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Structural and Dielectric Properties of PVA/In_2O_3/Fe_2O_3 Nanostructures for Electronic Devices

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In this study, PVA/In_2O_3/Fe_2O_3 nanocomposites are made using the solution casting method with different amounts 0%, 2%, 4%, and 6% of In_2O_3/Fe_2O_3 nanoparticles. Films' structures and insulating properties are investigated. The optical microscope shows that polymer is wrapped around nanoparticles in a continuous system. This network is comprised up of pathways, which lead into nanocomposites and provide access for carrier movement throughout those spaces. FTIR spectroscopy of PVA/In_2O_3/Fe_2O_3 nanocomposites shows that small vibrational molecular movement is caused by the addition of In_2O_3/Fe_2O_3 nanoparticles. The addition of In_2O_3/Fe_2O_3 nanoparticles also breaks polymer chains. Instead, a number of other groups are set up. The dielectric characteristics of films show that the dielectric constant, dielectric loss, and A.C. electrical conductivity of PVA/In_2O_3/Fe_2O_3 nanocomposites growth with growing concentrations. As the frequency of the electric field goes up, both the dielectric constant and the dielectric loss decrease, while A.C. electrical conductivity increases.

У цьому дослідженні нанокомпозити ПВС/In_2O_3/Fe_2O_3 (ПВС — полівініловий спирт) було виготовлено методом лиття з розчину з різними кількостями у 0%, 2%, 4% і 6% наночастинок In_2O_3/Fe_2O_3. Досліджено структуру й ізоляційні властивості плівок. Оптичний мікроскоп показує, що полімер згорнутий навколо наночастинок у безперервній системі. Ця мережа складається з шляхів, які ведуть до нанокомпозитів і забезпечують доступ для руху носіїв у цих просторах. Інфрачервона спектроскопія (на основі перетворення Фур'є) нанокомпозитів ПВС/In_2O_3/Fe_2O_3 показує, що малий коливний молекулярний рух спричинено додаванням наночастинок In_2O_3/Fe_2O_3. Додавання наночастинок In_2O_3/Fe_2O_3 також розриває полімерні ланцюги. Замість цього створюється ряд інших груп. Діелектричні характеристики плівок показують, що діелектрична проникність, діелектричні втрати й електропровідність змінного струму нанокомпозитів ПВС/In_2O_3/Fe_2O_3 зростають із зростанням концентрації. З підвищенням частоти електричного поля діелектрична проникність і діелектричні втрати зменшуються, а електропровідність змінного струму зростає.

Key words: PVA, dielectric properties, structural properties, nano-Fe_2O_3, nanocomposites.

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

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1. INTRODUCTION

Nanotechnology has created a different part of study for the dispensation and creation of nanomaterials, which are substances that typically have crystallite sizes of less than 100 nanometres [1, 2]. Nanotechnology is a hot theme this time, reaching since new changes in technique physics to precisely new fields to educating novel materials with nanometer-dimensions' scale [3, 4]. That is fast emerging and rising, with vast fields in various research approaches, advancement, and industrialized activities. Nanoparticles with higher thermal conductivity than their surrounding liquid have been created to improve deferral effective thermal conductivity [5, 6].

Polymer matrix nanocomposites are an appealing and important part of today's materials because of their low weight, simple manufacturability, low cost, high fatigue strength, and good corrosion resistance. The addition for nanoparticles into a polymer matrix meaningfully alters its physical material properties such as structural–electrical–thermal–optical properties) [7–9]. The polyvinyl alcohol is good host medium for extensive variety for nanoparticles. It is motivated by the view of producing ultra-transparent films with superior optical properties. They have received a lot of attention due to their excellent dielectric properties [10–12]. Their flexibility is exceptional, and their dielectric strength is quite robust.

Due to they are created through erosion, iron oxides is intriguing due to their catalytic, magnetic, and semiconducting material properties [13–15]. They can be used as high-density magnetic storage materials and as catalysts in the production of styrene [17, 18]. The typical stoichiometric form of iron oxide is Fe_2O_3 at room temperature.

For its structural, dielectric properties, the polymer nanocomposite of ferrous oxide with PVA is included in nanocomposites [19].

2. EXPERIMENTAL PART

Nanocomposite films were produced by employing the casting method. The process includes dissolving pure PVA in 40 ml of distilled water for 40 minutes while stirring with a magnetic stirrer at 65°C to achieve a more homogeneous solution. The polymer was subjected to the addition of nanoparticles of indium trioxide In_2O_3 and iron trioxide Fe_2O_3 at varying concentrations of 0%, 2%, 4%, and 6% wt.%. The structural characteristics of PVA/SnO_2/Cr_2O_3 nanocomposites are tested by the optical microscope (OM) provided by Olympus (Top View, type Nikon-73346) and Fourier transformation infrared (FTIR) spectroscope (Bruker company type vertex-70, German origin) with range wavenumber 500–4000 cm^{-1}. The dielectric characteristics were studied in the range from 100 Hz to $5 \cdot 10^6$ Hz) by LCR meter (HIOKI 3532-50 LCR HI TESTER).

The dielectric constant (ε') of nanocomposites is given by the following equation [20]: $\varepsilon' = C_p/C_0$, where C_p is the capacitance and C_0 is the vacuum capacitor.

The dielectric loss (ε'') is calculated by

$$\varepsilon'' = \varepsilon' D, \tag{1}$$

where D is the dispersion factor [34].

The A.C. conductivity is determined by

$$\sigma_{\text{A.C.}} = w\varepsilon''\varepsilon_0, \tag{2}$$

where w is angular frequency [35].

3. RESULTS AND DISCUSSION

At a magnification of ×10, samples of different concentrations of PVA/In_2O_3/Fe_2O_3 nanocomposites films in use are shown in Fig. 1. As the pictures show, it is clear that the images (*a*, *b*, *c*, and *d*) are different. Once the amount of In_2O_3 and Fe_2O_3 nanoparticles in a films reaches 6 wt.% for PVA/In_2O_3/Fe_2O_3 nanocomposites, the nanoparticles start to form a network around the polymer. This network has ways for nanocomposites to let charge carriers through [24, 25].

FTIR spectroscopy has been used to study how atoms or ions in PVA/In_2O_3/Fe_2O_3 nanocomposites interact with each other (Fig. 2). These interactions can cause changes in the vibrational styles of the nanocomposites. The widening vibration of OH for PVA is assigned a broadband of about 3300 cm^{-1} in the FTIR band of PVA films, which may be because of the polymer and nanoparticles' intermolecular or intermolecular type of hydrogen bonding. At approximately 2930 cm^{-1}, the band corresponding to CH_2 asymmetric stretching vibration occurs. The peaks at 1710 and 1652 cm^{-1} are caused by the C=O, C=C stretching mode [26–29].

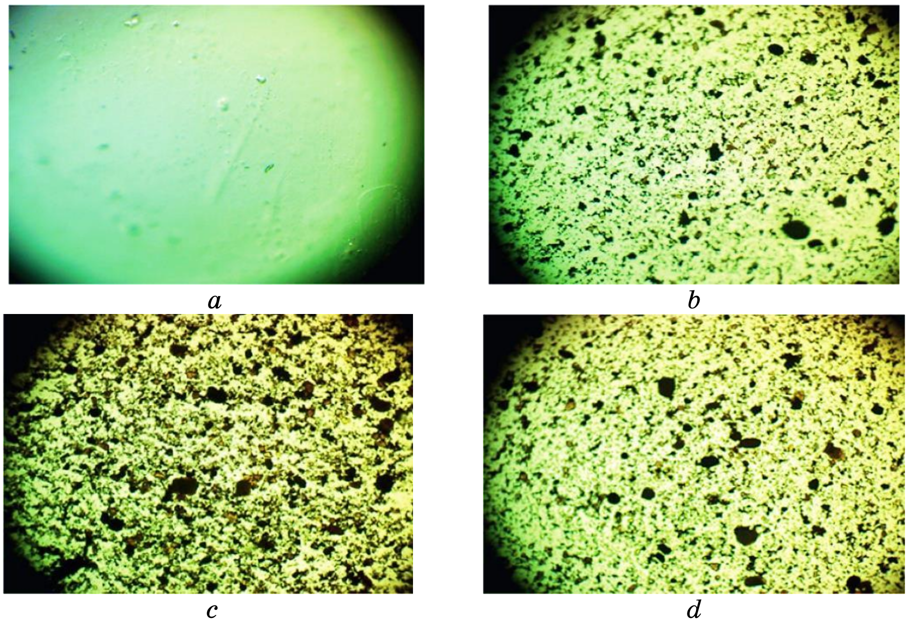

Fig. 1. The photomicrographs of PVA/In_2O_3/Fe_2O_3 nanocomposites: (*a*) for PVA; (*b*) for 2 wt.% of In_2O_3/Fe_2O_3; (*c*) for 4 wt.% of In_2O_3/Fe_2O_3; (*d*) for 6 wt.% of In_2O_3/Fe_2O_3.

The absorption peak at 1240 cm^{-1} has been given to the CH group. The C–O bending of carbonyl groups on the PVA backbone matches the 1105 cm^{-1} band. However, out of plane rings C–H bending has an absorption band of about 1963 cm^{-1}. The polymer–In_2O_3–Fe_2O_3 relationship results in a transition in the PVA spectral range. This is because there are no interactions between the PVA and the In_2O_3/Fe_2O_3 nanoparticles. According to FTIR readings, the transmittance is reduced owing to a slight growth in In_2O_3 and Fe_2O_3 concentrations, as displayed in Fig. 2 [30–34].

The relation between dielectric constant and frequency for PVA/In_2O_3/Fe_2O_3 nanocomposites is displayed in Fig. 3. From this figure, we can see the dielectric constant of nanocomposites decreases with increases frequency. This could be because dipoles in nanoparticle models tend to align themselves in the directions of practical electrical fields, which makes space charge polarization drop to total polarization [35, 36].

Figure 4 shows the connection between dielectric constant and concentration of In_2O_3/Fe_2O_3 nanoparticles for PVA/In_2O_3/Fe_2O_3 nanocomposites. We can see that as the number of In_2O_3 and Fe_2O_3 nanoparticles goes up, the dielectric constant goes up. This is because, in an alternating electric field, nanocomposites undergo interfacial polariza-

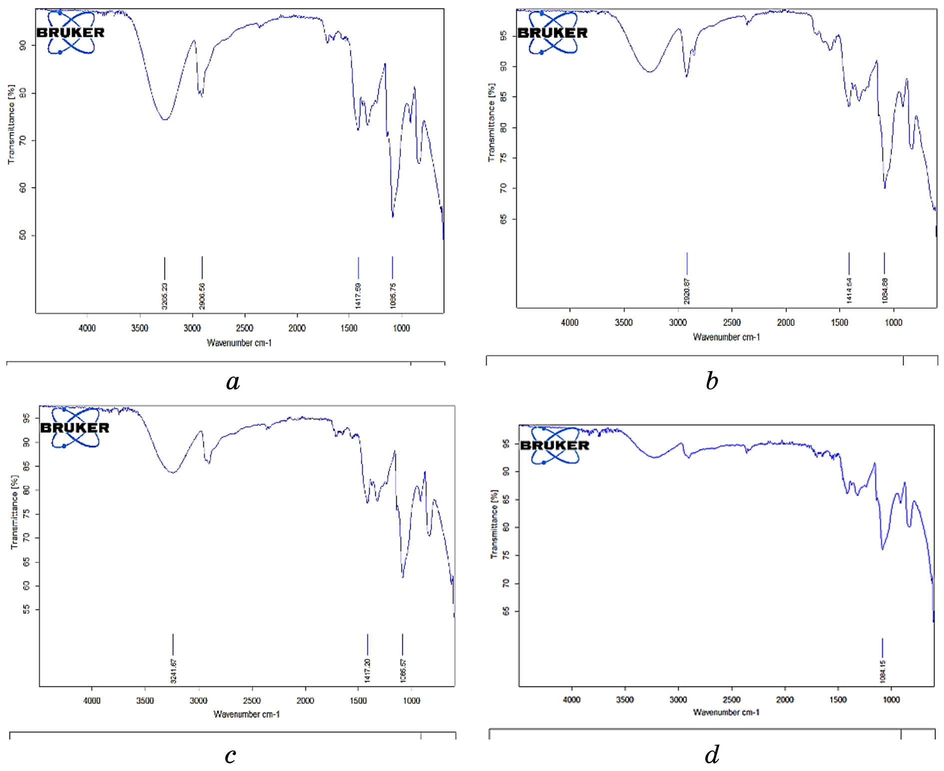

Fig. 2. FTIR spectra of PVA/In_2O_3/Fe_2O_3 nanocomposites: (*a*) for PVA; (*b*) for 2 wt.% of In_2O_3/Fe_2O_3; (*c*) for 4 wt.% of In_2O_3/Fe_2O_3; (*d*) for 6 wt.% of In_2O_3/Fe_2O_3.

tion, leading to an increase in charge carriers [37, 38].

The calculation of the dielectric loss ε'' of nanocomposites was performed using Eq. (1). The frequency-dependent dielectric loss of nanocomposites is illustrated in Fig. 5. The figure manifests that the dielectric loss gives a notable rises at lower applied frequencies, while it exhibits a drop as the applied frequencies rises. The mentioned phenomenon can be ascribed to the fact that with a rise in frequency, the extent of the space charge polarization component diminishes [39, 40].

Figure 6 illustrates the dielectric loss with concentration of In_2O_3/Fe_2O_3 nanoparticles for PVA/In_2O_3/Fe_2O_3 nanocomposites. We can get that the dielectric loss goes up as the concentration of In_2O_3 and Fe_2O_3 nanoparticles goes up. This is because the number of charge carriers goes up. When the concentration of nanoparticles is low, it forms clusters, but when it goes up to 6%, it forms a continuous network in the nanocomposite [41, 42].

The A.C. electrical conductivity was computed by using Eq. (2). Fig-

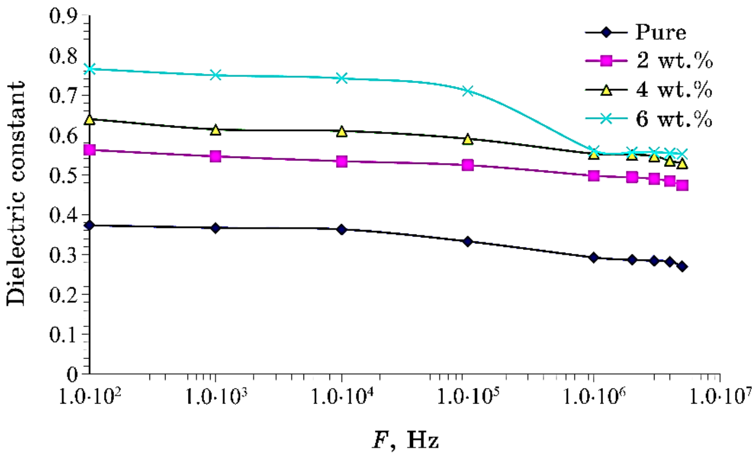

Fig. 3. Dielectric constant as a function of frequency for $PVA/In_2O_3/Fe_2O_3$ nanocomposites.

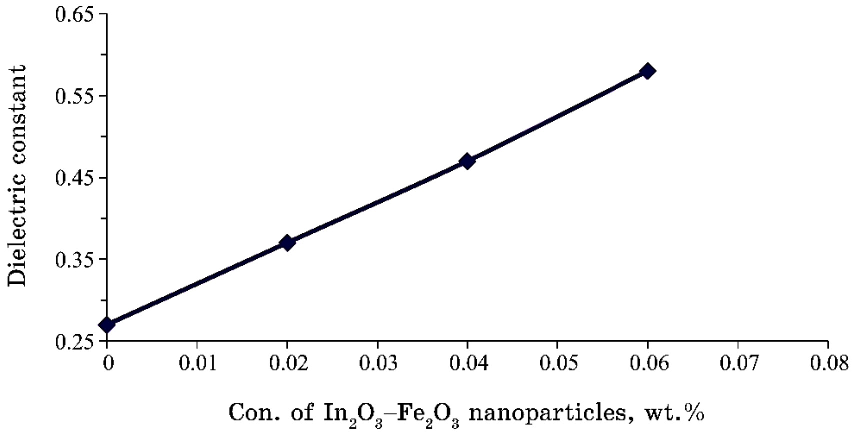

Fig. 4. Difference dielectric constant with concentration of In_2O_3/Fe_2O_3 nanoparticles in $PVA/In_2O_3/Fe_2O_3$ nanocomposites.

ure 7 illustrates the frequency-dependent alteration of A.C. electrical conductivity in $PVA/In_2O_3/Fe_2O_3$ nanocomposites. The A.C. electrical conductivity of nanocomposites increases with increasing of the frequency of the applied electric field. The observed phenomenon can be rationalized by the polarization effect and hopping mechanism. Consequently, there is a polarization effect between finite networks or clusters, and electron hopping happens between adjacent states that are randomly distributed within these finite networks [43, 44].

Figure 8 shows A.C. electrical conductivity and concentration for $PVA/In_2O_3/Fe_2O_3$ nanocomposites. From this figure, we can see the

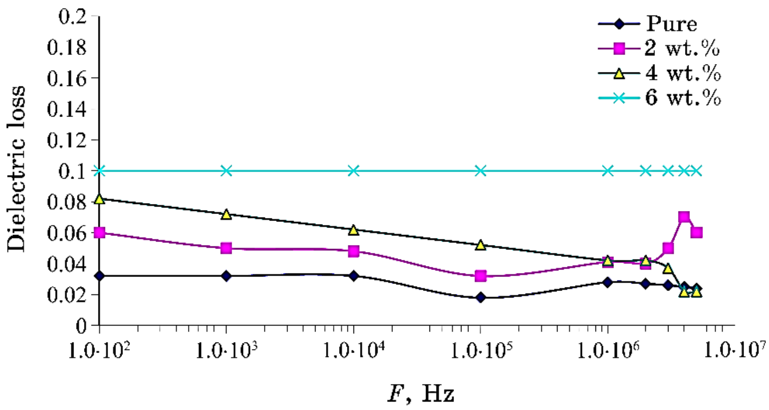

Fig. 5. Change of dielectric loss with frequency for PVA/In_2O_3/Fe_2O_3 nanocomposites.

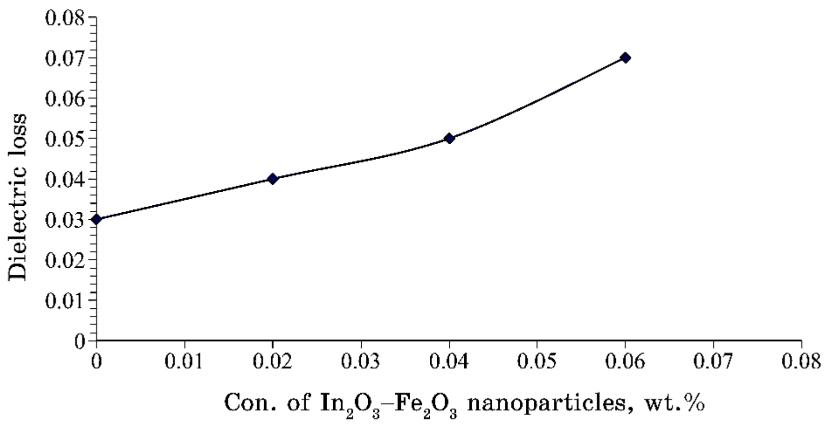

Fig. 6. Relation between dielectric loss and concentration of In_2O_3/Fe_2O_3 nanoparticles for PVA/In_2O_3/Fe_2O_3 nanocomposites.

A.C. electrical conductivity growths as concentration for In_2O_3 and Fe_2O_3 nanoparticles growths, resulting from a growth in the total number of charge carriers present in the polymer medium [45].

4. CONCLUSION

The findings of the optical microscope revealed that nanoparticles form a continuous network in films (polyvinyl alcohol). The nanoparticles inside the polymer are related together in this network. This creates paths for charge carriers to move over, which changes the way the material works. The PVA/In_2O_3/Fe_2O_3 nanocomposites contributed to

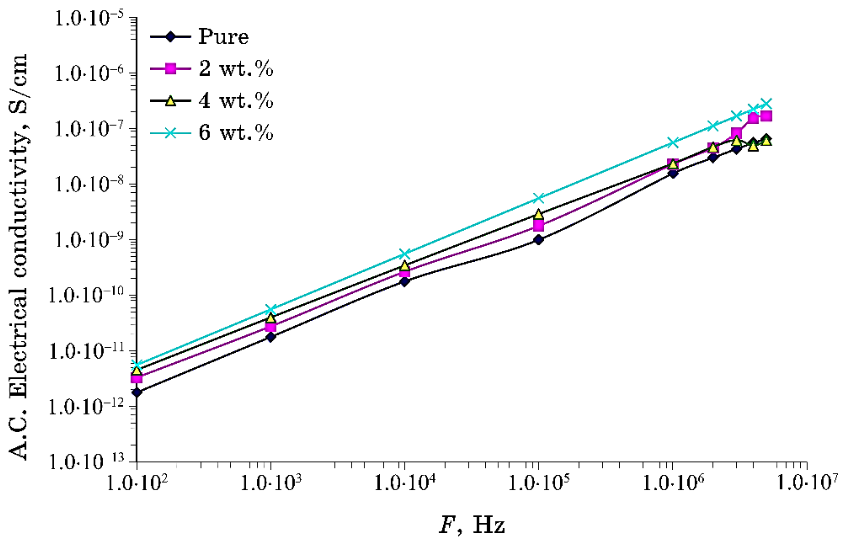

Fig. 7. A.C. electrical conductivity *vs.* frequency for PVA/In_2O_3/Fe_2O_3 nanocomposites.

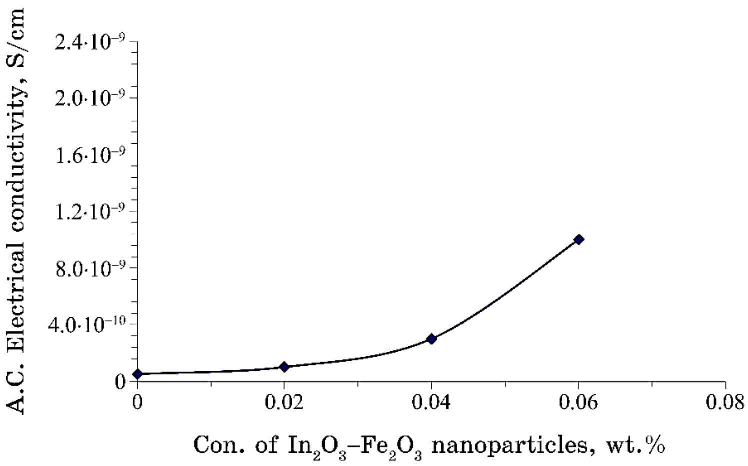

Fig. 8. A.C. electrical conductivity *vs.* concentration for PVA/In_2O_3/Fe_2O_3 nanocomposites.

small vibrational molecular movement, according to the FTIR.

Next, the adding of In_2O_3/Fe_2O_3 nanoparticles, number of polymer chains has too been broken. Instead, a number of different chains were created. The dielectric properties of PVA/In_2O_3/Fe_2O_3 nanocomposite films (dielectric constant, dielectric loss, and A.C. electrical conductivity) go up as the concentration of In_2O_3/Fe_2O_3 nanoparticles goes up. The dielectric constant and the dielectric loss both drop as the frequency of the electric field that is being used goes up, while A.C. conductivity increases.

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