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Tailored Dielectric Parameters of PVA/Si_3N_4/SiC Nanostructures for Nanoelectronics Fields

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The present work explores the synthesis of new PVA–Si_3N_4–SiC nanostructures and investigates their dielectric properties to utilize in different nanoelectronics fields. The dielectric properties of PVA–Si_3N_4–SiC nanostructures are tested with frequency ranged in 100 Hz–2 MHz. The results confirm that the dielectric constant and the dielectric loss of PVA–Si_3N_4–SiC nanostructures are decreased, while the electrical conductivity is raised with rising frequency. The dielectric parameters (dielectric constant, dielectric loss, and electrical conductivity) of PVA are enhanced with increasing Si_3N_4–SiC-nanoparticles' content. The final results of dielectric properties for PVA–Si_3N_4–SiC nanostructures exhibit the fabricated nanostructures as suitable for various nanoelectronics applications.

У цій роботі досліджуються синтеза нових наноструктур PVA–Si_3N_4–SiC та їхні діелектричні властивості для використання у різних галузях наноелектроніки. Діелектричні властивості наноструктур PVA–Si_3N_4–SiC було протестовано в діяпазоні частот від 100 Гц до 2 МГц. Результати підтвердили, що діелектрична проникність і діелектричні втрати наноструктур PVA–Si_3N_4–SiC зменшилися, тоді як електропровідність зросла зі зростанням частоти. Діелектричні параметри (діелектрична проникність, діелектричні втрати й електропровідність) PVA поліпшувалися зі збільшенням вмісту наночастинок Si_3N_4–SiC. Остаточні результати дослідження діелектричних властивостей наноструктур PVA–Si_3N_4–SiC показали, що виготовлені наноструктури придатні для

різних застосувань у наноелектроніці.

Key words: PVA, Si_3N_4, SiC, nanostructures, dielectric properties.

Ключові слова: полівініловий спирт, Si_3N_4, SiC, наноструктури, діелектричні властивості.

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1. INTRODUCTION

Polymer materials have fascinated scientists because they are safe, economical, plentiful, and have eco-sustainable properties and extensive application in technical and scientific study. They can be used in optoelectronics, solar cells, UV-filters, coatings, photovoltaics, light-emitting diodes (LEDs), laser production, as well as several other potential applications [1]. Recent research has demonstrated the benefits of using inorganic nanofillers in preparing polymeric nanocomposites. For example, integrating semiconductor materials as nanofillers doped onto polymer membranes has attracted critical attention due to their potential applications in optics and electronics. The high miscibility of these materials on polymeric membranes explains the complexity of their interaction, although it is important to note that adding nanofillers to the polymer matrix can alter the properties of the polymer itself [2–5].

PVA is one of the most promising examples of biodegradable matrix polymers used in mulch films. These polymers have good potential as biodegradable matrices in environmental friendly composites, in comparison to carbon fibres composites or any non-biodegradable, recyclable fillers. PVA is widely used in agricultural mulch films or biodegradable packaging. For many innovative and environmentally conscious manufacturers, composite consisting of PVA, a biopolymer, with natural fibres, that will further improve PVA biodegradability and physical properties, is choice of eco-sustainable materials [6]. Silicon nitride (Si_3N_4) has outstanding physical, mechanical and chemical characteristics involving hardness, fracture toughness and strength at room and high temperatures, which compose them appropriate for employ in many structural fields [7].

Silicon carbide (SiC) is one of major fillers for developed elevated power and elevated temperature electronic fields. SiC has devised in the structural ceramics improvement with elevated behaviour in the materials fabrication that demand a low thermal expansion coefficient and elevated thermal conductivity properties [8]. The nanocomposites were included huge applications in different approaches like optical fields [9–18], antibacterial defence [19–27], *etc*. This study aims to prepare of new PVA–Si_3N_4–SiC nanostructures and examining the dielectric properties to use in altered nanoelectronics applications.

2. MATERIALS AND METHODS

The samples of PVA–Si_3N_4–SiC nanostructures were fabricated with different concentrations of PVA and Si_3N_4–SiC nanoparticles (NPs) using casting method. 1 gm of PVA was dissolved in 30 ml of distilled water to fabricate the pure PVA film. The Si_3N_4–SiC NPs were added to polymer solution with concentration 1:1, and ratios are of 1.3, 2.6 and 3.9 wt.%. The dielectric properties were investigated in the range of frequencies between 100 Hz and 2 MHz by LCR-meter type by means of the HIOKI 3532-50 LCR HI TESTER. The dielectric constant, ε', was calculated by [28]

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

where C_p is the matter capacitance and C_0 is the vacuum capacitance. The dielectric loss, ε'', is determined by [29]

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

where D represents the dispersion factor. The A.C. conductivity is given by [30]

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

where ω is the angular frequency.

3. RESULTS AND DISCUSSION

Figures 1 and 2 display the performances of dielectric constant and dielectric loss, respectively, with frequency for PVA–Si_3N_4–SiC nanostructures with different ratios of Si_3N_4–SiC NPs. The dielectric constant and dielectric loss are increased as the Si_3N_4–SiC-NPs' content increased that is related to rise in the number of charges' carriers. The significant trend of reduced dielectric constants with frequency increases. The high frequency reveals a diminished spatial charge polarization within the binding with an electrode. Moreover, imperfections and deficiencies may exist, causing the loss of the dielectric properties of the polymer. The importance of dielectric constant in electronics and insulating materials is established. However, the dependence on frequency is revealed with the permittivity of dielectric loss. At a high frequency, the dielectric loss permittivity is low; this pattern provides convincing evidence of the

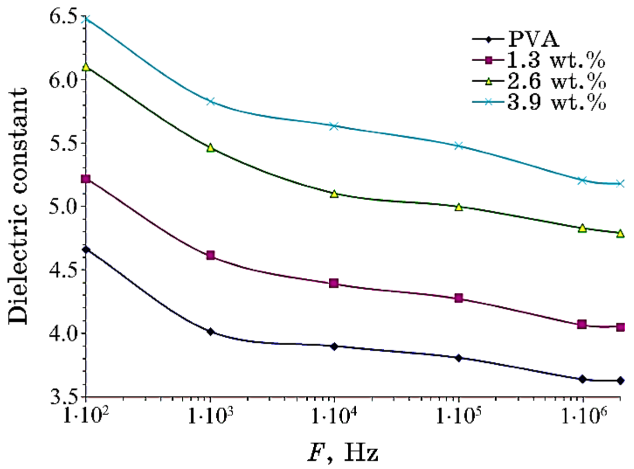

Fig. 1. Performance of dielectric constant with frequency for PVA–Si_3N_4–SiC nanostructures.

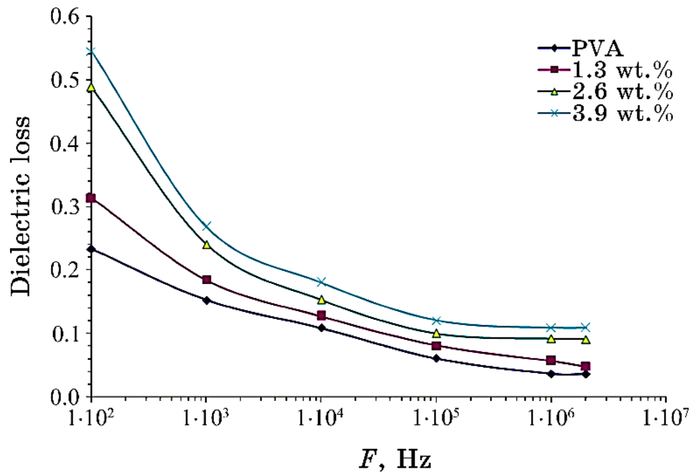

Fig. 2. Variation of dielectric loss with frequency for PVA–Si_3N_4–SiC nanostructures.

minor participation of ionic polarization at this frequency. Meanwhile, the production of the polarization mechanism is discovered at lower frequencies [31–48].

Figure 3 shows the variation of electrical conductivity of PVA–Si_3N_4–SiC nanostructures with frequency for different contents of Si_3N_4–SiC NPs. At elevated frequency, the A.C. conductivity increases due to the excess charges' carriers produced, which are assigned to the trapped charge activation in the polymeric material

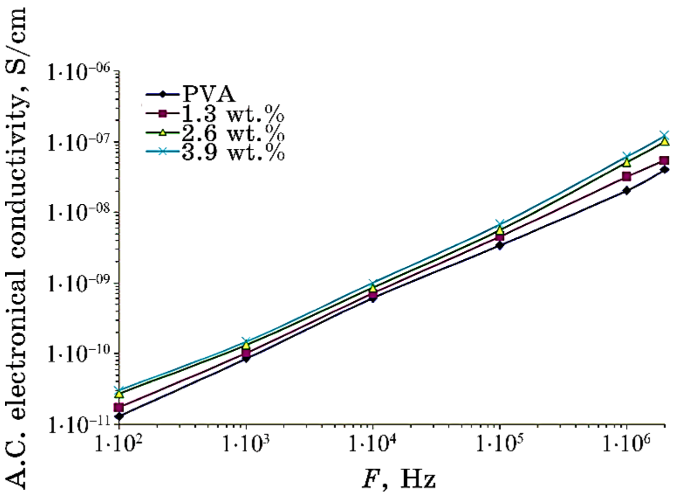

Fig. 3. Behaviour of electrical conductivity of PVA–Si_3N_4–SiC nanostructures with frequency for different contents of Si_3N_4–SiC NPs.

that undergoes localized motion. The highest value of conductivity was at highest content of Si_3N_4–SiC NPs that can be assigned efficient conductive networks created when Si_3N_4–SiC NPs are filling in polymeric medium [49–60].

4. CONCLUSIONS

The current study covered the fabrication of PVA–Si_3N_4–SiC nanostructures to employ in a variety of nanoelectronics fields. The dielectric properties of PVA–Si_3N_4–SiC nanostructures were studied. The results showed that the dielectric parameters (dielectric constant, dielectric loss, and electrical conductivity) of PVA were enhanced with increasing Si_3N_4–SiC-NPs' content. The dielectric constant of PVA is increased by about 28%, when the Si_3N_4–SiC-NPs' content reached to 3.9% at 100 Hz. The dielectric constant and the dielectric loss of PVA–Si_3N_4–SiC nanostructures are decreased, while the electrical conductivity is raised with increasing frequency. The results of dielectric properties for PVA–Si_3N_4–SiC nanostructures exhibited that the fabricated nanostructures are suitable for various nanoelectronics applications.

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