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Fabrication of PMMA/PS/$CoFe_2O_4$ Nanocomposites and Tailored Dielectric Properties for Electronics Applications

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Films of PMMA/PS/$CoFe_2O_4$ nanocomposites are fabricated with little cost, lightweight and good physical properties to use in various electronics applications. The dielectric properties of PMMA/PS/$CoFe_2O_4$ nanocomposites are studied in frequency range from 100 Hz to 5 MHz. Results show that both the dielectric constant and the dielectric loss of PMMA/PS/$CoFe_2O_4$ nanocomposites are decreased, while the A.C. electrical conductivity is increased, with increasing the frequency. The dielectric parameters such as dielectric constant, dielectric loss and A.C. electrical conductivity of PMMA/PS blend are increased with increasing the $CoFe_2O_4$ nanoparticles' content. The final results show that the PMMA/PS/$CoFe_2O_4$ nanocomposites may be useful for various electronics fields.

Плівки з нанокомпозитів ПММА/ПС/$CoFe_2O_4$ (ПММА — поліметилметакрилат, ПС — полістирол) виготовляються за невеликою ціною, легкістю та хорошими фізичними властивостями для використання в різних електронних застосуваннях. Досліджено діелектричні властивості нанокомпозитів ПММА/ПС/$CoFe_2O_4$ в діяпазоні частот від 100 Гц до 5 МГц. Результати показують, що як діелектрична проникність, так і діелектричні втрати нанокомпозитів ПММА/ПС/$CoFe_2O_4$ зменшуються, тоді як електрична провідність змінного струму збільшується зі збільшенням частоти. Діелектричні параметри, такі як діелектрична проникність, діелектричні втрати й електропровідність змінного струму суміші ПММА/ПС, збільшуються зі збільшенням вмісту наночастинок $CoFe_2O_4$. Остаточні результати показують, що нанокомпозити ПММА/ПС/$CoFe_2O_4$ можуть бути корисними для різних галузей електроніки.

Key words: polymethyl methacrylate, polystyrene, $CoFe_2O_4$, nanocomposites, dielectric properties.

Ключові слова: поліметилметакрилат, полістирол, $CoFe_2O_4$, нанокомпозити, діелектричні властивості.

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1. INTRODUCTION

Polymeric nanocomposites are promising materials that can be used in industry and in research. They offer considerable property benefits at far lower loadings than the structure of polymer composites with typical micron-scale fillers, resulting in decreased component weight and the capacity to simplify processing. Furthermore, their versatile properties may open up new applications for polymers. They find widespread application in a variety of fields, including the information industry, packaging, safety, energy, transportation, electromagnetic shielding, defence systems, sensors, and catalysis [1].

Acrylic-based polymers are one of the major thermoplastic polymers due to their excellent thermal, mechanical and optical properties. Among acrylic polymers, polymethyl methacrylate (PMMA) and polybutyl methacrylate are extensively investigated due to their high surface clearance, good transparency and mechanical properties. PMMA, also known as acrylic glass, contains a methyl ester group, which makes it bond with other polar polymers or polar fillers. Because of its insulating and brittle nature, PMMA cannot be used in applications that need conductivity or ductility. Several experiments have been performed in order to improve the electrical and mechanical properties of PMMA. Several inorganic nanoparticles (NPs) have been widely studied to improve the properties of polymers [2].

Polystyrene (PS) is a commercial thermoplastic polymer. It is rather brittle, clear and has good mechanical properties and a low-cost price. Thus, PS has a wide range of applications as construction materials, packaging, disposable cups, consumer electronics, cassette boxes, compact disks and medical uses [3]. The addition of nanosize fillers to a polymer blend is an effective way to improve the desirable properties. Reinforcing polymeric blend materials using nanoparticles improves their mechanical, thermal and conductive characteristics. Individual nanoparticles are homogeneously dispersed in a blend matrix, which is the perfect nanocomposite design. Nanocomposites have attracted a lot of attention due to their wide range of applications in industry [4].

Cobalt ferrite ($CoFe_2O_4$) is a ferromagnetic oxide that has attracted considerable attention due to its excellent magnetic properties, such as high coercivity, modest saturation magnetization, high Curie temperature at 520°C, large magnet crystalline anisotropy, high mechanical hardness and remarkable chemical stability. $CoFe_2O_4$ crystallizes into an inverse spinel structure, where one-half of the Fe^{3+} ions occupy the tetrahedral sites, while the other half are located in the octahedral sites together with Co^{2+} ions [5]. The polymers nanocomposites of inorganic materials doped polymers have many applications in various optical, electronics and optoelectronics fields [6–30].

This study aims to fabricate of PMMA/PS/$CoFe_2O_4$ nanocomposites and investigating the dielectric properties to employ in different electronics applications.

2. MATERIALS AND METHODS

The PMMA/PS/$CoFe_2O_4$ nanocomposites films were synthesized by dissolving of 1 gm PMMA and PS in 30 ml of chloroform with ratio of 50 wt.% PMMA and 50 wt.% PS by using magnetic stirrer to mix the polymers for 1 hour to obtain solution that is more homogeneous. The $CoFe_2O_4$ nanoparticles added to PMMA/PS blend with various concentrations of 2.1%, 4.2% and 6.3%. The casting method was used to fabricate the PMMA/PS/$CoFe_2O_4$ nanocomposites films. The dielectric properties of PMMA/PS/$CoFe_2O_4$ nanocomposites films were examined at frequency (F) range from 100 Hz to $5\cdot10^6$ Hz by using LCR meter type (HIOKI 3532-50 LCR HI TESTER).

The dielectric constant (ε') is determined by [31]:

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

wherever C_p is the matter capacitance and C_0 is the vacuum capacitance.

Dielectric loss (ε'') is given by [32]:

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

where D represents the dispersion factor.

The A.C. electrical conductivity is defined by [33]:

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

3. RESULTS AND DISCUSSION

Figures 1–4 show the dielectric constant and dielectric loss performances with frequency and $CoFe_2O_4$ NPs concentration respectively. With increasing frequency, the dielectric constant and di-

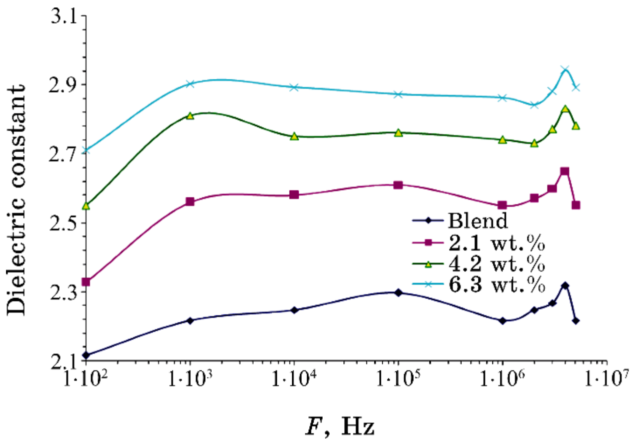

Fig. 1. Dielectric constant performance with frequency for PMMA/PS/$CoFe_2O_4$ nanocomposites.

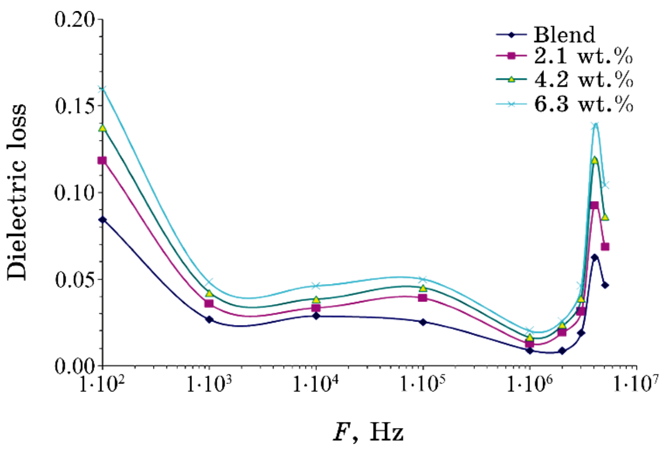

Fig. 2. Variation of dielectric loss with frequency for PMMA/PS/$CoFe_2O_4$ nanocomposites.

electric loss are decreased. This is because of the available relaxation time of the polymer.

At low frequencies, polymer molecules get sufficient time to orient themselves according to the applied field. However, as the frequency increases, molecules are not getting sufficient time to orient themselves according to the direction of the electrical field. Therefore, the overall polarization effect decreases and, consequently, the value of dielectric constant decreases too as it is directly proportional to the amount of polarization. At high frequencies, as the polarization decreases, the dielectric loss and dissipation factor also

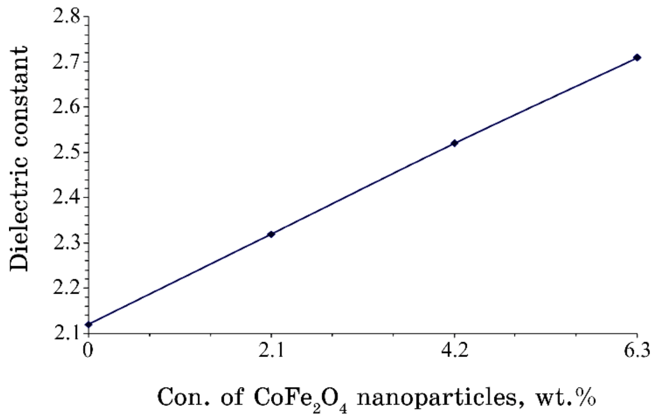

Fig. 3. Behaviour of dielectric constant with $CoFe_2O_4$ NPs concentration.

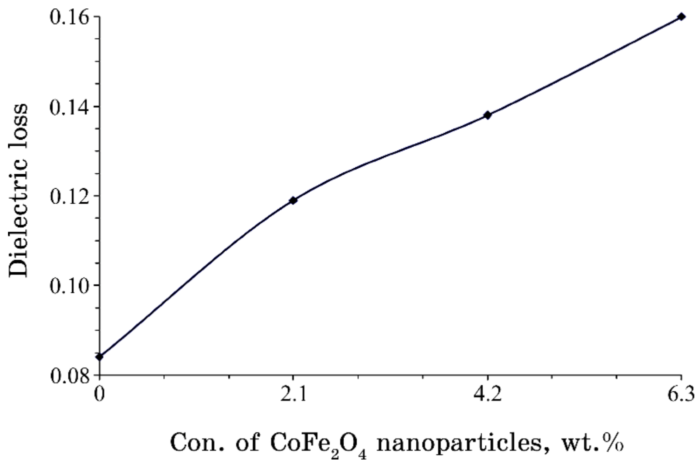

Fig. 4. Dielectric loss performance with $CoFe_2O_4$ NPs concentration.

decrease, as sufficient time is not provided to the polymer chain to generate phase angle.

Thus, at high frequencies, the contribution of orientation or dipole polarization vanishes and the effect is only for electronic polarization, which is instantaneous. The dielectric constant and dielectric loss rise with raising the $CoFe_2O_4$ NPs concentration due to the increase in charge carriers [34–46].

The A.C. electrical conductivity variation for PMMA/PS/$CoFe_2O_4$ nanocomposites with frequency and $CoFe_2O_4$ NPs content are represented in Figs. 5 and 6, respectively.

As the $CoFe_2O_4$ NPs content is increased, the inorganic filler molecules start bridging the gap separating the two localized states

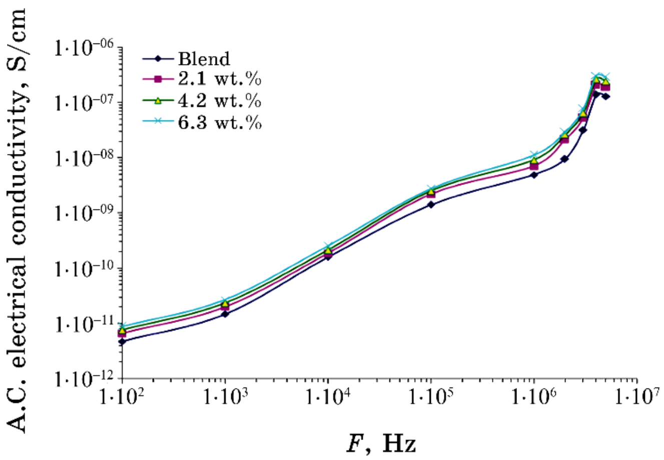

Fig. 5. Variation of A.C. electrical conductivity for PMMA/PS/$CoFe_2O_4$ nanocomposites with frequency.

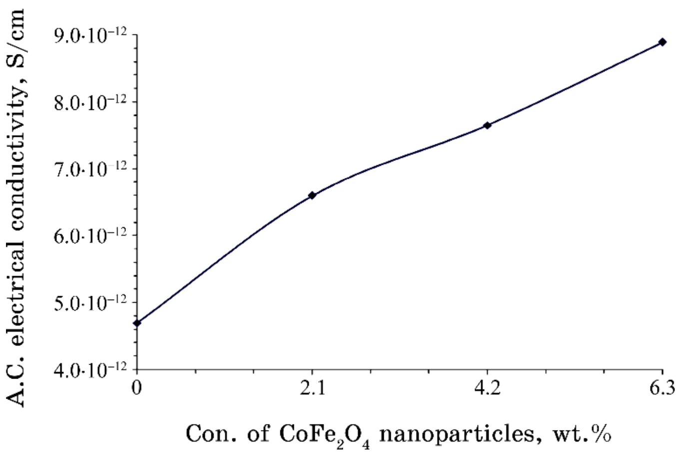

Fig. 6. Behaviour of A.C. electrical conductivity with $CoFe_2O_4$ NPs content.

and lowering the potential barrier between them, thereby, facilitating the transfer of charge carriers between two localized states; hence, the conductivity increases as a result of increase the charge carriers' numbers. The frequency-dependent conductivity is caused by the hopping of charge carriers in the localized state. The term hopping refers to the sudden displacement of charge carriers from one position to another neighbouring site and, in general, includes both jumps over a potential barrier and quantum-mechanical tunnelling [47–55].

4. CONCLUSIONS

This study includes preparation of PMMA/PS/$CoFe_2O_4$ to use in different electronics fields.

The dielectric properties of PMMA/PS/$CoFe_2O_4$ nanocomposites were tested in frequency ranged from 100 Hz to 5 MHz. Results showed that the dielectric constant and dielectric loss of PMMA/PS/$CoFe_2O_4$ nanocomposites are decreased, while the A.C. electrical conductivity increased, with increasing the frequency. The dielectric parameters such as dielectric constant, dielectric loss and A.C. electrical conductivity of PMMA/PS blend are increased with increasing the $CoFe_2O_4$ nanoparticles' content.

The final results demonstrate that the PMMA/PS/$CoFe_2O_4$ nanocomposites may be useful for various electronics fields.

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