STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 14, Special Issue 2, 2026
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Research JoPC

Gamma Irradiation Effects on Structural and Optical Properties of PVA/Al_2O_3/TiC Polymer Nanocomposites for Optoelectronic Applications

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Abstract

PVA/TiC/Al_2O_3 nanocomposite (PTA) films were successfully prepared via the solution casting method. The impact of high-dose gamma (γ) irradiation (30 kGy) on the structural and optical properties of PVA/TiC/Al_2O_3 nanocomposites was systematically explored using X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), and UV–Visible spectroscopy. XRD analysis confirmed the semi-crystalline nature of the nanocomposites, which was found to decrease upon incorporation of Al_2O_3 nanoparticles and exposure to γ-radiation. FTIR spectra revealed significant interactions and modifications among the functional groups of the host matrix and the embedded TiC and Al_2O_3 nano-fillers both before and after irradiation. UV–Vis measurements indicated that the refractive index increased as a result of Al_2O_3 incorporation and radiation treatment. Detailed analysis of the optical dispersion parameters further demonstrated the combined effect of nano-filler loading and γ- irradiation. These results highlight the potential of using nano-fillers and controlled radiation doses to finely tune the structural and optical characteristics of PVA-based nanocomposite films, making them promising candidates for applications in photocatalysis, sensing technologies, and optoelectronic devices.

INTRODUCTION

In the current research, polymer nanocomposites (PNC) are very interesting from a scientific and technological point of view because of their favorable optical, electrical, and mechanical properties. These materials have found applications such as nano-electronic devices, solar cells, optoelectronic devices, and magneto-optic data storage [1]. Recently, numerous polymers, such as PVA, PVP, CMC, and PEG, have been studied for their optoelectronic and electrical properties. Among all polymers, PVA has gained much attention because it is an excellent host material for different types of metal/metal oxide nanoparticles due to its large surface area, high degree of flexibility, and superior mechanical and optical qualities [2].

Furthermore, when inorganic nanoparticles are used as fillers in the above polymers, superior electrical, optical, and other properties can be attained in the resulting PNC [3]. In the present work, Al_2O_3 nanoparticles are used as fillers in the PVA matrix due to their suitable dielectric, ceramic, and catalyst qualities. They are also used in the development of flexible-type materials with

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Received Date: November 21, 2025
Accepted Date: February 07, 2026
Published Date: April 13, 2026

Citation: Shivanand Mendigeri, K. Leela Kumar, Devidas G.B., Ravikiran Y.T., Suryanarayana P.S. Kornu. Gamma Irradiation Effects on Structural and Optical Properties of PVA/Al_2O_3/TiC Polymer Nanocomposites for Optoelectronic Applications. Journal of Polymer & Composites. 2026; 14(Special Issue 2): S717–S729p.

controllable optical properties. Furthermore, Al_2O_3 is recognized as the ceramic material with the greatest potential for creating a variety of electronic devices, such as nonvolatile memory cells and metal oxide semiconductor transistors [4].Very recently, three major transition metal carbides, such as tungsten carbide (WC), niobium carbide (NbC), and silicon carbide (SiC), have also been used as fillers in the above polymers due to their high thermal stability and favorable electrical and magnetic properties [5]. One of the important fillers used in the present work with the PVA matrix is TiC, because it generates chemical heterogeneity, diminishing the material's resistance to corrosion. For industrial applications, titanium and its compounds must possess appropriate mechanical and tunable optical characteristics, in addition to enhanced surface attributes such as surface fictionalizations and atomic coordination [6].

In recent years, researchers have studied the polymer composites before and after gamma (γ), electron beam and heavy ion radiation to establish the physical as well as chemical changes in them [7]. The high-intensity exposure, creates free radicals, atom displacement, and carbonization in these composites, which in turn leads to the cross-linking of the polymers, changing their microstructure and crystallinity [8]. The kind of radiation, the structure of the polymer, the dosage rate, the applied dose, and the irradiation circumstances all affect these microstructures and crystallinity [9]. This technology is very promising and presents interesting and possible opportunities to achieve excellent multifunctional, mechanical, electrical, and thermal characteristics in composite materials [10].

In this perspective, as a first-ever attempt, this study aims to investigate the potential of γ irradiation a non-chemical and environmentally sustainable technique to enhance the linear and nonlinear optical properties of synthesized PTA nanocomposite films, with a focus on their applicability in optoelectronic device technologies.

EXPERIMENTAL METHOD

Materials and methods

Materials

Polyvinyl alcohol (PVA, molecular weight ~125,000 g/mol) was procured from SD Fine Chemicals. Titanium carbide (TiC) and aluminum oxide (Al_2O_3) nanoparticles were obtained from Nano Research Lab, Jamshedpur, India. All experiments were conducted using Millipore-grade deionized water.

Preparation of films

PTA composite films were fabricated using the solution casting method.Poly vinyl alcohol (PVA, 0.985g) was dissolved in 30 ml of DD water under continuous stirring for 1 h until a clear solution was obtained, subsequently; Titanium carbide (Tic, 0.015g) was added to the PVA solution and stirred for addition 1 h to achieve a homogeneous dispersion. Aluminum oxide (Al_2O_3) nanoparticle were then incorporated at different weight percentages (0.0,1.0, 2.0 and 3.0 wt%), followed by magnetic stirring for 1 h to ensure uniform distribution. The resulting solution was poured into glass Petri dishes and allowed to dry at room temperature for a period of six days to obtain uniform thin films. The formation process of the PTA films is illustrated in Figure 1. The chemical compositions used in the preparation of the PTA films, along with their corresponding nomenclature, are presented in Table 1.

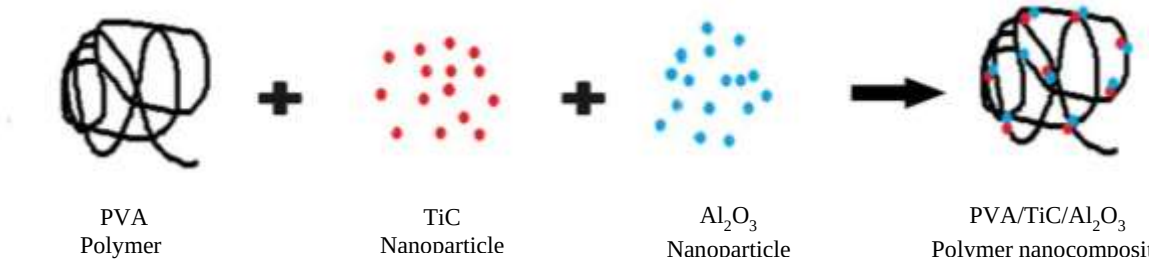


Figure 1. Illustrate formation process of PTA composite film.

Table 1. Composition table of PTA nanocomposite film.

Sl. No.	PVA (in g)	TiC (in g)	Al_2O_3 Nanoparticles (in % W/W)	Nomenclature
1	0.985	0.015	0%	PTA-0
2	0.985	0.015	1%	PTA-1
3	0.985	0.015	2%	PTA-2
4	0.985	0.015	3%	PTA-3

Gamma Irradiation Procedure

Gamma irradiation was conducted at the Centre for Application of Radiation Technology (CARRT), Manglore, using a Co-60 gamma irradiator. This irradiator comprises a shielded chamber containing a Cobalt-60 radioactive source that emits high-energy γ- rays. The films were positioned within this chamber and subjected to irradiation for 6 hours duration to achieve the desired dose of 30 kGy.

Characterization

To characterize the non-irradiated and irradiated PTA nanocomposite films, a variety of analytical techniques were employed. X-ray diffraction (XRD) analysis was conducted using a Rigaku smartlab SE (Cu, kβ) diffractometer to investigate the structural properties of the films. Fourier transform infrared (FTIR) spectroscopy (Nicolet IN-10) was used to identify the functional groups present in the nanocomposite film. The morphology of PTA films was examined using scanning electron microscopy (SEM) by JSM –IT 500LA instrument. Finally, the optical and optoelectronic properties of the films were evaluated by Model UV-1601 UV–visible spectrophotometer. The parameters related to optical and optoelectronic properties were computed using the following equations:

To analyze the dispersion behavior, the Wemple–DiDomenico (WDD) single-oscillator model was employed. The model is described by the relation [12]:

$$\frac{1}{n^2-1} = \frac{E_o}{E_d} - \frac{(h\vartheta)^2}{E_o E_d} \quad (5)$$

The static refractive index (n_0) is related to the oscillator energy (E_0) and dispersion energy (E_d) by:

$$n_0 = \sqrt{\left(1 + \frac{E_d}{E_o}\right)} \quad (6)$$

Furthermore, the nonlinear optical (NLO) parameters were calculated as follows [16]:
Linear optical susceptibility:

$$\chi^{(1)} = \frac{E_d}{4\pi E_o} \quad (7)$$

Third-order nonlinear optical susceptibility:

$$\chi^{(3)} = 6.82 \times 10^{-15} \left(\frac{E_d}{E_0}\right)^4 \quad (8)$$

Nonlinear refractive index (n_2):

$$n_2 = 12\pi \left(\frac{\chi^{(3)}}{n_0}\right) \quad (9)$$

Where, $\chi(1)$ is the linear optical susceptibility, $\chi(3)$ is third-order nonlinear optical susceptibility, and n_2 is the nonlinear refractive index.

The lattice dielectric constant, ε_L and the ratio of free carrier concentration to effective mass (N/m*) for the films were determined using equation [13].

$$(n^2-k^2) = \varepsilon_L - \frac{e^2}{4\pi^2 \varepsilon_0 c^2} \left(\frac{N}{m^*}\right)(\lambda)^2 \quad (10)$$

Where,Where ε_L is the high frequency dielectric constant, e is the charge of the electron, m* effective mass of the charge carrier, N is the concentration of free carrier and ε_0 is the free space of dielectric.

The plasma resonance frequency (ω_p) calculated by the relation:

$$\omega_p = \frac{e^2}{\varepsilon_0} X \frac{N}{m^*} \quad (11)$$

Using the single oscillator model, the average oscillator wavelength (λ_0) and oscillator strength (S_0) of the nanocomposite films were determined from the refractive index data [14]:

$$\frac{1}{(n^2-1)} = \left(\frac{1}{S_0 \lambda_0^2}\right) - \left(\frac{1}{S_0}\right)\lambda^{-2} \quad (12)$$

RESULT AND DISCUSSION

FTIR

Figure 2(a) presents the FTIR spectra of PTA nanocomposite films prior to γ-irradiation, prepared with varying concentrations of Al_2O_3 nanoparticles. The spectra exhibit distinct bands corresponding to the stretching and bending vibrations of functional groups present in the composite films, as summarized in Table 2. The FTIR spectra reveal characteristic absorption bands of PVA, along with prominent bands attributable to Al_2O_3 and TiC, confirming the successful incorporation and interaction of all three components in the nanocomposite system. Notably, increasing the concentration of Al_2O_3 leads to observable changes in both the intensity and position of specific FTIR bands, indicating strong interfacial interactions between PVA and Al_2O_3 nanoparticles.

Figure 2(b) shows the FTIR spectra of the PTA nanocomposite films after exposure to γ-irradiation. Post-irradiation spectra demonstrate slight shifts in the positions of the characteristic functional group bands, along with a noticeable decrease in band intensity compared to the pre-irradiation spectra. These spectral changes indicate structural modifications induced by γ-irradiation, including rearrangements and possible cross-linking of polymer chains within the PVA matrix, as supported by the shifts detailed in Table 2 and consistent with previous studies [15, 16].

XRD

Figure 3, (a) displays the XRD spectra of PTA nanocomposite films before γ-irradiation. A prominent broad peak observed at 2θ = 19.68° corresponds to the semi-crystalline nature of PVA [15]. An additional diffraction peak at 2θ = 31° with the (220) plane [JCPDS Card No. 29-0063**]** confirms the presence of Al_2O_3 nanoparticles in the composite films. Furthermore, peaks located at 2θ = 35.9° with the (111) plane and 41.72° with the (200) plane [JCPDS Card No. 65-8417] are indicative of TiC nanoparticles within the matrix. As the concentration ofAl_2O_3 nanoparticles increases, the intensity of the PVA-associated peak at 2θ = 19.68° decreases significantly, as shown in Figure 3(a), suggesting a reduction in the crystallinity of PVA due to its strong interaction with Al_2O_3 and TiC. Simultaneously, the peak intensity related to Al_2O_3 increases markedly, while the TiC-related peaks show a slight decrease in intensity. A Similar kind of observation was reported in earlier literature [17, 3].

Table 2. FTIR bands of PTA nanocomposite films before and after γ- irradiation.

Sl. No	Functionality	Wave number (cm^{-1})	
		Before	***After***
1	O-H stretching of elemental hydroxyl groups in PVA	3287	3320
2	Aliphatic –CH stretching in PVA	2929	2939
3	C=O stretching of residual acetate groups in PVA	1723	1729
4	C=O stretching vibration band in PVA	1647	1653
5	Bending vibration of CH_2 in PVA	1441	1438
6	–C-O-C stretching in PVA	1265	1258
7	CO stretching and bending of O-H in PVA	1088	1091
8	Ti-C stretching	945	942
9	Al-O stretching	843	848

Figure 3(b) shows the XRD spectra of PVA nanocomposite films after γ-irradiation. Post irradiation spectra reveal further disruption in the crystalline structure of the films, leading to a notable decrease in PVA crystallinity and an increase in the amorphous region [2], as highlighted in Figure 3(b).

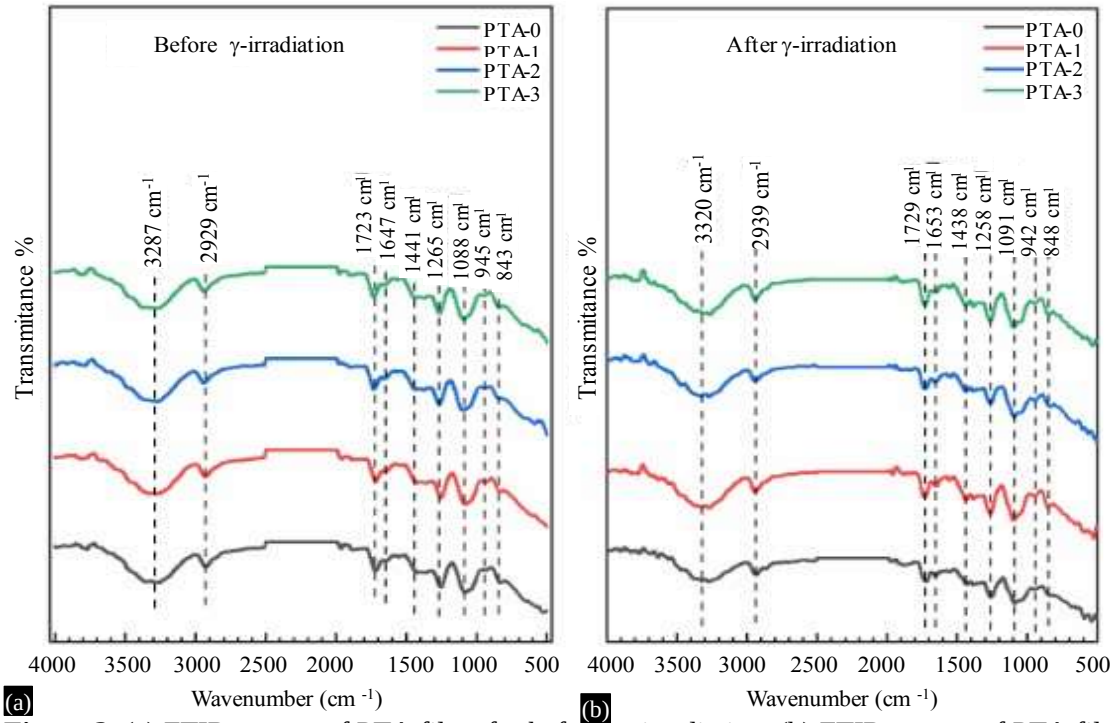
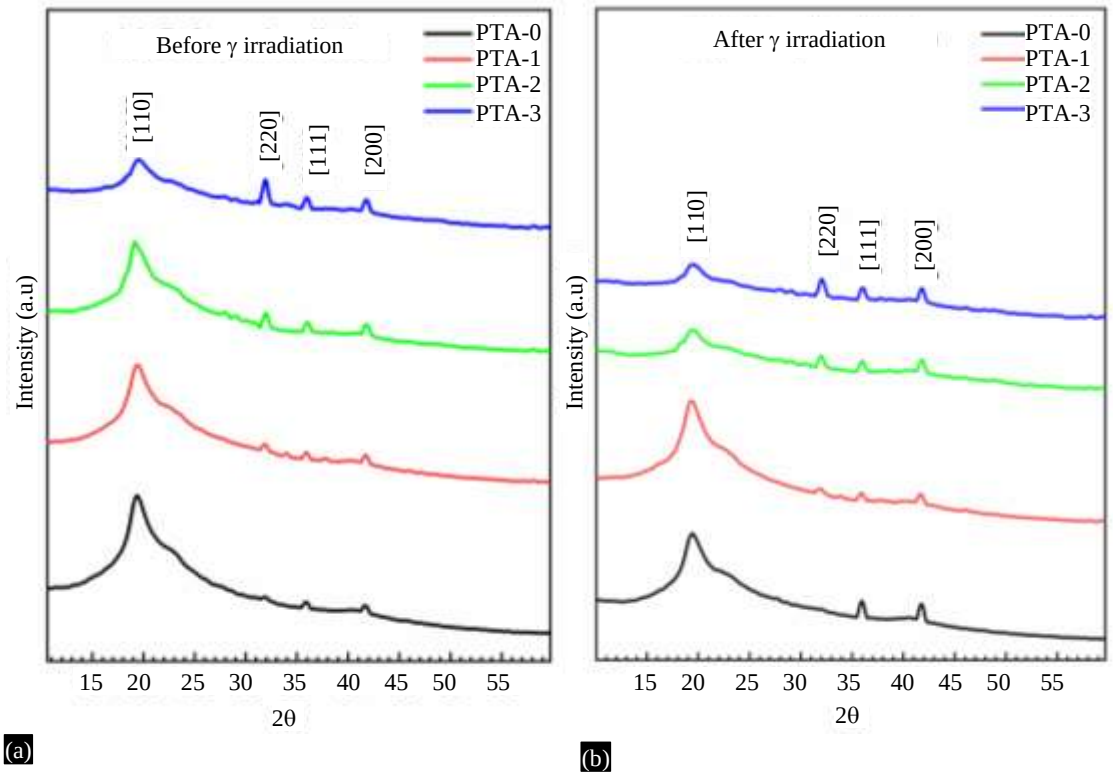


Figure 2. (a) FTIR spectra of PTA films for before γ- irradiation, (b) FTIR spectra of PTA films for after γ- irradiation



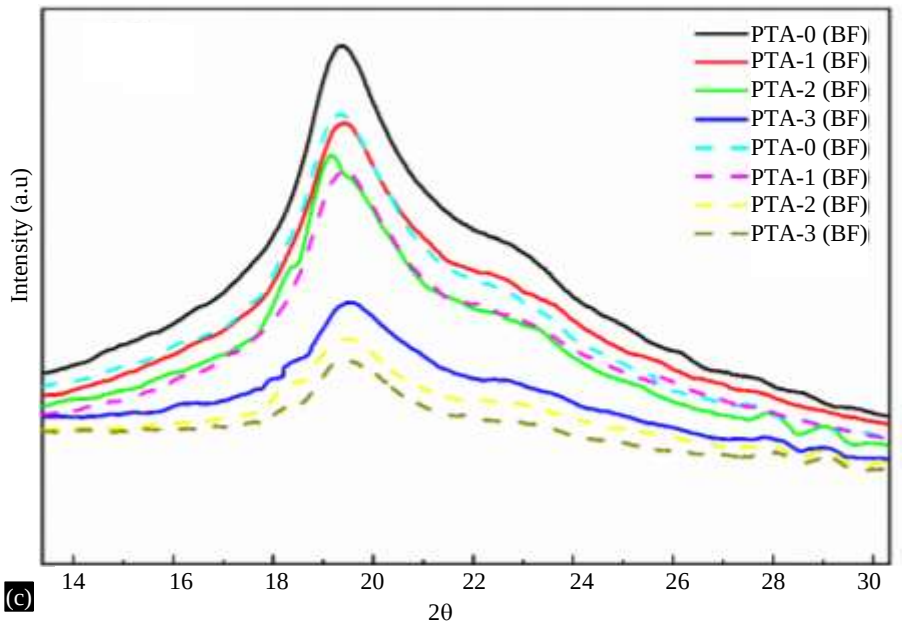


Figure 3. (a) XRD spectra of PTA films for before γ- irradiation, (b) XRD spectra of PTA films for after γ- irradiation and (c) Variations of intensity XRD of peaks for PTA film.

These structural changes can be attributed to irradiation induced defects within the crystalline lattice, disruption of the polymer matrix, and internal strain within the material [18, 19]. Such modification affects the X-ray scattering behavior, leading to peak broadening and changes in intensity.As a result, these structural alterations are expected to enhance charge carrier mobility, suggesting improved optoelectronic properties in the irradiated nanocomposite films [20].

SEM

The morphology of the PTA-3 film, as shown in Figure 4(a), reveals a uniform and favourable distribution of a small quantity of Al_2O_3 and TiC nanoparticles across the PVA matrix. This suggests effective complexation among PVA, Al_2O_3, and TiC nanoparticles, contributing to a well-organized nanocomposite structure.

In contrast, Figure 4(b) illustrates the morphological changes observed in the PTA-3 film following γ-irradiation. The previously homogeneous dispersion of Al_2O_3 and TiC nanoparticles becomes disrupted, leading to noticeable agglomeration. This shift indicates that γ-irradiation adversely affects the nanoparticle distribution, possibly due to radiation-induced mobility and clustering. It is well-documented that γ- irradiation increases surface roughness in polymer composite films. Accordingly, the surface of the irradiated PTA-3 film exhibits greater roughness compared to its non-irradiated counterpart. This increase in roughness can be attributed to the formation of surface impurities and defects during irradiation, which promote air entrapment and elevate the polar component of the surface energy. These effects collectively alter the surface characteristics, resulting in more pronounced irregularities and a rougher topography post-irradiation. Furthermore, the inclusion of TiC and Al_2O_3 nanoparticles within the PVA matrix significantly alters the surface morphology, potentially enhancing effects such as localized surface plasmon resonance (LSPR) and promoting wavelength-selective light absorption and scattering [21]. The resulting increase in surface roughness intensifies light scattering, which may reduce optical transparency while increasing haze, thereby making these nanocomposite films well-suited for applications like light diffusers in photovoltaic systems and display technologies. The resulting increase in surface roughness intensifies light scattering, which may reduce optical transparency while increasing haze, thereby making these nanocomposite films well-suited for applications like light diffusers in photovoltaic systems and display technologies [19].

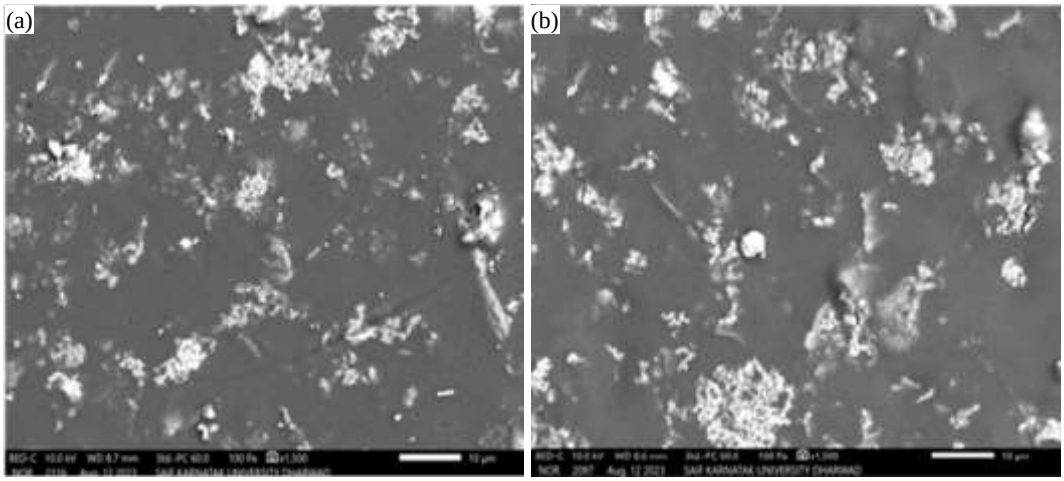


Figure 4. (a) SEM images (10µm) of PTA-3 film for before γ- irradiationand (b) SEM images (10µm) of PTA-3 film for after γ- irradiation.

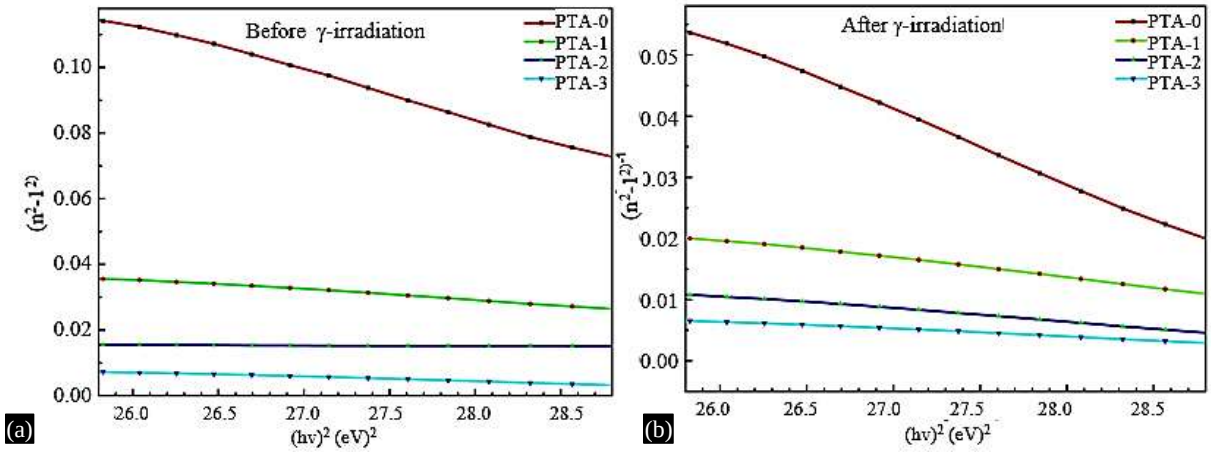


Figure 5. (a) Dispersion graph of PTA films for the before γ- irradiationand (b) Dispersion graph of PTA films for after γ- irradiation.

Optical Parameters

Dispersion Parameters

Optical dispersion characteristics are crucial parameters in the design and performance of optoelectronics devices. The Wemple-DiDomenico single- oscillator model is widely used to extract dispersion parameters. In this model, the dispersion energy (E_d) represents the strength of the inter-band optical transitions, while the single-oscillator energy (E_o) corresponds to the average excitation energy required for electronic transitions. Importantly, E_o is closely related to the optical band gap of the material, whereas E_d is generally independent of the band gap. Both the parameters are fundamentally linked to the refractive index [11, 22].The oscillator energy is denoted by E_o, the dispersion energy by E_d, the static refractive index by n_o, and the optical oscillator strength by f. The value of E_d and E_0 were obtained from the slope and intercept of the $(n^2-1)^{-1}$ V/s $(h\upsilon)^2$plot, as presented in Figure 5 and illustrated in Table 3**.**

Prior to γ-irradiation, the oscillator energy E_o for the control PTA-0 (0%) film was 5.83 eV with the incorporation of Al_2O_3 nanoparticles, this value decreased significantly, reaching 5.55 eV for the PTA-3 (3%) Al_2O_3 loaded film. This reduction is attributed to the interaction between the nanoparticles and the polymer matrix, which restricts polymer chain mobility. Consequently, the dispersion energy E_d enhanced from 11.4 to 123.4 eV, indicating inter-band transition strength [23].

Table 3. The optical dispersion parameters values for the PTA films.

Sample Name	E_d, eV		E_0, eV		n_0	
	Before	***After***	***Before***	***After***	***Before***	***After***
PTA-0	11.4	11.7	5.83	5.75	1.71	1.74
PTA-1	50.2	47.4	6.03	5.69	3.053	3.054
PTA-2	67.9	68.2	5.57	5.46	3.63	3.67
PTA-3	123.3	123.4	5.55	4.93	4.81	5.1

Table 4. The nonlinear optical parametrs values for the PTA films.

Sample Name	$\chi^{(1)}$		$\chi^{(3)}$ e.s.u		n_2 ,e.s.u	
	Before	***After***	***Before***	***After***	***Before***	***After***
PTA-0	0.15	0.16	0.9×10^{-13}	1.1×10^{-13}	0.21×10^{-11}	0.25×10^{-11}
PTA-1	0.66	0.663	3.27×10^{-11}	3.28×10^{-11}	4.04×10^{-10}	4.05×10^{-10}
PTA-2	0.96	0.99	1.5×10^{-10}	1.66×10^{-10}	1.5×10^{-09}	1.7×10^{-09}
PTA-3	1.76	1.99	1.6×10^{-09}	2.6×10^{-09}	1.3×10^{-08}	1.9×10^{-08}

The observed enhancement in dispersion energy E_d for PTA nanocomposites arises from variations in polymer chain density induced by orientation, resulting in pronounced changes in intermolecular interactions. Elevated E_d values reflect stronger optical transitions within the PTA films [24, 25].The static refractive index n_o of the PVA/TiC PNC also increased, ranging from 1.71 to 4.83, due to the rise in optical density and enhanced in polarized ability introduced by embedded nanoparticles [26, 27].

After γ-irradiation, the PTA-3 (3%) PNC film demonstrated further enhancement in both the dispersion energy (E_d) and the static refractive index (n_o), reaching values of 123.4 eV and 5.1, respectively, while the oscillator energy (E_o) decreased to 4.93 eV. The γ-irradiation led to increased disorder within the polymer matrix, as confirmed by XRD analysis. This irradiation process promotes cross-linking and induces structural modifications, which contributes to enhanced optical dispersion characteristics [28].

Non Linear Optical Properties

The enhancement of the nonlinear optical (NLO) properties of the PVA/TiC blend is a significant objective of the current study, aimed at validating its applicability in various NLO applications. These applications include optical and ultrafast switching devices, frequency converters, optical data storage, and other photonic technologies [27, 29]. The NLO parameters of such optical materials provide insights into the nonlinear polarization response that occurs during the propagation of electromagnetic waves **[**30**]**.

Using the linear optical properties and applying Equations 7 to 9, the linear optical susceptibility $\chi^{(1)}$, third-order NLO susceptibility $\chi^{(3)}$ and NLO refractive index (n_2) of the films were calculated as shown in Table 4. $\chi^{(1)}$ increases from 0.15 to 1.76, and $\chi^{(3)}$rises from 0.9×10^{-13} to1.6×10^{-09} esu. with increasing nanoparticles concentration. Similarly, n_0 enhances from 0.21×10^{-11} to 1.38×10^{-08} esu. The linear optical susceptibility quantifies the material's polarization response proportional to an applied electric field, while $\chi^{(3)}$ is associated with phenomena such as third-harmonic generation (THG) and Kerr effects that arise under high-intensity light excitation [31].The dispersion of nanoparticles within the polymer matrix significantly enhances the nonlinear refractive index with increasing nanoparticles concentration. Following γ-irradiation, $\chi^{(1)}$ further increased to 1.99, and $\chi^{(3)}$ rose to 2.6×10^{-09}esu, while n_0 reached 1.9×10^{-08} esu for the PTA-3 (3%) film. These alterations in plasmonic properties due to γ-irradiation amplified the third-order nonlinear effects $\chi^{(3)}$ by intensifying the electric field around the nanoparticles dispersed within the polymer matrix [32].

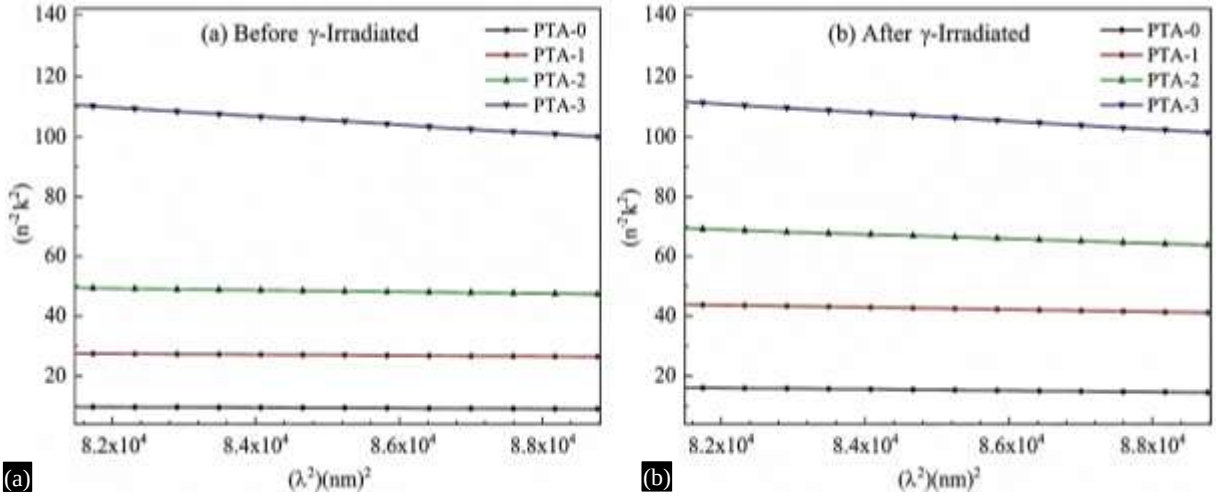


Figure 6. (a) Dielectric graph of PTA films for the before γ- irradiation and (b) Dielectric graph of PTA films for after γ- irradiation.

Table 5. The Dielectrical and oscilltor parametrs values for the PTA films.

Sample Name	ε_L		$(N/m^*) \times 10^{42}$		ω_p(Hz) $\times 10^{15}$		$S_0 \times 10^{-4}$ $(nm)^{-2}$		λ_0 nm	
	Before	***After***	***Before***	***After***	***Before***	***After***	***Before***	***After***	***Before***	***After***
PTA-0	15.8	31.4	0.09	0.22	0.2	0.6	0.4	1.52	214.02	215.3
PTA-1	39.7	71.2	0.18	0.41	0.5	1.1	1.62	1.64	214.5	216.3
PTA-2	128.2	138.5	0.98	1.03	2.7	2.9	2.4	2.8	222.8	224.4
PTA-3	227.1	235.8	1.69	1.87	4.7	5.2	4.3	4.9	223.5	224.7

Moreover, when the PNC films were subjected to γ-irradiation, the polymer matrix exhibited increased disorder, as confirmed by X-ray diffraction (XRD) analysis. This irradiation induced cross-linking and modified the molecular structure, resulting in enhanced dispersion [26]. Consequently, the observed improvements in dispersion and nonlinear parameters of the nanoparticles within the polymer matrix led to enhanced refractive indices and more effective light scattering, thereby bolstering the linear optical response. These characteristics render the films highly suitable for applications in all-optical switching, optical limiting, and other photonic devices [33, 34].

Dielectric Properties

As shown in Figure 6**,** the slope and intercept of the versus $(n^2\text{-}k^2)$ V/s $(\lambda)^{-2}$ plot were used to determine the values of ε_L andN/m*, which were subsequently calculated using Equation (10) and presented in Table 5**.** Prior to γ-irradiation, the ε_L for the control PTA-0 (0%) film was 15.8 with the incorporation of Al_2O_3 nanoparticles, this value increased significantly, and reaching227.1 for the PTA-3 (3%) Al_2O_3-loaded film. This increase is attributed to thestrong interfacial (Maxwell–Wagner–Sillars) polarization between the polymer matrix and Al_2O_3 nanoparticles, which enhances lattice vibrations and dipole alignment, thereby increasing the overall lattice dielectric response [35]. Consequently, the N/m* also increased from 0.09×10^{42} to 1.69×10^{42}.The ratio N/m* (free carrier concentration to effective mass) increased with Al_2O_3 nanoparticle incorporation because the nanoparticles introduce additional defect states and charge trapping centers at the polymer–filler interfaces, which enhance free carrier density (N) and improve charge transport pathways, while possibly reducing the effective mass (m*) through localized field effects and improved carrier mobility [36].

After γ-irradiation, the PTA-3 (3%) PNC film demonstrated further enhancement in both the ε_L and N/m*, reaching values of 235.8 and 1.89×10^{42} respectively. The γ-irradiation led to increased disorder within the polymer matrix, as confirmed by XRD analysis. This irradiation process promotes cross-linking and induces structural modifications, which contributes to enhanced optical characteristics [28].

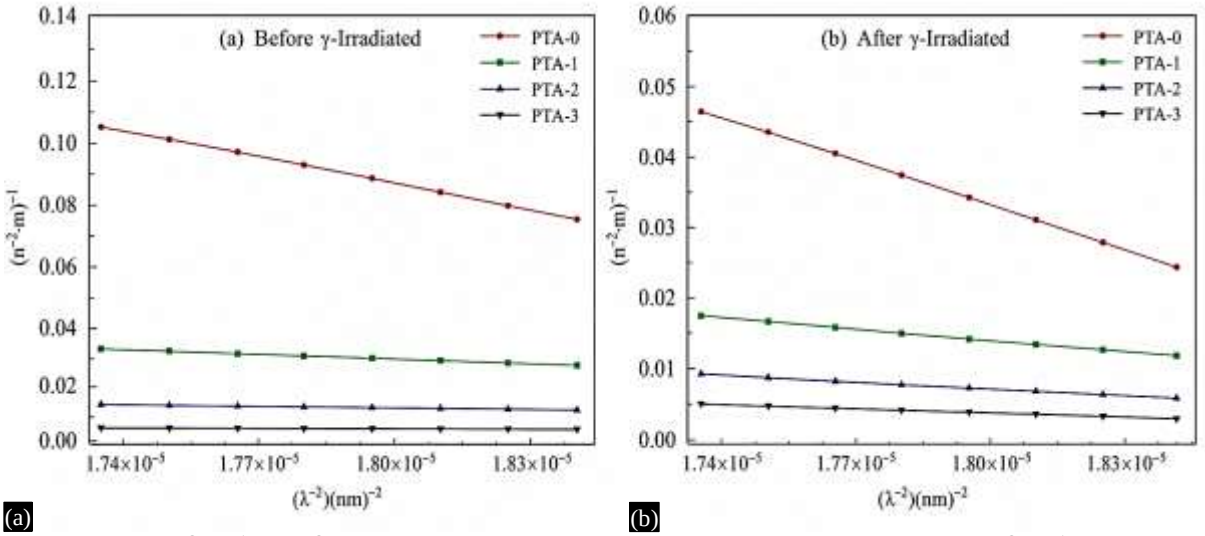


Figure 7. (a) $(n^2-1)^{-1}$ Vs λ^{-2} graph of PTA films for the before γ- irradiation and (b) $(n^2-1)^{-1}$ Vs λ^{-2}graph of PTA films for after γ- irradiation.

The plasma resonance frequency (ω□) was determined using Equation (11) and was found to increase with increasing nanoparticle concentration for both unirradiated and γ-irradiated films, as summarized in Table 5.Before γ-irradiation, the $\omega_p$value for the control PTA-0 (0%) film was 0.2×10^{15} Hz, which increased notebly to 4.7×10^{15} Hz for the PTA-3 (3%) Al_2O_3-loaded film. The incorporation of Al_2O_3 nanoparticles into the PTA matrix enhanced ω_p by introducing additional free charge carriers, generating defect states at the polymer-filler interfaces, and strengthening interfacial polymerization, all of which contribute to higher carrier density and collective oscillation of electrons. After γ-irradiation, the PTA-3 (3%) PNC film exhibited a further increase in ω_p to 5.2×10^{15} Hz, attributed to structural rearrangment within the polymer nanocomposite, including increased disorder and cross-linking. This variation in $\omega_p$enhances the polymerization process within the films [37].

Oscillator Parameters

A linear fit of the $(n^2-1)^{-1}$versus λ^{-2} plot (Figure 7) provided the slope $(1/ s_0)$ and intercept$(1/ s_0\lambda_0^2)$, from which S_0andλ_0 were determined using Equation (12), as listed in Table 5.Before γ-irradiation, the S_0 value for the pure PTA-0 film was 0.4×10^{-4} $(nm)^{-2}$. With addition of Al_2O_3 Nanoparticles, this parameter enhanced notaby, reaching 4.3×10^{-4} $(nm)^{-2}$ for the PTA-3 film. Correspondingly , λ_0 also rose from 214.02 nm to 223.5nm, indicating the Al_2O_3Nanoparticles introduces new localized energy states and enhances interfacial polarization within the polymer.

After γ-irradiation, the PTA-3 PNC exhibited further enhancement in both S_0 andλ_0, attaining values of $4.9\times10^{-4}(nm)^{-2}$ and 224.7 nm, respectively. The shift in λ_0 indicates that the material is evolving to absorb lower-energy photons, which is advantageous for photovoltaic and infrared applications [38]. Furthermore, γ-irradiation induces defect and cross-linking in the polymer structure confirmed by the XRD analysis [28]. The observed improvement in oscillator parameter highlights the potential of these materials for nonlinear optical and optical sensing applications.

CONCLUSIONS

In this study, PVA/TiC/Al_2O_3 polymer nanocomposite (PNC) films were successfully synthesized using the casting method and subjected to gamma (γ) irradiation to investigate their structural and optical behaviour. The experimental results demonstrated that γ-irradiation significantly influenced the structural organization and optical responses of the films. XRD analysis confirmed a reduction in crystallinity with increasing nanoparticle concentration and a further decrease after γ-irradiation, indicating an enhanced amorphous nature due to increased cross-linking within the polymer matrix.

FTIR spectra verified strong interactions between the PVA chains and the incorporated nanoparticles through hydrogen bonding, while SEM images showed improved homogeneity and dispersion of nanoparticles after irradiation. Optical studies revealed that both linear and nonlinear optical parameters increased with nanoparticle concentration and were further improved under γ-irradiation, highlighting the material's enhanced optical performance. Overall, the findings suggest that PVA/TiC/Al_2O_3 nanocomposite films possess superior structural stability and enhanced optical properties, establishing them as potential materials for advanced optoelectronic applications such as sensors, solar cells, capacitors, and diodes.

REFERENCE

1. Zein K. Heiba, Essam E. Ali,et al. Enhancement the Dielectric and Radiation Shielding Characteristics of PVA/PVP/ PEG Blend Through Doping with Nano SnS2/Y, Journal of Macromolecular Science, Part B, DOI: 10.1080/00222348.2025.2556485
2. Soliman TS, Vshivkov SA, Elkalashy SI. Structural, linear and nonlinear optical properties of Ni nanoparticles–Polyvinyl alcohol nanocomposite films for optoelectronic applications. optical materials. 2020 Sep 1;107:110037.
3. Johnson V, Maadhu T, et al. Synthesis and investigations on PVA/CMC/La0. 85Nd0. 15AlO3 polymer nanocomposites for optoelectronic applications. Inorganic Chemistry Communications. 2025 Apr 30:114629.
4. Dhatarwal P, Sengwa RJ. Investigation on the optical properties of (PVP/PVA)/Al2O3 nanocomposite films for green disposable optoelectronics. Physica B: Condensed Matter. 2021 Jul 15;613:412989.
5. Hashim A, Hadi Q. Structural, electrical and optical properties of (biopolymer blend/titanium carbide) nanocomposites for low cost humidity sensors. Journal of Materials Science: Materials in Electronics. 2018 Jul;29(13):11598–604.
6. Jena S, Madhuri A, Gupta M, et al. Comparative assessment and experimental analysis of atomic coordination and mechanical properties of sputter deposited Ti-rich TiN, TiC, and TiCN thin films. Journal of Alloys and Compounds. 2024 Oct 15;1002:175217.
7. Manikandan KM, Yelilarasi A, Pandaram P, et al. The effect of γ-ray-irradiated conducting polymer electrolyte and its application of dye-sensitized solar cells to building window glass system. Journal of Solid State Electrochemistry. 2020 Feb;24(2):251–61.
8. Nouh SA, Gweily N, et al. Tailoring the Optical and Color Properties of Gamma Irradiated Polycarbonate/Cerium Oxide Nanocomposite Films for Their Application in Optoelectronic Devices. Journal of Macromolecular Science, Part B. 2025 Dec 2;64(12):1667–82.
9. Nouh SA, Alghamdi EE, et al. Tailoring the optical and color properties of gamma-irradiated PC/CuO nanocomposite films for their application in optoelectronic devices. Radiation Effects and Defects in Solids. 2025 Jan 2;180(1-2):209–26.
10. Nouh, S.A., Alsufyani, et al., 2026. Optical Investigation of the Effect of Gamma Ray Irradiation on Polycarbonate/Poly (Methyl Methacrylate)/Polyethylene Oxide/Cadmium Selenide Nanocomposite Films for Their Application in Optoelectronic Devices. Journal of Macromolecular Science, Part B, 65(1), pp.28–43.
11. Yassin AY. Synthesized polymeric nanocomposites with enhanced optical and electrical properties based on gold nanoparticles for optoelectronic applications. Journal of Materials Science: Materials in Electronics. 2023 Jan;34(1):46.
12. Alhassan S, Alshammari K, Alshammari M, et al. Linear and nonlinear optical investigations of polyvinyl chloride modified La2O3 nanocomposite films. Results in Physics. 2024 Mar 1;58:107456.
13. Abdelhamied MM, Atta A, Abdelreheem AM, et al. Synthesis and optical properties of PVA/PANI/Ag nanocomposite films. Journal of Materials Science: Materials in Electronics. 2020 Dec;31(24):22629–41.

14. Khasraw SS, Mamand DM, Saeed SR, et al. Structural, morphological, and optical properties of PVA polymer composites incorporated with various concentrations of GO: linear and nonlinear optoelectronic studies. Journal of Materials Science: Materials in Electronics. 2025 Jun;36(18):1067.
15. Abdel Maksoud MI, Awed AS, Sokary R, Bekhit M. Effect of gamma irradiation on the free-standing polyvinyl alcohol/chitosan/Ag nanocomposite films: insights on the structure, optical, and dispersion properties. Applied Physics A. 2021 Aug;127(8):619.
16. Alamouti AF, Nadafan M, Dehghani Z, et al. Structural and optical coefficients investigation of γ-Al2O3 nanoparticles using Kramers-Kronig relations and Z–scan technique. Journal of Asian Ceramic Societies. 2021 Jan 2;9(1):366–73.
17. Alshahrani B, Fares SS, Alqurashi RS, et al. Effect of gamma irradiation on the structural, optical, and electronic properties of PVC/BiVO4/ZnO nanocomposite films. Physics Open. 2025 May 1;23:100252.
18. Heiba ZK, Mohamed MB. Effect of Gamma radiation on structural and optical parameters of Sm2O3: Mn/PVA nanocomposite film. Optical and Quantum Electronics. 2020 Feb; 52(2):99.
19. Nouh SA, Benthami KA, AlSomali F, et al. Impact of gamma radiation on the linear and nonlinear optical properties of PVA/CMC/ZnS-NiO nanocomposite films. Radiation Effects and Defects in Solids. 2024 Jan 2;179(1-2):43–63.
20. Filak-Mędoń, K., Fornalski, K.W., Bonczyk, M. et al. Graphene-based nanocomposites as gamma- and X-ray radiation shield. Sci Rep 14, 18998 (2024). https://doi.org/10.1038/s41598-024-69628-5
21. Tashmetov MY, Ismatov NB, Allayarov SR. Surface roughness and Raman spectra of gamma-irradiated low-density polyethylene. High Energy Chemistry. 2022 Jun;56(3):180–3.
22. Dhatarwal P, Choudhary S, Sengwa RJ. Dielectric and optical properties of alumina and silica nanoparticles dispersed poly (methyl methacrylate) matrix-based nanocomposites for advanced polymer technologies. Journal of Polymer Research. 2021 Feb;28(2):63.
23. El Sayed AM, Ibrahim A. Structural and optical characterizations of spin coated cobalt-doped cadmium oxide nanostructured thin films. Materials science in semiconductor processing. 2014 Oct 1;26:320–8.
24. Alruwaili A, AlziyadiMO,et al. Enhanced the structural, dielectric constants, and linear/non-linear optical properties of PVB/Gd2O3 nanocomposites for flexible optoelectronics. Journal of Inorganic and Organometallic Polymers and Materials. 2025 Feb 15:1–9.
25. Zaidi SM, Aslam M, Kalyar MA. Effect of laser irradiance on linear and nonlinear optoelectrical properties of PVA/copper ferrite nanocomposites. Journal of Materials Science: Materials in Electronics. 2025 Dec;36(35):2251.
26. Sengwa RJ, Choudhary S, Dhatarwal P. Nonlinear optical and dielectric properties of TiO2 nanoparticles incorporated PEO/PVP blend matrix based multifunctional polymer nanocomposites. Journal of Materials Science: Materials in Electronics. 2019 Jul 1;30(13):12275–94.
27. Ali HE, Khairy Y. Optical and electrical performance of copper chloride doped polyvinyl alcohol for optical limiter and polymeric varistor devices. Physica B: Condensed Matter. 2019 Nov 1;572:256–65.
28. Loste J, Lopez-Cuesta JM, Billon L, et al. Transparent polymer nanocomposites: An overview on their synthesis and advanced properties. Progress in Polymer Science. 2019 Feb 1;89:133–58.
29. Dhatarwal P, Sengwa RJ. Structural, dielectric dispersion and relaxation, and optical properties of multiphase semicrystalline PEO/PMMA/ZnO nanocomposites. Composite Interfaces. 2021 Aug 3;28(8):827–42.
30. Sengwa RJ, Dhatarwal P. Polymer nanocomposites comprising PMMA matrix and ZnO, SnO2, and TiO2 nanofillers: a comparative study of structural, optical, and dielectric properties for multifunctional technological applications. Optical Materials. 2021 Mar 1;113:110837.
31. Urbach F. The long-wavelength edge of photographic sensitivity and of the electronic absorption of solids. Physical review. 1953 Dec 1;92(5):1324.

32. Taha TA, Saleh A. Dynamic mechanical and optical characterization of PVC/fGO polymer nanocomposites. Applied Physics A. 2018 Sep;124(9):600.
33. Alsaad AM, Ahmad AA, Al Dairy AR, et al. Spectroscopic characterization of optical and thermal properties of (PMMA-PVA) hybrid thin films doped with SiO2 nanoparticles. Results in Physics. 2020 Dec 1;19:103463.
34. Santhosh G, Nayaka GP, Madhukar BS. Optical properties of PVP/Li3GaO3 nanocomposites. Materials Today: Proceedings. 2017 Jan 1;4(11):12061–9.
35. El-Nagar H, El-Sadek MA, Ibrahim EM, Elnobi S. Structural and optical properties of SnO nano-filler in eco-friendly PVA polymer for flexible optoelectronic applications. Scientific Reports. 2025 Aug 20;15(1):30614.
36. Al-Muntaser AA, Alzahrani E, et al. Linear and nonlinear optical properties of PVC/PMMA polymer blends reinforced with TiO2/GNP hybrid fillers for optoelectronics applications. Physica Scripta. 2025 Jul 24;100(8):085904.
37. Althubiti NA, Atta A, Al-Harbi N, et al. Structural, characterization and linear/nonlinear optical properties of oxygen beam irradiated PEO/NiO composite films. Optical and Quantum Electronics. 2023 Apr;55(4):348.
38. Habeeb MA, Oreibi I, Hamza RS. Synthesis and Boosting the Morphological, Structural, Dielectric, and Linear/Nonlinear Optical Features of PVA-Fe2O3/SiO2 Hybrid Nanostructures for Promising Nanoelectronic and Radiation Attenuation Applications. Journal of Electronic Materials. 2025 Jun 2:1–6.

