International Journal of Computational and Experimental Science and ENgineering
(IJCESEN)

Vol. 11-No.1 (2025) pp. 1344-1349
http://www.ijcesen.com

ISSN: 2149-9144

Research Article

Improvement of the Structural and Electrical Properties of PVA through the Addition of Bi_2O_3 and SiO_2 Nanoparticles for Electronic Devices

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Article Info:

DOI: 10.22399/ijcesen.1042
Received : 03 November 2024
Accepted : 17 February 2025

Keywords :

PVA,
Bi_2O_3 and SiO_2 NPs,
XRD,
Electrical Characteristic.

Abstract:

This study focuses on the preparation of ($PVA/Bi_2O_3/SiO_2$) nanocomposites using the solution casting method, incorporating different amounts (0, 2, 4, 6, and 8 wt.%) of Bi_2O_3 and SiO_2 nanoparticles into polyvinyl alcohol (PVA) polymer. The XRD results revealed that PVA exhibited an amorphous nature, which transformed into a polycrystalline structure with the incorporation of high loading (8 wt.%) Bi_2O_3 and SiO_2 nanoparticles. The dielectric constant and loss of the ($PVA/Bi_2O_3/SiO_2$) nanocomposite were observed to decrease with increasing frequency, whereas they improved with the content ratio of Bi_2O_3 and SiO_2 nanoparticles. The A.C. conductivity of the ($PVA/Bi_2O_3/SiO_2$) nanocomposite increases with the frequency and the concentration of Bi_2O_3 and SiO_2 nanoparticles. Ultimately, this outcome indicates that the ($PVA/Bi_2O_3/SiO_2$) nanocomposites have potential applications in electronic properties.

1. Introduction

Nanocomposites include fillers with at least one hundred nanometers of dimensionality that can improve the characteristics of polymers in a variety of ways, including spheres, platelets, fibers, and more [1]. By combining different materials, structures, and compositions, nanocomposites are able to create a wide range of desirable qualities, making them highly adaptable. Much of the funding for research into materials with multiple purposes has come from the nanocomposite industry [2]. Examining the effect of thermal treatment on the surface morphology and Structural properties of tin dioxide thin films Grown was studied using an economical spray deposition method [3]. Researchers are interested in polyvinyl alcohol (PVA) due to its unusual physical and chemical features. PVA is used in several industries. Their outstanding optical attributes, lightweight composition, and superior mechanical properties are the main causes. PVA is used in adhesives, drug sending schemes, coatings, and fuel cells. Due to powerful hydrogen bonding created by hydroxyl collections within and superficially, PVA has a tall tender point approximately matching its decomposition infection. PVA melting is complicated by this characteristic, making water-based solutions better [4]. Its compatibility with the body makes it a potential medicine [5]. PVA also preferentially adsorbs copper, palladium, and mercury. The chemical formula for polyvinyl alcohol (PVA) is $(C_2H_4O)x$. The substantial has a tender point of 230°C and a thickness of 1.19-1.31 g/cm^3. This thermoplastic polymer degrades quickly over 200°C. The flexible material has C–O–C connections. It dissolves in organic solvents, interacts with water, is crystalline, and self-lubricates [6]. Bismuth oxide (Bi_2O_3) is distinguished from other metal oxide semiconductors by its photoconductivity, broad band-gap, high refractive index, and significant dielectric permittivity [7]. Due to their distinctive characteristics, fuel cells, sensor technologies, ion conductors, oxide varistors, optoelectronic materials, functional ceramics, and high-temperature superconductors have all been evaluated. Optical coating and transparent ceramic glass are essential [8].

Quartz is the most prevalent silicon oxide (SiO_2) in nature. The chemical composition of all silica varieties is same, differing only in atomic arrangement. Silica particles generate non-explosive dust [9]. SiO_2 particles enhance the chemical and mechanical characteristics as solid plasticizers. Silica is a fine white powder characterized by a substantial exact superficial area, current stability, and powered makings. Ultrasound vibrations of high frequency are employed to embed silica nanoparticles within a polymer matrix to inhibit agglomeration [10]. Synthesis of novel polymer nanocomposites tailored for polymer electronics requirements is conducted. Polymer matrices infused with SiO_2 nanoparticles are primarily examined for their thermal, insulator, and motorized properties [11]. The lined visual coefficients of polymer composites including SiO_2 are rarely inspected [12, 13]. Fumed silica (SiO_2) nanoparticles are employed in the industry as nanofillers in electronic packaging and thermoplastic polymers. SiO_2 is an amorphous, non-toxic compound that can be integrated with polymer matrices including nanopores to create a nanocomposite material appropriate for optoelectronic applications [14, 15].

The main goal of this work is to make a nanocomposite out of (PVA/Bi_2O_3/SiO_2) nanocomposites and study its electrical and structural qualities for use in electronics.

2. Experimental Work

1 g of PVA was dissolved in 50 mL of distilled water for 30 minutes at room temperature, followed by 20 minutes at 75-80°C using a magnetic stirrer to facilitate the dissolution of the PVA solvent. The solution was positioned on a clean glass Petri dish and allowed to dry at RT for 240 hours until the solvent completely evaporated. PVA was combined with Bi_2O_3 and SiO_2 nanoparticles at concentrations of 2, 4, 6, and 8 wt.% to produce nanocomposite films. The films produced exhibit a thickness of approximately. The crystal structures were analyzed utilizing an X-ray diffractometer (XRD Bruker D8, Germany), Cu Kα1 radiation (λ = 1.5406 Å) was employed at 40 kV and 100 Ma. The dielectric characteristic was calculated at (f=100 Hz to 5 ×10^6 Hz) by LCR meter (HIOKI 3532-50 LCR HI TESTER). The dielectric constant, $\acute{\varepsilon}$ is specified by [16]

$$\acute{\varepsilon} = Cp\, d / \varepsilon_o A \qquad (1)$$

wherever, Cp is capacitance of matter, thickness (d in cm), A= (in cm^2). Dielectric loss, ε'' is calculated by [17]:

$$\varepsilon'' = \acute{\varepsilon}\, D \qquad (2)$$

Wherever, D: dispersion influence. The $A.C$ electrical conductivity is given by [18]:

$$\sigma_{A.C} = 2\pi f\, \acute{\varepsilon}\, D\, \varepsilon_o \qquad (3)$$

3. Result and Discussion

The XRD patterns facilitated the determination of the crystallographic structure of nanocomposite films. The nanocomposites exhibited different ratios of Bi_2O_3/SiO_2 NPs, specifically 2, 4, 6, and 8 wt.% as shown in figure 1. The figure demonstrates that the pure PVA shows broad diffraction peaks positioned at (101) is 2θ = 21.19° (strong), indicating its amorphous nature of PVA [19]. The nanocomposites containing a significant Bi_2O_3 loading of 8 wt.% exhibited distinct XRD peaks at 27.07°, 29.43°, 30.86°, 31.81°, 42.39°, 43.61°, 45.43°, 49.53°, 53.46°, 54.67°, 57.01° and 73.79°, which align with the Miller indices of (120), (012), (222), (123), (122), (422), (023), (133), (530), (600), (145) and (800). According to JCPDS Card No. 74-1375, all of the observed diffraction peaks fall into the cubic space group of pure bodies with a cell parameter of a = 10.08 Å. The products were found to be pure γ-Bi_2O_3 phase when they were synthesized [20]. The X-ray diffraction patterns brought out the materials' amorphous characteristics, as seen in these pictures. A wide band centered at 19.45° is the sole object that is not visible. The distinctive peak of amorphous SiO_2 is obscured by the wide band associated with the PVA. The findings are further juxtaposed with the JCPDS file for SiO_2, demonstrating an absence of impurity peaks for SiO_2 [21].

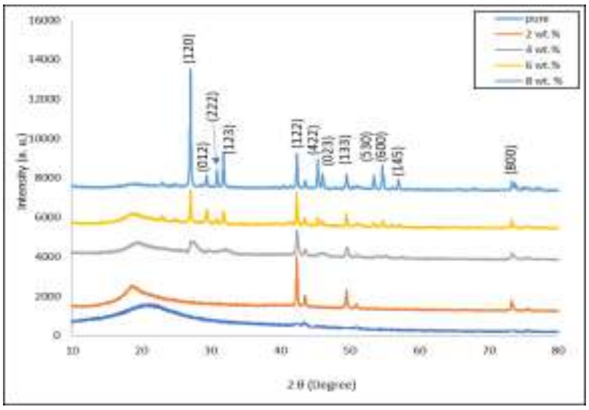

Figure 1. *X-ray diffraction for (PVA/Bi_2O_3/SiO_2) nanocomposites*

The analysis of the nanocomposite patterns indicates that the incorporation of Bi_2O_3/SiO_2 NPs at a loading of 8 wt.% has affected the structural characteristics of PVA. The alteration is due to the incorporation of Bi_2O_3/SiO_2 NPs, which converted the amorphous characteristics of pure PVA into a polycrystalline structure.

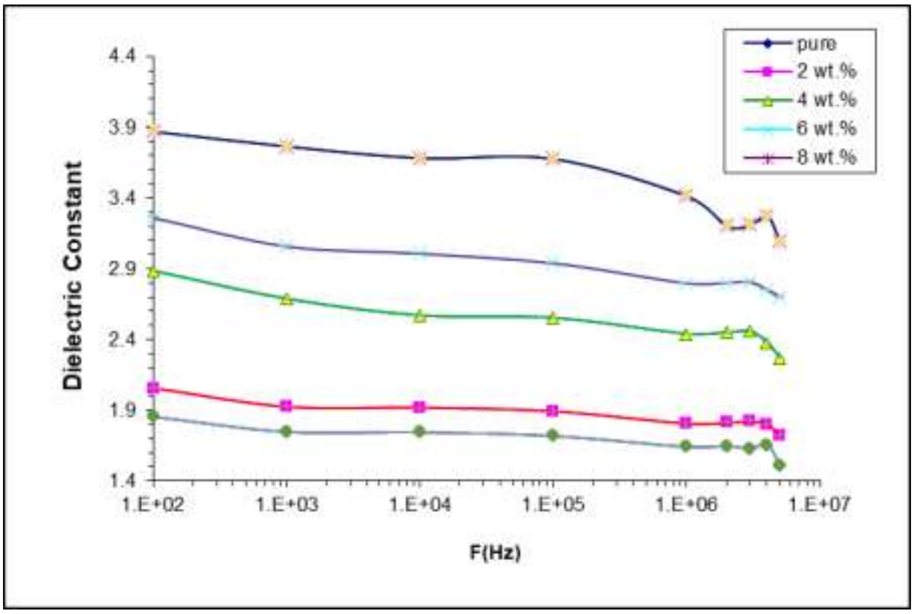

Figure 2. *Variance of the έ of (PVA/Bi_2O_3/SiO_2) nanocomposites with frequency.*

The dielectric constant was calculated utilizing equation (1). Figure 2 shows that the dielectric constant varies with frequency for all samples of the (PVA/Bi_2O_3/SiO_2) nanocomposites. In relation to the changes in polarization states, the results show that the dielectric constant decreases with increasing applied frequency. The dielectric constant is much higher at lower frequencies due to the polarization of the space charge. The influence of polarization on the frequency rise develops more noticeable and decreases with increasing electrical field frequency. This activity leads to a decrease in the dielectric constant values across all samples, subsequently resulting in different forms of polarization at elevated frequencies [22]. Effect of Thermal Activation on the Mineralogical Structure of Magnesium Slag and Characterization of Microstructure of Fe-TiC and Fe-B4C Composites were studied [23,24].

Figure 3 shows the dielectric constant changes at 100 Hz when Bi_2O_3/SiO_2 nanoparticles are introduced. An obvious relationship exists among the concentration of Bi_2O_3/SiO_2 NPs and the dielectric constant, showing that the dielectric constant increases as the concentration does. It is highly probable that this finding is due to the fact that the nanocomposite's Bi_2O_3/SiO_2 nanoparticles have formed a cohesive network. The evaluation of dielectric loss in nanocomposites was conducted through the application of equation (2). The illustration (4) presents the dielectric loss characteristics of the (PVA/Bi_2O_3/SiO_2) nanocomposites as a function of frequency. The graph demonstrates a decrease in the dielectric loss of (PVA/Bi_2O_3/SiO_2) nanocomposites with an increase in the functional electric field.

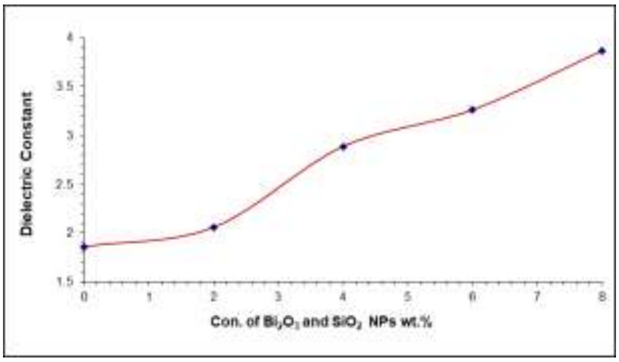

Figure 3. *Inequality of έ with content of Bi_2O_3/SiO_2 NPs at 100Hz*

An increased concentration of Bi_2O_3/SiO_2nanoparticles results in a proportional increase in dielectric loss. As the frequency increases, there is a minor change in the equal of dielectric loss. At elevated frequencies, various types of polarization may manifest [25]. Figure 4 is the variance of the ε″ of (PVA/Bi2O3/SiO2) nanocomposites with frequency (Hz). The data presented in figure 5 indicates that an increase in the concentration of Bi_2O_3/SiO_2 NPs correlates with a higher quantity of ionic charge carriers. This consequently results in a growth in the value of dielectric loss. The findings align with those of the researchers [26]. The alternating current electrical conductivity was assessed utilizing relation (3). Figure 6 illustrates the correlation between electrical conductivity and frequency. The figure demonstrates that an increase in frequency corresponds with a rise in electrical conductivity. This result is due to the localized movement of charge transporters and the excitation of higher-level conduction bands. The $\mathbf{o}\boldsymbol{\sigma}_{A.C}$ is determined by two primary factors: the motion of the main chain

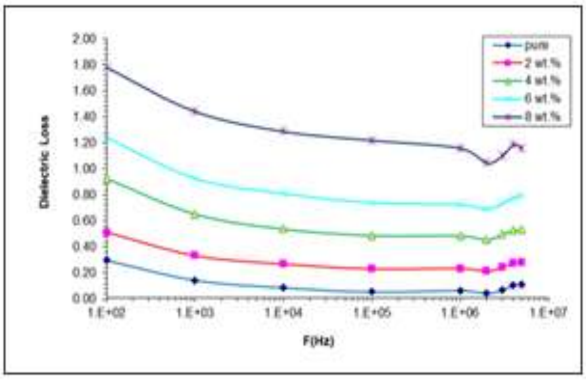

Figure 4. *Variance of the ε″ of (PVA/Bi_2O_3/SiO_2) nanocomposites with frequency (Hz).*

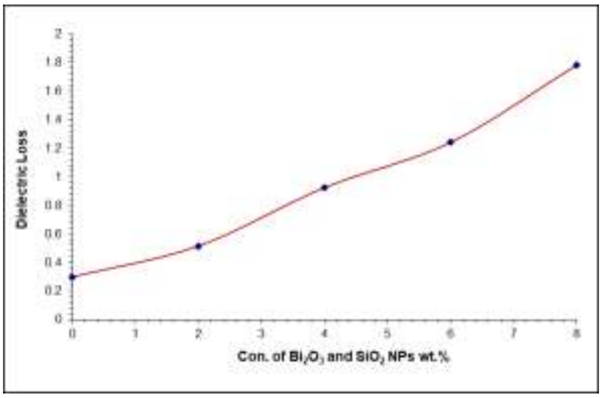

Figure 5. *Variance of* $\boldsymbol{\varepsilon''}$ *with content of* $\boldsymbol{\sigma_{A.C}}$ *Bi_2O_3/SiO_2 NPs at 100Hz*

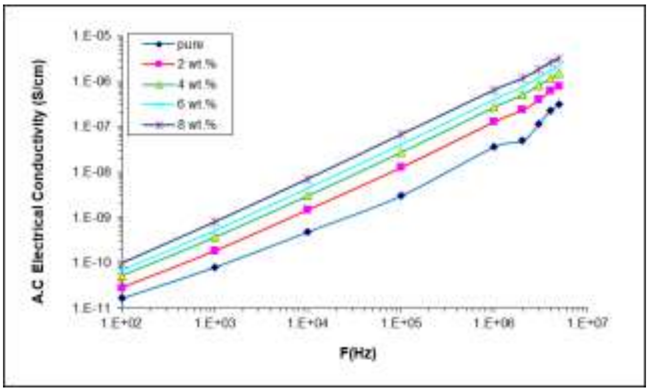

Figure 6. *Variance of the $\sigma_{A.C}$ with frequency (Hz) for (PVA/Bi_2O_3/SiO_2) nanocomposites*

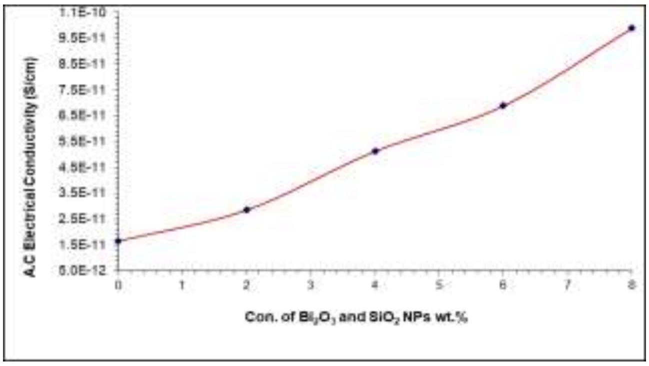

Figure 7. *Variance of $\sigma_{A.C}$ with content of Bi_2O_3/SiO_2 NPs at 100Hz*

and the movement of ions. Figure 7 illustrates those elevated concentrations of Bi_2O_3/SiO_2 nanoparticles lead to an increase in the **o**$\boldsymbol{\sigma_{A.C}}$. This phenomenon arises from an increase in the amount of ionic charge carriers, along with the founding of a continuous network of Bi_2O_3/SiO_2 NPs embedded within the polymer matrix. XRD is used in different applications [27,28.] The outcomes align with previous findings [29].

4. Conclusion

This study provides a clear summary of an effective casting technique used in the production of (PVA/Bi_2O_3/SiO_2) nanocomposites. The XRD results revealed that PVA exhibited an amorphous nature, which transformed into a polycrystalline structure with the incorporation of high loading (8 wt.%) Bi_2O_3 and SiO_2 nanoparticles. The insulator constant and loss of the PVA/Bi_2O_3/SiO_2nanocomposite decreased with frequency and rose with nanoparticle content. A.C. conductivity of the PVA/Bi_2O_3/SiO_2 nanocomposite increases with nanoparticle frequency and concentration. Ultimately, this result indicates that the (PVA/Bi_2O_3/SiO_2) nanocomposites are suitable for electronic applications.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.
- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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