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Augmented Dielectric Properties of PVP/Si_3N_4/Al_2O_3 Nanostructures

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The present study aims to prepare the PVP/Si_3N_4/Al_2O_3 nanostructures to use them in different electrical and electronics fields. The dielectric properties of PVP/Si_3N_4/Al_2O_3 nanostructures are tested. The experimental results illustrate that the dielectric constant (ε') and dielectric loss (ε'') of PVP/Si_3N_4/Al_2O_3 nanostructures decrease, while the electrical conductivity ($\sigma_{A.C.}$) is rising with a rise in the frequency. The dielectric parameters (dielectric constant, dielectric loss, and electrical conductivity) are rising with a rise in the concentration. Finally, the results show that the PVP/Si_3N_4/Al_2O_3 nanostructures can be appropriate in various electronics fields.

Це дослідження спрямовано на підготовку наноструктур полівінілпіролідон/Si_3N_4/Al_2O_3 для використання їх у різних галузях електротехніки й електроніки. Вивчено діелектричні властивості наноструктур полівінілпіролідон/Si_3N_4/Al_2O_3. Результати експерименту показують, що діелектрична проникність (ε') і діелектричні втрати (ε'') наноструктур полівінілпіролідон/Si_3N_4/Al_2O_3 зменшуються, тоді як електропровідність ($\sigma_{A.C.}$) зростає зі збільшенням частоти. Діелектричні параметри (діелектрична проникність, діелектричні втрати й електропровідність) зростають зі збільшенням концентрації. Нарешті, результати показують, що наноструктури полівінілпіролідон/Si_3N_4/Al_2O_3 можуть бути доречними в різних областях електроніки.

Key words: polyvinylpyrrolidone, Si_3N_4/Al_2O_3, nanostructures, dielectric constant, conductivity.

Ключові слова: полівінілпіролідон, Si_3N_4/Al_2O_3, наноструктури, діелектрична проникність, електропровідність.

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1. INTRODUCTION

Polymeric materials are generally insulating or nonconductive materials in nature and normally used in electric and electronic applications as insulators, but likely to accumulate the electronic discharge.

The composites are the wonder materials, which are an essential part of today's materials due to the advantages such as low weight, corrosion resistance, high fatigue strength, and faster assembly. They are extensively used as materials in making aircraft structures, electronic packaging to medical equipment, and space vehicle to home building. The composites offer unusual combinations of materials properties such as weight, strength, stiffness, permeability, electrical, biodegradability and optical properties that is difficult to attain separately by individual components [1].

As the demand for electronics and capacitor devices increases, high dielectric materials have attracted increasing attention.

Polymer materials own advantages of ease of processing, flexibility, and good mechanical properties but the dielectric properties are usually less than satisfactory. Therefore, the preparation of high dielectric composites by introducing high dielectric fillers has become a research hotspot [2]. Polyvinylpyrrolidone (PVP) has a high polar group, low toxicity, biodegradable and amorphous nature with good film properties. It has two interactive sites N atom and C=O group. It acts as a protecting agent with other surfaces of inorganic compounds [3].

Silicon nitride (Si_3N_4) is a highly stable covalent compound with great application value in many fields due to good corrosion resistance and excellent resistance to temperature change. It may be an effective filler to improve the performance of polymer materials [4]. Alumina particles act as barriers to dislocations, and the increase of its content increases hardness, compressive strength and Young's modulus, however, decreases ductility [5].

The nanocomposites have huge applications in different fields like antibacterial [6–11], energy storage [12–14], optical fields [15–24], radiation shielding and bioenvironmental [25–30], electronics and optoelectronics [31–45] sensors [46, 47].

This work deals with preparation of $PVP/Si_3N_4/Al_2O_3$ nanostructures and investigating the A.C. electrical properties to use in various electronics applications.

2. MATERIALS AND METHODS

The materials were used in present work are PVP as matrix with Si_3N_4/Al_2O_3 nanoparticles (NPs) as additive. The PVP/Si_3N_4/Al_2O_3 nanostructures were prepared using casting method with concentrations ($C_1 = 12.5$ gm/L, $C_2 = 25$ gm/L, and $C_3 = 50$ gm/L) and constant ratio of Si_3N_4/Al_2O_3 NPs (6%) with concentration of 50% Al_2O_3 and 50% Si_3N_4. The dielectric properties of PVP/Si_3N_4/Al_2O_3 nanostructures were tested at frequency range (100 Hz–5 MHz) by LCR meter (HIOKI 3532-50 LCR HI TESTER).

The dielectric constant (ε′) was calculated by [48]:

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

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

Dielectric loss (ε″) was found by [48]:

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

where D is the dispersion factor.

The A.C. electrical conductivity was given [49]:

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

3. RESULTS AND DISCUSSION

Figures 1–4 show the variation of dielectric constant (ε′) and dielectric loss (ε″) with frequency and concentration, respectively. The figures show that ε′ and ε″ have large values at low frequencies. The interfacial effects present in the majority of the film and the electrode effects might both be responsible for the high values of ε′ and ε″. It can be observed that for all frequency ranges, the values of ε′ and ε″ for PVP/Si_3N_4/Al_2O_3 nanostructures rise with increasing concentration. The increase of ε′ and ε″ values can be related to raise in the number charges carriers [50–63].

The behaviour of A.C. electrical conductivity for the PVP/Si_3N_4/Al_2O_3 nanostructures with frequency and concentration are shown in Figs. 5 and 6, respectively. From these figures, the conductivity increases with rising of the concentration. The low-frequency region exhibits dispersion due to spatial charging or inter polarization.

In addition, the decrease of conductivity at lower frequency was due to decrease number of mobile ions resulting from charged cumulative at polymer interfaces. The improvement of electrical con-

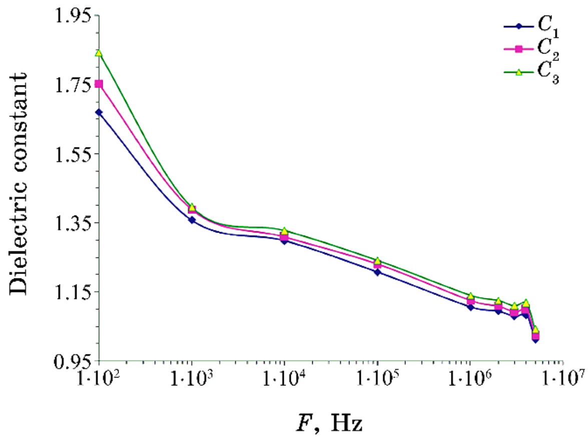

Fig. 1. Variation of dielectric constant for the PVP/Si_3N_4/Al_2O_3 nanostructures with frequency.

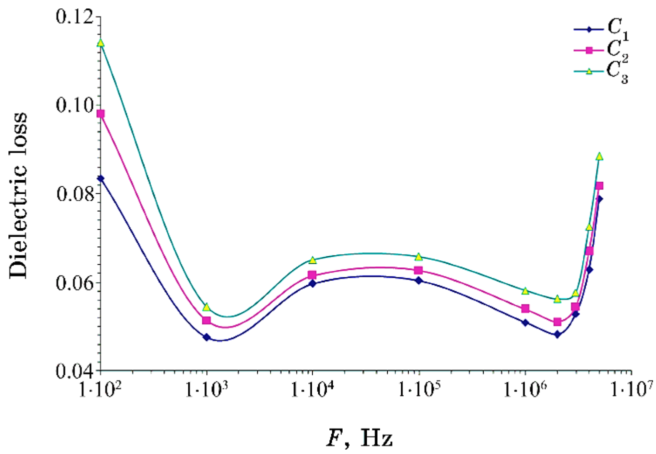

Fig. 2. Dielectric loss variation for the PVP/Si_3N_4/Al_2O_3 nanostructures with frequency.

ductivity with concentration was because of the raising the number of dopants, where the Si_3N_4/Al_2O_3NPs 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; hence, the conductivity increases as a results of increase the number of charges carriers.

Moreover, this improvement is assigned to the higher conductivity of the added Si_3N_4/Al_2O_3 NPs and increased charge mobility due to the increased amorphous degree within the doped samples [64–69].

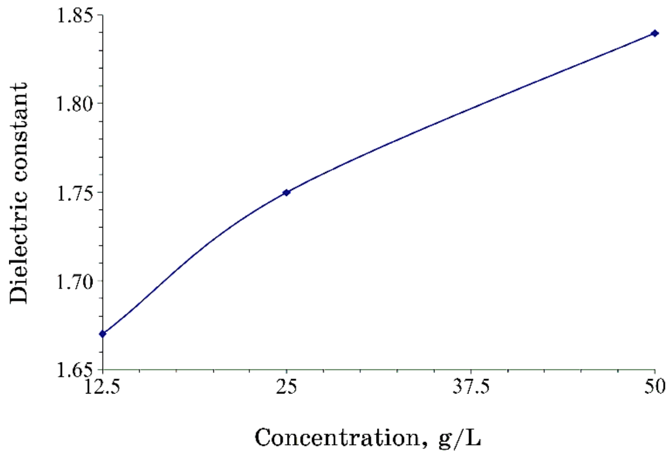

Fig. 3. Behaviour of dielectric constant for the $PVP/Si_3N_4/Al_2O_3$ nanostructures with concentration.

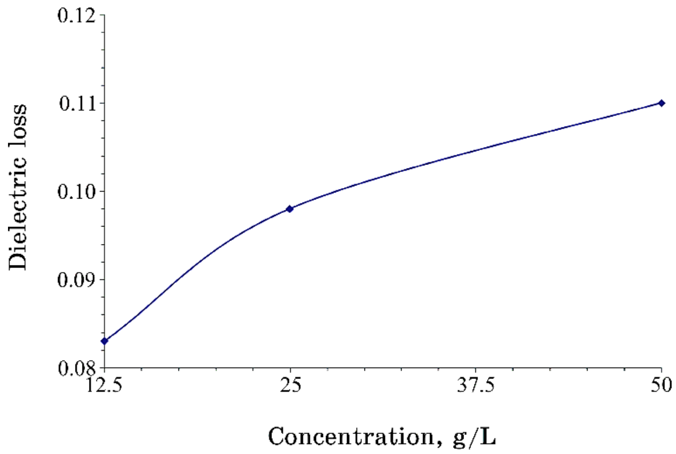

Fig. 4. Dielectric loss performance for the $PVP/Si_3N_4/Al_2O_3$ nanostructures with concentration.

4. CONCLUSIONS

This work involved fabrication of $PVP/Si_3N_4/Al_2O_3$ nanostructures to use in various electrical and electronics applications. The dielectric properties of $PVP/Si_3N_4/Al_2O_3$ nanostructures were examined. The results showed that the dielectric constant and dielectric loss of $PVP/Si_3N_4/Al_2O_3$ nanostructures decreased while the electrical conductivity was rise with a rise in the frequency. The dielectric parameters (dielectric constant, dielectric loss and electrical conductivity) were

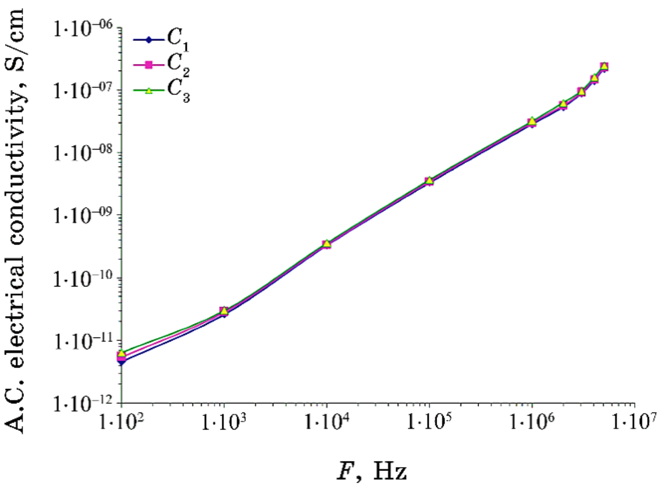

Fig. 5. Variation of A.C. electrical conductivity for the PVP/Si_3N_4/Al_2O_3 nanostructures with frequency.

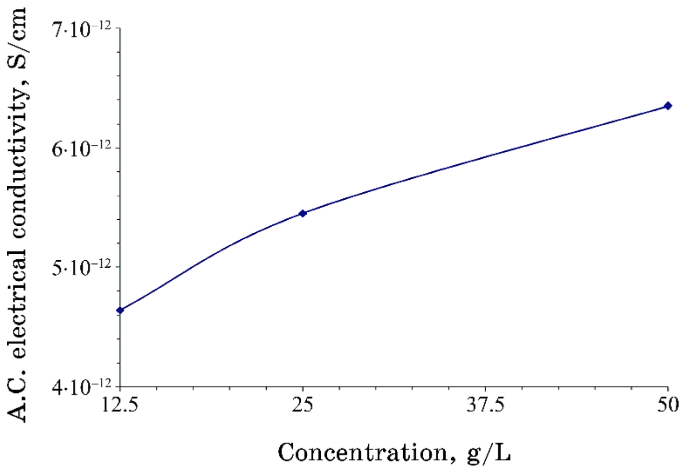

Fig. 6. Behaviour of A.C. electrical conductivity for the PVP/Si_3N_4/Al_2O_3 nanostructures with concentration.

raised with a rise in the concentration. The obtained results showed that the PVP/Si_3N_4/Al_2O_3 nanostructures could be suitable in many electronics applications.

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