RESEARCH PAPER

Spin-Coated PVA–PEG Nanocomposite Thin Films: Structural, Surface, and Optical Properties

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ABSTRACT

Thin films were successfully prepared from a liquid composite of polyvinyl alcohol (PVA), polyethylene glycol (PEG), and a mixture of PVA/PEG using the spin-coating technique, resulting in a uniform film thickness of approximately 132 nm. The structural properties were analyzed using X-ray diffraction (XRD), and the results indicated that the doping process contributed to a notable increase in grain size (G/S) along with a corresponding decrease in the full width at half maximum (FWHM), as expected due to their inverse relationship. Additionally, Miller indices and inter-planar distances were calculated to further understand the crystal structure. Surface morphology analysis revealed that the doping process led to the formation of homogeneous films with a significant number of pores or holes, suggesting their potential suitability for gas sensing applications. Furthermore, optical characterization showed an enhancement in absorbance, accompanied by a reduction in both transmittance and optical bandgap values, further supporting their utility in optoelectronic and sensing devices.

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INTRODUCTION

Thin Film Physics is among the professional specializations in the physics of solid states that has crystallized and develop into its own branch. This field focuses on microdevices, which are all distinguished by their extremely thin thickness, a little less than (1 mμ) [1].

As seen by the numerous recent studies in this area, physicists have been interested in the characteristics of matter in the form of thin films since the second half of the seventeenth century. When semiconductors became available for use at the start of the nineteenth century, research into the practical side of things started [2].

Due to the thinness of these membranes, they are deposited on substrates of different materials depending on the nature of use and study, such as various types of glass, quartz, silicon, aluminum, and others [3].

Spin coating was used to create films of PVA, PEG, and PVA/PEG. For polymer films, spin coating is a flexible and efficient method. It is a productive way to make a variety of powders and film materials for different industrial uses. This method was used to deposit polymer films. The shape of the films can be controlled using spin coating. The process parameters have a significant impact on the films' quality and characteristic.

The development of new technologies for various industries, including medicine,

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transportation, information technology, and civil engineering components, depends heavily on research into new materials. A precise understanding of the tight relationship between a material's structure and properties serves as the foundation for creating new and more effective systems, and this knowledge enables the creation of hybrid materials to meet evolving performance requirements. Polymers are the most widely used materials because of their affordability, ease of processing, stability, and reproducibility [4].

This study makes use of two polymers. Polyvinyl alcohol (PVA) is a popular polymer used in a wide range of applications, particularly in semiconductors. Its unique properties and excellent visible light transmission make it a crucial component in the development of electronics. PVA is semi-amorphous, resistant to oils and solvents, and possesses exceptional electrical, optical, tensile, and storage properties. Poly (vinyl acetate) is hydrolyzed in commercial manufacture [5,6].

The other polymer used in this study is polyethylene glycol, which was first documented to be synthesized in 1859. Charles Adolphe Wurtz and A. V. Lourenço isolated the products independently, and they were polyethylene glycols [7]. PEG is a polyether molecule with a wide range of applications in industries and medicine. Depending on its molecular weight, PEG is commonly referred to as either polyethylene oxide (PEO) or polyoxyethylene (POE). [8].

The aim of this main study was to use the spin-coating method to synthesize and characterize the prepared PVA, PEG, and PVA/PEG films. The optical, structural, and morphological properties of the produced samples were investigated using an 1800 UV-Vis spectrometer, scanning electron microscopy, and X-ray diffraction.

MATERIALS AND METHODS

First, a PVA polymer liquid was made in order to create the PVA, PEG, and PVA/PEG films. To make the liquid, 15 grams of PVA polymer powder were added to a 200 ml glass beaker, along with 100 ml of deionized distilled water. The polymer powder was then continuously stirred with a magnetic needle using a stirrer, and the mixture was heated to 50°C for 30 minutes. After obtaining the PVA polymer liquid, the produced liquid was left to settle and cool to room temperature.

After that PEG polymer liquid was prepared by placing a weight of 20 grams of PEG polymer powder in a 200 ml glass beaker and adding 100 ml of distilled water free of ions. A stirrer was used to dissolve the polymer powder through continuous stirring using a magnetic needle and a heating temperature of 50 degrees Celsius for half an hour. PEG polymer liquid was obtained, after which the prepared liquid was left to settle and cool at laboratory temperature.

In order to create the PEG/PVA polymer mixture, 50 milliliters of the PVA polymer liquid were first made and then added to a 200 milliliter glass beaker. For 30 minutes, the mixture was continually agitated at 50 °C using a magnetic needle and a stirrer. The result was a well-homogeneous mixture of polymers.

Following the preparation procedure, measurements are made of the prepared samples' optical and structural characteristics.

RESULTS AND DISCUSSION

X-ray diffraction measurements results

X-ray technology was used to study the crystal structure of the films of the prepared material, and through it the type of material structure was confirmed. By observing Figure 1, it was found that the prepared PVA/PEG film has an orthorhombic crystal structure, and the other thin film prepared PEG has a monoclinic crystal structure . Also, the prepared PVA membrane is of the amorphous type and there are no values representing Miller coefficients when measuring.

Eq. 1 was used to determine the interfacial distance (dhkl) between the atomic levels of all thin films made from X-ray diffraction spots and Bragg angles. The distances between the atomic levels were found to be extremely near to their theoretical values, and this result is in good agreement with [9,10].

$$n\lambda = 2d_{\mathrm{h\,k\,l}}\ sin\ \theta \quad (1)$$

The lattice constants (a, b, c) for the planes representing the Miller coefficients of the PVA/PEG compound with the orthorhombic crystal structure were computed using the values of the interatomic plane spacing and Miller coefficients. It was discovered that the acquired lattice constant values matched their theoretical values exactly.

From the X-ray spectra of every thin film that was created, the full width half maximum (FWHM) was also computed. The full width half maximum was observed to rise when PVA was added to PEG.

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The negative relationship between the full width half maximum and the particle size is the source of the decline in the average particle size values]11,12[.

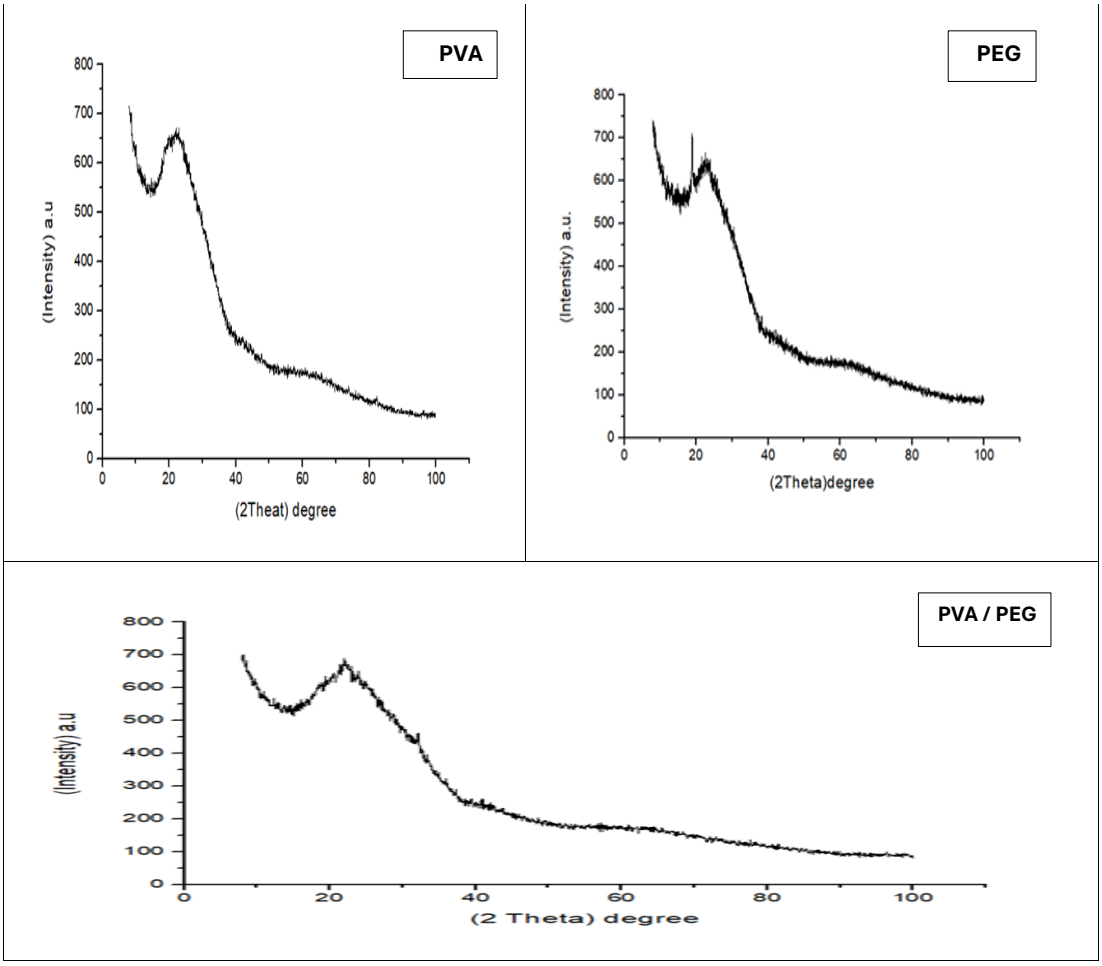

Fig. 1. displays the sample's X-ray diffraction measurement.

Table 1. Displays the PEG thin film's X-ray results prior to irradiation.

N0.	Exp. Pos. 2 Theta degree	FWHM degree	Crystallite size Nm	Exp.d-spacing A	(hkl)	Cell Parameter	Crystal System	Reference Code
1	18.888	0.090	87.5	5.819	(120)			
2	23.239	0.080	112.6	3.862	(-131)	a ≠ b ≠ c a=8.229 b=13.036 c=19.061	Monoclinic	00-052-2279
ave.	-----	0.085	105.4	-------	------			

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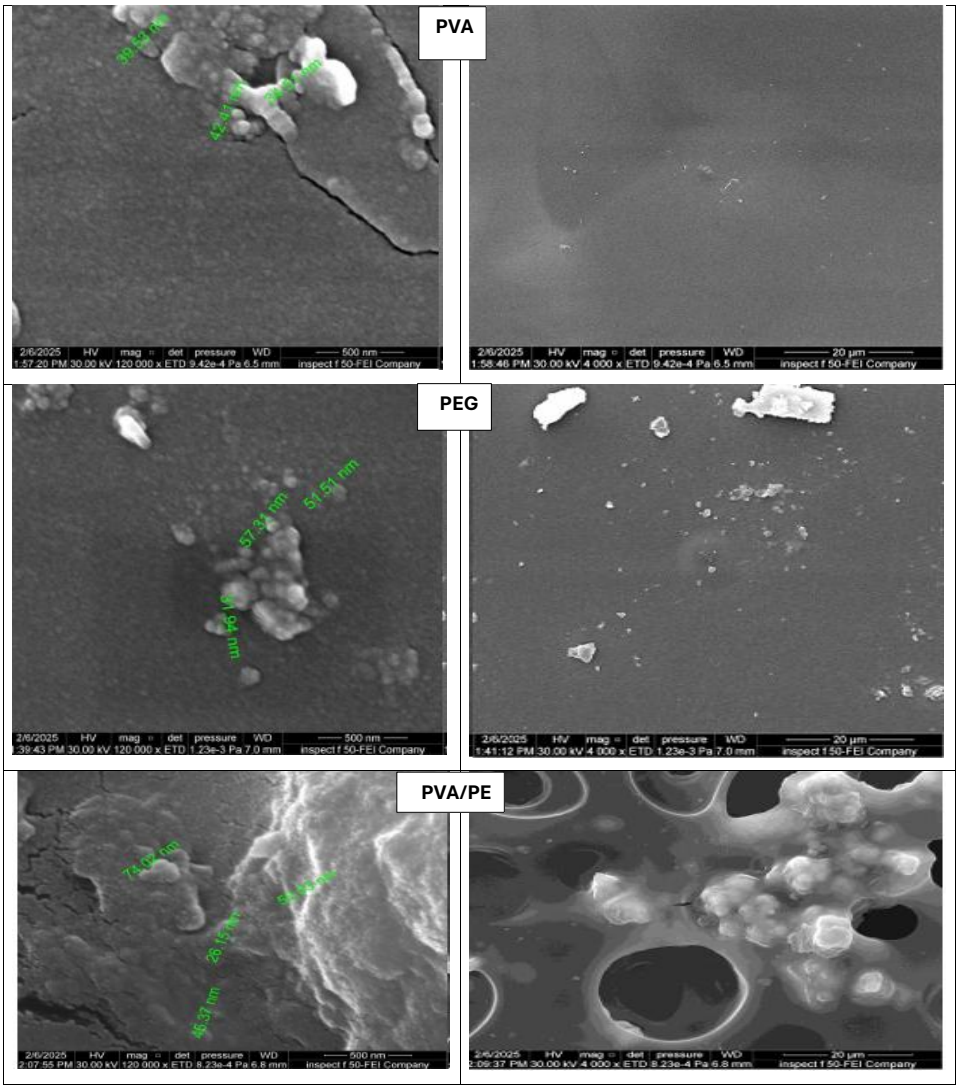

Fig. 2. A display a picture of the sample taken using a scanning electron microscope.

Table 2. Displays the PVA/PEG thin film's X-ray results prior to irradiation.

N0.	Exp. Pos. 2 Theta degree	FWHM degree	Crystallite size Nm	Exp.d-spacing A	(hkl)	Cell Parameter	Crystal System	Reference Code
1	18.587	0.123	87.5	4.77	(200)			
2	20.423	0.549	112.1	3.981	(210)	a ≠ b ≠ c a=9.542 b=10.531 c=5.666	Orthorhombic	00-038-1969
3	35.337	0.09	101.7	2.538	(231)			
ave.	-----	0.254	100.43	-------	------	-----	-----	------

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Using Debye-Sherrer Eq. 2 and the values of the whole width half maximum, the average grain size (G.S.) of all manufactured thin films was computed by substituting the values derived from the X-ray diffraction data [13].

$$D = \frac{k\lambda}{\beta\cos\theta} \quad (2)$$

Tables 1 and 2 displays all of the X-ray diffraction measurement results for all prepared thin films. The results were found to be somewhat identical when compared to the values on the cards numbered (00-052-2279) and (00-038-1969) of the American Standard of Testing Materials (ASM).

Scanning electron microscope (SEM) results

The surface morphology of the prepared films and the grain size were measured on all prepared samples using a scanning electron microscope (SEM). The results indicated that the films were relatively homogeneous, but that they had holes. This was because the polymers were prepared in a viscous liquid, which causes holes to form when thin films are prepared using the spin-coating method. These films can be used in gas sensor applications]14,15.[

As would be predicted given the variations in the chemical ingredients utilized in their synthesis, the results also revealed a variance in the hue of the created membranes.

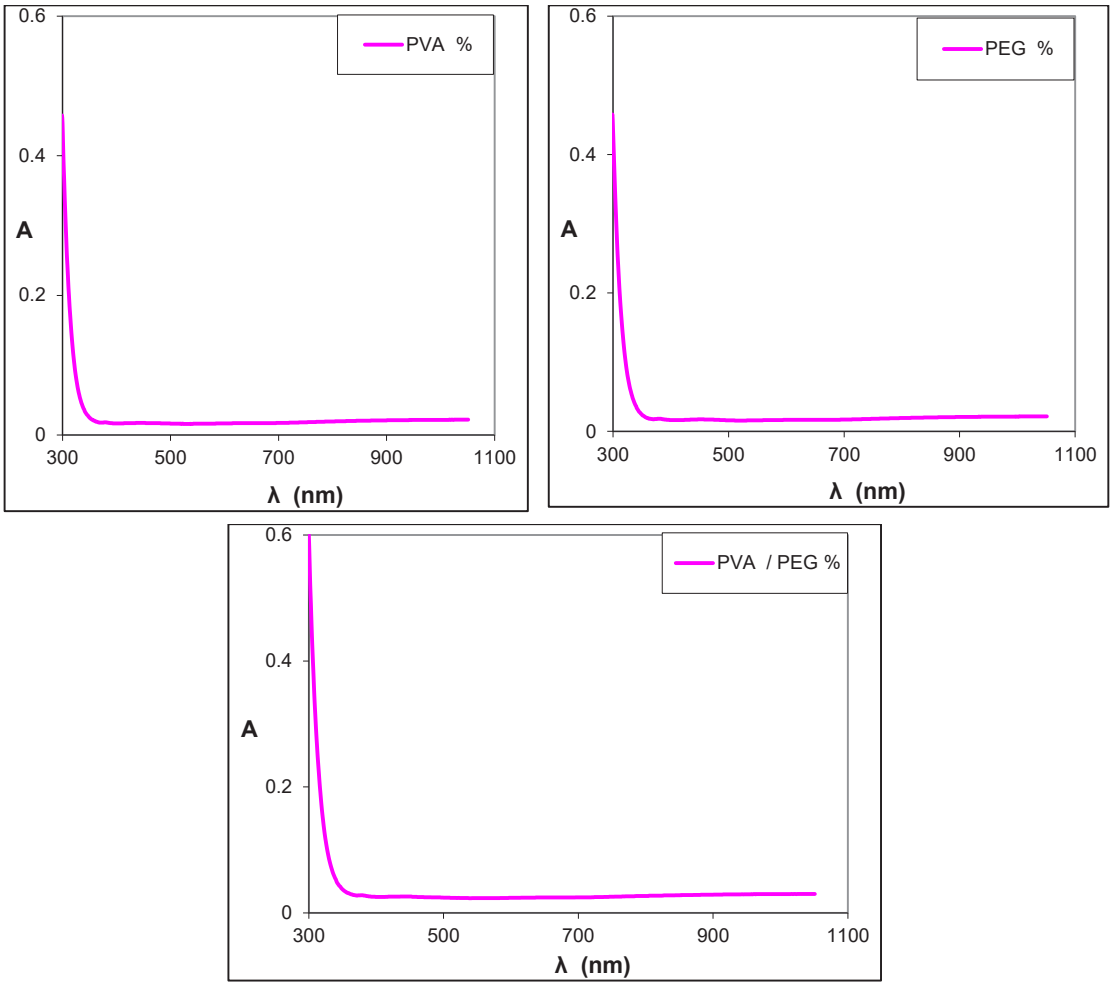


Fig. 3. The relationship between absorbance and wavelength of the sample.

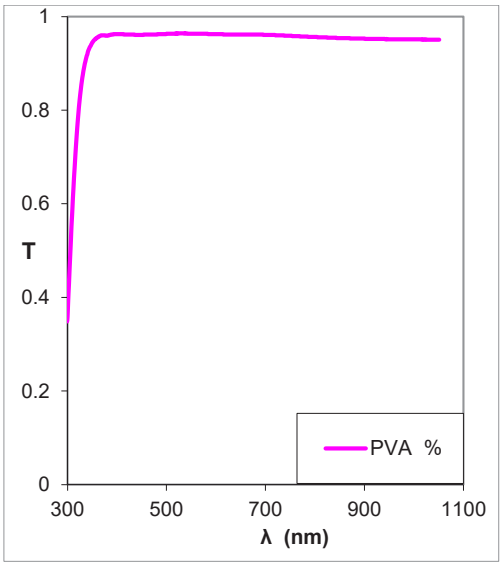
The SEM examination images, which can evaluate the manufactured thin films at 500 nm, are displayed in Fig. 2.

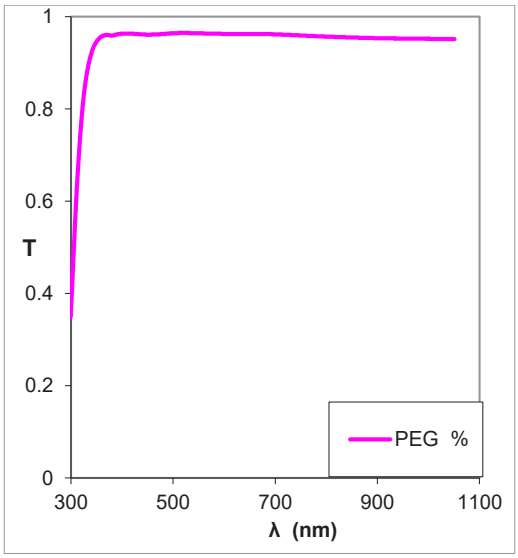
Investigation of optical characteristics

Fig. 3 illustrates how A was determined for PVA, PEG, and PVA/PEG films using a UV-visible1800 device as a function of wavelength in the 300–1100 range. Because the incident photon's energy is smaller than the energy gap value in semiconductors, it is unable to excite the electron and move it from the valence band to the conduction band, which raises the absorbance value [16].

T was measured as a function of wavelength in the 300–1100 range, as shown in Fig. 4. The transmittance results indicate that the films' lowest transmittance value is at 300 nm, where we observe that the PVA, PEG, and PVA/PEG films' mixing process caused a decrease in transmittance values, which is the opposite of the absorbance behavior.

In Fig. 5 demonstrates the direct optical energy gap curves transmission for all prepared films. The values of the optical energy gap for direct electronic transitions were calculated by drawing the linear connection between $(\alpha\hbar\nu)^2$ and the incident photon energy ($\hbar\nu$) and by cutting the photon energy axis at a location by extending the curve's straight line portion. $(\alpha\hbar\nu)^2 = 0$ and the Eq.





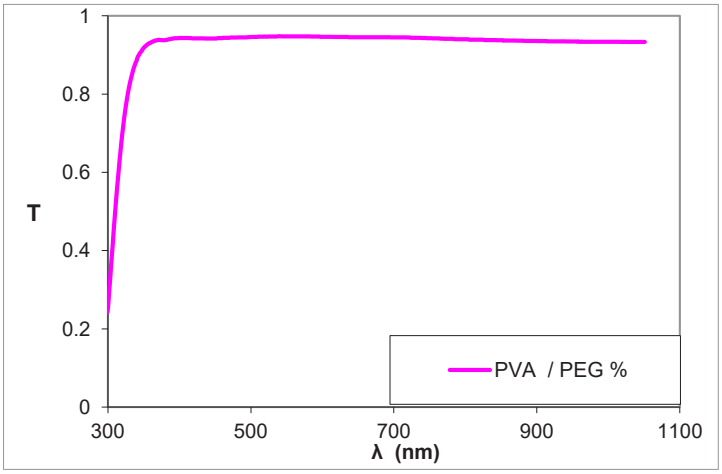


Fig. 4. The relationship between transmittance and wavelength of the sample

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3 is achieved [17,18].

$$\alpha\, h\upsilon = B\,(h\upsilon - E_g^{opt.} \pm E_{ph.})^r \quad (3)$$

Where:

$E_{ph.}$: The phonon's energy, is (-) when phonon absorption, and (+) when photon emission.

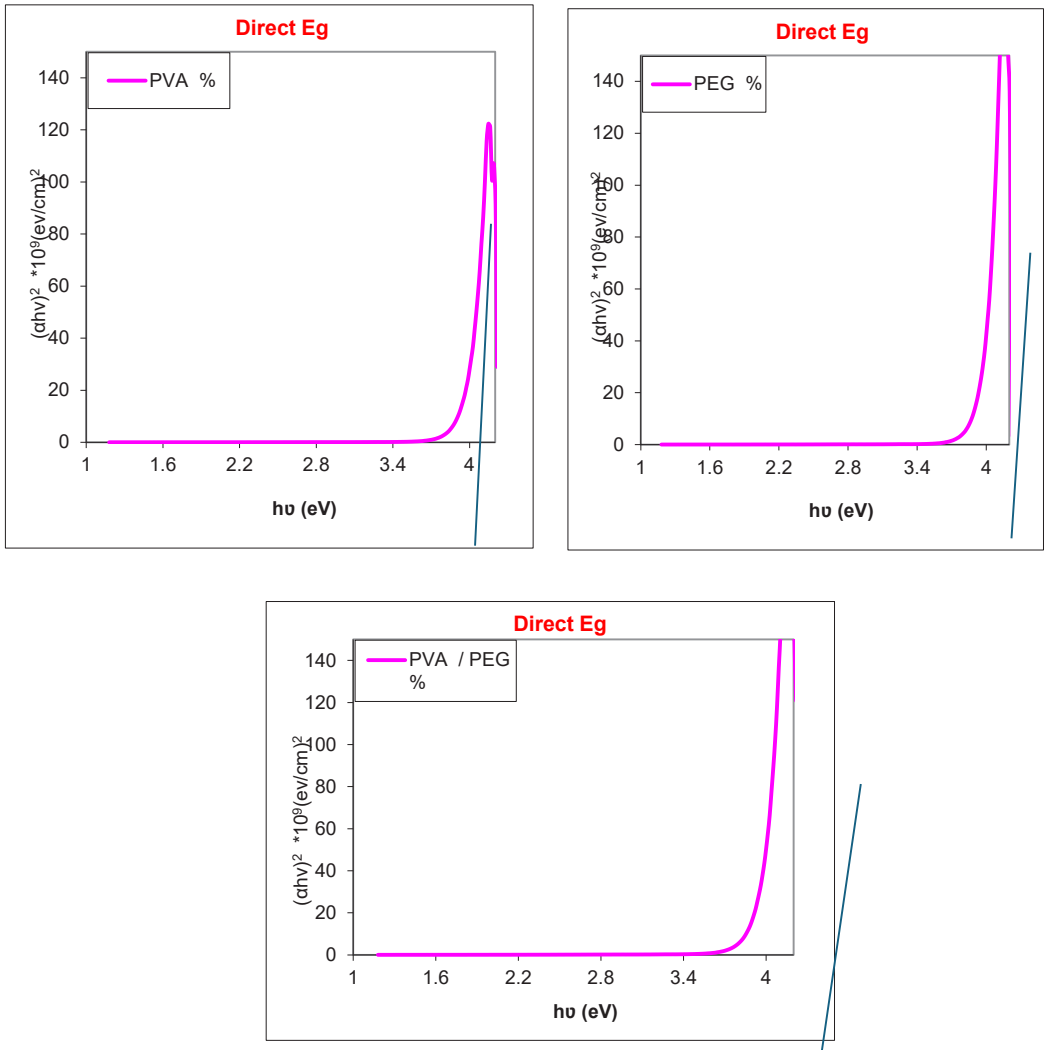

Fig. 5. The relationship between the energy gap and the photon energy of the sample

Table 3. The direct energy gap values of all thin films.

sample	Eg eV
PVA	4
PEG	3.95
PVA / PEG	3.83

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r = 2 for the permitted indirect change.

r = 3 for the prohibited indirect transition.

The optical energy gap values for direct electronic transitions for each produced film are displayed in Table 3. The results showed that adding PVA to PEG resulted in a decrease in the energy gap values.

CONCLUSION

In this work, the effective deposition of thin aluminum films of PVA, PEG, and PVA/PEG was performed using an electronic technique. Based on general measurements and observations, the following points can be concluded:

1. The outer coating technique is well-suited for light thickness preparation.

2. From the results of full-spectrum X-ray diffraction measurements, the PVA/PEG composite has an orthorhombic crystal structure.

3. From the optical properties results, a decline in energy gap values and a rise in absorbance values were concluded.

4. From the results of SEM measurements, the prepared PVA/PEG film exhibits an increase in perforation that can be utilized for gas sensor applications.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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