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EFFECT OF GAMMA- IRRADIATION ON THE OPTICAL PROPERTIES OF HDPE/GaAs<Te> COMPOSITE FILMS

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Abstract. This work presents a systematic investigation of the effect of gamma irradiation on the optical properties and band gap characteristics of high-density polyethylene (HDPE) polymer and HDPE/GaAs<Te> composite films irradiated at absorbed doses of $\Phi_\gamma = 100$, 200, and 300 kGy at room temperature. The optical absorption coefficient was determined from UV–Visible spectra, and the dependences of $(\alpha h\nu)^2$ and $(\alpha h\nu)^{\frac{1}{2}}$ on photon energy were analyzed for pristine and irradiated samples. The optical absorption edge parameters associated with direct- and indirect-type electronic transitions were evaluated using the Mott–Davis approach, and their dose-dependent evolution was established. A comparative analysis reveals a linear decrease of the optical gap parameters with increasing irradiation dose for both polymer and composite films. Notably, the slope of the dose dependence associated with indirect-type transitions exhibits a pronounced sensitivity to gamma irradiation, indicating the dominant role of radiation-induced localized states and interfacial disorder in governing optical absorption. The results demonstrate that controlled gamma irradiation provides an effective route for tuning the optical response of polymer–semiconductor composite systems intended for radiation-resistant optoelectronic applications.

Keywords: HDPE (high-density polyethylene), GaAs<Te> (gallium arsenide doped with tellurium), composite films, optical properties, gamma irradiation.
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1 Introduction

Polymer composite materials incorporating semiconductor fillers are of significant scientific and technological interest. The introduction of new fillers generally enhances the functional applicability of composite materials (Hsissou et al., 2021). In particular, the addition of semiconducting fillers into a polymer matrix can substantially modify its structural and functional properties. From this perspective, a comprehensive study of composites based on high-density polyethylene (HDPE) and gallium arsenide doped with tellurium (GaAs<Te>) is of significant scientific interest. When GaAs<Te> particles are introduced into the HDPE matrix, the resulting composites exhibit modified electrophysical, dielectric, thermal, optical, luminescent, and mechanical properties. Despite these advantages, it is important to note that there is a lack of sufficient scientific information on the study of these composites in the literature (Aliev et al., 2014; Gadzhieva et al., 2024).

Radiation technologies are currently widely employed to enhance the physical and chemical properties of polymers and polymer-based composite materials for high-technology applications (Kamoun et al., 2024). Exposure to ionizing radiation induces irreversible physical and chemical modifications in the macromolecular structure of these materials. The acquisition of a comprehensive dataset describing the structural transformations and property changes in polymer–semiconductor composite systems under the influence of ionizing gamma radiation will significantly facilitate their design and industrial production as multifunctional composites. Such advances will enable the development of novel polymer composite materials with tailored properties for electronic devices and systems, as well as the creation of specialized electrical insulation materials for high-voltage technologies. In addition, these materials offer effective radiation protection, making them suitable for use in space vehicles, navigation equipment, and instrument panels of specialized devices operating under high-radiation environments.

Recent studies have intensively focused on clarifying the influence of ionizing radiation on polymers and composite materials (Raghuvanshi et al., 2012; Aarya et al., 2009; Dhillion et al., 2013). Advanced spectroscopic methods, including Fourier-transform infrared spectroscopy (FTIR), ultraviolet–visible (UV–VIS) spectroscopy, and electron paramagnetic resonance (EPR), are widely employed to probe radiation-induced structural modifications and associated changes in optical, luminescent, and electro physical properties (Khonakdar et al., 2005; Sinha et al., 2012; Moez et al., 2012; Kuptsov et al., 2001; Weber, 2002). These investigations address the pressing challenge of developing materials with controllable structures and predictable responses to radiation exposure.

HDPE is recognized as a versatile polymer with broad industrial applicability, while GaAs<Te> semiconductors are distinguished by their high resistance to radiation damage and their effectiveness as neutron-sensitive materials, thereby extending the functional scope of the resulting composites (Gadzhieva et al., 2024; Anu et al., 2022; Grigoriadou et al., 2013, Nabiyev et al., 2019; Abulyazed et al., 2018). It is well established that radiation-induced structural changes in polymeric and composite systems are commonly accompanied by variations in optical characteristics, including shifts in the optical band gap energy (Sardarly et al., 2019; Abdel Moez, 2012; Eltohamy et al., 2015; Prasad et al., 2021; Migahed et al., 2006).

Accordingly, the present work reports a systematic experimental study of the optical properties of HDPE and GaAs<Te> composite films exposed to gamma irradiation at doses of Φ_γ = 100, 200, and 300 kGy at room temperature. The absorption coefficient ($\alpha h\nu$) was evaluated, and the dependences of $(\alpha h\nu)^2$ and $(\alpha h\nu)^{1/2}$ on photon energy ($h\nu$) were analyzed for unirradiated and irradiated samples. The optical band gap energy (E_g) for direct and indirect electronic transitions was determined using the Mott–Davis approach, and the evolution of E_g as a function of irradiation dose was established (Mott et al., 1979).

In contrast to previous studies primarily addressing qualitative radiation-induced trends or structural modifications in HDPE-based composites, the present work provides a systematic dose-dependent comparison of direct- and indirect-type optical transitions in HDPE and HDPE/GaAs<Te> composite films under high-dose gamma irradiation. Special emphasis is placed on the linearity and slope variations of Tauc plots, which enable the identification of radiation-induced localized states and interfacial disorder as key factors governing the optical absorption edge (Makula et al, 2018). This comparative approach allows a clearer distinction between matrix-related effects and polymer–semiconductor interfacial contributions, thereby extending the physical interpretation of radiation-modified optical properties in such composite systems (Thomas et al., 2016).

2 Experimental

High-density polyethylene (HDPE) powders with a density of 947 kg/m^3 and a melting point of 130°C, grade 2NT11-285D (Russia, Kazan) were used as the polymer matrix. Gallium arsenide (GaAs<Te>), a semiconductor, was used as the filler. HDPE polymer and HDPE/GaAs<Te> composite films with a thickness of $d = (80 \pm 2)$ μm (relative error: 2.5%) were obtained by hot pressing in accordance with the method described in (Aliev et al., 2014).

The GaAs<Te> content in the HDPE matrix was varied from 1 to 10 mass%. For the optical studies, HDPE/4 mass% GaAs<Te> composite films were selected, in which the degree of crystallinity was k = 68%, since previous structural and spectroscopic studies have demonstrated that this composition exhibits relatively same crystallinity and stable polymer–semiconductor interfacial interaction, similar to that observed in HDPE/GaAs composite films. This enables a more reliable isolation of radiation-induced optical effects while minimizing compositional and morphological variability. These compositions enable the evaluation of the radiation resistance of both HDPE/GaAs and HDPE/GaAs<Te> composite films (Aliev et al., 2014; Gadzhieva et al., 2023).

The HDPE and HDPE/GaAs<Te> films were irradiated using the MRX-γ-20 gamma facility (^{60}Co) with an absorbed dose rate of $d\Phi_\gamma/dt$ = 1.06 Gy/s (Azerbaijan, Baku). The samples were irradiated at doses Φ = 100, 200, and 300 kGy at room temperature (T = 300 K).

The optical absorbance spectra (A) of the initial and gamma-irradiated HDPE polymer and HDPE/GaAs<Te> composite films were obtained using a UV-Visible spectrophotometer (Cary 50Scan, Varian) in the wavelength range of λ = 200–800 nm at room temperature. To ensure the reliability of the extracted optical parameters, each UV–Visible absorption spectrum was recorded at least three times under identical experimental conditions. The reported optical absorption edge values represent averaged data, with an estimated uncertainty of $\pm$0.01 eV arising primarily from instrumental resolution and linear fitting of the Tauc plots. The observed trends were fully reproducible within this uncertainty range.

3 Results and discussion

3.1 Study of optical behavior

Figure 1 presents the optical absorbance spectra of initial and gamma-irradiated HDPE polymer (a) and HDPE/GaAs<Te> composite (b) films subjected to irradiation doses of 100, 200, and 300 kGy. The spectra illustrate the changes in optical absorption behavior induced by gamma irradiation, allowing a comparative evaluation of radiation effects on the pure polymer matrix and the semiconductor-filled composite system.

From the recorded spectra, the optical absorption coefficient, $\alpha(\nu)$, was calculated using the relation (Weber, 2002):

$$\alpha(\nu) = \frac{A}{d}, \tag{1}$$

where A denotes the absorbance ($A = \lg\frac{I_0}{I}$), I_0 and I are the intensities of the incident and transmitted beams, respectively, and d represents the sample thickness.

3.2 Optical Energy Gap

One of the most important parameters derived from optical measurements is the energy band gap. The optical energy gap is a fundamental quantity that governs the optical transmission behavior of materials and is defined as the energy difference between the bottom of the conduction band and the top of the valence band (Darwesh et al., 2022; Abdul-Kader, 2013, Ahmad et al., 2022; Mohamed et al., 2020).

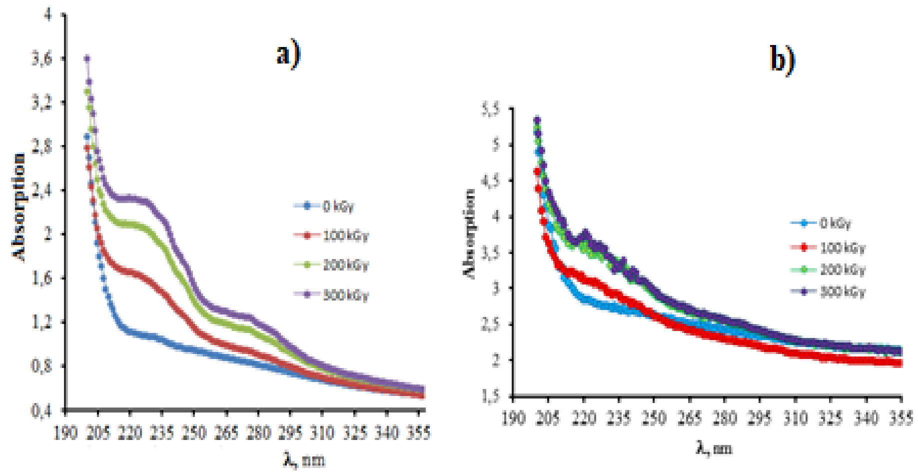

Figure 1: UV-Visible absorbance spectra of the initial and gamma-irradiated HDPE polymer (a) and HDPE/GaAs<Te> composite (b) films at doses of 100, 200, and 300 kGy.

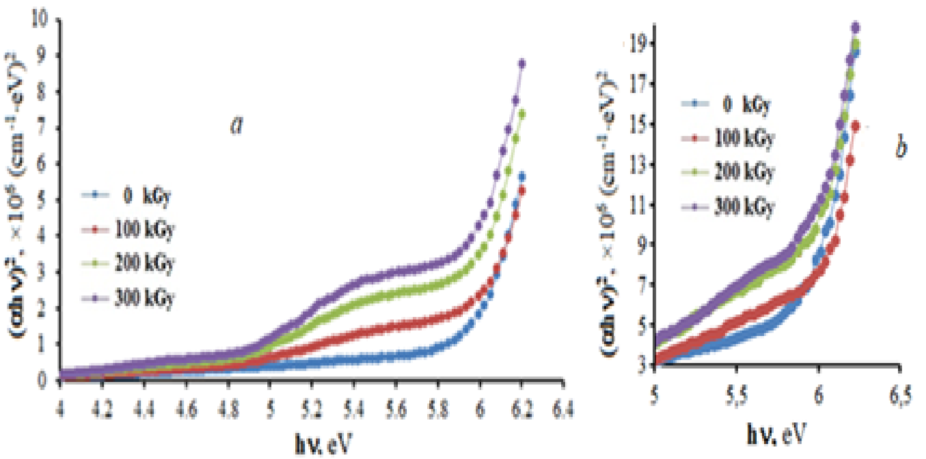

Figure 2: Dependence of $(\alpha h\nu)^2$ versus incident photon energy (hν) for the initial and gamma-irradiated HDPE (a) and HDPE/GaAs<Te> (b) films at doses of 100, 200, and 300 kGy.

The optical band gap energy was determined using the Mott–Davis relation (Mott et al., 1979), expressed as:

$$\alpha h\nu = B(h\nu - E_g)^n \qquad (2)$$

where B is a constant related to the probability of electronic transitions and is assumed to remain constant over the investigated optical frequency range, $h\nu$ is the photon energy, and E_g is the optical band gap energy. The exponent n depends on the nature of the electronic transition responsible for absorption and may take values of 2, 3, 1/2, and 3/2. In particular, n=2 and 1/2 correspond to direct and indirect transitions, respectively.

Figures 2 and 3 illustrate the dependence of $(\alpha h\nu)^2$ and $(\alpha h\nu)^{1/2}$, respectively, on the incident photon energy (hν) for the initial and gamma-irradiated HDPE polymer and HDPE/GaAs<Te> composite films at doses of 100, 200, and 300 kGy.

From these dependencies, the optical band gap values for direct ((E_{gd}) and (E_{gi}) indirect transitions were determined by extrapolating the linear portions of the curves to the energy axis where $(\alpha h\nu)^2$ and $(\alpha h\nu)^{1/2}$=0, respectively. The obtained values of E_{gd} and E_{gi} are summarized in Table 1.

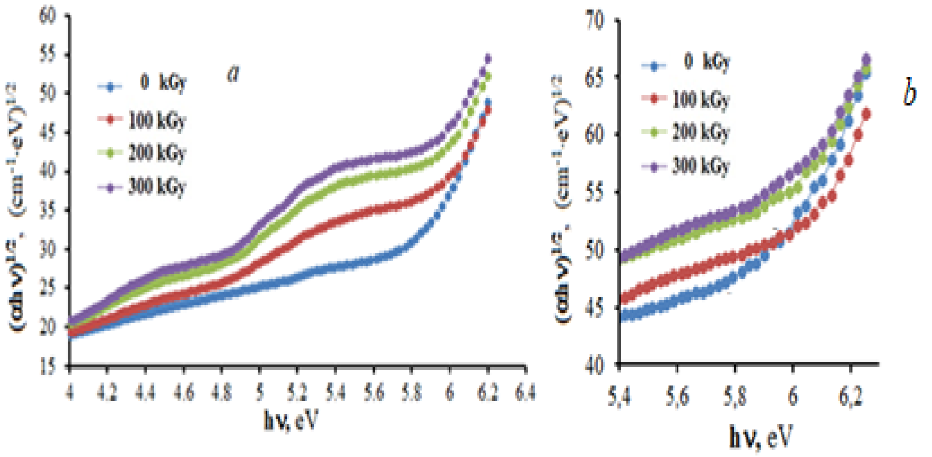

Figure 3: Dependence of $(\alpha h\nu)^{1/2}$ versus incident photon energy (hν) for the initial and gamma-irradiated HDPE (a) and HDPE/GaAs<Te> (b) films at doses of 100, 200, and 300 kGy.

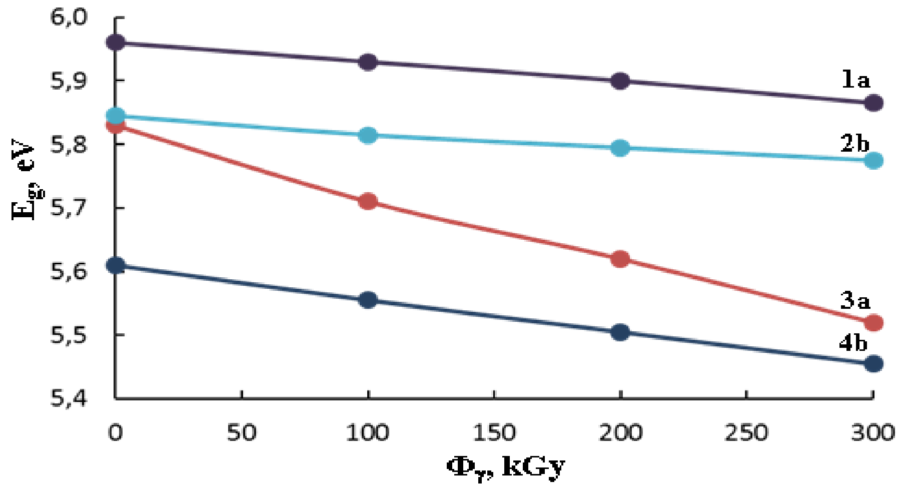

Figure 4: Dose dependences of the optical band gap energy (E_g) for HDPE (a) and HDPE/GaAs<Te> (b) films, due to direct (1, 2) and indirect (3, 4) transitions.

Table 1: The optical band gap values for direct ((E_{gd}) and (E_{gi}) indirect transitions of gamma-irradiated HDPE polymer and HDPE/GaAs composite films at doses of 100, 200, and 300 kGy.

Φ_γ (kGy)	HDPE		HDPE/GaAs<Te>	
	E_{gd} (eV)	E_{gi} (eV)	E_{gd} (eV)	E_{gi} (eV)
0	5,955	5,825	5,84	5,53
100	5,925	5,705	5,81	5,49
200	5,895	5,615	5,79	5,46
300	5,86	5,515	5,77	5,44

As observed from the table, the values of E_{gd} corresponding to direct transitions are significantly higher than those of E_{gi} for indirect transitions across all investigated initial and gamma-irradiated samples. These findings are consistent with previously reported results (Gadzhieva et al., 2024).

Figure 4 presents the dose dependences of the direct E_{gd} (1, 2) and indirect E_{gi} (3, 4) optical band gap energies for HDPE polymer and HDPE/GaAs<Te> composite films.

A comparison of these dependencies reveals that all curves exhibit a linear trend. For direct transitions, the curves are nearly parallel, while for indirect transitions, the slopes differ by of

~2 times. The observed features are associated with the formation of a radiation defects in the HDPE matrix and a change in the interaction at the interface. Due to changes in the interfacial interaction, the supramolecular structure (SMS) of polymer changes. The active centers created in the HDPE matrix after γ-irradiation interact with the surface of GaAs<Te> which leads to structural modification and changes in the optical properties of the composite films. It is prominently manifested in the dose-dependent behavior of the optical band gap energy (E_g) for the HDPE polymer and HDPE/GaAs<Te> composite films associated with indirect transitions. These dependencies indicate that the studied polymer and composite films are predominantly indirect band gap materials (Gadzhieva et al., 2022).

The observed decrease of the optical absorption edge parameters with increasing gamma irradiation dose can be attributed to radiation-induced disorder and the formation of localized electronic states within the forbidden energy region (Kostyukov et al, 2021). In polymer-based systems, such states typically arise from chain scission, cross-linking processes, and defect-assisted electronic configurations, which enhance indirect-type optical transitions (Gadzhieva et al., 2024). In the case of HDPE/GaAs<Te> composites, additional contributions may originate from irradiation-induced modifications at the polymer–semiconductor interface, leading to enhanced carrier localization and altered absorption pathways. Consequently, the optical absorption edge of both HDPE and HDPE/GaAs<Te> films is predominantly governed by indirect-type transition behavior rather than a strict crystalline band gap.

4 Conclusion

A systematic experimental study of the effect of gamma irradiation on the optical properties of HDPE polymer and HDPE/GaAs<Te> composite films irradiated at absorbed doses of Φ_γ = 100, 200, and 300 kGy has been presented. The optical absorption coefficient was determined from UV–Visible spectra, and the evolution of direct- and indirect-type optical absorption edge parameters was analyzed using the Mott–Davis approach. The results reveal a gradual, nearly linear decrease of the optical gap parameters with increasing irradiation dose for both polymer and composite films. The analysis indicates that the optical absorption edge in these systems is predominantly governed by indirect-type transitions associated with radiation-induced disorder and localized electronic states rather than a strict crystalline band gap. In composite films, irradiation-induced modifications at the polymer–semiconductor interface further enhance carrier localization effects. These findings demonstrate that controlled gamma irradiation represents an effective tool for tailoring the optical response of polymer–semiconductor composites intended for applications in radiation-resistant electronic and optoelectronic systems.

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