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RESEARCH ARTICLE

Preparation and Modification of the Structural and Optical Characteristics of PVA/Bi_2O_3-CuO Nanocomposites for Radiation Attenuation

Aseel Saad Ibrahim*, Ali R. Abdulridh

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

***Corresponding author:** Aseel Saad Ibrahim, pure199.aseel.saad@student.uobabylon.edu.iq

ABSTRACT

This study focuses on the fabrication of advanced nanocomposite films based on polyvinyl alcohol (PVA), reinforced with bismuth oxide (Bi_2O_3)/copper oxide (CuO) nanoparticles at total filler loadings of 1, 2, 3, and 4 wt.% relative to the PVA matrix, using a controlled solution casting technique. This method makes sure that the nanoparticles are spread out equally throughout the polymer matrix. This makes the material stronger and better at blocking gamma radiation. It is also light, flexible, and beneficial for the environment. Visual microscopy and field emission scanning electron microscopy investigations exhibited substantial consistency in nanoparticle dispersion, indicating the absence of large agglomerations. Fourier-transform infrared spectroscopy (FTIR) further substantiated the notable physical interactions between the nanoparticles and the PVA polymer molecules. X-ray diffraction (XRD) studies demonstrated that both Bi_2O_3 and CuO existed in their pure phases. The PVA films, on the other hand, remained semi-crystalline, which meant that the nanoparticles had been successfully incorporated to the structure. Optical tests showed that the absorbance went up a lot, reaching 93.73%. The transmittance dropped to 79.03% at a wavelength of 300 nm. The prohibited energy gap shrank from 3.9 eV to 2.0 eV, and the optical energy gap shrank from 4.0 eV to 2.7 eV. The nanoparticles' ability to generate concentrated energy levels inside the energy gap is responsible for this change. The (N/N_0) ratio for protecting against radiation dropped from 0.975 for pure polymer to 0.835 for a 40% weight concentration. This suggests that the radiation protection only worked about 17.81% of the time. The results show that the (PVA/ Bi_2O_3-CuO) composites work well to improve optics and block gamma radiation. This means that they can be utilized for many things, including as medicine, optics, and flexible shielding. They are also safer and better for the environment than items that contain lead.

Keywords: PVA, Nanocomposites, Structural properties, Optical properties, (Bi_2O_3/CuO) nanoparticles, Gamma Shielding.

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1. Introduction

Materials science is going through a big change in technology, and polymers are a big part of this change. In the last few decades, there have been substantial improvements in the study and use of polymers in science and technology. By the end of 2001, companies throughout the world were making almost 200 million tons of plastic every year. Polymers are good for many things in electronic systems because they are easy to work with, cheap, long-lasting, flexible, and have a lot of other useful properties [1]. Nanomaterials are often used with larger polymeric materials to improve them because they have such great features. Nanocomposites are materials that have nanoparticles in them. The type of material utilized in the matrix determines how nanocomposites are grouped. Some of these groups are metallic matrix composite materials, ceramic matrix composite materials, and composites that use a polymer matrix. The arrangement of nanofillers within the bulk polymer matrix is the most important part of making polymer matrix composites. The nanoparticles' uniform dispersion makes their qualities better. The weak van der Waals interactions that help particles stick together, on the other hand, make the nanomaterials less effective. Recent studies indicate that the integration of a compatibilizer significantly improves the dispersion of nanoparticles inside the polymer matrix. By changing and adding functions to the outer layer of nanomaterials, the interactions or connections between the filler and matrix are made better. This process enhances dispersion and facilitates the transfer of strain between the matrix and the filler. The end product is a group of lightweight composites that work very well and are perfect for advanced uses [2]. PVA, or polyvinyl alcohol, is a flexible polymer that is employed in a lot of various areas. They are quite popular because they have remarkable optical properties, are light, and are very strong. Polyvinyl alcohol (PVA) is used in a wide range of goods and systems, including coatings, medicine delivery devices, fuel cells, and adhesives [3]. The hydroxy groups on the outside and inside of PVA are held together by strong hydrogen bonds. These linkages cause PVA to melt at a temperature that is very close to the temperature at which it breaks down. PVA is better for processing from aqueous solutions because it can absorb metal ions like mercury, palladium, and copper very well when it melts. Polyvinyl alcohol (PVA) has the chemical formula $(C_2H_4O)_x$ [4]. It has a melting point of 230°C and a density of 1.19 to 1.31 g/cm^3. When the temperature goes over 200°C, this thermoplastic polymer starts to break down. The C-O-C bonds in this polymer make it flexible. It might also dissolve in organic solvents, react with water, have a crystalline structure, and be able to lubricate itself [5]. Nanomaterials have many advantages over their bulk counterparts when it comes to physicochemical properties. They also look very promising for things like storing and converting energy, cleaning water, using them in medicine, storing data, and processing information, to mention a few. Nanomaterials have garnered significant interest recently; yet, their advantageous features are affected not only by their chemical composition but also by their structural characteristics and size distribution. Thus, nanotechnology enables the development of multifunctional, highly sensitive systems that exhibit significant surface effects, extensive coverage, strain resistance, and catalytic activity. The distinctive characteristics of nanoparticles can be ascribed to their minuscule dimensions [6]. People utilize bismuth oxide for a lot of various things, such varistors, catalysts, and gas sensors. When it comes to solid electrolytes, bismuth oxide (Bi_2O_3)-based compounds work better than stabilized zirconia. The face-centered cubic (FCC) Bi_2O_3 has the highest ionic conductivity of any oxide ion conductor. A p-type Bi_2O_3 heterogeneous semiconductor is a great photo catalyst and is very important in modern solid-state applications because it has unique structures and physical properties, like a high refractive index, higher oxygen-ion conductivity, high dielectric permittivity, and stability in heat. Bi_2O_3 doesn't react with neutral water, and its band gap energy in the visible region is 2.8 eV. This feature makes it easier for water to oxidize, which makes particularly reactive substances that initiate oxidation reactions that break down gasses, medications, and dyes [7]. Copper oxide is an important metal oxide. CuO, the simplest copper molecule, has many useful properties, such as being a superconductor at high temperatures, having electrical correlation, and not being poisonous. The crystal structure, which has a narrow band gap, has a lot of potential for use in solar cells and photoconductive devices [8]. A lot of people are interested in CuO. CuO is a p-type semiconductor because it has a band gap energy of about 1.2 eV at room temperature. CuO has been shown to work well in superconductors, gas sensors, magnetic storage media, catalysis, and field emitters when the temperature is high [9]. The combined incorporation of Bi_2O_3 and CuO nanoparticles provides a synergistic enhancement to the PVA matrix. Bi_2O_3 contributes high atomic number and density, which improve gamma-ray attenuation capability, whereas CuO enhances charge transfer, optical absorption, and electronic interactions within the polymer network. The coexistence of both fillers promotes interfacial interactions, increases localized energy states, and improves the structural and optical performance of the nanocomposite films. This research aims to fabricate nanometric films of PVA/ Bi_2O_3-CuO nanocomposites for prospective applications in optical nanotechnology, owing to their enhanced optical characteristics relative to other nanometric composites. The composites are inexpensive, lightweight, and durable against environmental variables, rendering them suitable for many optical and electrical nanotechnology applications.

2. Experimental Work

The incorporation of Bi_2O_3/CuO nanoparticles significantly enhances the structural, optical, and thermal properties of the PVA matrix. This study effectively produced polyvinyl alcohol (PVA)-based nanocomposite films augmented with copper oxide (CuO) and bismuth oxide (Bi_2O_3) nanoparticles by the solution casting technique. Bi_2O_3 nanoparticles with an average particle size of 20–30 nm and a purity of 99.5% were purchased from Hongwu New Material (China), whereas CuO nanoparticles with an average particle size of 40 nm and a purity of 99% were obtained from SkySpring Nanomaterials, Inc. A magnetic stirrer was used to mix 1 g of high-purity PVA (Thomas Baker, India) with 50 mL of distilled water for 30 minutes at a temperature of 75–80°C. The polymer was entirely dissolved by doing this. The uniform solution was deposited on a sterile glass Petri dish and permitted to dry at room temperature for 240 hours, or until all of the solvent had evaporated. Next, the PVA matrix was reinforced with combined Bi_2O_3/CuO nanoparticle loadings of 1, 2, 3, and 4 wt.%. To make sure that each mixture was very well mixed, it was whirled with a magnet for an hour at 75–80°C. After that, the solutions were put into molds to make nanocomposite films. The samples were all about the same thickness, with an average of about 0.41 mm. We looked at the surface morphology and nanoparticle dispersion of the films we created with an optical microscope (Nikon-73346) and a digital camera at a magnification of ×10. We also utilized X-ray diffraction (XRD) to look at the crystalline structure and evaluate how adding nanoparticles changed the crystallinity of the PVA matrix. We used a Bruker Vertex-70 spectrometer from Germany to collect Fourier-transform infrared (FTIR) spectra between 600 and 4000 cm^{-1}. This helped us understand how chemicals link and how the polymer matrix and nanoparticles might interact with each other. We utilized a UV-Vis spectrophotometer (UV-1800, Shimadzu) to examine how the PVA/ Bi_2O_3-CuO nanocomposite films looked.

3. Results and Discussion

3.1. Field Emission Measurements with a Field Emission Scanning Electron Microscope (FE-SEM) Nanocomposites Composed of PVA/Bi2O3-CuO

Figure 1 shows the surface of clean PVA and (PVA/ Bi_2O_3-CuO) nanocomposite films. The pure sample in Figure (a) has a smooth surface, which is what would be expected from PVA, which is semi-amorphous and doesn't have any agglomerates or sharp surface characteristics. The surface morphology of the nanocomposites illustrated in Fig. 1 (B, C, D, and E) was altered when the (Bi_2O_3/CuO) ratio in the polymer matrix rose in the (PVA/ Bi_2O_3-CuO). The surface of the nanocomposite films is densely disseminated with numerous finely dispersed Bi_2O_3/CuO nanoparticles that are well-distributed and not aggregated. The uniform distribution of particles, which are densely arranged on the surface and devoid of agglomerates, may signify a uniform growth mechanism [10].

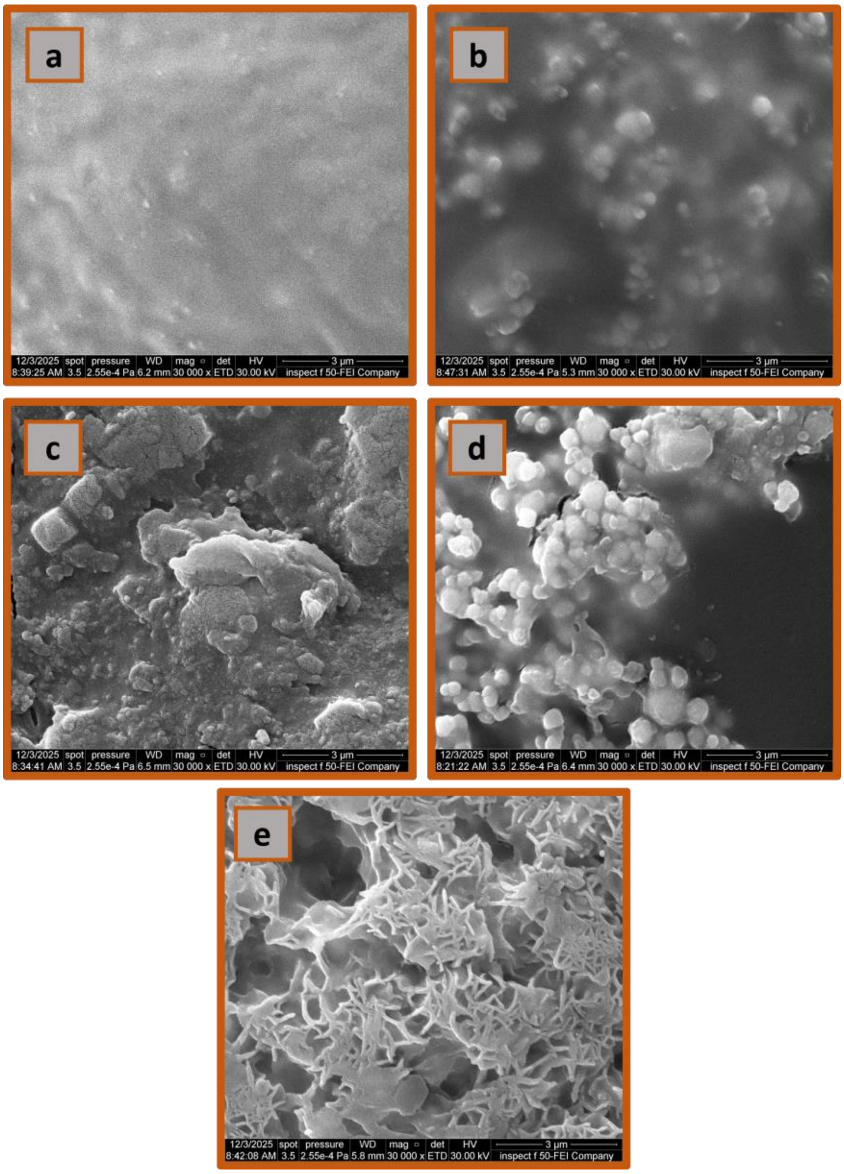

Figure 1. The FESEM pictures show (a) pure PVA, (b) NPs containing 1% Bi_2O_3 and CuO, (c) NPs containing 2% Bi_2O_3 and CuO, (d) NPs containing 3% Bi_2O_3 and CuO, and (e) NPs containing 4% Bi_2O_3 and CuO.

3.2. X-ray Diffraction Analyses

Figure 2 shows the XRD patterns of (PVA/ Bi_2O_3-CuO) nanocomposites. XRD diffraction was employed to determine the structural composition of the percentages. Figure 2 indicates that the pure PVA film displays a wide diffraction band attributed to the (101) plane at $2\theta = 18.91°$, hence affirming the primarily amorphous (semicrystalline) characteristics of PVA [11]. The nanocomposite with the greatest Bi_2O_3/CuO loading of 4 wt.% shows many distinct diffraction peaks at 27.08°, 30.94°, 31.52°, 35.65°, 38.75°, 45.53°, 46.19°, 54.84°, 55.45°, 57.72°, 68.47°, 74.46°, and 75.90°. The peaks match the Miller indices of the crystalline Bi_2O_3 and CuO phases, which is what you'd expect from regular JCPDS data. This confirms the creation of pure crystalline Bi_2O_3/CuO phases in the PVA matrix [12]. The nanocomposite with the greatest Bi_2O_3/CuO loading of 4 wt.% shows many distinct diffraction peaks at 27.08°, 30.94°, 31.52°, 35.65°, 38.75°, 45.53°, 46.19°, 54.84°, 55.45°, 57.72°, 68.47°, 74.46°, and 75.90°. The peaks match the Miller indices of the crystalline Bi_2O_3 and CuO phases, which is what you'd expect from regular JCPDS data. This confirms the creation of pure crystalline Bi_2O_3/CuO phases in the PVA matrix [13]. The examination of the nanocomposite patterns reveals that the addition of Bi_2O_3/CuO nanoparticles, especially at a concentration of 4 wt.%, has profoundly altered the structural characteristics of PVA. Adding Bi_2O_3/CuO nanoparticles to the polymer matrix caused this modification. This turned the pure

PVA film's amorphous characteristics into a polycrystalline structure, which increased the crystallinity and improved the internal structural organization of the nanocomposite films.

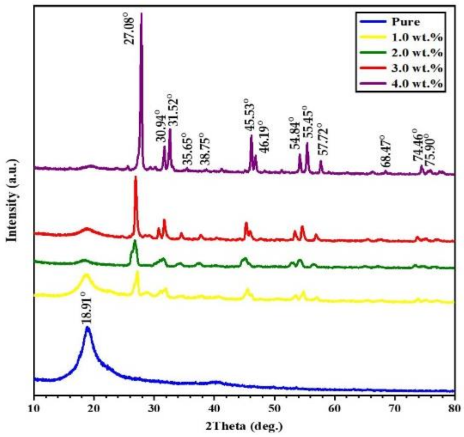

Figure 2. The X-ray diffraction of nanocomposites composed of (PVA/Bi_2O_3-CuO)

3.3. Fourier Transform Infrared (FTIR)

Figure 3 shows the FTIR spectra of both the pure PVA and the PVA/ Bi_2O_3-CuO nanocomposite. It was discovered between 4000 and 500 cm^{-1}. The spectra of pure PVA show clear absorption bands: a broad O–H stretching vibration at 3262.90 cm^{-1}, an asymmetric CH_2 stretching at 2907.21 cm^{-1}, a CH_2 bending at 1442.32 cm^{-1}, an O–H bending coupled with CH vibrations at 1325.84 cm^{-1}, a prominent C–O stretching/O–H bending peak at 1088.16 cm^{-1} (which shows that the PVA is amorphous), a CH_2 vibration at 914.11 cm^{-1}, and C–C stretching/intrachain vibrations at 836.00 cm^{-1}[14]. Adding Bi_2O_3 makes the spectrum alter a lot, which suggests that there are two types of interactions. You can observe the main PVA peaks, like the O–H stretch at 3260.88 cm^{-1}, the CH_2 stretch at 2908.49 cm^{-1} (which could be due to residual C=O/water), and the CH_2 bend at 1446.81 cm^{-1}. There are significant changes and oscillations in intensity, including a bathochromic shift of the O-stretch from 3262.90 to 3260.88 cm^{-1}. New bands appear at lower wavenumbers (833.23 cm^{-1} - 636.57 cm^{-1}), which means that Bi-O and Cu-O vibrational modes are present [15, 16]. The changes in wavenumber, intensity, and the presence of peaks unique to fillers indicate significant interactions between the PVA matrix and the Bi_2O_3 and CuO particles. These interactions are probably hydrogen bonding or coordination. This shows that the filler was put in the right way [17, 18].

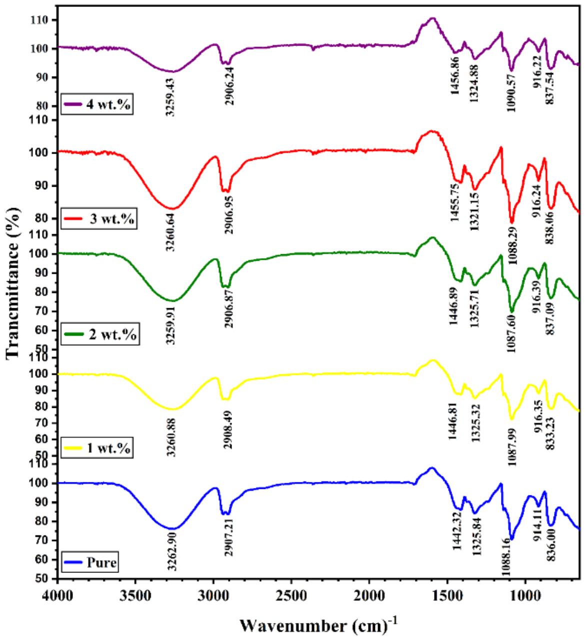

Figure 3. FTIR spectra of (PVA/Bi_2O_3-CuO) nanocomposites

3.4. Optical Microscopy (OM)

The pure PVA film and the (PVA/ Bi_2O_3-CuO) nanocomposites have had their surface architecture altered. Figure 4 displays optical microscopy (OM) images of the pure film and the produced nanocomposites at 10× magnification. Image (a) shows the pure PVA film with only one homogeneous phase, which means that there is no phase separation. The surface looks smoother and more regular, which illustrates how well the polymer works to make a continuous network. Images (B-E) indicate that the nanoparticles of Bi_2O_3 and CuO are spread out rather evenly across the surface of the PVA film. The density of surface granules and the clarity of these particles increase as the weight content of the added oxides increases. The overview of the nanoparticles shows a clear and repeating pattern of grain density, which means that the surface morphology gets more regular and continuous as the concentration of the additive rises. At low concentrations, on the other hand, the film surface shows irregular patterns and clusters that are randomly spread out. As the concentrations of Bi_2O_3 and CuO particles rise, these grains develop into a linked network of nanoparticles within the polymer blend [19, 20].

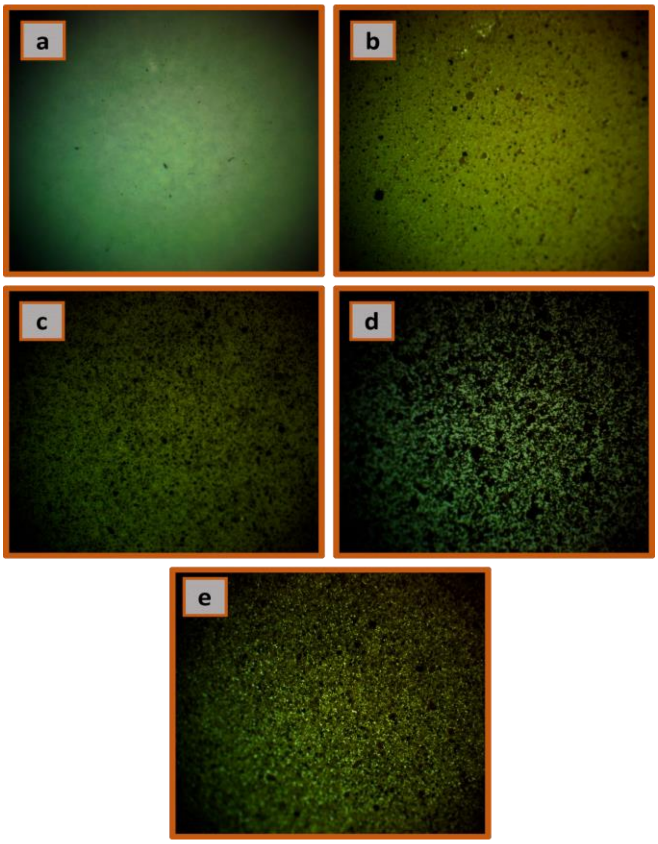

Figure 4. Optical Microscope for the (a) pure PVA, (b) 1 wt.% Bi_2O_3 and CuO NPs, (c) 2 wt.% Bi_2O_3 and CuO NPs, (d) 3 wt.% Bi_2O_3 and CuO NPs, (e) 4 wt.% Bi_2O_3 and CuO NPs

Figure 5 displays the absorbance (A) of (PVA/ Bi_2O_3–CuO) nanocomposites changes with the wavelength. The results show that the absorbance of all the nanocomposite films that were made goes up a lot when the concentration of nanoparticles goes up. More nanoparticles in a polymer matrix means more charge carriers. The samples' ability to absorb UV and visible light increased significantly at higher concentrations. This data shows that nanoparticles directly affect the polymer's ability to absorb light. In general, the absorbance of all the samples goes down as the wavelength goes up. This means that the photon that hits the electron can't excite it and move it from a lower energy level to a higher one since its energy is lower than the energy gap value of the composites. At these energy levels, donor electrons can move to the conduction band when they come into contact with high-energy photons. This feature makes all samples in the UV spectrum more absorbent because photons have enough energy to interact with atoms and create a lot of absorption. The UV absorption spectrum of PVA polymer is limited; however, it significantly improves with the incorporation of Bi_2O_3/CuO nanoparticles [21].

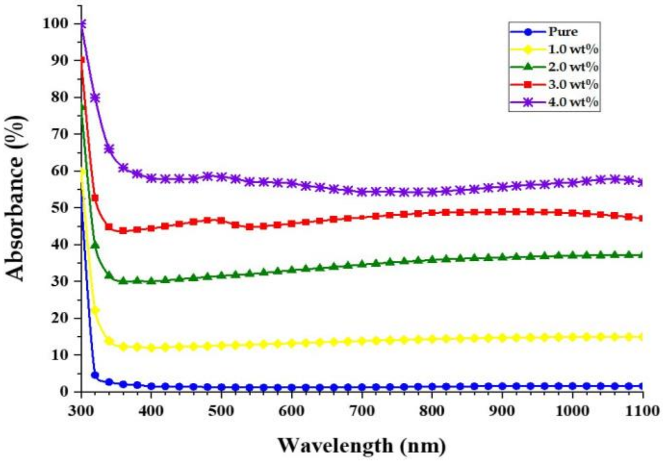

Figure 5. The absorbance spectra of (PVA/Bi_2O_3-CuO) nanocomposites as it changes with wavelength.

Figure 6 shows how the transmittance (T) of (PVA/Bi_2O_3-CuO) nanocomposites changes with the wavelength (λ) of the light that hits them. This picture shows that the best approach to get an electron excited is to move it from the valence band to the conduction band [22]. The slow and nonlinear decrease in transmission within the visible spectrum is due to the incorporation of (Bi_2O_3/CuO) nanoparticles into polyvinyl alcohol, a polymer [23, 24]. Our findings indicate that the optical transmission of (PVA/ Bi_2O_3-CuO) nanocomposites diminishes to 65% at 660 nm with an increase in the weight proportion of (Bi_2O_3/CuO) nanoparticles. The nanoparticles spreading out in the polymer matrix is what makes it hard to see through. This happens when the wavelength is bigger than the size of the particle. Another possibility is that electrons are flowing between the polymer and the (Bi_2O_3/CuO) nanoparticles. The addition of nanoparticles greatly limits the ability of polymers and nanocomposites to let light through in the ultraviolet range. In the visible range, on the other hand, the ability to let light through at 9 nm drops considerably [25, 26].

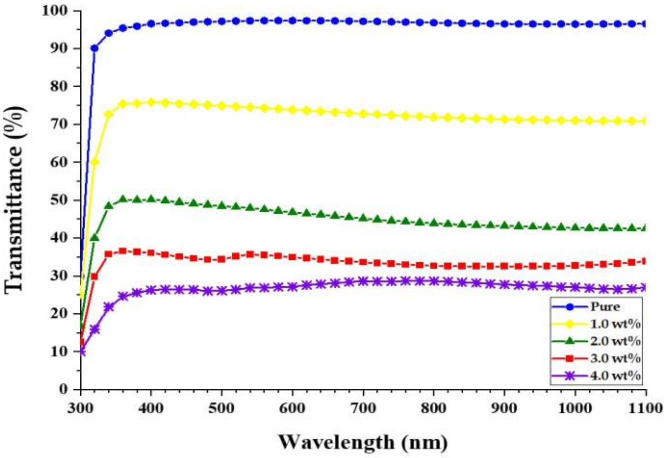

Figure 6. Transmission spectrum of (PVA/Bi_2O_3-CuO) nanocomposites based on wavelength

Figure (7) shows how the absorption coefficient of PVA/ Bi_2O_3-CuO nanocomposite coatings and photon energy are related. The energy of the photons increases with the increased absorption coefficient, reaching approximately 4.0 eV. At these thresholds, the energy of the photon is insufficient to directly move an electron from the valence band to the conduction band, as the energy required for this transition is small. At an energy level of approximately 4.0 eV, all samples exhibit a considerable increase in absorption coefficient values [27]. This suggests that the conduction band electrons have changed a lot and that electronic transitions across the energy gap have started.The reduction in the absorption coefficient at low energies suggests that the absorptivity is below unity, indicating that the electronic transition takes place indirectly within the material, as evidenced by the cited study [28].

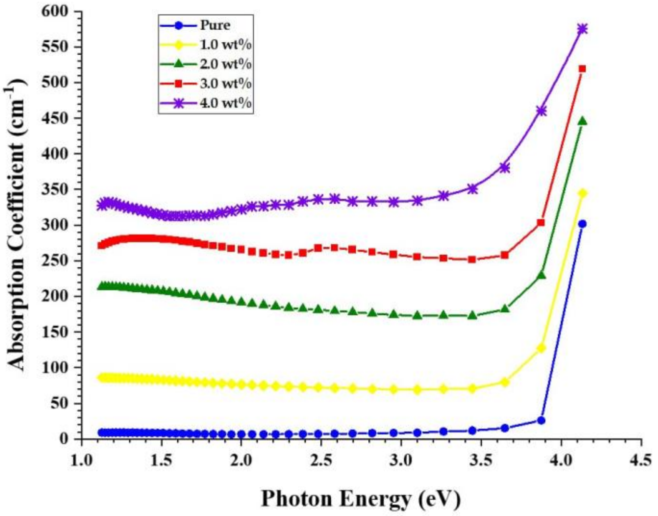

Figure. 7 Illustrates the variation of the absorption coefficient of PVA/Bi_2O_3-CuO nanocomposites as a function of photon energy.

The energy gap is ascertained via [29].

$$(\alpha hv)\ 1/r = C(hv - Eg) \tag{3}$$

Figure 8 shows the energy gap values for both allowed and not allowed transitions of (PVA/ Bi_2O_3-CuO) nanocomposites. The results show that the energy gap (Eg) of the pure polymer gets less as the number of nanoparticles increases. For instance, the optical band gap decreased from approximately 4.026 eV for pure PVA to 2.778 eV for the nanocomposite containing 4 wt.% Bi_2O_3/CuO nanoparticles. The extra nanoparticles and the polymer chains work together to create new energy levels in the energy gap, which is what this is all about. The drop in Eg shows that charge transfer complexes are linked to the creation of flaws in the polymer medium. These defects make the energy gap smaller by creating energy levels that are only found in some regions [30]. The energy gap values we found suggest that the composites have optical and electronic properties that make them good for use in nano-semiconductors, electronics, and optical systems.

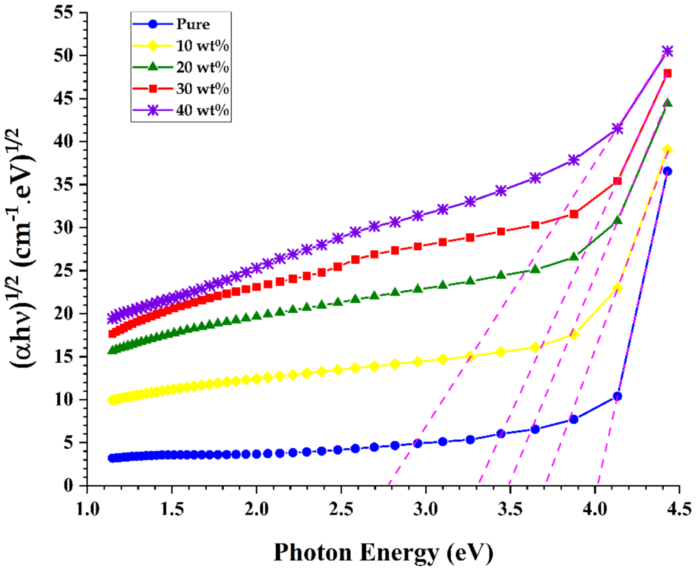

Figure. 8 Eg for allowed transition of PVA/Bi_2O_3-CuO nanocomposites

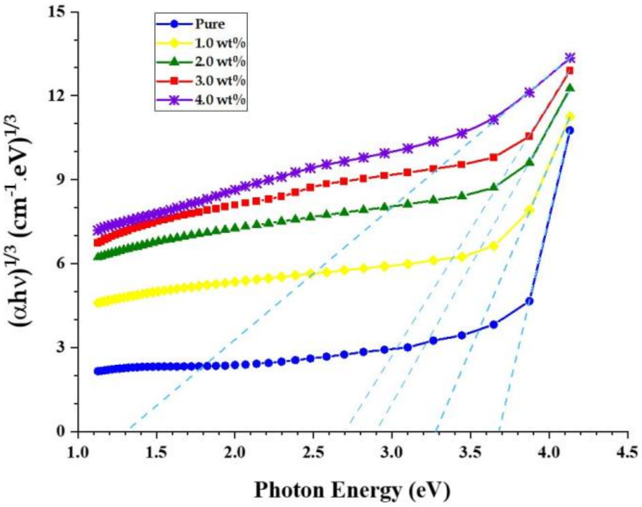

Figure. 9 Eg for the forbidden transition of PVA/Bi_2O_3-CuO nanocomposites

Table 1. Energy gap values for allowed and forbidden indirect transitions in (PVA-Bi_2O_3-CuO) nanocomposites

Sample	Allowed Eg	Forbidden Eg
pure	4.026	3.918
1wt.%	3.722	3.448
2wt.%	3.475	3.075
3wt.%	3.308	2.823
4wt.%	2.778	2.025

We found the refractive index (n) by employing the connection [31].

$$n = (1 + \sqrt{R}) / (1 - \sqrt{R}) \quad (4)$$

'R' stands for reflectance. The refractive index contours of PVA/ Bi_2O_3-CuO nanocomposites are shown in Figure 10. These contours show that the refractive index changes a lot depending on the wavelength. Adding Bi_2O_3 and CuO particles to the polymer raised the specimen's refractive index. This behavior is attributed to enhanced electronic polarization and increased interaction between the electromagnetic field and charge carriers within the nanocomposite. The refractive index increases better when there are more particles of CuO and Bi_2O_3. This makes the electromagnetic field and electrons interact with each other more strongly. This behavior aligns with the results of previous studies in this field [32].

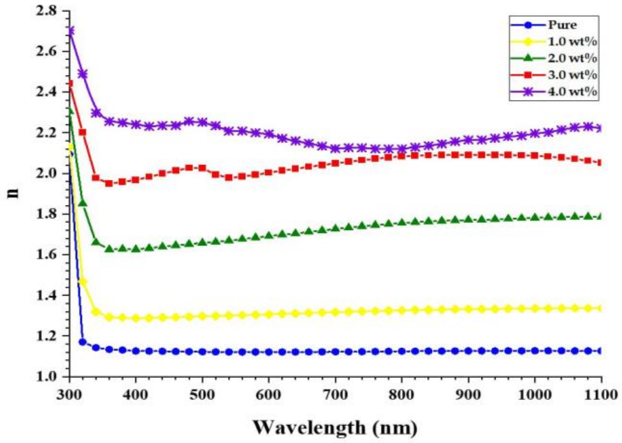

Figure 10. The refractive index of the PVA/Bi_2O_3-CuO nanocomposite as a function of wavelength

The following is the definition of the extinction coefficient (k) [33]:

$$k = \alpha\lambda/4\pi \tag{5}$$

where λ is the wavelength. Figure 11 shows how the attenuation coefficient and wavelength are related by showing nanocomposite films made of PVA with different amounts of the extra particles Bi_2O_3/CuO. The extinction coefficient of the composites exhibits a distinct peak at short wavelengths, approximately 300 nm, followed by a steep decline around 330 nm. Following this dip, the extinction coefficient rises linearly as the wavelength increases to 1100 nm. The nanoparticles cause the energy levels of the photons to rise and the polymer matrix to have more energy levels. There is a very definite connection between the amount of nanoparticles and the pace of extinction. In all bands, samples with higher concentrations have higher k values. This result demonstrates that nanoparticles could assist with absorption and make the mixture have more places where light can interact with it. The ability of the material to absorb light is enhanced through the interaction of electromagnetic radiation with nanoparticles [34].

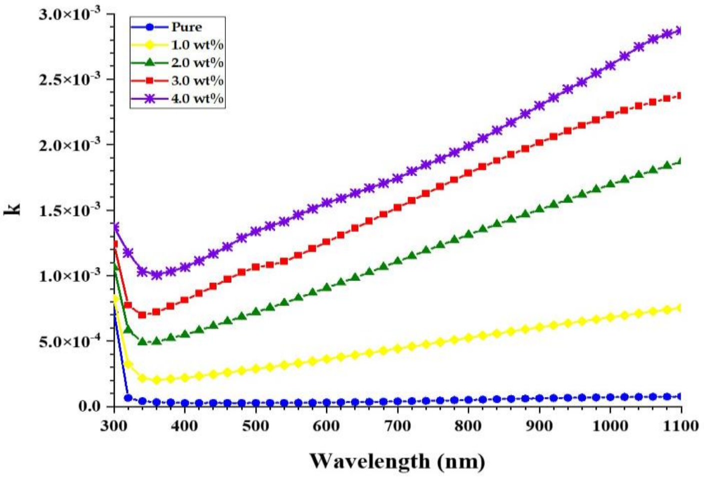

Figure 11. The extinction coefficient of the PVA/Bi_2O_3-CuO nanocomposite varies with the wavelength.

The dielectric constant comprises two components: the real part (ε_1) and the imaginary part (ε_2) [35].

$$\varepsilon_r = n^2 - k^2 \tag{6}$$

$$\varepsilon_i = 2nk \tag{7}$$

Figures (12) and (13) show how the real (ε_1) and imaginary (ε_2) parts of the electric permittivity of the PVA/ Bi_2O_3-CuO samples changed. The results show that the pure sample has high values for both ε_1 and ε_2

at short wavelengths, and then these values slowly decrease as the wavelength gets longer. On the other hand, when the wavelength gets shorter, the energy levels drop because the real and imaginary electric permittivity of the nanomembranes goes up. This rise means that there are more local energy levels forming inside the polymer matrix. This makes the material more polarized and more responsive to the electric field. The refractive index (n) is also the most important factor in figuring out the effective electric permittivity. This is because the values of the absorption index (k) are much smaller, especially when squared, which means that the refractive index has a bigger effect on the total permittivity of the material [36].

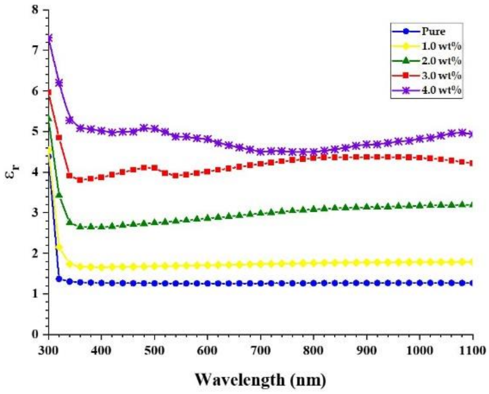

Figure 12. The wavelength is what determines the real dielectric constant of the PVA/Bi_2O_3-CuO combination.

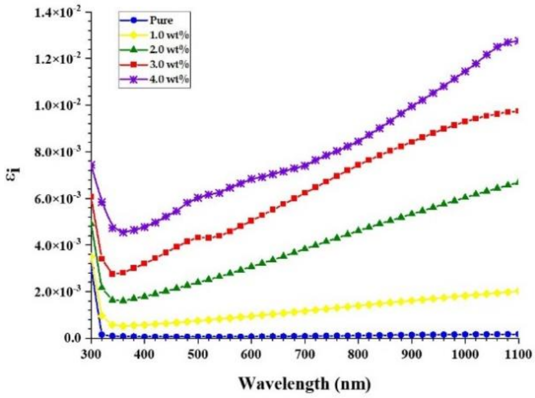

Figure 13 illustrates the imaginary dielectric constant of PVA/Bi_2O_3-CuO nanocomposite as a function of the wavelength

The optical conductivity (σ_{op}) of PVA/ Bi_2O_3-CuO sheets fluctuates with the wavelength of light, as seen in Figure 14. As the energy of the photons increases, the optical conductivity rises. This happens when photons push electrons around. As the amount of Bi_2O_3/CuO nanomaterial increases, the σop values get up. When the concentration of Bi_2O_3/CuO goes up, σop goes up too. This is because more energy states are created in the energy gap (Eg), which makes it easier for electrons to move about. The number of local levels in the electronic structure goes up as the amount of Bi_2O_3/CuO goes up. This behavior elucidates the rise in absorption coefficient α values, thus improving the optical conductivity σ_{op} [37–40]. The σ_{op} results show that PVA/ Bi_2O_3-CuO composites can be used in many electrical and optical applications. The optical conductivity (σop) is defined by [41]:

$$\sigma_{op} = \alpha n c / 4\pi \tag{8}$$

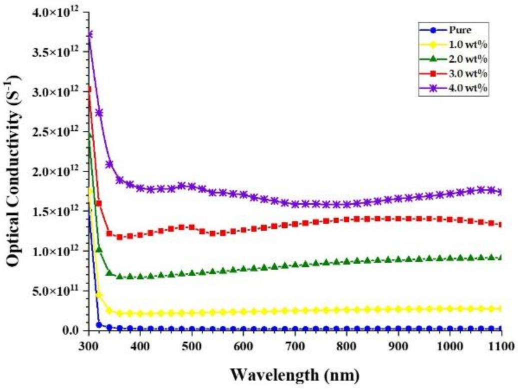

Figure 14. shows how the optical conductivity of PVA/Bi_2O_3-CuO nanocomposites changes when the wavelength changes

You can use the following equation, which is about the thickness of the substance that absorbs light, to find the linear attenuation coefficient (μ) [42]:

$$N/N_0 = e^{(-\mu t)} \qquad (9)$$

In this case, N_0 is the number of radiation particles that were found in a certain amount of time without an absorber. N is the number of particles that were counted in the same period of time after traveling through a material that is t thick. The linear attenuation coefficient for gamma rays is represented by the symbol μ. Figure 15 shows how nanoparticles affect the gamma ray attenuation graph by showing how the (N/N_0) ratio changes with varying amounts of Bi_2O_3. CuO particles were mixed with the PVA polymer matrix. The decreased radiation transmission at elevated concentrations of Bi_2O_3. The radiation that goes through the sample is less powerful because CuO particles can absorb and attenuate radiation better. When the ratio of (Bi_2O_3/CuO) nanoparticles changes, the gamma radiation attenuation coefficients vary too, as shown in Figure 16. As the number of nanoparticles increases, the attenuation coefficients rise. The nanoparticles' shielding materials make the shielding perform better by either bouncing back or soaking up gamma radiation. The very high atomic numbers of Bi_2O_3 and CuO make polymer nanocomposites with both particles have the highest attenuation coefficient values yet known. This means that adding more Bi_2O_3 and CuO to the nanocomposite makes it considerably better at blocking radiation. The Bi_2O_3/CuO system is a strong alternative to other fillers that are often used, such as bismuth oxide (Bi_2O_3), tungsten oxide (WO_3), and lead oxide (PbO). These fillers usually have RSE values between 12% and 25%, depending on how much filler is in the radiation and how much energy it has. Lead oxide is not used very often since it is poisonous, even though it is highly good at blocking radiation because it has a high atomic number and density. Gamma rays can be stopped best with lead, but it is hazardous for the environment and health and can't be used in many different ways. The PVA/ Bi_2O_3-CuO nanocomposite is a lightweight, flexible, and non-toxic material that can be used for wearable and low- to moderate-shielding purposes. These nanocomposites could make a big difference in radiation shielding technology by continuing to improve the integration and thickness of nanoparticles. PVA/ Bi_2O_3-CuO nanocomposites have great radiation shielding qualities and are good for the environment; however, there are several problems that could make them hard to use in many situations. The composite's ecological stability is of paramount importance. Polyvinyl alcohol (PVA) is a polymer that loves water and is very sensitive to moisture and humidity. Over time, this kind of exposure can make the material work less well and lose its structural integrity [43]. Despite the promising radiation shielding performance of PVA/ Bi_2O_3-CuO nanocomposites, several limitations should be considered. The hydrophilic nature of PVA makes the composite sensitive to moisture and humidity, which may affect its long-term environmental stability. Furthermore, excessive nanoparticle loading can lead to agglomeration and reduced mechanical flexibility. Large-scale fabrication also remains challenging due to the difficulty in achieving homogeneous nanoparticle dispersion and the high cost associated with high-purity nanofillers. Therefore, further optimization of fabrication methods and surface treatments is necessary to enhance the durability and industrial applicability of these nanocomposites [44].

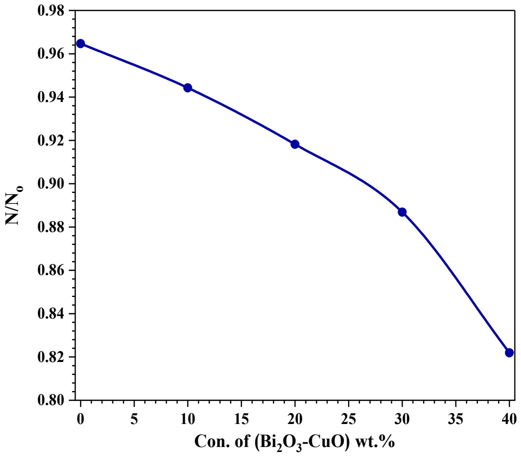

Figure 15. Fluctuation of (N/N0) for (PVA/Bi_2O_3-CuO) nanostructures

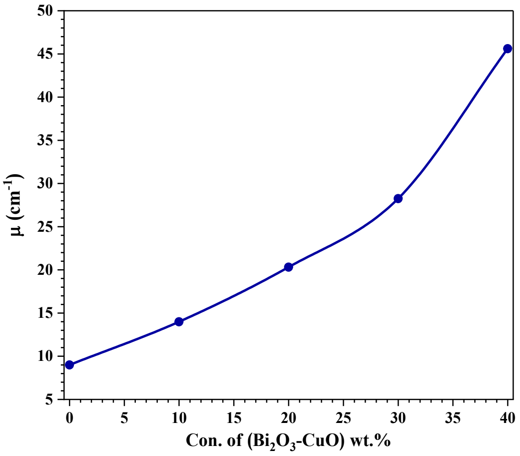

Figure 16. Gamma radiation attenuation coefficient fluctuations in (PVA/Bi_2O_3-CuO) nanostructures

4. Conclusion

This research establishes a systematic and reproducible technology for synthesizing nanocomposites utilizing polyvinyl alcohol (PVA) polymer, enhanced with bismuth oxide (Bi_2O_3) and copper oxide (CuO) nanoparticles, through the casting technique of solutions. Field emission scanning electron microscopy (FE-SEM) and optical microscopy (OM) tests showed that the nanoparticles were evenly spread out in the polymer matrix and that there were no big clumps. This means that the process of creating it was highly steady and of high quality. The FT-IR spectra showed that the nanoparticles and polymer chains were close together, which showed that they were quite compatible at the interface. X-ray diffraction (XRD) research showed that the PVA films retain their semi-crystalline characteristics subsequent to the incorporation of nanoparticles. This is seen from distinct diffraction peaks corresponding to the Bi_2O_3 and CuO phases. This information shows that the nanoparticles were introduced to the polymer matrix without weakening it. The visual inspection shows that having more (Bi_2O_3/CuO) nanoparticles makes the absorption, extinction, and refractive index coefficients much better. It also lowers the optical transmittance, notably in the UV band. The best results were at a wavelength of 300 nm. This number means that the refractive index went up by 41.06%, the extinction coefficient went up by 93.72%, and the optical conductivity went up by 97.05%. This signal suggests that introducing the nanoparticles has made it much easier for photons to interact with each other and for electronic states to exist. The energy gap that was permitted decreased by 11.11%, and the energy gap that was not permitted diminished by 18.13% in comparison to the pure PVA sample. Localized energy levels occur in the energy gap, which makes indirect electronic transitions more important. This behavior is attributed to the formation of localized energy states within the band gap, which facilitate indirect electronic transitions. The (PVA/ Bi_2O_3-CuO) composites were very good in blocking gamma rays, with a shielding effectiveness of 17.81%. This score is better than the scores of a number of different polymer fillers that have the same amount of loading. The results show that nanoparticles of bismuth oxide and copper oxide work together to improve radiation shielding and optical qualities while keeping the polymer matrix light and flexible. The (PVA/ Bi_2O_3-CuO) composites indicate that they can perform more than one thing. These materials are ideal for protecting against radiation, especially in hospitals. They are also useful for manufacturing flexible protective materials that are safer and better for the environment than ones made with lead.

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