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Effect of Fe_2O_3/MgO Nanoparticles on the Structural and Dielectric Properties of PVA for Electronic Nanodevices

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In this work, PVA/Fe_2O_3/MgO-nanocomposite films are prepared using casting method with various concentrations of Fe_2O_3/MgO nanoparticles (NPs) (0, 2, 4, and 6 wt.%). The structural and dielectric characteristics are studied. FT-IR spectra show that there are not chemical interaction between PVA and Fe_2O_3/MgO NPs. Optical microscopy shows that a continuous network is formed. The dielectric properties of PVA/Fe_2O_3/MgO nanocomposites show that the dielectric constant, dielectric loss, and a.c. electrical conductivity of PVA/Fe_2O_3/MgO films increase with increasing NPs' concentration. As the frequency of the electric field rise, both the dielectric constant and the dielectric loss decrease, while a.c. electrical conductivity increases. Finally, the PVA/Fe_2O_3/MgO nanocomposites may be useful in different electronics fields.

У даній роботі нанокомпозитні плівки PVA/Fe_2O_3/MgO було виготовлено методом лиття з різними концентраціями наночастинок (НЧ) Fe_2O_3/MgO (0, 2, 4 та 6 мас.%). Було досліджено структурні та діелектричні характеристики. ІЧ-спектроскопія з Фур'є-перетвором показує відсутність хемічної взаємодії між полівініловим спиртом (PVA) і Fe_2O_3/MgO-НЧ. Оптична мікроскопія показує утворення безперервної сітки. Діелектричні властивості нанокомпозитів PVA/Fe_2O_3/MgO показують, що діелектрична проникність, діелектричні втрати та змінна електропровідність плівок PVA/Fe_2O_3/MgO зростають зі збільшенням концентрації Fe_2O_3/MgO-НЧ. Зі збільшенням частоти електричного поля як діелектрична проникність, так і діелектричні втрати зменшуються, тоді як змінна електропровідність зростає. Зрештою, нанокомпозити PVA/Fe_2O_3/MgO можуть стати корисними в різних галузях електроніки.

Key words: polyvinyl alcohol, nanocomposites, dielectric properties, structural properties.

Ключові слова: полівініловий спирт, нанокомпозити, діелектричні властивості, структурні властивості.

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1. INTRODUCTION

They are found in many daily products, such as rubber, plastics, resins, adhesives, and adhesive tapes. All of these materials include lengthy chains of atoms that are covalently bound together as a structural characteristic. They are a remarkably adaptable class of materials, with a particular type's attributes frequently having drastically different values for other polymers and occasionally even for the same polymer in various physical states [1, 2]. We are in the polymer era. Terms like plastics, fibres, elastomers, coatings, rubber, and cellulose are all part of our contemporary lexicon [3]. Most people are probably unaware of this, but polymers are a known concept to everyone. Subsequently, polymer research has begun to advance at an exponential rate. Scientists are working to create polymers that can be utilized in a variety of industrial applications [4, 5].

The most adaptable materials used in various chemical industries are plastics. They are robust, affordable, adaptable, and multifunctional. They are employed in packing, electrical equipment, vehicles, aircraft, and as electrical insulators. Their significance in the production of satellites, space exploration, and thermal barriers is growing [6, 7]. Electronic applications have also made use of composite materials, which are often made with a concentration on mechanical strength and other attributes. Among the possible uses are electronic packaging, acoustic emission sensors, angular acceleration accelerometers, and integrated decoupling capacitors [8, 9]. The novel composite materials are now the basis for developing and altering technical designs for a wide range of industrial and commodity goods. Ships, airplanes, and building materials are the three most significant sectors of the automobile industry [10, 11].

PVA is a synthetic polymer that dissolves in water. PVA has been employed in numerous biomaterial applications because of its great chemical resistance, outstanding mechanical qualities, ease of manufacturing, and good biodegradability [12, 13]. Fe_2O_3 nanoparticles (NPs) ranged in size from 30 to 40 nm on average. To keep them from clumping together, NPs were suspended in water. Because of its unique thermal, optical, electrical, and chemical properties [14, 15], magnesium oxide (MgO) is one of the most significant metal oxides and has a great deal of promise for usage in a variety of applications [16, 17]. MgO particles at the nanoscale can be util-

ized as fillers in paint, paper, cosmetics, rubber, plastic, and as consistent materials in some electrical materials [18, 19].

2. MATERIALS AND METHOD

Nanocomposites of PVA/Fe_2O_3/MgO were prepared by using the casting method. The method include dissolving pure PVA in 35 ml of distilled water for 40 minutes The mixture was then mixed with a magnetic stirrer to achieve a more homogenous mixture at a temperature of 70°C. Next, the weight percentages of additives (0%, 2%, 4%, and 6%) of magnesium oxide (MgO) and iron oxide (Fe_2O_3) were added; we were able to obtain films from this mixture by pouring each of these ratios into a template (Petri dish) with a diameter of 5 cm. The mixture was then allowed to dry.

3. RESULTS AND DISCUSSION

Changes in PVA/Fe_2O_3/MgO-nanocomposites' surface morphology can be seen with an optical microscope. PVA/Fe_2O_3/MgO nanocomposites are shown optically microscopy (OM) images in Fig. 1 at (×10 magnification for each sample. The pure polymer blend (*a*) exhibits a homogeneous and even consistent phase, when viewed from

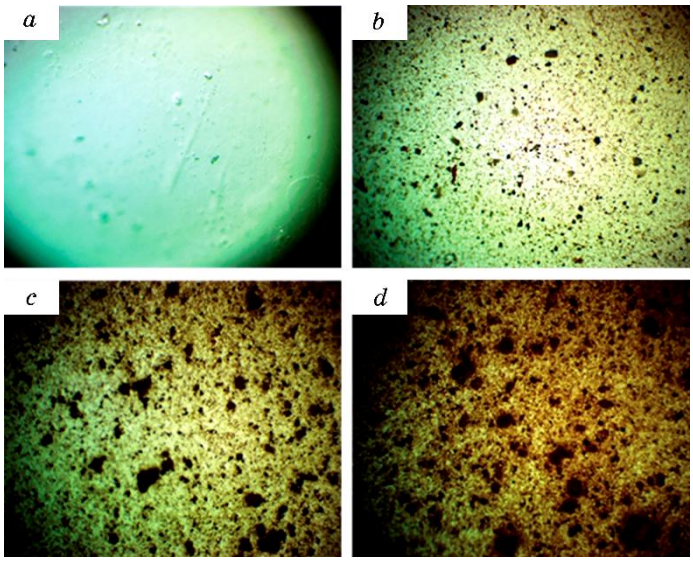

Fig. 1. Photomicrographs (×10) for PVA/Fe_2O_3/MgO nanocomposites: (*a*) for pure PVA; (*b*) for 2 wt.% Fe_2O_3/MgO NPs; (*c*) for 4 wt.% Fe_2O_3/MgO NP; (*d*) for 6 wt.% Fe_2O_3/MgO NPs.

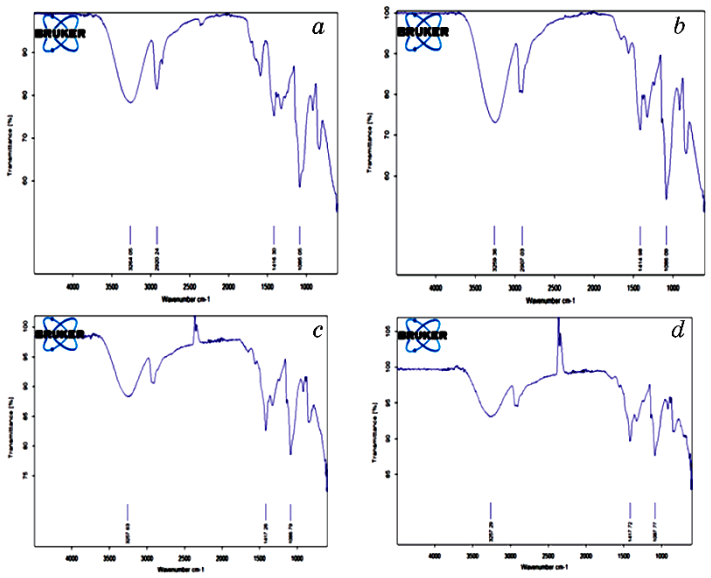

Fig. 2. FT-IR spectra for PVA/Fe_2O_3/MgO nanocomposites: (*a*) for pure PVA; (*b*) for 2 wt.% Fe_2O_3/MgO NPs; (*c*) for 4 wt.% Fe_2O_3/MgO NPs; (*d*) for 6 wt.% Fe_2O_3/MgO NPs.

above. The surface of the PVA polymer films displays a homogeneous distribution of Fe_2O_3/MgO NPs, as seen in images (*b*–*d*). Lower concentrations of the MgO and Fe_2O_3 NPs form a cluster together [20, 21]. The features of the material change when the concentrations of Fe_2O_3 and MgO NPs in the PVA polymer increase because a network of pathways for charge carriers to travel through is formed within the polymer. This conduct aligns with Refs. [22, 23].

The vibration and rotation of molecular groups in a substance are revealed by FT-IR spectra. The FT-IR spectra of PVA/Fe_2O_3/MgO nanocomposites in the wave number range 500–4000 cm^{-1} are shown in Fig. 2. In image (*a*), FT-IR spectra of pure PVA polymers are reveals absorption band at 3264.05 cm^{-1} was attributed to the O–H stretching vibrations and 2920.24 cm^{-1} assigned to the asymmetric stretching of CH_2. The band at 1261 cm^{-1} was attributed to the C–O stretching vibration [24, 25]. The absorption bands at 1640 cm^{-1} which can be attributed to the C=O carbonyl stretch. The two bands at 1416.30 cm^{-1} and 1085.06 cm^{-1} can be attributed to the stretching of CO and bending of OH. The absorption band at 839 cm^{-1} attributed to the C–C stretching vibration accordingly [26, 27].

Images in Figure 2, *b*, *c*, and *d* display the spectra of PVA with different concentrations of Fe_2O_3/MgO NPs. The photos show that the presence of Fe_2O_3/MgO NPs caused a shift in certain bands and

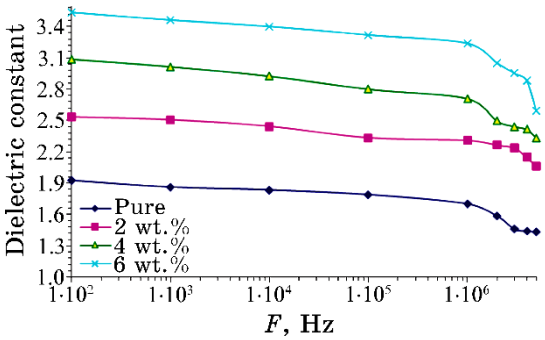

Fig. 3. Variation of dielectric constant for PVA/Fe_2O_3/MgO nanocomposites with frequency at room temperature.

a variation in some intensities. FT-IR analysis shows that adding different amounts of Fe_2O_3/MgO NPs (in pictures *b*, *c*, and *d*) causes a shift in some bonds without creating new peaks [28]. Consequently, there is no interaction between the Fe_2O_3/MgO NPs and the PVA polymer matrix. These findings pertain to researchers with Refs. [29, 30].

Figure 3 shows how the dielectric constant changes with frequency for polymer mixes PVA/Fe_2O_3/MgO and their nanocomposite films that have different amounts (0, 2, 4, and 6% wt.%) of Fe_2O_3/MgO NPs. This picture shows that as the frequency goes up, the space charge polarization goes down compared to the total polarization. As a result, the dielectric constant values for all examples of the PVA/Fe_2O_3/MgO nanocomposite go down. This means that the space charge polarization is a bigger part of the general polarization at lower frequencies [31, 32]. The dielectric constant (ε') is given by Ref. [33]:

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

C_0 and C_p are vacuum and parallel capacitances.

Figure 4 shows the link between the dielectric constant and the amount of presented Fe_2O_3/MgO NPs. The picture shows that the dielectric constant of nanocomposites goes up as the Fe_2O_3/MgO concentration goes up. The observed effect is due to the interfacial polarization that happens in the nanocomposites when they are exposed to an alternating electric field and the increase in charge carriers [34, 35].

The dielectric loss of nanocomposites is calculated by using following equation [36]:

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

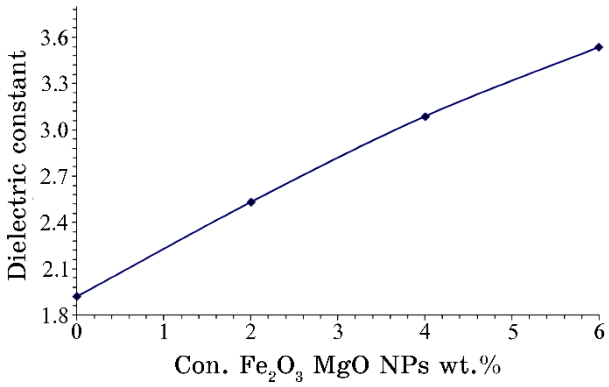

Fig. 4. Effect of Fe_2O_3/MgO concentrations on dielectric constant for PVA/Fe_2O_3/MgO nanocomposites at 100 Hz.

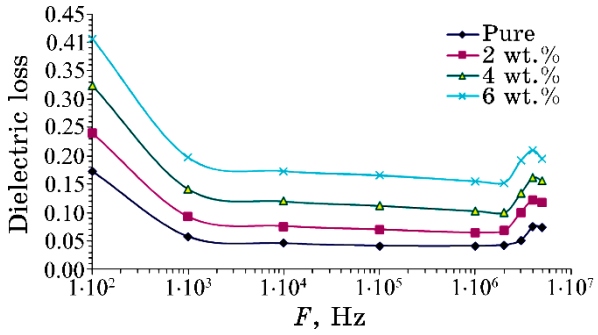

Fig. 5. Variation of dielectric loss for PVA/Fe_2O_3/MgO nanocomposites with frequency at room temperature.

where D is dispersion factor.

Figure 5 shows how the dielectric loss changes with electric field frequency of PVA/Fe_2O_3/MgO nanocomposites. All of the examples show that as the frequency of the electric field goes up, the dielectric loss of the nanocomposites goes down. The reason for this behaviour is that space charge polarization is becoming less important [37, 38].

In addition, the nanocomposite films with 6% Fe_2O_3/MgO NPs show the highest dielectric loss of 0.41 at 10^2 Hz, which is a very low frequency.

Figure 6 shows that, as the concentration of NPs grows, so the dielectric loss of nanocomposites does. This has to do with increasing the number of charge carriers [39].

The a.c. electrical conductivity of nanocomposites is calculated by using following equation [40]:

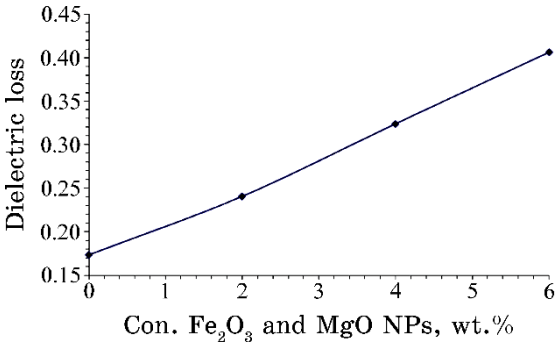

Fig. 6. Effect of Fe_2O_3/MgO and concentrations on dielectric loss for PVA/Fe_2O_3/MgO nanocomposite at 100 Hz.

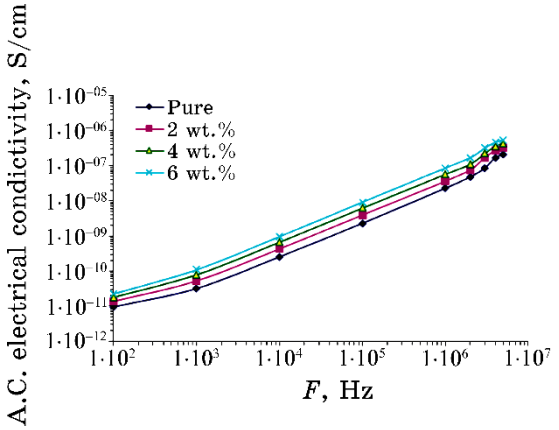

Fig. 7. Variation of a.c. electrical conductivity for PVA/Fe_2O_3/MgO nanocomposites with frequency at room temperature.

$$\sigma_{a.c.} = \omega\varepsilon'\varepsilon_0 , \tag{3}$$

where ω is angular frequency.

The graph in Fig. 7 shows how the a.c. electrical conductivity changes with the frequency of the electric field for PVA/Fe_2O_3/MgO films. For all samples, the a.c. conductivity goes up a lot as the frequency of the electric field goes up. Charge carriers move through a process called 'hopping', which is linked to the polarization of space charge at low frequencies and this effect [41, 42]. We also found that the conductance of the PVA/Fe_2O_3/MgO nanocomposite at 10^2 Hz increases as the weight percentage of Fe_2O_3/MgO increases, as shown in Fig. 8. The conductivity of the nanocomposite goes up, when NPs are added because they increase the amount of

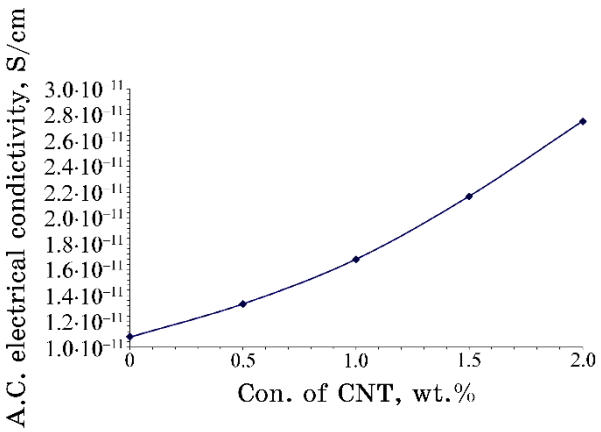

Fig. 8. Effect of Fe_2O_3/MgO concentrations on a.c. electrical conductivity for PVA/Fe_2O_3/MgO nanocomposite at 100Hz.

charge carriers [43]. Because of this, the nanocomposites' resistance goes down, and its ability to carry a.c. electricity goes up. The same kind of behaviour was recorded in [44, 45].

4. CONCLUSION

This paper gives a short outline of a very good casting method that is used to make PVA/Fe_2O_3/MgO nanocomposites. The optical microscopy pictures showed that, as the NPs' concentration roses, network paths are formed within the polymeric matrix for charge carriers. FT-IR spectra showed the physical interaction between PVA-polymer matrix and Fe_2O_3/MgO NPs. The dielectric constant and dielectric loss decrease as the frequency increases and its increase as concentration of Fe_2O_3/MgO NPs increases. On the other hand, the a.c. electrical conductivity rise as the frequency and concentration of Fe_2O_3/MgO NPs rises. Finally, these findings suggest that the PVA/Fe_2O_3/MgO nanocomposites can be used in different nanoelectronic fields.

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