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Augmented Dielectric Properties of PVA/Si₃N₄/CoFe₂O₄ Nanocomposites for Electronic Nanodevices

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This study investigates the fabrication of new polyvinyl alcohol (PVA)–silicon nitride (Si₃N₄)–cobalt ferrite (CoFe₂O₄) nanocomposites to use them in various electrical and electronics fields. The dielectric properties of PVA–Si₃N₄–CoFe₂O₄ nanocomposites are examined in frequency range from 100 Hz to 2 MHz. The results indicate that the dielectric constant and dielectric loss of PVA–Si₃N₄–CoFe₂O₄ nanocomposites are reduced, while the electrical conductivity is increased with increasing of the frequency. The dielectric constant, dielectric loss, and electrical conductivity of PVA are raised with rising of the Si₃N₄–CoFe₂O₄-nanoparticles' content. The obtained results of dielectric properties demonstrate that the PVA–Si₃N₄–CoFe₂O₄ nanocomposites are useful for different electrical and electronics fields.

Це дослідження стосується виготовлення нових нанокompозитів на основі полівінілового спирту (ПВС)–нітриду Силіцію (Si₃N₄)–фериту Кобальту (CoFe₂O₄) для використання в різних галузях електротехніки та електроніки. Діелектричні властивості нанокompозитів ПВС–Si₃N₄–CoFe₂O₄ досліджували в діапазоні частот від 100 Гц до 2 МГц. Результати показали, що діелектрична проникність і діелектричні втрати нанокompозитів ПВС–Si₃N₄–CoFe₂O₄ зменшуються, тоді як електропровідність збільшується зі збільшенням частоти. Діелектрична проникність, діелектричні втрати й електропровідність ПВС зростають зі збільшенням вмісту наночастинок Si₃N₄–CoFe₂O₄. Одержані результати дослі-

дження діелектричних властивостей продемонстрували, що нанокompозити ПВС– Si_3N_4 – CoFe_2O_4 є корисними для різних галузей електротехніки й електроніки.

Key words: polyvinyl alcohol (PVA), Si_3N_4 , CoFe_2O_4 , nanocomposites, dielectric properties, conductivity.

Ключові слова: полівініловий спирт (ПВС), Si_3N_4 , CoFe_2O_4 , нанокompозити, діелектричні властивості, провідність.

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1. INTRODUCTION

Polymer matrix composites are used in various fields, such as automotive, aircraft, aerospace, and marine machinery, due to their exceptional mechanical and physical properties. Polymeric composites have replaced conventional metal parts in ships because they are lightweight and wear-resistant [1–4]. Poly(vinyl alcohol) (PVA) is a semi-crystalline, water-soluble, environmentally friendly biopolymer that is produced nowadays on a large scale. It has a hydrophilic nature and exhibits good processability, film forming abilities, flexibility, high transparency, non-toxicity, excellent tensile strength, and good thermal stability (200°C) for applications, which do not require higher temperatures for optimal functionality of the material and interesting dielectric properties as was described in certain studies [5]. PVA $[(\text{C}_2\text{H}_4\text{O})_n]$ is an exciting polymer due to its physical, chemical, mechanical, and thermal characteristics. Moreover, PVA has particular features such as semi-crystalline, adhesive properties, and water-soluble. It is suitable for a wide range of scientific, biomedical, and technological applications [6]. Among the fillers, ferrimagnetic materials, such as cobalt ferrite (CoFe_2O_4), are characterized by permanent magnetization, raised coercivity, heat stability, good dielectric features, and moderate hardness; however, the research regarding the implication of the CoFe_2O_4 -loading on the physical properties of a polymer matrix is not so abundant [7]. Silicon nitride (Si_3N_4) is amid the mainly significant ceramic substances for elevated-temperature fields as a result of combination of its mechanical characteristics at the room and elevated temperatures, resistance for oxidation, low thermal-expansion coefficient, and low density compared of refractory metals [8]. The nanostructures materials were added to improve the optical, electrical, and electronics properties to employ in different fields like sensors [9–15], electronics and optoelectronics [16–31].

The present work deals with fabrication of PVA– Si_3N_4 – CoFe_2O_4

nanocomposites and studying their dielectric constant to employ in different electrical and electronic applications.

2. MATERIALS AND METHODS

The PVA–Si₃N₄–CoFe₂O₄-nanocomposites' films have been prepared employing casting technique. The film of pure PVA was prepared by dissolving of 1 gm in 30 ml of distilled water. Then, the Si₃N₄–CoFe₂O₄ nanoparticles (NPs) were added to polymer (PVA) with ratio 1:1 and various concentrations of 2.1, 4.2 and 6.3 wt.%.

The dielectric properties were examined in frequency range from 100 Hz to 2 MHz by LCR meter type (HIOKI 3532-50 LCR HI TESTER).

The dielectric constant, ε' , is defined by Ref. [32] as

$$\varepsilon' = \frac{C_p}{C_0}, \quad (1)$$

where C_p is the matter capacitance and C_0 is the vacuum capacitor.

The dielectric loss, ε'' , is determined by Ref. [33] as

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

where D represents the dispersion factor.

The A.C. conductivity is given by Ref. [34] as follows:

$$\sigma_{A.C.} = \omega \varepsilon'' \varepsilon_0, \quad (3)$$

where ω is the angular frequency.

3. RESULTS AND DISCUSSION

Figures 1 and 2 show the variation of dielectric constant and dielectric loss for PVA–Si₃N₄–CoFe₂O₄ nanocomposites with frequency of applied field for different contents of Si₃N₄–CoFe₂O₄ nanoparticles. The behaviour of the dielectric properties concerns the increasing values of dielectric constant and dielectric loss. It has been observed that the provided attitude leads to an enhancement in the conductivity of the films. This is attributed to the increase in carrier concentration and mobility.

Additionally, the rise in dielectric constant and dielectric loss in the lower-frequency region is ascribed to the effect of polarization on the films. The dielectric constant and dielectric loss of PVA were rising with rising of the Si₃N₄–CoFe₂O₄-nanoparticles' content. These behaviours are related to increase the density of carriers'

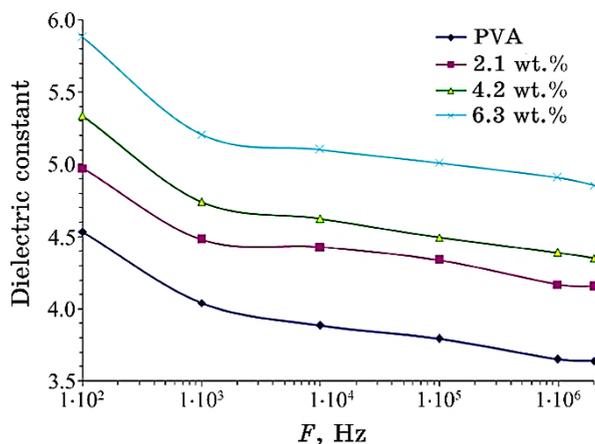


Fig. 1. Variation of dielectric constant for PVA-Si₃N₄-CoFe₂O₄ nanocomposites with frequency.

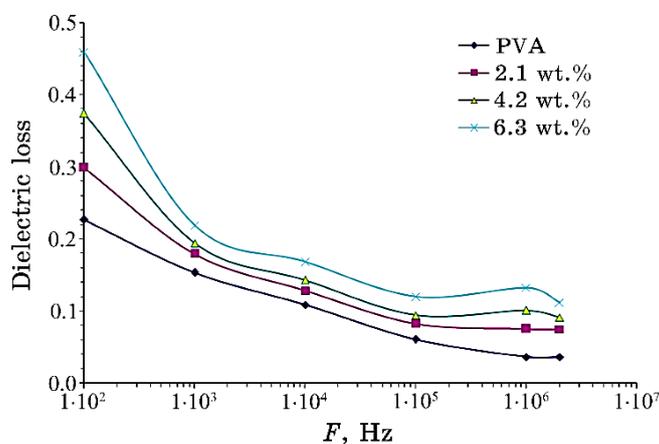


Fig. 2. Variation of dielectric loss for PVA-Si₃N₄-CoFe₂O₄ nanocomposites with frequency.

numbers [35–50].

Figure 3 demonstrates the performance of A.C. electrical conductivity for PVA-Si₃N₄-CoFe₂O₄ nanocomposites with frequency for various contents of Si₃N₄-CoFe₂O₄ nanoparticles. The conductivity has low values at low frequencies that could be related to spatial charge polarization, suggesting non-Debye properties of the films. The conductivity value increases, when the frequency is increased. Furthermore, the conductivity values of the PVA-Si₃N₄-CoFe₂O₄ nanocomposites were found to be greater than those are for PVA, that implying the insertion of Si₃N₄-CoFe₂O₄ NPs into the PVA

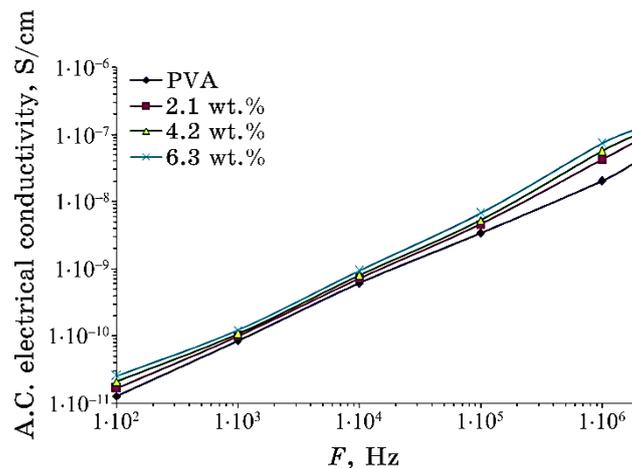


Fig. 3. Performance of A.C. electrical conductivity for PVA-Si₃N₄-CoFe₂O₄ nanocomposites with frequency for various contents of Si₃N₄-CoFe₂O₄ nanoparticles.

could enhance significantly rapidly the charge-conduction mechanism. Furthermore, such enhancement may indicate an increase in disorder degree that regulates charge-carriers' movement and obtaining the formation of a linked percolating chain that is suitable for the mechanism of charge transfer [51–64].

4. CONCLUSIONS

The present work comprises fabrication and dielectric properties of PVA-Si₃N₄-CoFe₂O₄ nanocomposites. The results indicate that the dielectric constant and dielectric loss of PVA-Si₃N₄-CoFe₂O₄ nanocomposites were decreased, while the electrical conductivity was increased with increasing frequency. The dielectric constant, dielectric loss, and electrical conductivity of PVA were rising with rising of the Si₃N₄-CoFe₂O₄-nanoparticles' content. The dielectric constant is increased from 4.53 for PVA to 5.88, when Si₃N₄-CoFe₂O₄-nanoparticles' content reached 6.3%. The obtained results of dielectric properties demonstrate that the PVA-Si₃N₄-CoFe₂O₄ nanocomposites are useful for different electrical and electronics fields.

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