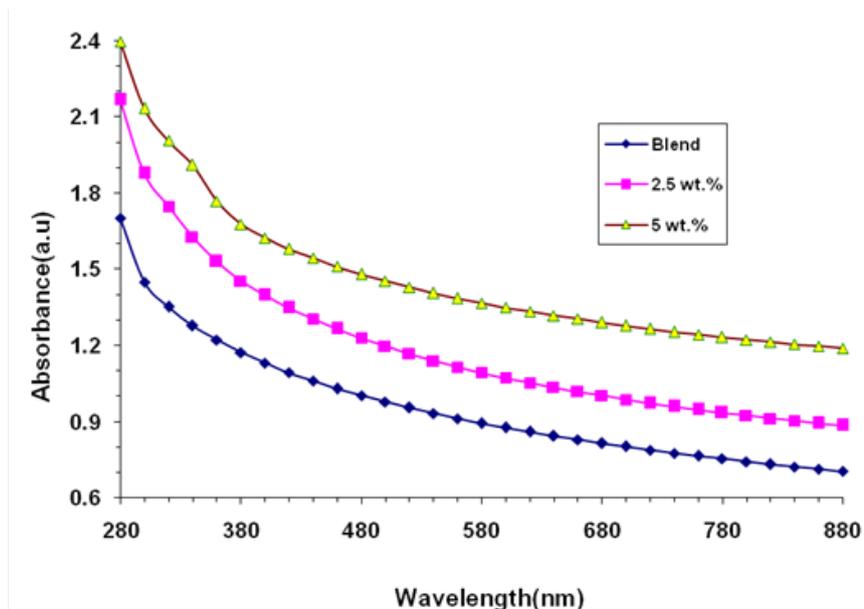


Figure 4 Variation of absorbance for (PEG-PMMA/BaTiO<sub>3</sub>) films with  $\lambda_{ph}$ .

Figure 5 shows the change in transmittance spectra of BaTiO<sub>3</sub>/PEG-PMMA films with varying photon wavelengths. The transmittance decreases with increasing BaTiO<sub>3</sub> NPs content. BaTiO<sub>3</sub> NPs absorb incident light photons, making electrons to transfer to

higher levels of energy and occupy vacant regions in the energy bands. The reduce of transmittance with rising of BaTiO<sub>3</sub> related to rise of charges carriers [61-64].

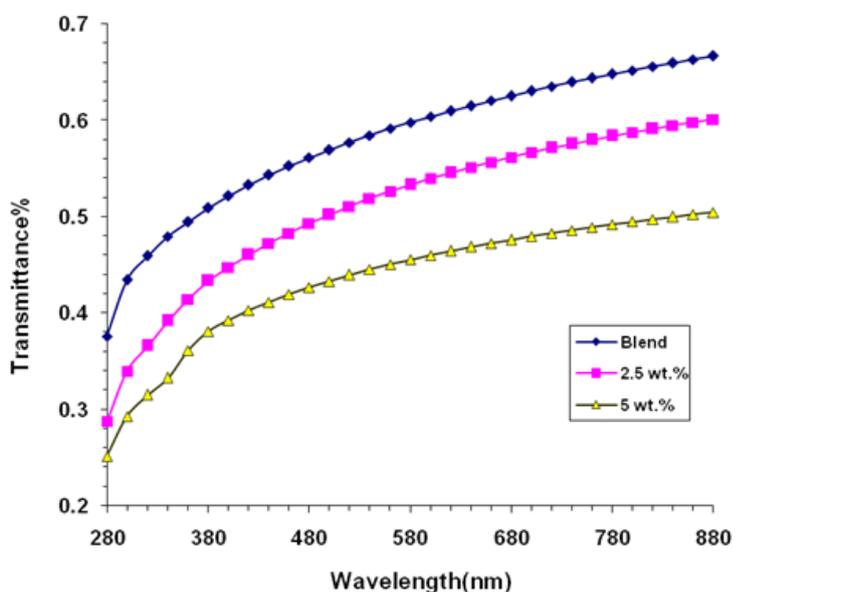
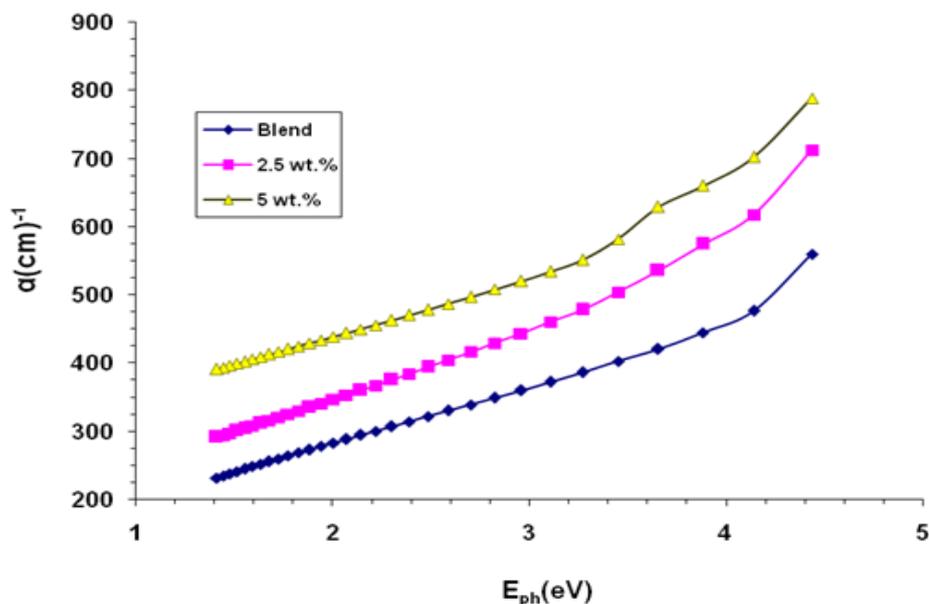


Figure 5 Variation of transmittance for (PEG-PMMA/BaTiO<sub>3</sub>) nanocomposites with wavelength.

**Figure 6** illustrates how the coefficient of absorption for (PEG-PMMA/BaTiO<sub>3</sub>) films varies with energy of photon. The absorption coefficient is low at low energy, suggesting that electron transmission is improbable due to insufficient energy from the input photon ( $h\nu < E_g$ ). Higher energy absorption means greater possibility of electrical transitions. The external photon has sufficient energy to transfer an electron

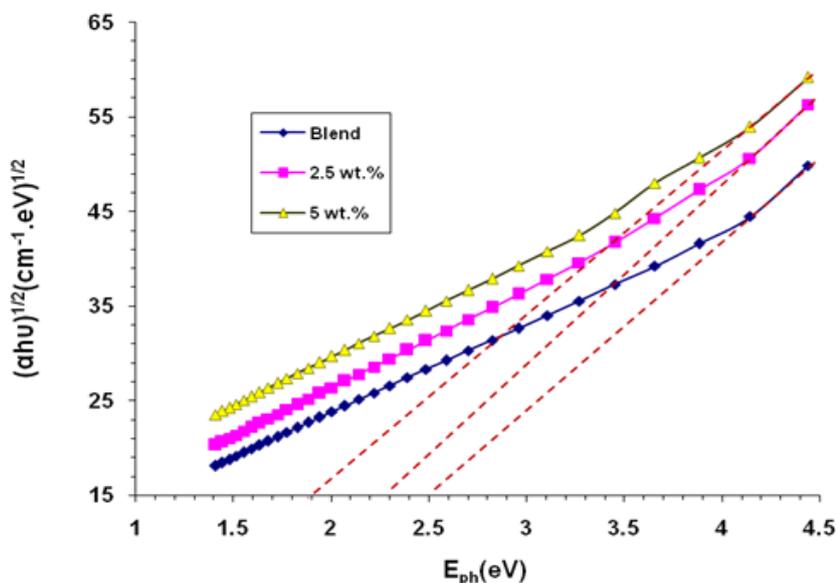
from the valence to the conduction band, thus crossing the forbidden energy gap. The  $\alpha$  of the (PEG-PMMA/BaTiO<sub>3</sub>) films is less than  $10^4 \text{ cm}^{-1}$  at all contents. The  $\alpha$  of the nanocomposite rises with increasing concentration of (BaTiO<sub>3</sub>) nanoparticles. This is because the number of charge carriers has increased [65-68].



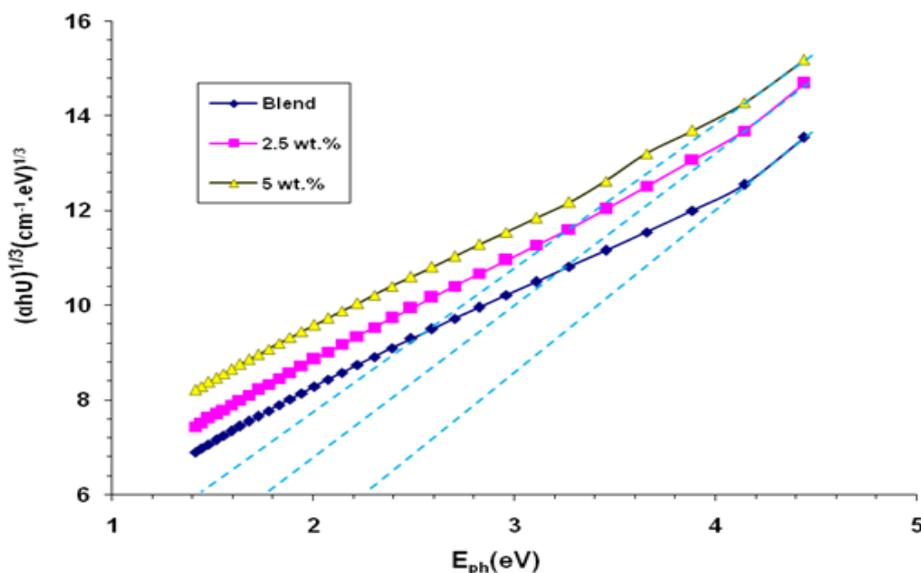
**Figure 6** Variation of  $\alpha$  for (PEG-PMMA/BaTiO<sub>3</sub>) films with  $E_{ph}$ .

**Figures 7 and 8** illustrate the band gap values for the PEG-PEG/BaTiO<sub>3</sub> films for the allowed and forbidden transitions, respectively. The band gap for the allowed and forbidden transitions was determined at  $r = 2$  and  $r = 3$ , respectively. Increasing the concentration of BaTiO<sub>3</sub> nanoparticles reduces the optical band gap. With higher BaTiO<sub>3</sub> NPs loading, the formation of on-site levels in the band gap causes electrons to move from the valence band to the localized levels to the conduction band in 2 stages. Increasing the barium titanate NPs provides electron channels in the polymer, allowing electrons to pass from the valence band to the conduction band, leading to a reduction in the optical band gap. The values of the

energy gap for (PEG-PMMA/BaTiO<sub>3</sub>) films are reduced with a rise in the BaTiO<sub>3</sub> nanoparticles ratio owing to form of charges transfer complexes between the functional groups of polymer and the atoms of nanoparticles. The embedded BaTiO<sub>3</sub> nanoparticles form an intermediate band among the polymer structure and thus decrease the energy gap of nanostructure films. The reduction of the values of the ( $E_g$ ) is assumed to rise with a degree of disturbance to generate the localized state in the nanostructures, as the BaTiO<sub>3</sub> nanoparticles produce energy levels in the band gap in the polymer matrix, leading to decline of the energy gap ( $E_g$ ) [69-80]. These results are agree with [81-85].



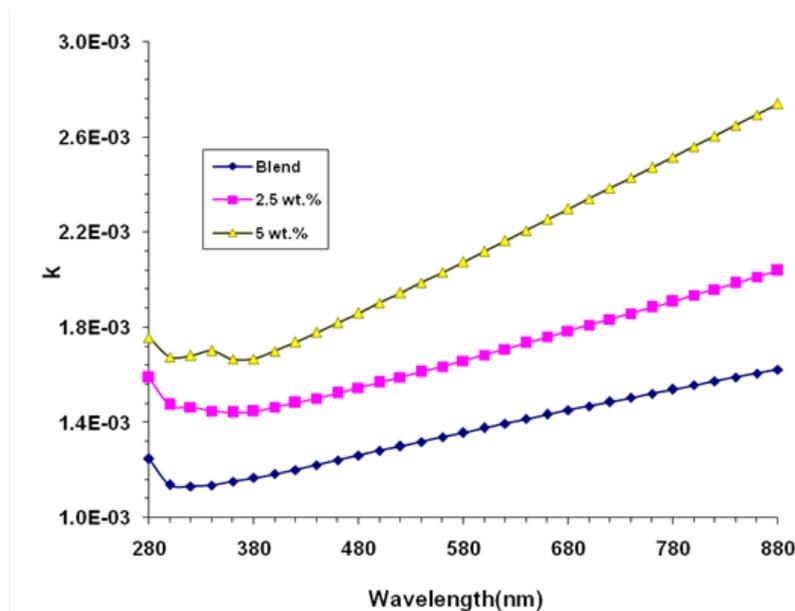
**Figure 7** Behavior of  $(\alpha h\nu)^{1/2}$  for (PEG-PMMA/BaTiO<sub>3</sub>) films with  $E_{ph}$ .



**Figure 8** Behavior of  $(\alpha h\nu)^{1/3}$  for (PEG-PMMA/BaTiO<sub>3</sub>) films with  $E_{ph}$ .

The extinction coefficient of (PEG-PMMA/BaTiO<sub>3</sub>) films as a function of wavelength is represented in **Figure 9**. The  $k$  is a measure of the amount of absorption loss produced by electromagnetic waves dispersing as they travel through material. As photon energy rises, the extinction coefficient falls, suggesting that more light is lost by scattering and

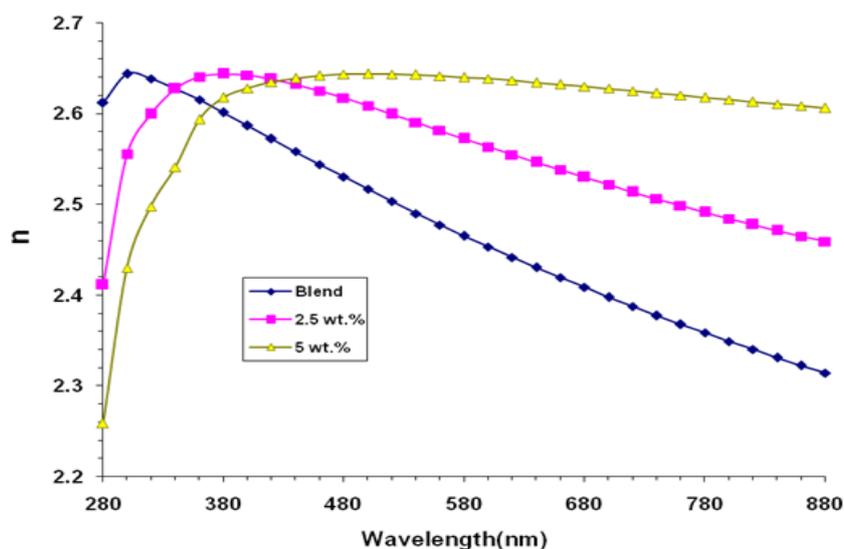
absorption. Furthermore, when the  $E_{ph}$  rises, the factor of loss reduces. Because BaTiO<sub>3</sub> NPS absorbs photons. Nanocomposites with larger concentrations of BaTiO<sub>3</sub> nanoparticles display better attenuation coefficients because of amended absorption and dispersion of photon in the matrix of polymer [86-88].



**Figure 9** Variation of  $k$  for (PEG-PMMA/BaTiO<sub>3</sub>) films with  $\lambda_{ph}$ .

**Figure 10** depicts the difference of refractive index with wavelength for (PEG-PMMA/BaTiO<sub>3</sub>) nanocomposites. The  $n$  values of PEG-PMMA blend are rise with growing BaTiO<sub>3</sub> nanoparticles concentration. The  $n$  for (PEG-PMMA/BaTiO<sub>3</sub>) films reduced with increasing wavelength. The increase of BaTiO<sub>3</sub> concentration leads to increase the density in nanocomposites, which explains the observed effect.

At high photon energy, the absorbance for (PEG-PMMA/BaTiO<sub>3</sub>) nanocomposites is higher, hence the reflectance is low leads to lower values of  $n$ . The concentration of 5 wt.% has high reflectance at VIS and NIR regions, hence its included higher values of  $n$ . The increase demonstrates faster radiation of electromagnetic transitory during the substance at low photon energy levels [89-95].



**Figure 10** Variation of  $n$  for (PEG-PMMA/BaTiO<sub>3</sub>) films with  $\lambda_{ph}$ .

**Figures 11 and 12** illustrate the performance of the real and imaginary dielectric constant with wavelength for PEG-PMMA/BaTiO<sub>3</sub> nanocomposites. As the content of BaTiO<sub>3</sub> NPs increases, both the  $\epsilon_1$

and  $\epsilon_2$  of PEG-PMMA increase. The addition of BaTiO<sub>3</sub> NPs increases the electric polarization, resulting in a higher dielectric constant of the PEG-PMMA blend and a partial increase in the polymer

charges. The figures also illustrate how the dielectric constant of the PEG-PMMA/BaTiO<sub>3</sub> nanocomposite changes with rising wavelength. This is due to the effect of the n values on the  $\epsilon_1$ . The k affects the  $\epsilon_2$ ,

especially at wavelengths (380 - 880 nm), where the n values remains constant but k increases with wavelength [96-101].

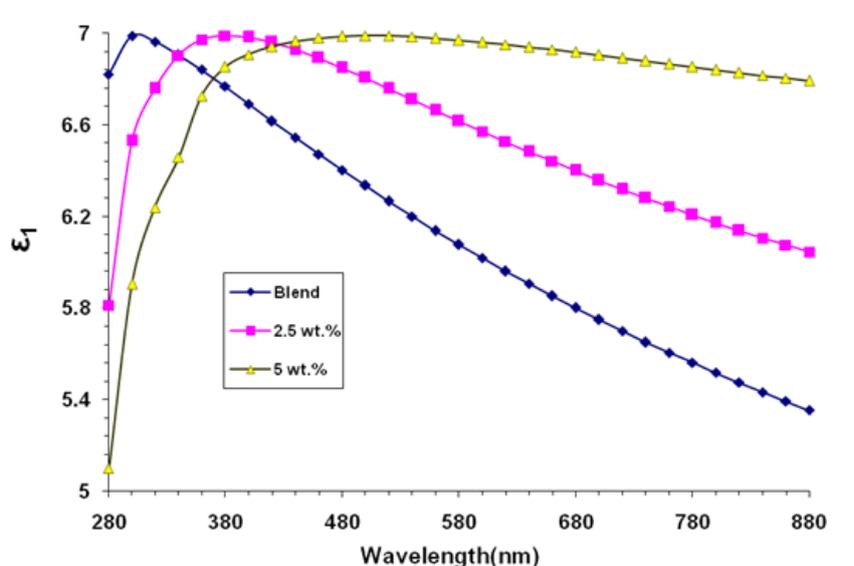


Figure 11 Performance of  $\epsilon_1$  for (PEG-PMMA/BaTiO<sub>3</sub>) films with  $\lambda_{ph}$ .

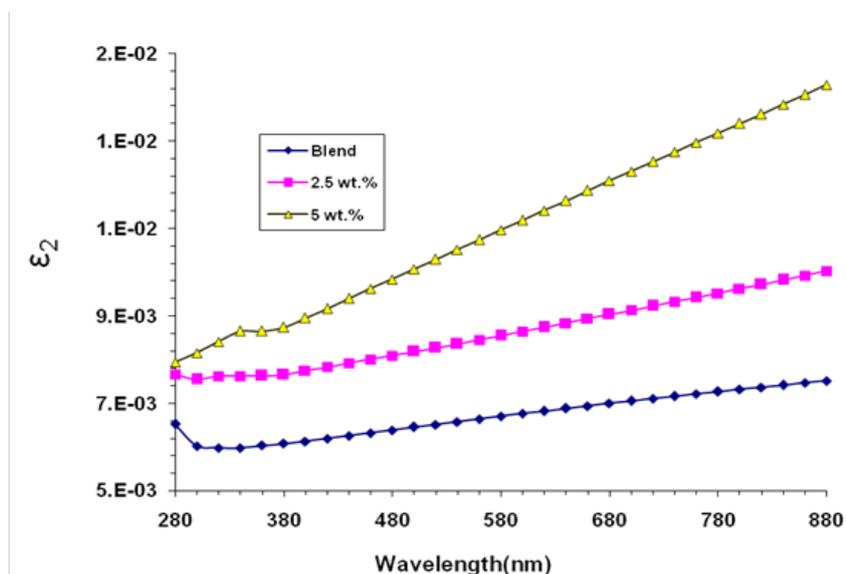
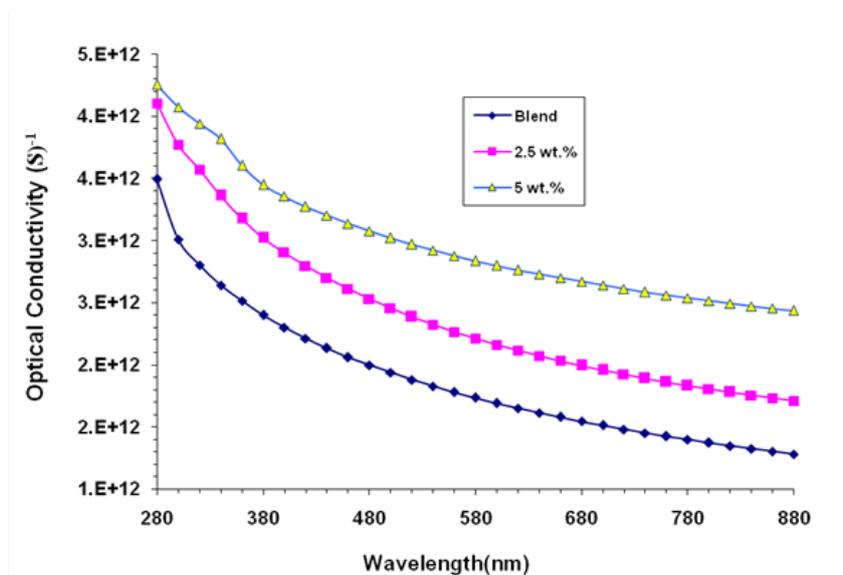


Figure 12 Behavior of  $\epsilon_2$  for (PEG-PMMA/BaTiO<sub>3</sub>) films with  $\lambda_{ph}$ .

Figure 13 shows the variation of the photoconductivity of the PEG-PMMA/BaTiO<sub>3</sub> nanocomposites with photon wavelength. The figure shows a decrease in the photoconductivity of the PEG-PMMA/BaTiO<sub>3</sub> nanocomposites with increasing wavelength. The nanocomposite samples exhibit better photoconductivity at lower photon wavelengths, due to

increased absorption resulting from excitation charge transfer. The addition of BaTiO<sub>3</sub> nanoparticles improved the photoconductivity by producing localized levels in the energy gap, resulting in an increased concentration of BaTiO<sub>3</sub> NPs. The number of nanoparticles increases the density of localized states within the band structure [102-106].



**Figure 13** Variation of optical conductivity for (PEG-PMMA/BaTiO<sub>3</sub>) nanocomposites with wavelength.

## Conclusions

This study included fabrication of BaTiO<sub>3</sub>/PEG/PMMA nanostructures for nanoelectronics and photonics applications including photovoltaic cells, optical devices, sensors, and electrical gates. The morphology and optical properties of BaTiO<sub>3</sub>/PEG/PMMA nanostructures were investigated. The results showed that the raising of (BaTiO<sub>3</sub>) NPs ratio to 5 wt.% leads to improve of (PEG-PMMA) absorption while transmission reduces with increasing BaTiO<sub>3</sub> content. The PEG-PMMA/BaTiO<sub>3</sub> nanostructures exhibit excellent photon energy absorption at UV-spectra making them appropriate for use in optoelectronic nanodevices. The energy gap ( $E_g$ ) of the (PEG-PMMA) blend decreased from 2.5 to 1.9 eV with increasing BaTiO<sub>3</sub> NPs concentration to reach of 5 wt.% making the (PEG-PMMA/BaTiO<sub>3</sub>) nanostructures important for optical and optoelectronic nanodevices. The other optical parameters increased with increasing BaTiO<sub>3</sub> NPs concentration. Finally, the obtained results indicated that the (PEG-PMMA/BaTiO<sub>3</sub>) nanostructures might be employed in a range of nanoelectronics applications.

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## References

- [1] HM Mohssin. Investigation of optical properties for (PVA-PEG-Ag) polymer nanocomposites films. *International Journal of Engineering Research & Technology (IJERT)* 2017; **6(7)**, 164-170.
- [2] A Hashim, IR Agool and KJ Kadhim. Novel of (polymer blend-Fe<sub>3</sub>O<sub>4</sub>) magnetic nanocomposites: Preparation and characterization for thermal energy storage and release, gamma ray shielding, antibacterial activity and humidity sensors applications. *Journal of Materials Science: Materials in Electronics* 2018; **29(12)**, 10369-10394.
- [3] FL Rashid, A Hadi, NH Al-Garah and A Hashim. Novel phase change materials, MgO nanoparticles, and water based nanofluids for thermal energy storage and biomedical applications. *International Journal of Pharmaceutical and Phytopharmacological Research* 2018; **8(1)**, 46-56.
- [4] A Hashim and A Hadi. Synthesis and characterization of novel piezoelectric and energy storage nanocomposites: Biodegradable materials-magnesium oxide nanoparticles. *Ukrainian Journal of Physics* 2017; **62(12)**, 1050-1056.

- [5] R Singh, MS Smitha and SP Singh. The role of nanotechnology in combating multi-drug resistant bacteria. *Journal for Nanoscience and Nanotechnology* 2014; **14(7)**, 4745-4756.
- [6] CC Okpala. Nanocomposites—an overview. *International Journal of Engineering Research and Development* 2013; **8(11)**, 17-23.
- [7] FL Rashid, SM Talib, A Hadi and A Hashim. Novel of thermal energy storage and release: Water/(SnO<sub>2</sub>-TaC) and water/(SnO<sub>2</sub>-SiC) nanofluids for environmental applications. *IOP Conference Series: Materials Science and Engineering* 2018; **454**, 012113.
- [8] A Hadi, FL Rashid, HQ Hussein and A Hashim. Novel of water with (CeO<sub>2</sub>-WC) and (SiC-WC) nanoparticles systems for energy storage and release applications. *IOP Conference Series: Materials Science and Engineering* 2019; **518(3)**, 032059.
- [9] H Bley, B Fussnegger and R Bodmeier. Characterization and stability of solid dispersions based on PEG / polymer blends. *International Journal of Pharmaceutics* 2010; **390(2)**, 165-173.
- [10] ZK Heiba, MB Mohamed and SI Ahmed. Exploring the physical properties of PVA/PEG polymeric material upon doping with nano gadolinium oxide: Exploring the physical properties of PVA/PEG polymeric material. *Alexandria Engineering Journal* 2022; **61(5)**, 3375-3383.
- [11] MS Zafar. Prosthodontic applications of polymethyl methacrylate (PMMA): An update. *Polymers* 2020; **12(10)**, 2299.
- [12] VK Thakur, D Vennerberg, SA Madbouly and MR Kessler. Bio-inspired green surface functionalization of PMMA for multifunctional capacitors. *RSC Advances* 2014; **4(13)**, 6677-6684.
- [13] G Ahmed and A Hashim. Development of nanometal nitride doped PMMA blend for biomedicine and industrial fields: Recent review. *World Journal of Advanced Research and Reviews* 2023; **17(3)**, 424-436.
- [14] A Hazim, HM Abduljalil and A Hashim. Structural, spectroscopic, electronic and optical properties of novel platinum doped (PMMA/ZrO<sub>2</sub>) and (PMMA/Al<sub>2</sub>O<sub>3</sub>) nanocomposites for electronics devices. *Transactions on Electrical and Electronic Materials* 2020; **21**, 550-563.
- [15] A Hazim, HM Abduljalil and A Hashim. First principles calculations of electronic, structural and optical properties of (PMMA-ZrO<sub>2</sub>-Au) and (PMMA-Al<sub>2</sub>O<sub>3</sub>-Au) nanocomposites for optoelectronics applications. *Transactions on Electrical and Electronic Materials* 2021; **22**, 185-203.
- [16] A Hazim, A Hashim and H Abduljalil. Fabrication of novel (PMMA-Al<sub>2</sub>O<sub>3</sub>/Ag) nanocomposites and its structural and optical properties for lightweight and low cost electronics applications. *Egyptian Journal of Chemistry* 2021; **64(1)**, 359-374.
- [17] Z Sattar and A Hashim. Quaternary PMMA-PEG/SnO<sub>2</sub>-SiC nanocomposite films for flexible nanodielectric and energy storage applications. *Silicon* 2025; **17**, 1681-1692.
- [18] G Ahmed, AF Kadhim, A Hashim and H Ibrahim. Fabrication and exploring the structural and optical features of Si<sub>3</sub>N<sub>4</sub>/SiO<sub>2</sub> hybrid nanomaterials doped PMMA for promising optoelectronics fields. *Optical and Quantum Electronics* 2024; **56**, 1308.
- [19] A Hashim, HH Abed and SM Alshrefi. Ameliorating and tuning the structural, morphological, and optical characteristics of chromium Oxide/Silicon carbide promising hybrid nanocomposites doped PMMA for futuristic nanoelectronics and photonics applications. *Silicon* 2024; **16**, 5087-5095.
- [20] E Pakizeh. Optical response and structural properties of Fe-doped Pb(Zr<sub>0.52</sub>Ti<sub>0.48</sub>)O<sub>3</sub> nanopowders. *Journal of Materials Science: Materials in Electronics* 2020; **31**, 4872-4881.
- [21] E Pakizeh and M Moradi. Kramers-Kronig method for determination of optical properties of PZT nanotubes fabricated by sol-gel method and porous anodic alumina with high aspect ratio. *International Journal of Modern Physics B* 2018; **32(8)**, 1850096.
- [22] E Pakizeh and M Moradi. Effect of particle size on the optical properties of lead zirconate titanate nanopowders. *Journal of the American Ceramic Society* 2018; **101(12)**, 5335-5345.

- [23] E Pakizeh, M Moradi and A Ahmadi. Effect of sol-gel pH on XRD peak broadening, lattice strain, ferroelectric domain orientation, and optical bandgap of nanocrystalline  $\text{Pb}_{1.1}(\text{Zr}_{0.52}\text{Ti}_{0.48})\text{O}_3$ . *Journal of Physics and Chemistry of Solids* 2014; **75(2)**, 174-181.
- [24] WS Cho. Structural evolution and characterization of  $\text{BaTiO}_3$  nanoparticles synthesized from polymeric precursor. *Journal of Physics and Chemistry of Solids* 1998; **59(5)**, 659-666.
- [25] AK Jha and K Prasad. Ferroelectric  $\text{BaTiO}_3$  nanoparticles: Biosynthesis and characterization. *Colloids and surfaces B: Biointerfaces* 2010; **75(1)**, 330-334.
- [26] ML Moreira, GP Mambrini, DP Volanti, ER Leite, MO Orlandi, PS Pizani, VR Mastelaro, CO Paiva-Santos, E Longo and JA Varela. Hydrothermal microwave: A new route to obtain photoluminescent crystalline  $\text{BaTiO}_3$  nanoparticles. *Chemistry of Materials* 2008; **20(16)**, 5381-5387.
- [27] HK Jaafar, A Hashim and BH Rabee. Fabrication and unraveling the morphological, structural, and dielectric features of PMMA-PEO-SiC- $\text{BaTiO}_3$  promising quaternary nanocomposites for multifunctional nanoelectronics applications. *Journal of Materials Science: Materials in Electronics* 2024; **35**, 128.
- [28] A Hashim, B Mohammed, A Hadi and H Ibrahim. Synthesis and augment structural and optical characteristics of PVA/SiO<sub>2</sub>/ $\text{BaTiO}_3$  nanostructures films for futuristic optical and nanoelectronics applications. *Journal of Inorganic and Organometallic Polymers and Materials* 2023; **34**, 611-621.
- [29] HK Jaafar, A Hashim and BH Rabee. Fabrication and tuning the morphological and optical characteristics of PMMA/PEO/SiC/ $\text{BaTiO}_3$  newly quaternary nanostructures for optical and quantum electronics fields. *Optical and Quantum Electronics* 2023; **55(11)**, 989.
- [30] HM Shanshool, M Yahaya, WMM Yunus and IY Abdullah. Investigation of energy band gap in polymer/ZnO nanocomposites. *Journal of Materials Science: Materials in Electronics* 2016; **27**, 9804-9811.
- [31] A Hashim, H Ibrahim and A Hadi. Fabrication of PS/Si<sub>3</sub>N<sub>4</sub>/ $\text{SrTiO}_3$  multifunctional nanocomposites and boosting their microstructure and optical and dielectric features for energy storage and nanodielectric applications. *Journal of Materials Science: Materials in Electronics* 2025; **36**, 312.
- [32] AF Kadhim and A Hashim. Fabrication and tuning the structural and dielectric characteristics of PS/SiO<sub>2</sub>/ $\text{SrTiO}_3$  hybrid nanostructures for nanoelectronics and energy storage devices. *Silicon* 2023; **15**, 4613-4621.
- [33] MH Meteab, A Hashim and BH Rabee. Synthesis and characteristics of SiC/MnO<sub>2</sub>/PS/PC quaternary nanostructures for advanced nanodielectrics fields. *Silicon* 2023; **15**, 1609-1620.
- [34] Hk Jaafar, A Hashim and BH Rabee. Tailoring the influence of hybrid SiC/ $\text{SrTiO}_3$  nanomaterials doped PMMA/PEO for promising nanodielectric and nanoelectronic applications. *Silicon* 2024; **16**, 1905-1915.
- [35] TS Soliman and SA Vshivkov. Effect of Fe nanoparticles on the structure and optical properties of polyvinyl alcohol nanocomposite films. *Journal of Non-Crystalline Solids* 2019; **519**, 119452.
- [36] RM Yas. Gamma radiation induced changes in the optical properties of CdTe thin films for dosimetric purposes. *Iraqi Journal of Physics* 2012; **10(17)**, 71-76.
- [37] S Agarwal, YK Saraswat and V Saraswat. Study of optical constants of ZnO dispersed PC/PMMA blend nanocomposites. *Open Physics Journal* 2016; **3(1)**, 63-72.
- [38] S Mohamed and N Kareem. Optical properties for prepared polyvinyl alcohol/ polyaniline/ ZnO nanocomposites. *Iraqi Journal of Physics* 2018; **16(36)**, 181-189.
- [39] AMA Henaish and AS Abouhaswa. Effect of WO<sub>3</sub> nanoparticle doping on the physical properties of PVC polymer. *Bulletin of Materials Science* 2020; **43(1)**, 149.
- [40] TA Taha. Optical properties of PVC/Al<sub>2</sub>O<sub>3</sub> nanocomposite films. *Polymer Bulletin* 2019; **76(2)**, 903-918.
- [41] G Ahmed and A Hashim. Synthesis of PMMA/PEG/Si<sub>3</sub>N<sub>4</sub> nanostructures and exploring

- the structural and dielectric characteristics for flexible nanoelectronics applications. *Silicon* 2023; **15**, 3977-3985.
- [42] SB Balakrishnan, M Alam, N Ahmad, M Govindasamy, S Kuppua and S Thambusamy. Electrospinning nanofibrous graft preparation and wound healing studies using ZnO nanoparticles and glucosamine loaded with poly(methyl methacrylate)/polyethylene glycol. *New Journal of Chemistry* 2021; **45(18)**, 7987-7998.
- [43] A Hashim, SM Alshrefi, HH Abed and A Hadi. Synthesis and boosting the structural and optical characteristics of pmma/sic/cds hybrid nanomaterials for future optical and nanoelectronics applications. *Journal of Inorganic and Organometallic Polymers and Materials* 2024; **34**, 703-711.
- [44] A Kareem, A Hashim and HB Hassan. Ameliorating and tailoring the morphological, structural, and dielectric features of Si<sub>3</sub>N<sub>4</sub>/CeO<sub>2</sub> futuristic nanocomposites doped PEO for nanoelectronic and nanodielectric applications. *Journal of Materials Science: Materials in Electronics* 2024; **35**, 461.
- [45] MH Abbas, H Ibrahim, A Hashim and A Hadi. Ameliorating and tailoring the features of silica-silicon carbide nanoceramic doped polyethylene oxide for promising optoelectronics applications. *Silicon* 2025; **17**, 697-707.
- [46] AHA Darwesh, PA Mohammed, SM Mamand, SA Hussen, SB Aziz, MA Brza, RM Abdullah and WO Karim. Investigation of structural and optical characteristics of biopolymer composites based on polyvinyl alcohol inserted with PbS nanoparticles. *Coatings* 2023; **13(3)**, 578.
- [47] IR Agool, FS Mohammed and A Hashim. The effect of magnesium oxide nanoparticles on the optical and dielectric properties of (PVA-PAA-PVP) blend. *Advances in Environmental Biology* 2015; **9(11)**, 1-10.
- [48] A Hashim and A Jassim. Novel of biodegradable polymers-inorganic nanoparticles: Structural, optical and electrical properties as humidity sensors and gamma radiation shielding for biological applications. *Journal of Bionanoscience* 2018; **12(2)**, 170-176.
- [49] H Ahmed, A Hashim and HM Abduljalil. Analysis of structural, electrical and electronic properties of (Polymer Nanocomposites/ Silicon Carbide) for antibacterial application. *Egyptian Journal of Chemistry* 2019; **62(4)**, 1167-1176.
- [50] IR Agool, KJ Kadhim and A Hashim. Fabrication of new nanocomposites: (PVA-PEG-PVP) blend-zirconium oxide nanoparticles) for humidity sensors. *International Journal of Plastics Technology* 2017; **21**, 397-403.
- [51] A Hashim and MA Habeeb. Synthesis and characterization of polymer Blend-CoFe<sub>2</sub>O<sub>4</sub> nanoparticles as a humidity sensors for different temperatures. *Transactions on Electrical and Electronic Materials* 2019; **20**, 107-112.
- [52] AD Acharya, B Sarwan, IA Malik, YA Bhat, K Silwal and MK Rathore. Optical properties of NiO: PVA thin films. *AIP Conference Proceedings* 2019; **2100(1)**, 020006.
- [53] FL Rashid, A Hashim, MA Habeeb, SR Salman and H Ahmed. Preparation of PS-PMMA copolymer and study the effect of sodium fluoride on its optical properties. *Journal of Engineering and Applied Sciences* 2013; **8(5)**, 137-139.
- [54] A Hashim and A Hadi. Synthesis and characterization of (MgO-Y<sub>2</sub>O<sub>3</sub>-CuO) nanocomposites for novel humidity sensor application. *Sensor Letters* 2017; **15(10)**, 858-861.
- [55] A Hashim, H Ibrahim and A Hadi. Fabrication and augmentation of optical and structural characteristics of PVA/SiC/CoFe<sub>2</sub>O<sub>4</sub> hybrid nanocomposites for tailored optical and quantum electronics applications. *Optical and Quantum Electronics* 2024; **56**, 1177.
- [56] H Ahmed and A Hashim. Structure, optical, electronic and chemical characteristics of novel (PVA-CoO) structure doped with silicon carbide. *Silicon* 2021; **13**, 4331-4344.
- [57] A Hashim and ZS Hamad. Fabrication and characterization of polymer blend doped with metal carbide nanoparticles for humidity sensors. *Journal of Nanostructures* 2019; **9(2)**, 340-348.
- [58] H Ahmed and A Hashim. Design and characteristics of novel PVA/PEG/Y<sub>2</sub>O<sub>3</sub> structure

- for optoelectronics devices. *Journal of Molecular Modeling* 2020; **26**, 210.
- [59] H Ahmed and A Hashim. Structural, optical and electronic properties of silicon carbide doped PVA/NiO for low cost electronics applications. *Silicon* 2021; **13**, 1509-1518.
- [60] H Ahmed and A Hashim. Geometry optimization, optical and electronic characteristics of novel PVA/PEO/SiC structure for electronics applications. *Silicon* 2021; **13**, 2639-2644.
- [61] H Neama and N Al-khegani. The effect of ferrous chloride (FeCl<sub>2</sub>) on some optical properties of polystyrene. *Academic Research International* 2014; **5(2)**, 161-166.
- [62] MH Meteab, A Hashim and BH Rabee. Synthesis and tailoring the morphological, optical, electronic and photodegradation characteristics of PS-PC/MnO<sub>2</sub>-SiC quaternary nanostructures. *Optical and Quantum Electronics* 2023; **55**, 187.
- [63] A Hashim, G Ahmed, H Ibrahim and A Hadi. Ameliorating the features of TiN/SiO<sub>2</sub> promising nanoceramic doped optical polymer for multifunctional optoelectronics applications. *Silicon* 2025; **17**, 585-598.
- [64] A Hashim, A Kareem and H Ibrahim. Production and ameliorating the characteristics of (SiO<sub>2</sub>-CdS) futuristic nanoceramic doped optical material for flexible nanoelectronics applications. *Silicon* 2025; **17**, 517-530.
- [65] M Matamoros-Ambrocio, E Sanchez-Mora, E Gomez-Barojas and JA Luna-Lopez. Synthesis and study of the optical properties of pmma microspheres and opals. *Polymers (Basel)* 2021; **13(13)**, 2171.
- [66] A Hashim, H Ibrahim and A Hadi. Fabrication of SiC-Al<sub>2</sub>O<sub>3</sub> nanoceramic doped organic polymer for flexible nanoelectronics and optical applications. *Silicon* 2024; **16**, 6575-6587.
- [67] HS Abdulsalam, A Hashim and MK Mohammed. Manufacturing and enhancing the features of PS/SiO<sub>2</sub>-CeO<sub>2</sub> nanostructures for energy storage and antimicrobials applications. *Journal of Inorganic and Organometallic Polymers and Materials* 2025. <https://doi.org/10.1007/s10904-025-03651-5>
- [68] A Hashim, A Hadi and MH Abbas. Synthesis and unraveling the morphological and optical features of PVP-Si<sub>3</sub>N<sub>4</sub>-Al<sub>2</sub>O<sub>3</sub> nanostructures for optical and renewable energies fields. *Silicon* 2023; **15**, 6431-6438.
- [69] LH Gaabour. Analysis of spectroscopic, optical and magnetic behaviour of PVDF/PMMA blend embedded by magnetite (Fe<sub>3</sub>O<sub>4</sub>) nanoparticles. *Optics and Photonics Journal* 2020; **10**, 197-209.
- [70] H Ahmed and A Hashim. Design of polymer/lithium fluoride new structure for renewable and electronics applications. *Transactions on Electrical and Electronic Materials* 2022; **23**, 237-246.
- [71] H Ahmed and A Hashim. Design and tailoring the optical and electronic characteristics of silicon doped PS/SnS<sub>2</sub> new composites for nano-semiconductors devices. *Silicon* 2022; **14**, 6637-6643.
- [72] H Ahmed and A Hashim. Design and tailoring the optical and electronic characteristics of PS/ZnS/SiBr<sub>4</sub> new structures for electronics nanodevices. *Silicon* 2023; **15**, 83-91.
- [73] H Ahmed and A Hashim. Design and tailoring the structural and spectroscopic characteristics of Sb<sub>2</sub>S<sub>3</sub> nanostructures doped PMMA for flexible nanoelectronics and optical fields. *Optical and Quantum Electronics* 2023; **55**, 280.
- [74] H Ahmed and A Hashim. Tunable spectroscopic, electronic and thermal characteristics of PS/Nb<sub>5</sub>Si<sub>3</sub>/ZnS nanostructures for optics and potential nanodevices. *Optical and Quantum Electronics* 2023; **55**, 9.
- [75] H Ahmed and A Hashim. Tuning the characteristics of novel (PVA-Li-Si<sub>3</sub>N<sub>4</sub>) structures for renewable and electronics fields. *Silicon* 2022; **14**, 4079-4086.
- [76] A Hadi and A Hashim. Development of a new humidity sensor based on (Carboxymethyl Cellulose-Starch) blend with copper oxide nanoparticles. *Ukrainian Journal of Physics* 2017; **62(12)**, 1044-1049.
- [77] H Ahmed and A Hashim. Exploring the design, optical and electronic characteristics of silicon doped (PS-B) new structures for electronics and renewable approaches. *Silicon* 2022; **14**, 7025-7032.
- [78] H Ahmed and A Hashim. Exploring the characteristics of new structure based on silicon

- doped organic blend for photonics and electronics applications. *Silicon* 2022; **14**, 7025-7032.
- [79] H Ahmed and A Hashim. Design and exploring the structure, optical and electronic characteristics of silicon doped PS/MoS<sub>2</sub> structures for electronics Nanodevices. *Optical and Quantum Electronics* 2022; **54**, 403.
- [80] H Ahmed and A Hashim. Tuning the spectroscopic and electronic characteristics of ZnS/SiC nanostructures doped organic material for optical and nanoelectronics fields. *Silicon* 2023; **15**, 2339-2348.
- [81] HM Shanshool, M Yahaya, WMM Yunus and IY Abdullah. Investigation of energy band gap in Polymer/ZnO nanocomposites. *Journal of Materials Science: Materials in Electronics* 2016; **27**, 9804-9811.
- [82] H Naser, SM Mohammad, HM Shanshool, Z Hassan, AMA Abbas and S Rajamanickam. Bimetallic impact on the energy band gap of the polymers PS, PMMA, and PVA nanocomposites. *Optical and Quantum Electronics* 2024; **56**, 897.
- [83] H Naser, SM Mohammad, HM Shanshool, Z Hassan, AMA Abbas and S Rajamanickam. Evaluation and analyzing the linear optical properties of Polymer/Al-Ag-ZnO nanocomposites. *Plasmonics* 2024; **19**, 3043-3058.
- [84] H Naser, HM Shanshool, SM Mohammad, Z Hassan, AMA Abbas, SM Abed and AA Sifawa. The Role of the polymer matrix on the energy band gap of nanocomposites of aluminium, silver and zinc oxide. *Plasmonics* 2025; **20**, 543-557.
- [85] H Naser, HM Shanshool, SM Mohammad, Z Hassan, AMA Abbas, SM Abed and AA Sifawa. Optical properties of polymers mixed with zinc oxide, silver, and aluminum nanoparticles. *Journal of Materials Science: Materials in Electronics* 2024; **35**, 1582.
- [86] PP Sahay, RK Nath and S Tewari. Optical properties of thermally evaporated CdS thin films. *Crystal Research and Technology* 2007; **42(3)**, 275-280.
- [87] A Hashim, KHH Al-Attiyah and S Fadhil. Fabrication of novel (Biopolymer Blend-Lead Oxide Nanoparticles) nanocomposites: Structural and optical properties for low cost nuclear radiation shielding. *Ukrainian Journal of Physics* 2019; **64(2)**, 157-163.
- [88] HB Hassan, A Hashim and HM Abduljalil. Tailoring structural, optical characteristics of CuO/In<sub>2</sub>O<sub>3</sub> nanoparticles-doped organic material for photodegradation of dyes pollutants. *Polymer Bulletin* 2023; **80**, 9059-9075.
- [89] TS Soliman and SA Vshivkov. Effect of Fe nanoparticles on the structure and optical properties of polyvinyl alcohol nanocomposite films. *Journal of Non-Crystalline Solids* 2019; **519**, 119452.
- [90] A Hashim, A Hadi, H Ibrahim and FL Rashid. Fabrication and boosting the morphological and optical properties of PVP/SiC/Ti nanosystems for tailored renewable energies and nanoelectronics fields. *Journal of Inorganic and Organometallic Polymers and Materials* 2024; **34**, 1678-1688.
- [91] HAJ Hussien and A Hashim. Fabrication and analysis of PVA/TiC/SiC hybrid nanostructures for nanoelectronics and optics applications. *Journal of Inorganic and Organometallic Polymers and Materials* 2024; **34**, 2716-2727.
- [92] A Hashim. Synthesis of SiO<sub>2</sub>/CoFe<sub>2</sub>O<sub>4</sub> nanoparticles doped CMC: Exploring the morphology and optical characteristics for photodegradation of organic dyes. *Journal of Inorganic and Organometallic Polymers and Materials* 2021; **31**, 2483-2491.
- [93] A Hashim, H Ibrahim, FL Rashid and A Hadi. Synthesis and augmented morphological and optical properties of Si<sub>3</sub>N<sub>4</sub>-TiN inorganic nanostructures doped PVP for promising optoelectronics applications. *Journal of Inorganic and Organometallic Polymers and Materials* 2025; **35**, 827-837.
- [94] A Hashim and A Jassim. Novel of (PVA-ST-PbO<sub>2</sub>) bio nanocomposites: Preparation and properties for humidity sensors and radiation shielding applications. *Sensor Letters* 2017; **15(12)**, 1003-1009.
- [95] Q Aljubouri, A Hashim and MA Habeeb. Fabrication, structural and optical properties for (Polyvinyl Alcohol-Polyethylene Oxide-Iron Oxide) nanocomposites. *Egyptian Journal of Chemistry* 2020; **63(2)**, 611-623.

- [96] OG Abdullah, SB Aziz, KM Omer and YM Salih. Reducing the optical band gap of polyvinyl alcohol (PVA) based nanocomposite. *Journal of Materials Science: Materials in Electronics* 2015; **26**, 5303-5309.
- [97] MJ Deka, U Baruah and D Chowdhury. Insight into electrical conductivity of graphene and functionalized graphene: Role of lateral dimension of graphene sheet. *Materials Chemistry and Physics* 2015; **163**, 236e244.
- [98] HAJ Hussien, RG Kadhim and A Hashim. Investigating the low cost photodegradation performance against organic Pollutants using CeO<sub>2</sub>/MnO<sub>2</sub>/ polymer blend nanostructures. *Optical and Quantum Electronics* 2022; **54**, 704.
- [99] HAJ Hussien, RG Kadhim and A Hashim. Tuning the optical characteristics of SiO<sub>2</sub>/MnO<sub>2</sub> nanostructures doped organic blend for photodegradation of organic dyes. *Optical and Quantum Electronics* 2021; **53**, 501.
- [100] HB Hassan, A Hashim and HM Abduljalil. Synthesis, structural and optical characteristics of PEO/NiO/In<sub>2</sub>O<sub>3</sub> hybrid nanomaterials for photodegradation of pollutants from wastewater. *Optical and Quantum Electronics* 2023; **55**, 556.
- [101] HAJ Hussien, RG Kadhim and A Hashim. Augmented structural and optical characteristics of SnO<sub>2</sub>/MnO<sub>2</sub>-doped PEO/PVP blend for photodegradation against organic pollutants. *Polymer Bulletin* 2022; **79**, 5219-5234.
- [102] A Kareem, A Hashim and HB Hassan. Synthesis and boosting the morphological, structural and optical features of PEO/Si<sub>3</sub>N<sub>4</sub>/CeO<sub>2</sub> promising nanocomposites films for futuristic nanoelectronics applications. *Silicon* 2024; **16**, 2827-2838.
- [103] H Ahmed, HM Abduljalil and A Hashim. Analysis of structural, optical and electronic properties of polymeric Nanocomposites/Silicon carbide for humidity sensors. *Transactions on Electrical and Electronic Materials* 2019; **20**, 206-217.
- [104] D Hassan and A Hashim. Preparation and studying the structural and optical properties of (Poly-Methyl Methacrylate-Lead Oxide) nanocomposites for bioenvironmental applications. *Journal of Bionanoscience* 2018; **12(3)**, 346-349.
- [105] Z Sattar and A Hashim. Fabrication and characteristics of PMMA-PEG/SiO<sub>2</sub>-SiC quaternary nanocomposites for gamma ray shielding and flexible optoelectronics applications. *Journal of Materials Science: Materials in Electronics* 2024; **35**, 1660.
- [106] EA Okoronkwo, PE Imoisili and SOO Olusunle. Extraction and characterization of amorphous silica from Corn Cob Ash by Sol-Gel method. *Chemistry and Materials Research* 2013; **3(4)**, 2225-2956.