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Exploring the Dielectric Properties of Fe_2O_3–In_2O_3 Nanocomposites for Electrical and Electronics Applications

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Nanocomposites' films of pure PVA and PVA doped with Fe_2O_3–In_2O_3 nanoparticles (NPs) are fabricated to utilize in numerous electrical and electronic applications. The dielectric properties at frequency ranged from 100 Hz to 5 MHz are tested for PVA–Fe_2O_3–In_2O_3 nanocomposites. Results show the improving dielectric constant, dielectric loss and electrical conductivity of PVA with adding various ratios of Fe_2O_3–In_2O_3 NPs. The dielectric constant and dielectric loss of fabricated nanocomposites are reduced, while the electrical conductivity is increased, when frequency rises. Finally, the dielectric-properties' results demonstrate that the PVA–Fe_2O_3–In_2O_3 nanocomposites may be applied in various electrical and electronics applications.

Нанокомпозитні плівки з чистого полівінілового спирту (ПВС) та полівінілового спирту, допованого наночастинками (НЧ) Fe_2O_3–In_2O_3, було виготовлено для використання в численних електричних та електронних застосуваннях. Для нанокомпозитів ПВС–Fe_2O_3–In_2O_3 перевіряли діелектричні властивості в діяпазоні частот від 100 Гц до 5 МГц. Результати показали поліпшення діелектричної проникности, діелектричних втрат та електропровідности ПВС із додаванням різних співвідношень НЧ Fe_2O_3–In_2O_3. Діелектрична проникність і діелектричні втрати виготовлених нанокомпозитів зменшуються, а електропровідність підвищується, коли частота зростає. Нарешті, результати стосовно діелектричних властивостей показали, що нанокомпозити ПВС–Fe_2O_3–In_2O_3 можуть бути застосовні в різних електричних та електронних застосуваннях.

Key words: polyvinyl alcohol (PVA), Fe_2O_3–In_2O_3, nanocomposites, dielectric properties, conductivity.

Ключові слова: полівініловий спирт, Fe_2O_3–In_2O_3, нанокомпозити, діелектричні властивості, електропровідність.

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1. INTRODUCTION

Nanocomposite materials have been a major area of research interest owing to their distinct electrochemical properties that differ significantly from those of their constituent components. Similarly, devices based on polymer nanocomposites have received an enormous attention owing to their ability to solve both energy and environmental problems [1]. Recently, oxide-based transparent conducting thin films have attracted much attention due to their wide applications in transparent thin-film transistors (TFTs), light-emitting diodes, solar cells, gas sensors, transparent display. In particular, In_2O_3 has several advantages for transparent electronic applications, because it has a high optical transparency, a low electrical resistivity of the order of 10^{-4} Ω·cm and a wide band gap of 3.7 eV [2].

Fe_2O_3 NPs have special properties like good electron mobility, magnetic ability, and a 2.2 eV optical-energy band gap, which are useful for optoelectronic applications. Fe_2O_3 NPs have potential applications in the fields of medicine, life sciences and computer technology like magnetic resonance imaging (MRI), drug carriers in delivery, gene carriers in gene therapy, nanofertilizers, non-fungicides, nanopesticides, nanofood, food packing, nanocoating, nanosensors, nanoscale memory, nanowires, spintronics etc. They can be used as filters in sunscreens, biosensors [3].

As one of the biodegradable polymers, polyvinyl alcohol (PVA) is a non-toxic, water-soluble, semi-crystalline synthetic biopolymer with excellent film-forming, emulsifying, and adhesive properties. It has a wide range of uses in fields such as pharmacology, food chemistry, biomedicine, biotechnology, paper coatings, and the production of water-soluble flexible packaging films. In recent studies, it has been reported that PVA is a safe material for food packaging because it is made from renewable resources and is environmentally friendly [4]. The properties of polymers may be improved by adding of various materials into polymers that caused to improve the optical properties, electronic properties and electrical properties [5–39].

The present work aims to prepare of nanocomposites films from pure PVA and PVA doped with Fe_2O_3–In_2O_3 nanoparticles to utilize in numerous electrical and electronic applications.

2. MATERIALS AND METHODS

The PVA–Fe_2O_3–In_2O_3 nanocomposites films were prepared from pure PVA and PVA doped with Fe_2O_3–In_2O_3 nanoparticles using casting method. The PVA film was fabricated by dissolving of 0.5 gm PVA in 30 ml of distilled water employing magnetic stirrer for 1 hour to obtain more homogeneous solution. The Fe_2O_3–In_2O_3 NPs were added to polymer solution by a variety of contents are 1%, 2% and 3% with concentration of 1:1. The dielectric properties of PVA–Fe_2O_3–In_2O_3 nanocomposites were tested different frequency ranged between 100 Hz and $5\cdot10^6$ Hz utilizing LCR meter type (HIOKI 3532-50 LCR HI TESTER).

The dielectric constant (ε') was found by [40] as follows:

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

where C_p is the material capacitance and C_0 is the vacuum capacitance.

Dielectric loss (ε'') was calculated by [41] as follows:

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

where D is the dispersion factor.

The A.C. electrical conductivity was given by [42] as follows:

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

3. RESULTS AND DISCUSSION

The performance of dielectric constant and dielectric loss for PVA–Fe_2O_3–In_2O_3 nanocomposites with frequency and Fe_2O_3–In_2O_3 NPs content are represented in Figs. 1–4, respectively. The dielectric constant and loss behaviour in the given frequency range as the following, the strong frequencies dispersion of the permittivity is seen at low range of frequency. The values of dielectric constant and loss are reduced with rise of frequency related to the relaxation process and may be attributed to charge accumulation inside the nanocomposites due to influence of interfacial polarization on permittivity. With addition of the filler, the values of both dielectric constant and loss are increased at the range of lower frequency and nearly the same at the range of the higher frequency attributed to the filler cause more localization of charge carriers along with mobile ions causing higher ionic conductivity. The increase of dielectric constant and dielectric loss with increasing filler content related to rise of charges carriers numbers [43–55].

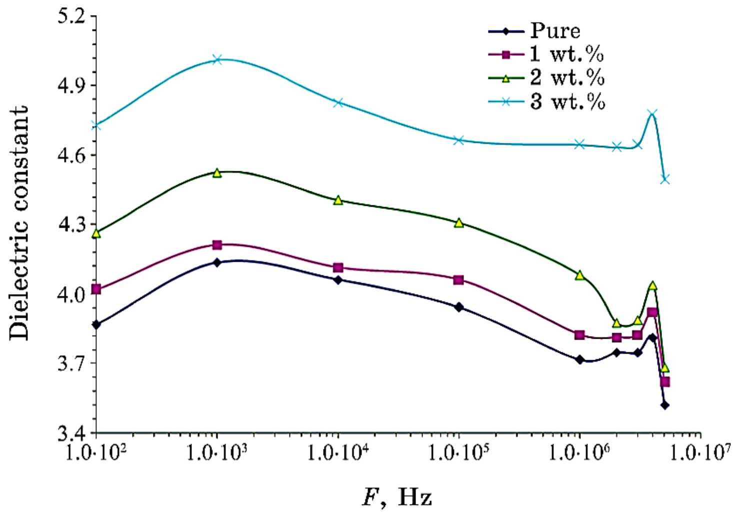

Fig. 1. Variation of dielectric constant for PVA–Fe_2O_3–In_2O_3 nanocomposites with frequency.

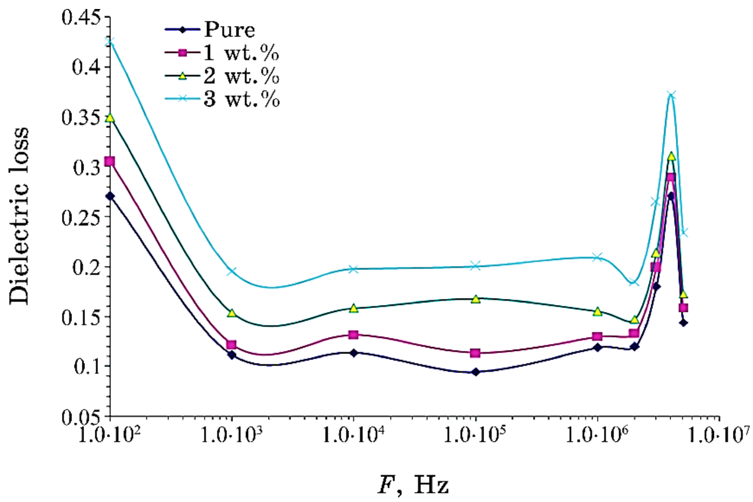

Fig. 2. Performance of dielectric loss for PVA–Fe_2O_3–In_2O_3 nanocomposites with frequency.

Figures 5 and 6 show the variation of A.C. electrical conductivity for PVA–Fe_2O_3–In_2O_3 nanocomposites with frequency and Fe_2O_3–In_2O_3-NPs' concentration, respectively. As shown in these figures, the conductivity increases with increasing of Fe_2O_3–In_2O_3-NPs' concentration. The low frequencies region exhibited dispersion due to spatial charging or interpolarization.

The reduced conductivity at lower frequency was related to decrease number of mobile ions resulting from charged cumulative at polymer interfaces. The electrical conductivity enhancement with Fe_2O_3–In_2O_3-NPs' concentration was because of the increasing the number of dopants, where the Fe_2O_3–In_2O_3-NPs' molecules begin to bridge the gaps between two localized states and lower potential barriers separating them, therefore the transfer of charge carriers is easy between them, according to the percolation theory; there-

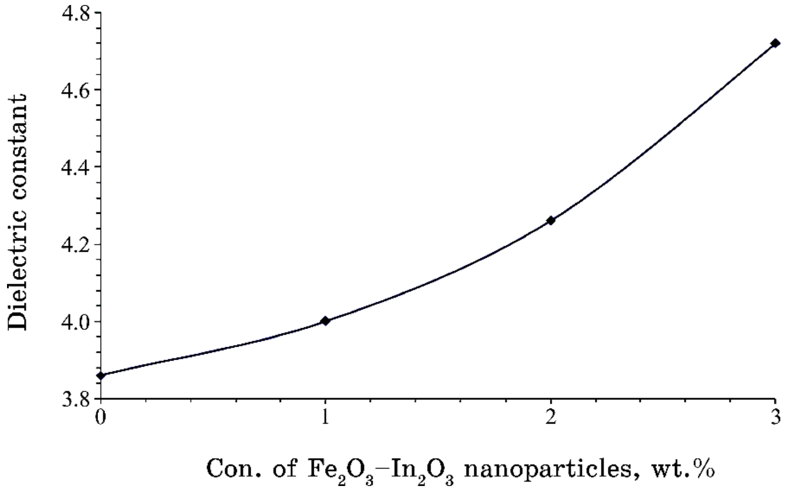

Fig. 3. Effect of Fe_2O_3–In_2O_3 NPs content on dielectric constant for PVA.

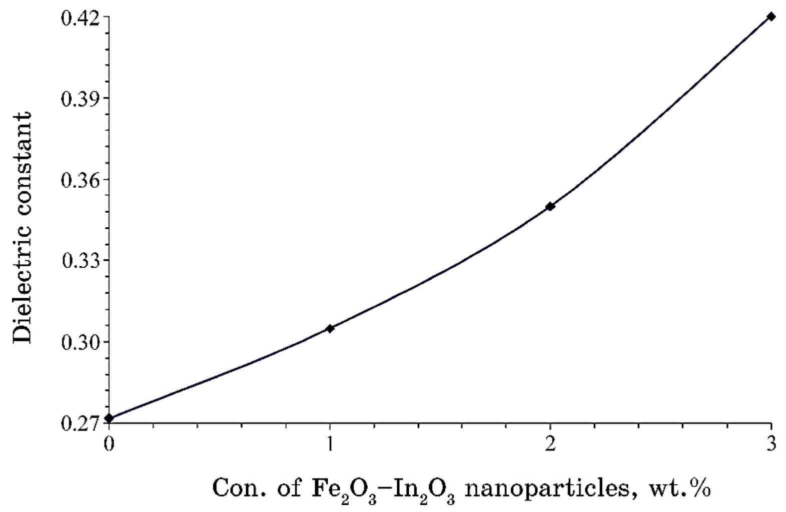

Fig. 4. Effect of Fe_2O_3–In_2O_3 NPs content on dielectric loss for PVA.

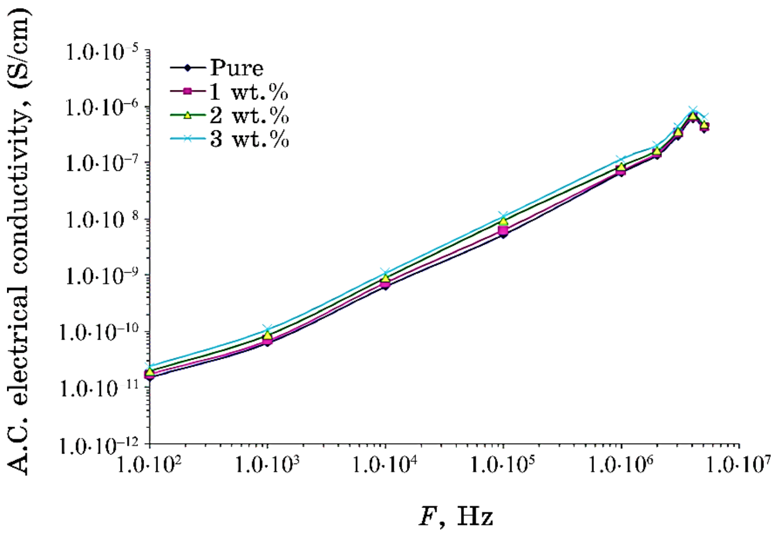

Fig. 5. Variation of A.C. electrical conductivity for PVA–Fe_2O_3–In_2O_3 nanocomposites with frequency.

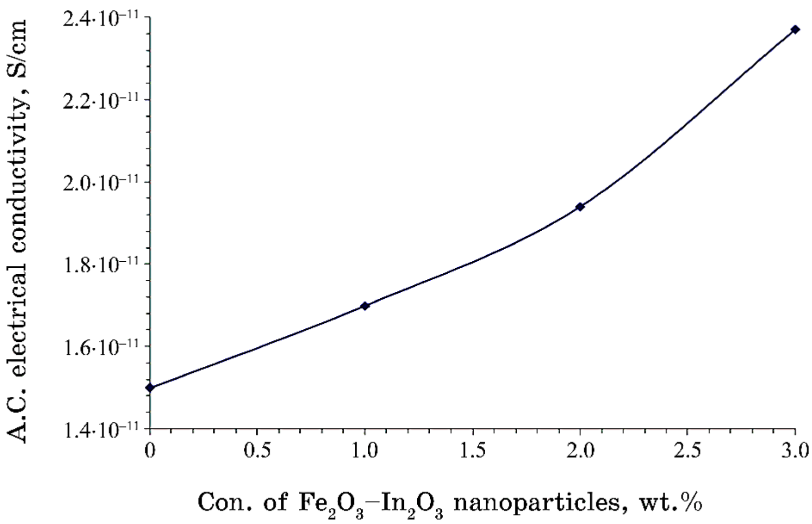

Fig. 6. Behaviour of A.C. electrical conductivity for PVA with Fe_2O_3–In_2O_3-NPs' concentration.

fore, the conductivity increases as a results of increase the number of charges carriers. Moreover, this enhancement is assigned to the higher conductivity of the added Fe_2O_3–In_2O_3 NPs and increased charge mobility, related to the increased amorphous degree inside the doped samples [56–67].

4. CONCLUSIONS

The current work includes fabrication of films from PVA and PVA doped with Fe_2O_3–In_2O_3 NPs to use in different electrical and electronic fields. The dielectric properties for PVA–Fe_2O_3–In_2O_3 nanocomposites were studied. Results showed that the dielectric properties: dielectric constant, dielectric loss and electrical conductivity of PVA are enhanced by adding various ratios of Fe_2O_3–In_2O_3 NPs. The final results of dielectric properties demonstrated that the PVA–Fe_2O_3–In_2O_3 nanocomposites may be useful in many electrical and electronics fields.

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