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Fabrication of PS–SiO_2–Si_3N_4 Nanocomposites and Tailored Dielectric Features for Promising Optoelectronic Applications

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This article aims to fabricate the silica (SiO_2)/silicon nitride (Si_3N_4) nanoparticles'-doped polystyrene (PS) for utilize in a variety of electronics and electrical nanodevices. By casting method, the films of PS–SiO_2–Si_3N_4 are synthesized at various weight percentages of 2.3%, 4.6%, 6.9% of SiO_2–Si_3N_4. The distribution of SiO_2–Si_3N_4 nanoparticles (NPs) are examined by optical microscopy (OM). The OM confirms a good distribution of SiO_2/Si_3N_4 NPs inside the matrix of polystyrene. The dielectric characteristics are evaluated at room temperature across a frequency range of $100–5\cdot10^6$ Hz. The results reveal that the dielectric constant and dielectric loss of PS–SiO_2–Si_3N_4 nanocomposites are reduced as the frequency of the applied electric field is increased. The electrical conductivity of alternating current rises with rising frequency. With increasing concentration of SiO_2–Si_3N_4 nanoparticles, the dielectric constant, dielectric loss, and A.C. electrical conductivity of PS–SiO_2–Si_3N_4 nanocomposites are enhanced. The results confirm that the dielectric properties of the PS–SiO_2–Si_3N_4 nanostructures might be used in a variety of nanoelectronics and electrical applications.

Ця стаття має на меті створення наноматеріялів на основі полістиролу (ПС), леґованого наночастинками діоксиду Силіцію (SiO_2)/нітриду Силіцію (Si_3N_4), для використання в різноманітних електронних та електричних нанопристроях. Методом лиття було синтезовано плівки ПС–SiO_2–Si_3N_4 з різним ваговим відсотком у 2,3%, 4,6%, 6,9% SiO_2–Si_3N_4. Розподіл наночастинок SiO_2–Si_3N_4 було досліджено за допомогою оптичної мікроскопії, що підтвердила хороший розподіл наночастинок

SiO_2/Si_3N_4 всередині полістиролової матриці. Діелектричні характеристики було оцінено за кімнатної температури в діяпазоні частот 100–($5\cdot10^6$) Гц. Результати показали, що діелектрична проникність і діелектричні втрати нанокомпозитів ПС–SiO_2–Si_3N_4 зменшуються зі збільшенням частоти прикладеного електричного поля. Електропровідність змінного струму зростає зі збільшенням частоти. Зі збільшенням концентрації наночастинок SiO_2–Si_3N_4 діелектрична проникність, діелектричні втрати та змінна електропровідність нанокомпозитів ПС–SiO_2–Si_3N_4 поліпшувалися. Результати підтвердили, що досліджені діелектричні властивості наноструктур ПС–SiO_2–Si_3N_4 можуть бути використані в різних наноелектронних та електротехнічних застосуваннях.

Key words: polystyrene (PS), silica (SiO_2), silicon nitride (Si_3N_4), dielectric constant, dielectric loss, conductivity, electrical nanodevices.

Ключові слова: полістирол (ПС), кремнезем (SiO_2), нітрид Силіцію (Si_3N_4), діелектрична проникність, діелектричні втрати, провідність, електричні нанопристрої.

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1. INTRODUCTION

Polymer nanocomposites are one of the most important materials in the academic and industrial areas, and are produced by dispersing nanofillers with one or more dimensions at nanoscale into the polymeric matrix. Recently, researchers have been attracted to polymer nanocomposites over conventional microcomposites due to their wide applications in electromechanical systems and their large interfacial area per unit volume of the dispersion medium [1]. Recently, the improvement of polymeric materials by modification of their physical properties has become of concern in order to fulfil the increasing requirements in various industrial applications such as cables, materials of electronic packaging, jackets, and films of capacitors [2]. Flexible composite materials have been receiving a great deal of attention in optical energy applications due to their remarkable electrical, thermal, mechanical, dielectric and optical properties *versus* the other traditional materials. Currently, polymer composites are of high interest in different energy applications because of their pliable characteristics and their easy to use. Huge attention has been given to reveal the optical properties of polymers and to potentiate their implementations in optical energy applications [3–6]. Silicon dioxide is developed as additive in polymer composites. Targeting to raise microwave absorption, behaviour for antimicrobial, mechanical characteristics, *etc.*, silica may be employed as a dispersed phase in polymer substance. In numerous cases, SiO_2 is accrued as to enhance the polymers processability in various fabricating techniques [7]. Si_3N_4 is an extremely stable covalent compound with large application value in numerous fields because of excellent resistance for corrosion and good resistance to temperature alter. It may be an effectual filler to enhance the behaviour of polymer substances [8].

This study examines how the SiO_2–Si_3N_4 addition affects on the dielectric characteristics of polystyrene nanocomposites.

2. EXPERIMENTAL PART

Polystyrene (PS), silicon dioxide (SiO_2) nanopowder, and silicon nitride (Si_3N_4) nanopowder (obtained from US Research Nanomaterials) were casted in varying amounts to create PS/SiO_2/Si_3N_4 nanostructure films. The film of pure polystyrene was prepared by one gram of polystyrene dissolved in 30 mole of chloroform. The proportions of the SiO_2/Si_3N_4 nanoparticles (NPs) added to the PS solution were of 2.3%, 4.6%, and 6.9%. We synthesized 100 μm-thick PS/SiO_2/Si_3N_4 nanostructure films. SiO_2/Si_3N_4 nanostructure distribution inside the PS medium is investigated using an optical microscope. The Hioki 3532-50 Hi Tester LCR analyser is used to evaluate dielectric characteristics in the frequency range of 100 Hz–5 MHz and at room temperature.

The dielectric constant (ε') of PS/SiO_2/Si_3N_4 nanocomposites is calculated by the following equation [9]:

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

where C_p is parallel capacitance and C_0 is vacuum capacitor.

The following formula calculates dielectric loss (ε'') [10]:

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

where D is dispersion factor.

The A.C. electrical conductivity of PS/SiO_2/Si_3N_4 nanocomposites is determined by the following equation [11]:

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

where ω is the angular frequency.

3. RESULTS AND DISCUSSION

Figure 1 shows that the SiO_2–Si_3N_4 NPs are dispersed as clusters at lower ratios. When the ratios of SiO_2–Si_3N_4 increase, the SiO_2/Si_3N_4

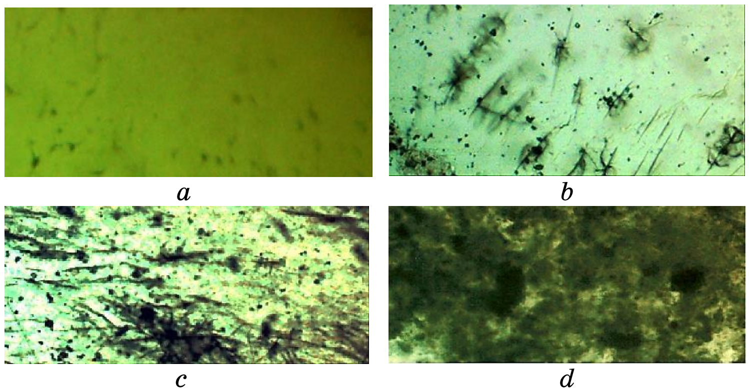

Fig. 1. Microscope images (×10) for PS–SiO_2/Si_3N_4 nanocomposites. *a*—PS; *b*—2.3 wt.% SiO_2/Si_3N_4; *c*—4.6 wt.% SiO_2/Si_3N_4; *d*—6.9 wt.% SiO_2/Si_3N_4.

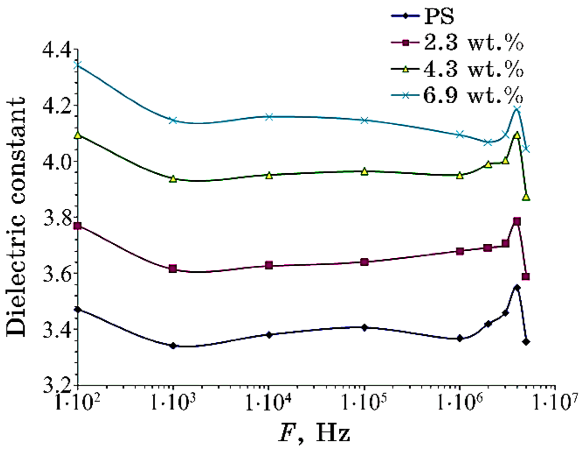

Fig. 2. Behaviour of dielectric constant against frequency for PS–SiO_2–Si_3N_4 nanocomposites.

particles form a network within the PS matrix. The nanoparticles specify the charge carriers inside the polymeric framework [12–19].

Figures 2 and 3 indicate that the dielectric constant and dielectric loss of the PS–SiO_2–Si_3N_4 nanocomposite decrease with increasing applied-field frequency. This is due to the nanocomposites' dipoles pointing in the direction of the applied electric field, resulting in a decrease in space charge polarization relative to total polarization. At low frequencies, space charge polarization contributes more to polarization, whereas polarization decreases at higher frequencies. As a consequence, all samples of PS–SiO_2–Si_3N_4 nanocomposites exhibit a drop in the dielectric-constant and dielectric-loss

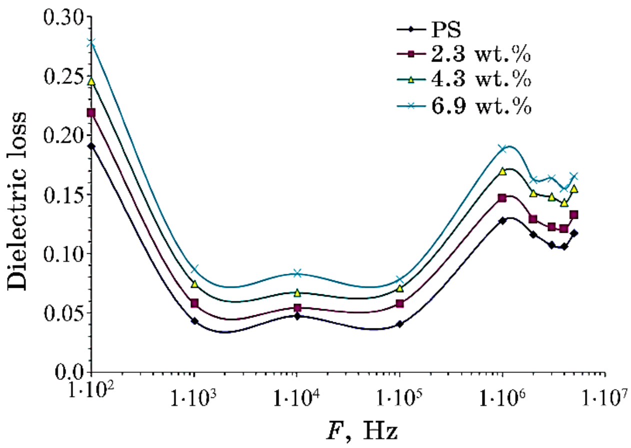

Fig. 3. Behaviour of dielectric loss of PS–SiO_2–Si_3N_4 nanocomposites against frequency.

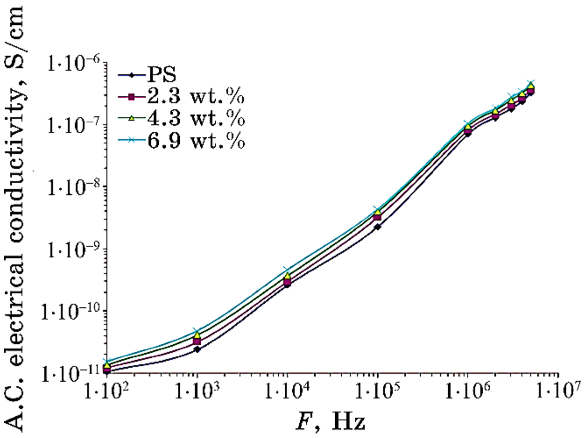

Fig. 4. Relation between A.C. electrical conductivity with frequency F for PS–SiO_2–Si_3N_4 nanocomposites.

values as the electric-field frequency increases. The figures show that, for nanocomposites at $f = 4$ MHz, ε' and ε'' increase to their highest values. The dielectric constant and dielectric loss of PS increase with rising SiO_2–Si_3N_4 that is due to increase in the number of charge carriers [20–35].

Figure 4 confirms that the A.C. conductivity of PS–SiO_2–Si_3N_4 nanocomposites changes with frequency at room temperature. The substantial increase in A.C. conductivity with frequency is caused by both the hopping process, which moves charge carriers, and space charge polarization, which occurs at low frequencies. In addition, the A.C. conductivity of PS rises with rising SiO_2–Si_3N_4-nanoparticles' content; this performance is related to rise of charge-carriers' number [36–48].

4. CONCLUSIONS

The current study comprises the fabrication of PS–SiO_2–Si_3N_4 nanocomposites for utilize in a variety of electronics and electrical nanodevices. The PS–SiO_2–Si_3N_4 nanocomposite films were synthesized by casting method. The distribution of SiO_2–Si_3N_4 nanoparticles were examined by optical microscopy (OM). The OM confirms a good distribution of SiO_2/Si_3N_4 NPs inside the matrix of polystyrene. The dielectric characteristics were evaluated at room temperature across a frequency range of $100–5\cdot10^6$ Hz. The results revealed that the dielectric constant and dielectric loss of PS–SiO_2–Si_3N_4 nanocomposites are reduced as the frequency of the applied electric field is increased. The electrical conductivity of alternating current rises with rising frequency. With increasing concentration of SiO_2–Si_3N_4 nanoparticles, the dielectric constant, dielectric loss, and A.C. electrical conductivity of PS–SiO_2–Si_3N_4 nanocomposites were enhanced. Finally, the results confirmed that the dielectric properties of the PS–SiO_2–Si_3N_4 nanostructures might be used in a variety of nanoelectronics and electrical applications.

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