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Fabrication and Tailored Dielectric Characteristics of ZrO_2–Sb_2O_3-Nanoparticles-Doped PVA for Electronics Applications

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Polymer-nanocomposites' films have numerous applications in various fields due to their few cost, lightweight, and good chemical and physical properties. The current study aims to investigate of dielectric properties of PVA–ZrO_2–Sb_2O_3 nanocomposites at frequency range from 100 Hz to 5 MHz. The results demonstrate that the dielectric constant, dielectric loss, and A.C. electrical conductivity of PVA are increased with increasing the ZrO_2–Sb_2O_3-nanoparticles' content. The dielectric constant and dielectric loss of PVA–ZrO_2–Sb_2O_3 nanocomposites are reduced, while the A.C. electrical conductivity is increased with rising frequency. The obtained results exhibited that the PVA–ZrO_2–Sb_2O_3 nanocomposites can be considered as promising nanomaterials to apply various electronics applications.

Полімерні нанокомпозитні плівки мають численні застосування в різних галузях завдяки своїй низькій вартості, легкій вазі та добрим хемічним і фізичним властивостям. Метою цього дослідження є вивчення діелектричних властивостей нанокомпозитів ПВС–ZrO_2–Sb_2O_3 в діапазоні частот від 100 Гц до 5 МГц. Результати показали, що діелектрична проникність, діелектричні втрати та змінна електропровідність полівінілового спирту збільшувалися зі збільшенням вмісту наночастинок ZrO_2–Sb_2O_3. Діелектрична проникність і діелектричні втрати нанокомпозитів ПВС–ZrO_2–Sb_2O_3 зменшувалися, тоді як змінна електропровідність збільшувалася зі зростанням частоти. Одержані результати показали, що нанокомпозити ПВС–ZrO_2–Sb_2O_3 можна розглядати як перспективні наноматеріяли для застосування в різних електронних пристроях.

Key words: PVA, ZrO_2–Sb_2O_3, nanocomposites, dielectric properties, electronics applications.

Ключові слова: полівініловий спирт, ZrO_2–Sb_2O_3, нанокомпозити, діелектричні властивості, застосування в електроніці.

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1. INTRODUCTION

Polymeric materials are used instead of traditional materials because they are cheap, light, and have the proper physical and chemical properties. The performance properties of polymer composites are superior to those of individual polymers. It is simple to modify the microstructural, electrical, mechanical, and other properties of polymers by adding nanofillers into the polymer matrices in varying amounts. Modified polymer composites are significantly affected by the size, shape, concentration, and interfacial contact with nanoparticles (NPs). The strength of the bonds between polymer and nanoparticles is an important consideration for composite material performance [1].

Inorganic particles embedded in the polymer matrix have been found to increase the density, mechanical, magnetic, redox, electronic, and thermal properties of the material. These properties depend on the shape, size, adhesion of particle–matrix interfaces, and filler content in the polymer matrix of the nanocomposites (NCs). Metal oxide nanoparticles have been found to be effective for potential applications in photocatalysis [2].

The surface of the nanoscale metal oxides provides vacancies' orbitals to interact with the host polymers that leads to charge transfer between them. The characteristics of individual polymeric nanocomposites are affected by the structure of the components, the content and shape of the nanometal oxides, the morphology of the composites, in addition to the nature of interactions at the interfaces between components in the NCs. Therefore, the improvement of such properties and interfacial interactions between polymers and nanometal oxides acquire a role in decorated the optoelectrical properties of polymeric nanocomposites.

In this article, the authors have focused on the effect and role of different nanometal oxides in the modification of the optical and electrical properties of host polymers to be suitable for optoelectronic and industrial applications [3].

ZrO_2 is a technologically important material due to its superior hardness, high refractive index, optical transparency, chemical stability, photothermal stability, high thermal-expansion coefficient, low thermal conductivity, high thermomechanical resistance, and high corrosion resistance. These unique properties of ZrO_2 have led to their widespread applications in the fields of optical, structural materials, solid-state electrolytes, gas-sensing, thermal barriers coatings, corrosion-resistant materials, catalysts [4].

Antimony oxide (Sb_2O_3) has a wide band gap of 3.4 eV that is widely used in various applications as catalyst, flame retardant, optoelectronic and photoelectric devices. The photocatalytic activity of pure Sb_2O_3 is low due to high band gap ($E_g = 3.4$ eV) [5].

A polar organic polymer such as polyvinyl alcohol (PVA) has received a lot of interest in recent years due to its highly transparent, mechanical flexibility, affordable, non-toxic, high-biocompatibility, and good storage properties as well as strong chemical and thermal stabilities [6]. The nanoparticles-doped polymers comprised of great applications for a variety of fields like optical, optoelectronics, and electronics approaches [7–31].

The current work aims to investigate of dielectric properties for PVA–ZrO_2–Sb_2O_3 nanocomposites to use in different electronics applications.

2. MATERIALS AND METHODS

The nanocomposites films of PVA doped with ZrO_2–Sb_2O_3 nanoparticles were fabricated *via* dissolving of 0.5 gm PVA in 30 ml of distilled water by using magnetic stirrer to mix the polymer for 1 hour to obtain solution that is more homogeneous. The ZrO_2 and Sb_2O_3 nanoparticles were added to PVA with different contents of 2.2%, 4.4% and 6.6% at constant ratio 1:1. The casting process was used to prepare the PVA–ZrO_2–Sb_2O_3-nanocomposites' films. The dielectric properties of PVA–ZrO_2–Sb_2O_3-nanocomposites' films were tested at frequency ranged between 100 Hz and $5\cdot10^6$ Hz using LCR meter type (HIOKI 3532-50 LCR HI TESTER).

The dielectric constant (ε') is given by [32]

$$\varepsilon' = C_p/C_0, \tag{1}$$

where C_p is the matter capacitance, C_0 is the vacuum capacitance.

Dielectric loss (ε'') is determined by [33]

$$\varepsilon'' = \varepsilon' D, \tag{2}$$

where D is the dispersion factor.

The A.C. electrical conductivity is found by [34]

$$\sigma_{A.C.} = 2\pi f \varepsilon' D \varepsilon_0. \tag{3}$$

3. RESULTS AND DISCUSSION

The variation of dielectric constant and dielectric loss for PVA–ZrO_2–Sb_2O_3 nanocomposites with frequency and ZrO_2–Sb_2O_3-NPs' content are shown in Figs. 1–4.

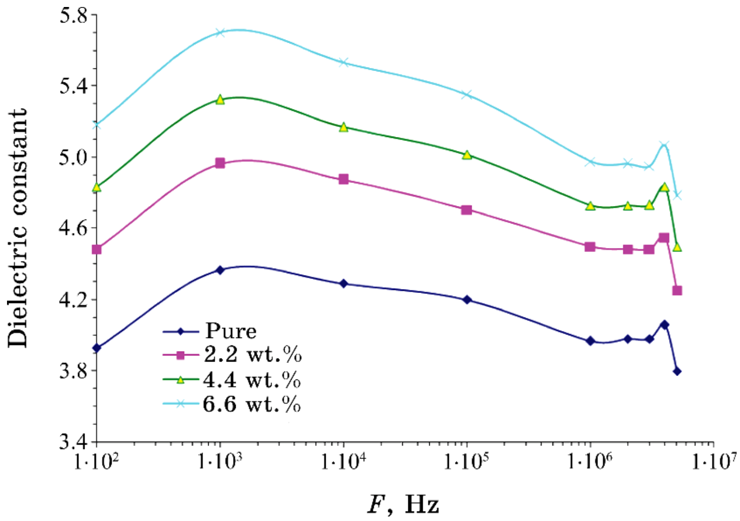

Fig. 1. Variation of dielectric constant for PVA–ZrO_2–Sb_2O_3 nanocomposites with frequency.

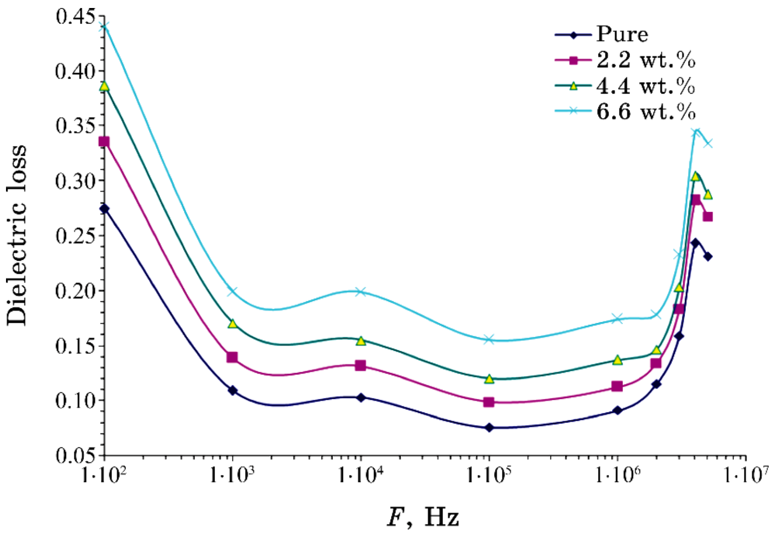

Fig. 2. Behaviour of dielectric loss for PVA–ZrO_2–Sb_2O_3 nanocomposites with frequency.

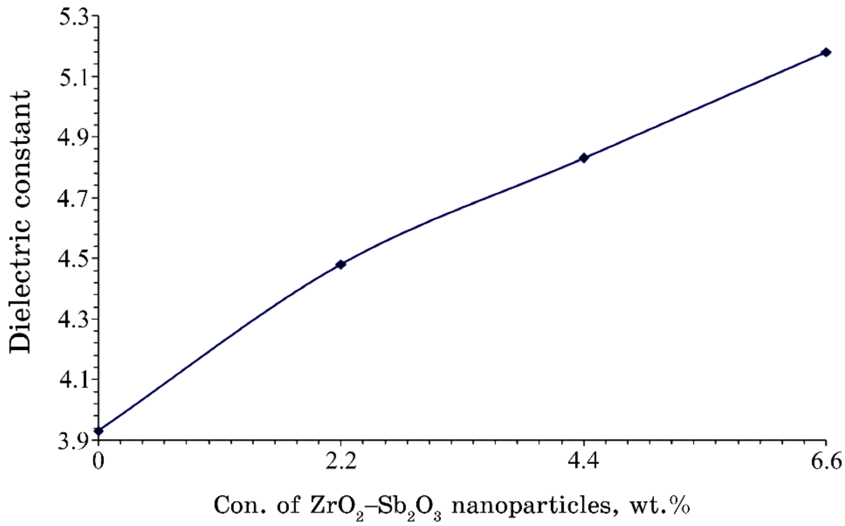

Fig. 3. Dielectric constant variation for PVA with ZrO_2–Sb_2O_3-NPs' content.

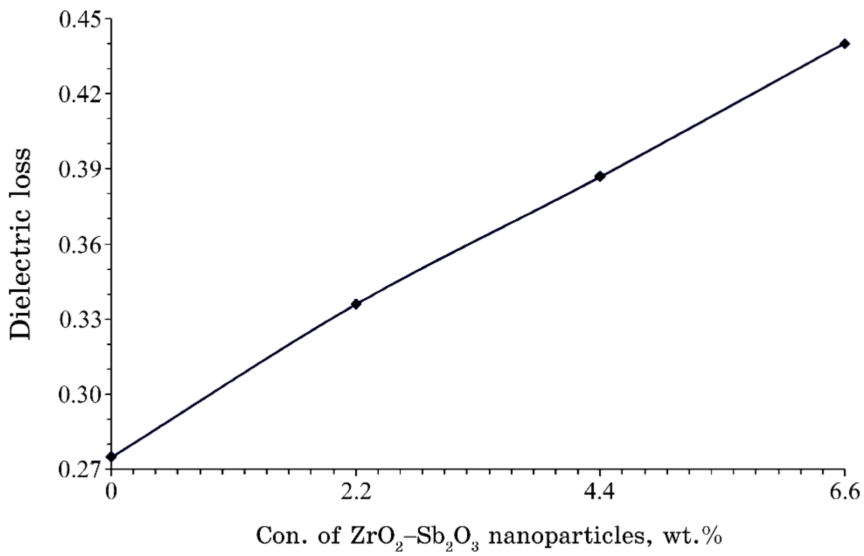

Fig. 4. Behaviour of dielectric loss for PVA with ZrO_2–Sb_2O_3-NPs' content.

The dielectric constant and dielectric loss of PVA increase with increasing ZrO_2–Sb_2O_3-NPs' content; this is due to increase in the number of charges' carriers. The elevated values of dielectric constant and dielectric loss at low frequencies were assigned to the availability of enough time for the dipoles to interact with the fields before it changes, while dielectric constant and dielectric loss values' decrease at high frequencies relate to the short time available to them [35–45].

Figures 5 and 6 illustrate behaviour of A.C. electrical conductivity for PVA–ZrO_2–Sb_2O_3 nanocomposites with frequency and ZrO_2–

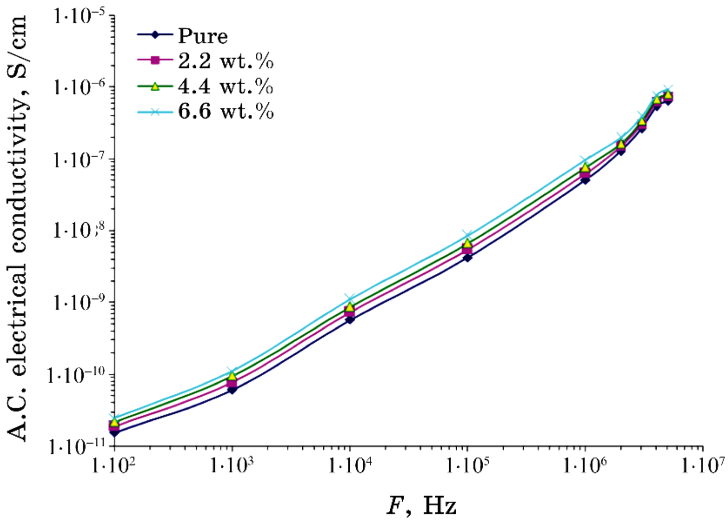

Fig. 5. Behaviour of A.C. electrical conductivity for PVA–ZrO_2–Sb_2O_3 nanocomposites with frequency.

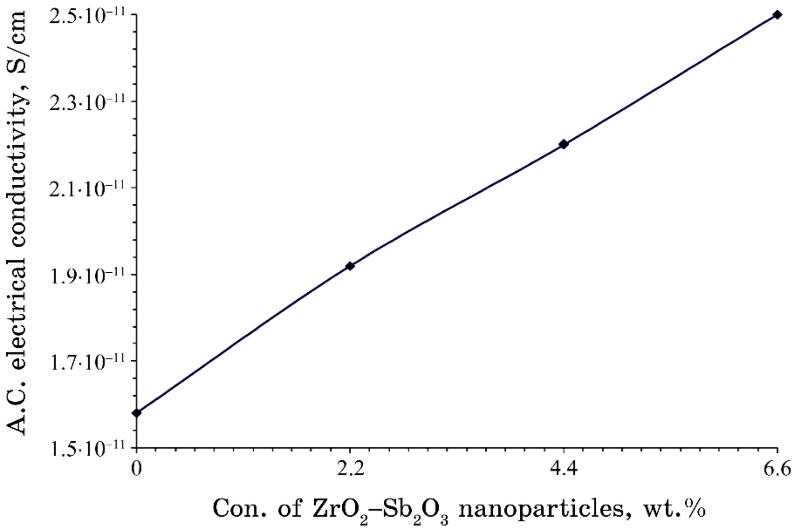

Fig. 6. Performance of A.C. electrical conductivity for PVA with ZrO_2–Sb_2O_3-NPs' content.

Sb_2O_3-NPs' content, respectively. The A.C. conductivity rises with increasing ZrO_2–Sb_2O_3-NPs' content. In all samples, the conductivity increases with frequency. The bonds are designed to switch at high frequencies, resulting in a dielectric transition with vulnerable trustworthy polar functional groups, which causes physiological adaptations within the polymer structure *via* the formation of charge transfer complexes, implying increased electrical conductivity of the films.

The rise of A.C. electrical conductivity with nanoparticles' content can be related to increase of charge-carriers' numbers [46–58].

4. CONCLUSIONS

The present work included investigation of dielectric properties for PVA–ZrO_2–Sb_2O_3 nanocomposites to employ in various electronics fields. The results showed that the dielectric constant, dielectric loss, and A.C electrical conductivity of PVA are increased with increasing the ZrO_2–Sb_2O_3-NPs' content. The dielectric constant and dielectric loss of PVA–ZrO_2–Sb_2O_3 nanocomposites are reduced, while the A.C. electrical conductivity is increased with rising frequency. Finally, the obtained results displayed that the PVA–ZrO_2–Sb_2O_3 nanocomposites can be suitable for various electronics applications.

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