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Synthesis and Evaluation of Dielectric Characteristics of PVA–CuO–Fe_2O_3 Nanocomposites for Nanoelectronics Fields

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In current study, fabrication of PVA–CuO–Fe_2O_3 nanocomposites with various contents of PVA and CuO–Fe_2O_3 nanoparticles is investigated. The dielectric properties of fabricated nanocomposites are examined at frequency range from 100 Hz to 5 MHz. The results display that the dielectric constant and dielectric loss of PVA–CuO–Fe_2O_3 nanocomposites are reduced, while the electrical conductivity is increased with rising frequency. The dielectric parameters such as dielectric constant, dielectric loss, and electrical conductivity of PVA are increased with increasing CuO–Fe_2O_3 nanoparticles' content. The final results show that the PVA–CuO–Fe_2O_3 nanocomposites could be useful in many nanoelectronics fields.

У даній роботі було досліджено виготовлення нанокомпозитів полівініловий спирт (ПВС)–CuO–Fe_2O_3 з різним вмістом ПВС та наночастинок CuO–Fe_2O_3. Діелектричні властивості виготовлених нанокомпозитів досліджували в діяпазоні частот від 100 Гц до 5 МГц. Результати показали, що діелектрична проникність і діелектричні втрати нанокомпозитів ПВС–CuO–Fe_2O_3 зменшуються, а електропровідність зростає зі збільшенням частоти. Діелектричні параметри, — діелектрична проникність, діелектричні втрати й електропровідність, — ПВС зростали зі збільшенням вмісту наночастинок CuO–Fe_2O_3. Остаточні результати показали, що нанокомпозити ПВС–CuO–Fe_2O_3 можуть бути корисними в багатьох галузях наноелектроніки.

Key words: nanocomposites, PVA, CuO–Fe_2O_3, dielectric constant, conductivity.

Ключові слова: нанокомпозити, полівініловий спирт, $CuO–Fe_2O_3$, діелектрична проникність, електропровідність.

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1. INTRODUCTION

According to the physical and chemical properties and applications in different medical and industrial fields, nanomaterials were attracted the interesting of many investigators. On other hand, nanomaterials have a long axis to absorb incident sunlight; one-dimensional nanostructures were gained attention in solar energy conversion [1]. Dielectrics with high permittivity are widely used in electronic industry. With the advancement of flexible electronics, high permittivity dielectric materials with excellent flexibility are in demand. As compared to conventional dielectrics like ceramics, polymers are widely being used as dielectric materials as polymers exhibit better properties, like relatively high electric breakdown field, processing ease, mechanical flexibility, *etc*. Moreover, their properties can be modified by incorporating inorganic materials into it. Many polymers like PVA, PVP, and PMMA has been studied for their electrical and dielectric properties. However, PVA is the most studied polymeric dielectric material due to its versatile properties like high solubility in water, low cost, easily process able, non-toxicity, good film forming, great insulating properties and the most important high dielectric permittivity. The above properties qualify PVA as a favourable organic material for interlayer dielectrics. PVA is produced by the hydrolysis of polyvinyl acetate that is obtained by polymerization of vinyl acetate monomer [2].

Fe_2O_3 is known as hematite with a rhombohedral crystal structure. Fe_2O_3 is resistant to chemical reactions and temperature, environmentally friendly, widely used in semiconductor applications, and it can absorb light. Fe_2O_3 can be used as a catalyst, gas sensor, solar cell, pigment, and lithium-ion battery [3]. Another metal oxide material is cupric oxide (CuO) which has been substantially explored for various applications. As a *p*-type semiconductor having a narrow band gap of 1.35 eV, it has a great potential for field emitters, catalyst, and gas-sensing devices. The physicochemical properties of CuO such as photoconductivity and photochemistry can be used for the optical switches and the solar cells [4]. Nanocomposites included enormous applications in various fields like sensors [5–13], antibacterial [14–20], optical fields [21–30], electronics and optoelectronics [31–46], energy storage [47–50], radiation shielding and bioenvironmental [51–57], *etc*. The present work deals with fabrication of $PVA–CuO–Fe_2O_3$ nanocomposites to use in nanoelectronics applications.

2. MATERIALS AND METHODS

Nanocomposites films of PVA as a matrix and the $CuO-Fe_2O_3$ nanoparticles (NPs) as an additive were synthesized by dissolving of 0.5 gm PVA in 30 ml of distilled water utilizing magnetic stirrer for 1 hour to obtain more homogeneous solution. The $CuO-Fe_2O_3$ NPs were added to PVA solution by various contents of 1%, 2%, and 3% with constant concentration 1:1. The casting method was employed to fabricate of $PVA-CuO-Fe_2O_3$ nanocomposites. The dielectric characteristics of $PVA-CuO-Fe_2O_3$ nanocomposites were measured with frequency range from 100 Hz to $5\cdot 10^6$ Hz using LCR meter type (HIOKI 3532-50 LCR HI TESTER).

The dielectric constant (ε') was determined by Ref. [58]:

$$\varepsilon' = C_p/C_0, \quad (1)$$

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

Dielectric loss (ε'') was given by Ref. [59]:

$$\varepsilon'' = \varepsilon' D, \quad (2)$$

where D is the dispersion factor.

The A.C. electrical conductivity was found by Ref. [60]:

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

3. RESULTS AND DISCUSSION

The behaviours of dielectric constant and dielectric loss for $PVA-CuO-Fe_2O_3$ nanocomposites with frequency and $CuO-Fe_2O_3$-NPs' content are conformed in Figs. 1–4, respectively. These figures demonstrate that the dielectric constant and dielectric loss have large values at low frequencies. The interfacial effects present in the majority of the sample and the electrode effects might both be responsible for the high values of dielectric constant and dielectric loss. It can be observed that for all frequency ranges, the values of dielectric constant and dielectric loss for $PVA-CuO-Fe_2O_3$ nanocomposites are increased with increasing $CuO-Fe_2O_3$-NPs' content. The increase of dielectric constant and dielectric loss values can be related to raise in the numbers of charges carriers [61–73].

Figures 5 and 6 display the variation of A.C. electrical conductiv-

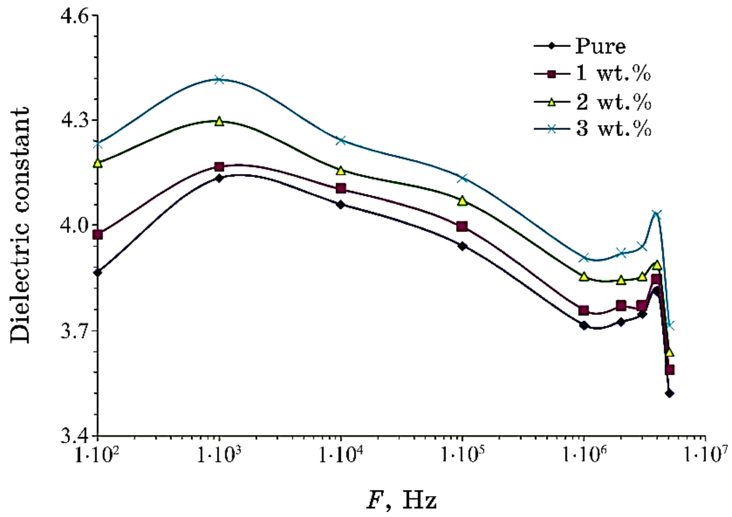

Fig. 1. Behaviour of dielectric constant for PVA–CuO–Fe_2O_3 nanocomposites with frequency.

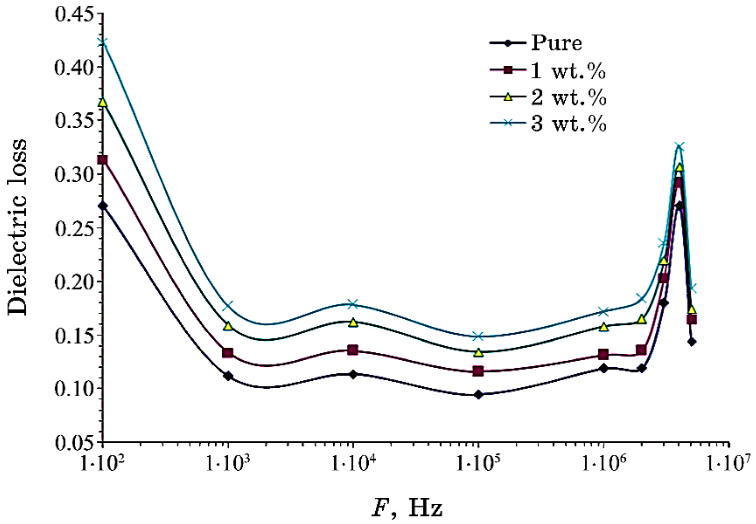

Fig. 2. Dielectric-loss performance for PVA–CuO–Fe_2O_3 nanocomposites with frequency.

ity for PVA–CuO–Fe_2O_3 nanocomposites with frequency and CuO–Fe_2O_3-NPs' content, respectively. These figures showed that the A.C. electrical conductivity increases with an increase in the frequency and CuO–Fe_2O_3-NPs' content.

It was also observed that the A.C. electrical conductivity values

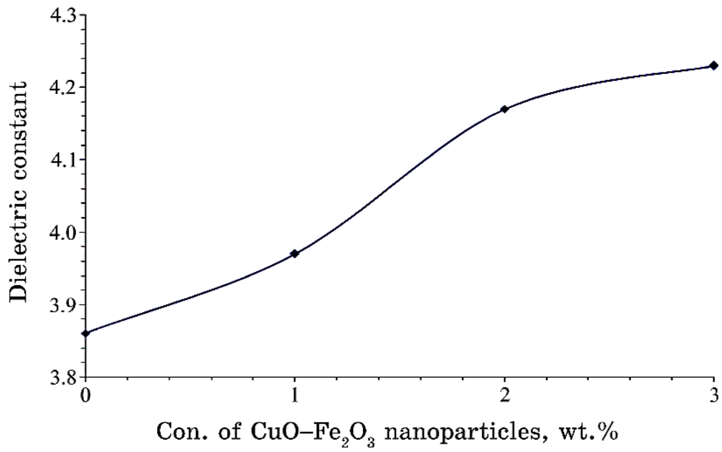

Fig. 3. Behaviour of dielectric constant for PVA with $CuO–Fe_2O_3$-NPs' content.

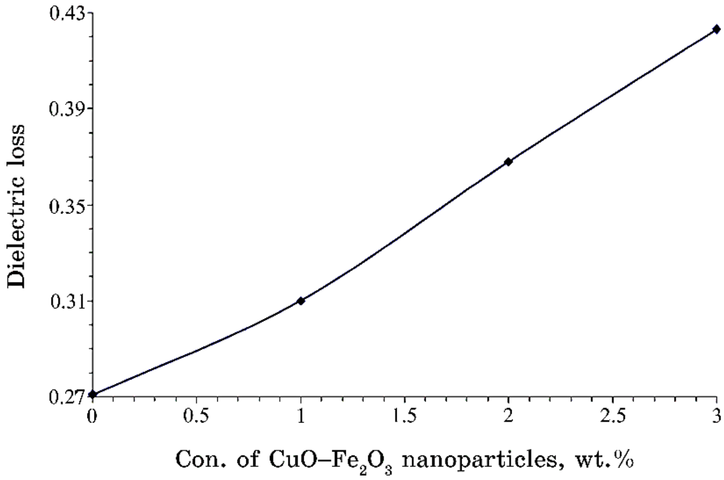

Fig. 4. Performance of dielectric loss for PVA with $CuO–Fe_2O_3$-NPs' content.

are increased as the content of $CuO–Fe_2O_3$ NPs increased into PVA medium. The increase of electrical conductivity attributed to increase the mobility and charges carriers numbers. Moreover, these observations might be related to space-charge polarization [74–85].

4. CONCLUSIONS

In this work, PVA–$CuO–Fe_2O_3$ nanocomposites have been prepared.

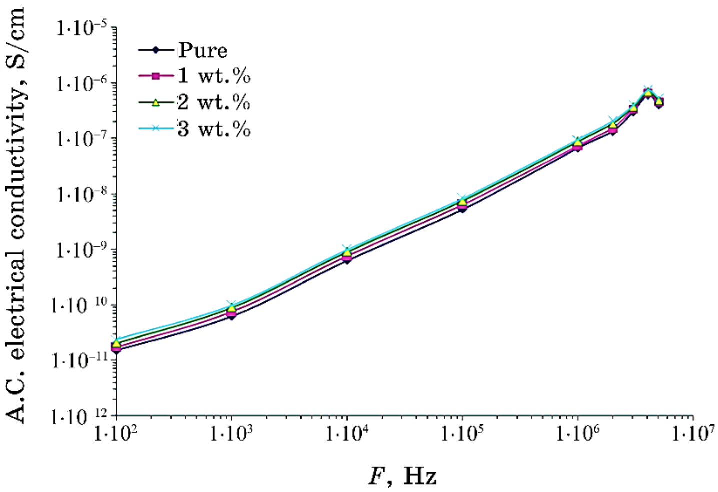

Fig. 5. Variation of A.C. electrical conductivity for PVA–CuO–Fe_2O_3 nanocomposites with frequency.

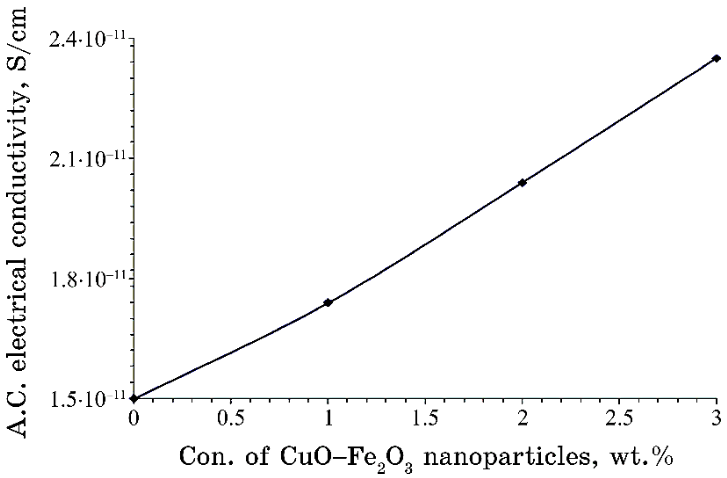

Fig. 6. Behaviour of A.C. electrical conductivity for PVA with CuO–Fe_2O_3-NPs' content.

The dielectric properties of PVA–CuO–Fe_2O_3 nanocomposites are tested. The experimental results confirmed that the dielectric parameters such as dielectric constant, dielectric loss, and electrical conductivity of PVA are increased with increasing CuO–Fe_2O_3-NPs' content. The dielectric constant and dielectric loss of PVA–CuO–Fe_2O_3 nanocomposites are decreased, while the electrical conductivity is increased with increasing frequency.

Finally, results of dielectric properties show that the PVA–CuO–Fe_2O_3 nanocomposites may be suitable in several nanoelectronics applications.

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