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Improvement of Dielectric Properties of PVA/MnO₂–SnO₂ Nanostructures for Nanodielectric Applications

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This study investigates the dielectric properties of polyvinyl alcohol (PVA) with manganese dioxide (MnO₂) and tin dioxide (SnO₂) nanoparticles. The objective is to utilize these properties in electronic and electric nanodevices. An investigation is conducted to analyse the impact of varying concentrations of MnO₂/SnO₂ nanoparticles on the dielectric properties and A.C. electrical conductivity of the composites. The findings indicate that, as the frequency increases, the dielectric constant and dielectric loss decrease. However, with a higher concentration of MnO₂/SnO₂ nanoparticles, both the dielectric constant and dielectric loss increase. On the other hand, the A.C. electrical conductivity shows an increase as the frequency and concentration of MnO₂/SnO₂ nanoparticles increase. The PVA/MnO₂/SnO₂ nanocomposites exhibit exceptional dielectric properties, making them highly versatile for a wide range of applications in the electronics and energy-storage industries. This study offers fresh perspectives on the development of materials for electrical and electronics applications.

Це дослідження стосується діелектричних властивостей полівінілового спирту (ПВС) із наночастинками діоксиду Мангану (MnO₂) та діоксиду Стануму (SnO₂). Метою є використання цих властивостей в електронних та електричних нанопристроях. Було проведено дослідження для аналізу впливу різних концентрацій наночастинок MnO₂/SnO₂ на діелектричні властивості та змінну електропровідність композитів. Результати дослідження показують, що зі збільшенням частоти діелектрична проникність і діелектричні втрати зменшуються. Однак з підвищенням концентрації наночастинок MnO₂/SnO₂ як діелектрична проникність, так і діелектричні втрати збільшуються. З іншого боку, змінна електропровідність зростає зі збільшенням частоти та концентрації наночастинок MnO₂/SnO₂. Наноккомпозити ПВС/MnO₂/SnO₂ демонструють виняткові діелектричні властивості, що робить їх дуже універсальними для широкого спектру застосувань в електроніці та накопиченні енер-

гії. Це дослідження пропонує нові перспективи розробки матеріалів для електричних і електронних застосувань.

Key words: PVA, MnO₂ and SnO₂ nanoparticles, nanocomposites, A.C. electrical properties.

Ключові слова: ПВС, наночастинки MnO₂ та SnO₂, нанокompозити, електричні властивості на змінному струмі.

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1. INTRODUCTION

Since polymers operate as carriers of charges by causing charge mobility along their chains *via* the π -electrons, they are regarded as organic materials with conjugating chains, which exhibit strong electric conduction [1, 2]. The properties of polymers are comparable to those of inorganic matter, but they also have a number of advantages (and disadvantages), including excellent flexibility, resistance to corrosion, process ability, low cost, and lightweight nature. Important properties like high mechanical properties and thermal stability are also present in inorganic materials [3, 4]. As a result, the polymer/inorganic system has several uses in many industries [5]. Nanocomposite materials show significant promise in several applications such as sensors, radiation shielding, antimicrobial agents, thermal energy storage and release, piezoelectric devices, solar cells, diodes, and other industries, which prioritize to lightweight and cost-effectiveness [6, 7]. Polymer-matrix nanocomposites (NCs) are increasingly being used in materials owing to their many advantages, such as their low weight, ease of production, affordability, superior resistance to fatigue, and exceptional ability to withstand corrosion [8, 9]. The incorporation of nanoparticles into a polymer matrix leads to significant modifications in the electrical, structural, thermal, and optical characteristics of the matrix [10]. Both organic and inorganic nanocomposites have great promise for applications in gas sensors, photovoltaic cells, photodiodes, light-emitting diodes, smart microelectronics, *etc.* [11, 12]. Because of their remarkable chemical and physical properties that set them apart from the bulk, metal-oxide nanoparticles have attracted a great deal of attention in solar cell applications, optoelectronics, sensing, catalysis, and other fields. Semi-crystalline polyvinyl alcohol (PVA) has poor electrical conductivity [13, 14].

PVA crystal–amorphous interfacial phenomena give rise to certain physical properties. By adding the appropriate doping material, its electrical properties may be precisely altered [15]. MnO₂ is re-

garded as one of the greatest catalysts because of its affordability, low toxicity, and friendliness with the environment. Manganese oxide is a transition-metal oxide that occurs in a variety of forms. Because of its special qualities, MnO₂ is one of the most appealing oxides. Manganese dioxide (MnO₂) is a semiconductor with a narrow band gap and a high optical constant that has catalytic and ferroelectric qualities [16, 17]. In the field of scientific study, tin oxide (SnO₂) is now a topic that is receiving a lot of attention. Because of its well-established features as an *n*-type semiconductor with a large band gap of 3.6–3.8 eV, this is the reason why it is so appealing [18, 19]. It has a significant potential for a variety of applications, including the use of transparent conducting electrodes in solar cells, the use of gas-sensing material in gas-sensor devices, and the use of transparent conducting electrodes in photochemical and photoconductive devices for liquid-crystal displays and gas dischastification [20].

2. EXPERIMENTAL PART

Nanocomposite films containing polyvinyl alcohol (PVA) and nanoparticles of manganese dioxide (MnO₂) and tin dioxide (SnO₂) were fabricated using the casting method. In order to conduct the experiment, 40 millilitres of distilled water were used to dissolve pure polyvinyl alcohol (PVA). Next, various weight percentages of 0, 2, 4, and 6 wt.% of tin dioxide (SnO₂) and manganese dioxide (MnO₂) nanoparticles were added to the polymer. This dissolving procedure was place at 70°C for 40 minutes with constant stirring of the solution using a magnetic stirrer. Achieving more homogeneity in the solution was the aim of this process. Following 3 days of air-drying at room temperature, polymer nanocomposites were successfully formed. The PVA/MnO₂/SnO₂ nanocomposites were taken out of the Petri dish and used as measurement samples. With an LCR meter of the HIOKI 3532-50 LCR HI TESTER type, the dielectric characteristics of nanocomposites were evaluated between 100 Hz and 5 MHz.

The dielectric constant (ϵ') is computed using the following formula [21, 22]:

$$\epsilon' = C_p / C_0 . \quad (1)$$

The sign C_0 is usually used to denote a vacuum capacitor, whereas the term C_p is generally used to describe capacitance. It is possible to express the dielectric loss (ϵ'') [23, 24] as follows:

$$\epsilon'' = \epsilon' D . \quad (2)$$

The variable ‘displacement’ (D) is utilized in this context.

The calculation for the alternating current (A.C.) electrical conductivity is as follows [25, 26]:

$$\sigma_{\text{A.C.}} = \omega \epsilon' \epsilon_0, \quad (3)$$

where ω denotes the angular frequency.

3. RESULTS AND DISCUSSION

As shown in Figures 1 and 2, the complex permittivity of the PVA/MnO₂/SnO₂ nanocomposite films changes in a way that is frequency dependent, with regard to both the real component (ϵ') and the imaginary part (ϵ''). The statistical findings show that at lower frequencies, both ϵ' and ϵ'' have substantial values. With increasing

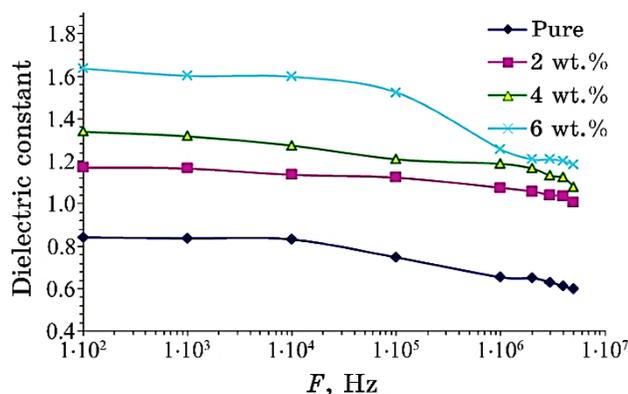


Fig. 1. Variation of ϵ' for PVA/MnO₂/SnO₂ films with frequency.

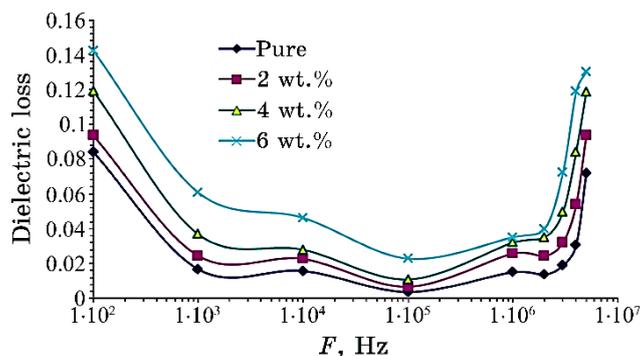


Fig. 2. Variation of ϵ'' for PVA/MnO₂/SnO₂ films with frequency.

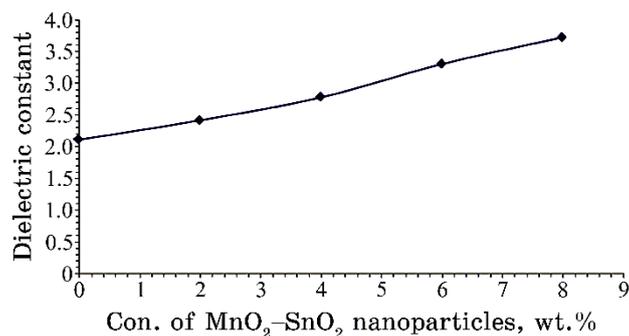


Fig. 3. Relation between dielectric constant and MnO₂/SnO₂-NPs' content for PVA/MnO₂/SnO₂ films.

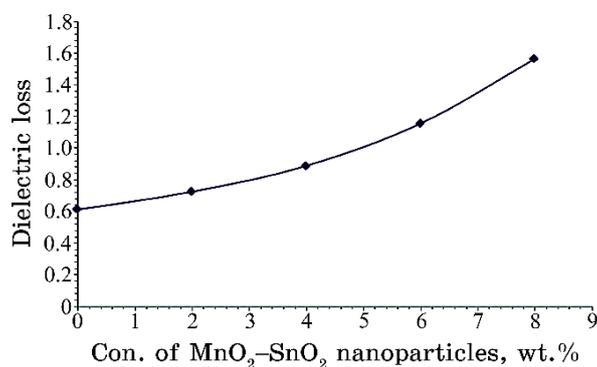


Fig. 4. Variation of ϵ'' with MnO₂/SnO₂-NPs' content for PVA/MnO₂/SnO₂ films.

frequency, the values of ϵ' and ϵ'' for PVA/MnO₂/SnO₂ NCs are noticeably reduced. This phenomenon is more accurately described as interfacial polarisation, which is also known as the Maxwell-Wagner effect [27–31].

Figures 3 and 4 give more information on how the inclusion of MnO₂/SnO₂ nanoparticles (NPs) influences the performance of ϵ' and ϵ'' for the PVA/MnO₂/SnO₂ films. When the concentration of MnO₂/SnO₂ NPs increases, the values of ϵ' and ϵ'' increase proportionally. This is clearly shown by the findings, which are clear and precise. One may deduce from the pattern that the MnO₂/SnO₂ nanoparticles are responsible for an increase in the total number of charge carriers [32–37].

The graphs in Figs. 5 and 6 illustrate the variations in the A.C. electrical conductivity ($\sigma_{A.C.}$) of the PVA/MnO₂/SnO₂-nanocomposite films as a function of frequency and the ratio of MnO₂/SnO₂ nano-

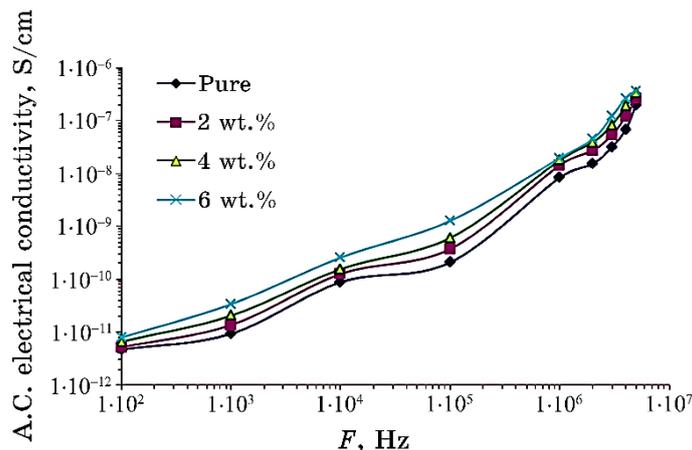


Fig. 5. Connection of $\sigma_{A.C.}$ for PVA/MnO₂/SnO₂ films with frequency.

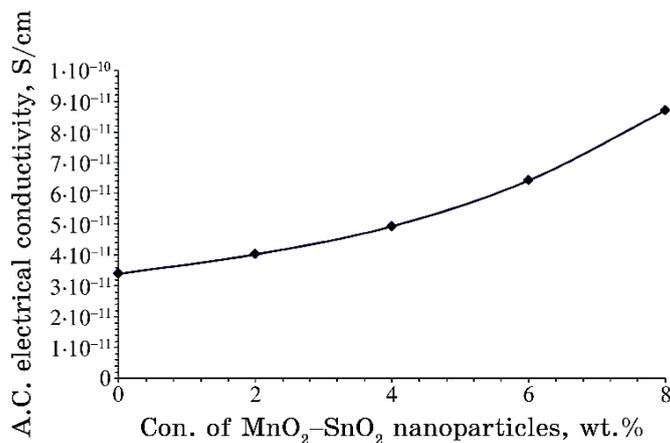


Fig. 6. Variation of $\sigma_{A.C.}$ with MnO₂/SnO₂-NPs' content in PVA/MnO₂/SnO₂ films.

particles. Based on these observations, it can be seen that the $\sigma_{A.C.}$ values of the PVA/MnO₂/SnO₂ films increase in tandem with the frequency and ratio of MnO₂/SnO₂ nanoparticles. There is a connection between the hopping process and the polarisation effect because the values of $\sigma_{A.C.}$ rise as the frequency increases [38–41]. Furthermore, the increase in conductivity values that occurs as the additive ratio rises may be attributed to an increase in the amount of charge carriers as well as the creation of a network of nanoparticles inside the composite [42–44].

Table show values of A.C. electrical conductivity, dielectric loss,

TABLE. Results for the A.C. electrical conductivity, dielectric loss, and dielectric constant of NCs composed of PVA/MnO₂/SnO₂ at 100 Hz.

Concentration of MnO ₂ /SnO ₂ , wt. %	Dielectric constant	Dielectric loss	A.C. electrical conductivity, S/cm
0	0.84	0.084	4.68·10 ⁻¹²
2	1.17	0.093	5.2·10 ⁻¹²
4	1.33	0.119	6.62·10 ⁻¹²
6	1.63	0.142	7.91·10 ⁻¹²

and dielectric constant for NCs composed of PVA/MnO₂/SnO₂ at 100 Hz.

4. CONCLUSIONS

This research aims to examine the dielectric properties, namely, the complex-permittivity real component (ϵ') and imaginary part (ϵ''), as well as the electrical conductivity ($\sigma_{A.C.}$). Understanding how the materials react to different electrical loads requires paying close attention to these vital details. During the process of assessing the results of the PVA/MnO₂/SnO₂ nanocomposite films, a distinct pattern was found. As the concentration of MnO₂/SnO₂ nanoparticles grew, it was observed that the dielectric constant (ϵ'), dielectric loss (ϵ''), and alternating current conductivity ($\sigma_{A.C.}$) values for the polyvinyl alcohol (PVA) rose. It has been observed that the electrical characteristics of the composite material are improved in proportion to the increase in the concentration of nanoparticles. A further finding from the experiment was that the ϵ' and ϵ'' values for the PVA/MnO₂/SnO₂-nanocomposite films decreased as the frequency rose. On the other hand, the $\sigma_{A.C.}$ values showed an increasing trend. It seems that there is a complex interplay taking place between the frequency and the dielectric properties of the material. Taking all of these findings into consideration, it is clear that the PVA/MnO₂/SnO₂ nanocomposite films have a significant amount of potential for use in the fields of electricity transfer and energy storage. Because of the unique dielectric properties, which they possess, they have the potential to be taken into consideration for further research and development in a variety of industries.

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