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IMPROVEMENT STRUCTURAL AND DIELECTRIC PROPERTIES OF $PS/SiC/Sb_2O_3$ NANOSTRUCTURES FOR NANOELECTRONICS DEVICES[†]

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In the current study, the $PS/SiC/Sb_2O_3$ nanocomposites have been prepared by using solution casting method with different concentrations of SiC/Sb_2O_3 nanoparticles (0,2,4,6,8) % wt. The structural and dielectric properties of ($PS/SiC/Sb_2O_3$) nanocomposites have been investigated. Full emission scanning electron microscope (FE-SEM) used to study the surface of nanocomposite. FE-SEM confirmed that good distribution of SiC and Sb_2O_3 NPs into the polymer matrix. Optical microscope (OM) was tested the morphological of nanocomposite that proven that the polystyrene is exceptionally miscible, as seen by its finer form and smooth, homogeneous surface, while the additive concentration SiC and Sb_2O_3 NPs are well distributed on the surface of the polymer nanocomposite films. Fourier transformation spectroscopy (FTIR) was examining the structural of nanocomposite and give the information of the vibration of molecules. From FTIR, the additive SiC and Sb_2O_3 NPs caused interaction with polymer matrix. FTIR proven that there is physical interactions between polystyrene and SiC and Sb_2O_3 NPs. According to AC electrical properties, dielectric constant and dielectric loss of the NCs reduce with increasing the frequency of the applied electric field and increased with increasing concentration of SiC/Sb_2O_3 nanoparticles, while AC electrical conductivity increased with increasing frequency and concentration of SiC/Sb_2O_3 NPs. The results of structural and electrical characteristics show that the $PS/SiC/Sb_2O_3$ nanocomposites may be used for various electronics devices.
Keywords: *Nanocomposites; Polystyrene; SiC and Sb_2O_3 Nanoparticles; AC electrical properties*
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1. INTRODUCTION

The nanocomposite material, which is made from non-metallic, metallic, and polymeric materials using a particular procedure, has the unique advantage of keeping key qualities that can be employed to resolve flaws and exhibit some novel properties. This variety of substance is a multistage cross of matrices and reinforcing substance. In contrast to the polymeric matrix, which is a phase separation made up of metallic, inorganic non-metallic, and polymer matrix materials, the reinforcement is a continuous phase that typically comprises of fibrous materials like glass fiber, organic fiber, and so on [1,2]. In comparison to the different phases, nanocomposite exhibits improved thermal, mechanical, electrical, and optical properties. It is a multiphase material that consists of the matrix phase and the contributing to better [2]. Nanocomposites have a wide range of possible uses because of how adaptable they are. The immediate result of the nanometer-sized particles put into nanocomposites as contrasted to typical scaled composites is their smaller size. Additionally, the connection of the nanoparticle with the polymer network sections as well as the role of the interfacial region between the nanoparticles and the polymer matrices are significant. The volume percentage of this contact area is high due to the high surface - to - volume of the nanoparticles [3,4]. Due to its expected remarkable thermal, optical, electrical, and antibacterial capabilities, polymer-based nanocomposites have received a lot of attention. Inorganic materials are favored because of their great thermal stability, good electrical characteristics, and high refractive index. However, research has indicated that inorganic nanoparticles cannot effectively serve a variety of industrial device applications due to a number of limitations [5, 6]. One of the extensively utilized plastics is polystyrene, which is produced at a rate of several million tons annually. Although polystyrene could be clear by nature, it can also be colored with colorants. Among the many uses for polystyrene are the following: It is employed in the manufacture of toys, refrigerator, and furniture, among other things. Additionally, polystyrene is used in the manufacture of radio knobs, clear plastic drinking cups, and a majority of the molded components found inside automobiles. Toys, hair dryers, televisions, and kitchen equipment all use polystyrene. It serves as a cushioning agent and is used in packing. About 70% of polystyrene is used in building and construction, 25% is used in packaging and 5% is utilized for other purposes [7,8]. High stability and colorless or white crystals are how polystyrene is described. It has a solubility of 730 g/L in water, making it easily soluble. PS dissolves in acidic water. Its symmetric structure, O-O bond distance of 1.497, and bond energy of 140 kJ/mol are all positive [9,10]. A non-oxide substance is silicon carbide (SiC). Semiconductor ceramic material has a variety of exceptional qualities, including great oxidation resistance, high thermal conductivity, reaction passivity for acids and melts, and thermal stability Microwave dielectrics and power energy storage materials extensively utilize this material due to its stress resilience and extraordinarily high toughness. Sic nanoparticles, however, are incredibly easy to make. impact the physicochemical characteristics of the composites as they aggregate. As a result, excellent results are achievable. Sic nanoparticles that have been surface modified increase composite performance [11,12]. A semiconducting substance with outstanding chemical stability in flame retardance and strong photocatalytic performance is antimony trioxide (Sb_2O_3). The creation of Sb_2O_3 films and the study of their new properties have received most of the attention thus far.

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Contrarily, it is anticipated that low-dimensional Sb_2O_3 nanoparticles, nanowires, nanotubes, and nanoribbons will each have distinctive features. Because many of the features of material at the nanoscale are known to be dependent on their form, carefully orchestrating the synthesis of desirable nanomaterial morphologies is essential. Despite significant research, it is still challenging for researchers to effectively and controllably synthesis a predefined material shape [13,14].

2. EXPERIMENTAL PART

($PS/SiC/Sb_2O_3$) nanocomposites were created by dissolving 1gm of polystyrene (PS) in 30 ml of chloroform and mixing the polymers for 30 minutes by using magnetic stirrer at room temperature to achieve a more homogeneous solution, silicon carbide (SiC) and tertiary antimony oxide (Sb_2O_3) nanoparticales were added to the polystyrene in various concentrations (0, 2, 4, 6 and 8) wt. %. The structural characteristics of ($PS/SiC/Sb_2O_3$) nanocomposites examined by (FE-SEM) analyses were performed using a Hitachi SU6600 variable pressure, optical microscope (OM) provided by Olympus (Top View, type Nikon-73346) and Fourier Transformation Infrared Spectroscopy (FTIR) (Bruker company type vertex-70, German origin) with range wavenumber (500-4000) cm^{-1}. The dielectric characteristics were studied at range ($f=100$ Hz to 5×10^6 Hz) by LCR meter (HIOKI 3532-50 LCR HI TESTER).
The dielectric constant ($\acute{\varepsilon}$) is given by [15]:

$$\acute{\varepsilon} = \frac{C_p}{C_o}, \tag{1}$$

Where, Cp is capacitance and C_o is a vacuum capacitance

Dielectric loss (ε'') is calculated by [16]

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

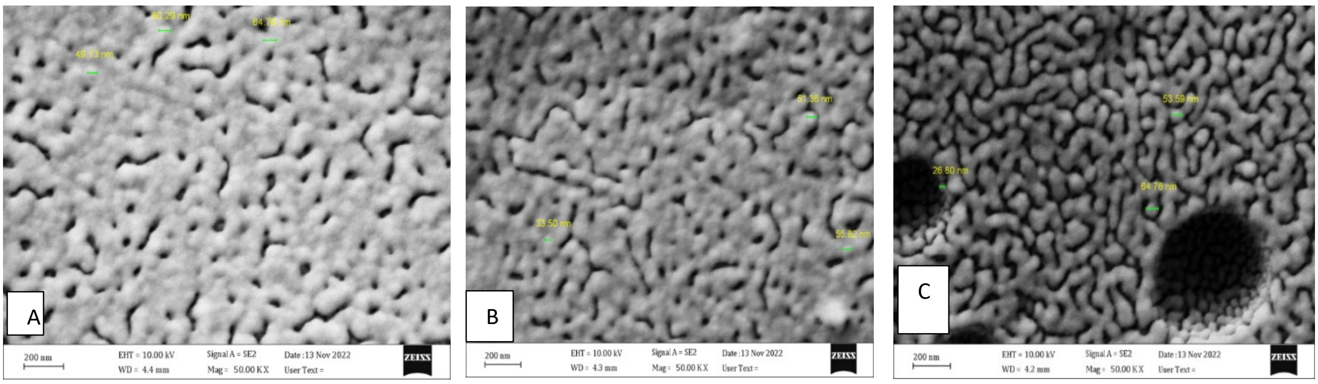
Where, D is displacement
The A. C electrical conductivity is determind by [17]

$$\sigma_{AC} = \omega \acute{\varepsilon}\, \varepsilon_o \tag{3}$$

Where, w is the angular frequency.

3. RESULTS AND DISCUSSION

Full emission scanning electron microscope (FE-SEM) is used to study the morphological of ($PS/SiC/Sb_2O_3$) nanocomposites. Fig. (1) illustration of (FE-SEM) images of pure polystyrene and ($PS/SiC/Sb_2O_3$) nanocomposites with various concentration 2, 4, 6 and 8 wt.% of SiC and Sb_2O_3 NPs with a magnification 50 KX and scale 200 nm. In the image (A), the surface of polymer is homogenous this indicates a good method for prepared film. In image (B, C, and D) which explain the increasing concentration of SiC and Sb_2O_3 NPs, the distribution uniform and homogenous inside the polymer matrix while in image E, the grain aggregates as nonuniform clusters, which may be attributed to the nature of the SiC and Sb_2O_3 NPs [18,19]. In nanocomposites, the number of groups or fragments that are spread out on the upper surface rises as the concentration of SiC/Sb_2O_3 nanoparticles.



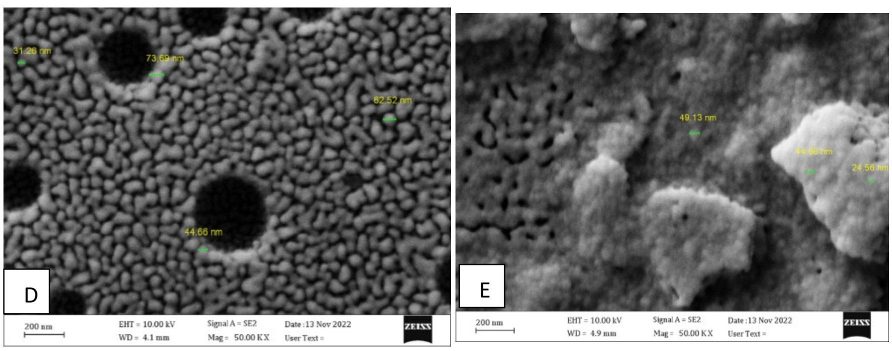


Figure 1. SEM images of PS/ SiC/Sb_2O_3 nanocomposites, (A) for (Ps), (B) 2 wt.% SiC/ Sb_2O_3 nanoparticles, (C) 4 wt.% SiC/ Sb_2O_3, (D) 6 wt.% SiC/ $Sb_2O_3$4 nanoparticles, (E) 8 wt.% SiC/ Sb_2O_3 nanoparticles

Fig. (2) shows optical microscope images of PS/SiC/Sb_2O_3 nanocomposites with and without different concentrations of SiC and Sb_2O_3 NPs at magnification power (10X). In portrait A, polystyrene (Ps) is exceptionally miscible, as seen by its finer form and smooth, homogeneous surface, while in portraits B, C, D and E, it can be seen, that SiC and Sb_2O_3 NPs are well distributed on the surface of the polymer. From these images, the SiC and Sb_2O_3 NPs formed a clusters in the form of chains that extended along the surface of the films, attributed to the novel property in SiC and Sb_2O_3 NPs [20,21], other than charge transport within polymer matrices, which also was enhanced by raising the percentages of SiC and Sb_2O_3 NPs.

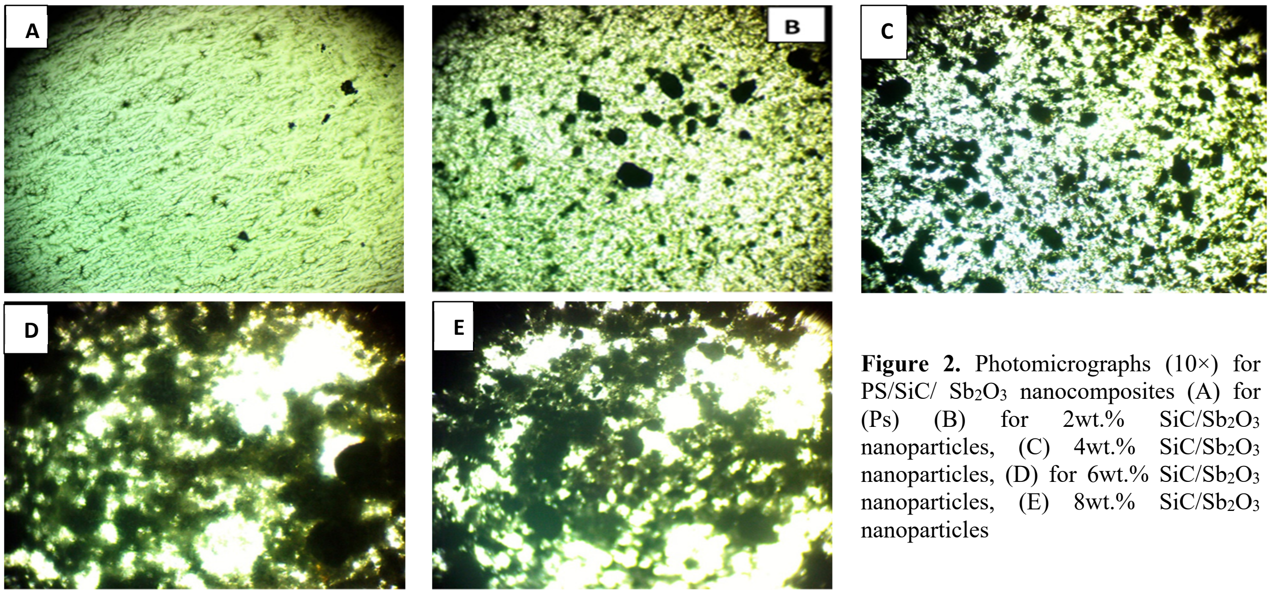


Figure 2. Photomicrographs (10×) for PS/SiC/ Sb_2O_3 nanocomposites (A) for (Ps) (B) for 2wt.% SiC/Sb_2O_3 nanoparticles, (C) 4wt.% SiC/Sb_2O_3 nanoparticles, (D) for 6wt.% SiC/Sb_2O_3 nanoparticles, (E) 8wt.% SiC/Sb_2O_3 nanoparticles

FTIR spectra of (Ps/SiC/Sb_2O_3) nanocomposites in the range (500-4000) cm^{-1} are shown in Figure (3). The absorption band of pure Ps in image (A) at 2980 cm^{-1} corresponding to the C-H stretching vibrations in the main chain and in aromatic rings [22,23].

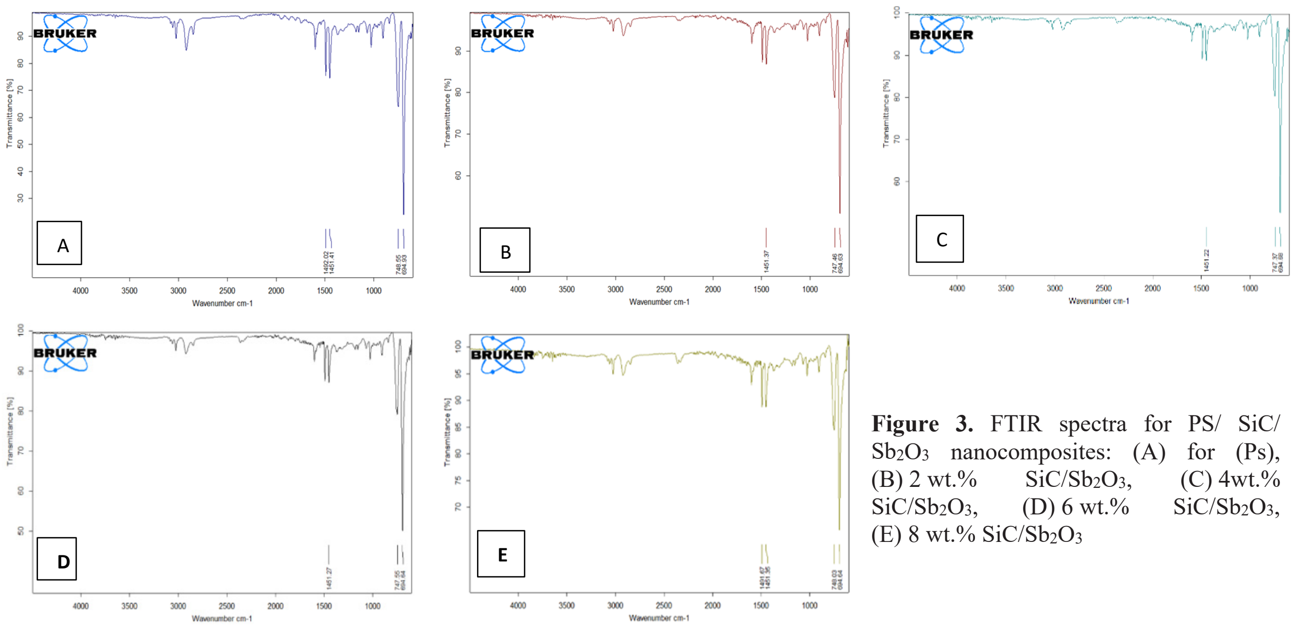


Figure 3. FTIR spectra for PS/ SiC/ Sb_2O_3 nanocomposites: (A) for (Ps), (B) 2 wt.% SiC/Sb_2O_3, (C) 4wt.% SiC/Sb_2O_3, (D) 6 wt.% SiC/Sb_2O_3, (E) 8 wt.% SiC/Sb_2O_3

The bands (1492.02 cm^{-1} and 1451.41 cm^{-1}) attributed to the C-H stretching vibrations [24,25] while the bands (748.55 cm^{-1} 694.93 cm^{-1} corresponding to the C-H out phase bend [26]. The spectral of polystyrene with additive different concentration of SiC and Sb_2O_3 NPs in images B, C, D and E respectively. In image B where the additive 2 wt.% from SiC and Sb_2O_3 NPs caused shift to low wavenumber in some bands and intensities at (1451.37, 747.45, 694.43) cm^{-1} but bands 1492.02 cm^{-1} and 2980 cm^{-1} there is not affected on this band. The image C which additive concentration of 4 wt.% from SiC and Sb_2O_3 NPs, the bands (1451.22, 747.37 cm^{-1}, 694.68) cm^{-1} was shifted to low wavenumber and the band 1492.02 cm^{-1} and 2980 cm^{1} there is not influenced. The bands (1451.27, 747.55 cm^{-1}, 694.64) cm^{-1} in image D where additive 6wt.% from NPs, caused shift to low wavenumber while in the other hand, the band 1492.02 cm^{-1} and 2980 cm^{-1} there is not change. From the additive concentration 8wt.% from NPs in image E, the band (1491.67, 694.64) cm^{-1} caused change to low wave number, while the band 748.03 cm^{-1} caused change to high wave number but the band 1451.37 cm^{-1} and 2980 cm^{-1} there is not affected. The FTIR proven that there are no chemical interactions between polystyrene and SiC and Sb_2O_3 NPs.

Equation (1) was used to calculate the dielectric constant (έ) of PS/SiC/Sb_2O_3 nanocomposites. The variation of the dielectric constant with frequency is shown in Fig. 4. As can be observed, the dielectric constant values drop with increasing applied frequency, which leads to a reduction in the space charge to total polarization ratio. At low frequencies, space charge polarization is the most significant type of polarization, and as frequency rises, its significance decreases. As the electric field frequency rises, different kinds of polarizations take place, and the dielectric constant values for all samples of Ps/SiC/Sb_2O_3 drop. Ionic polarization responds to variations in field frequency in a slightly different manner than electronic polarization because an ion has a larger mass than an electron [27-29].

The dielectric constant for (PS/SiC/Sb_2O_3) NCs at 100Hz variation with concentrations as shown in Fig. 5. As the percentage of SiC and Sb_2O_3 NPs rise, the dielectric constant of nanocomposites also rises. Interfacial polarization, a process that occurs when two surfaces within NCs are separated by an alternating electric field and causes a rise in charge carriers, could be used to explain this activity [30-33].

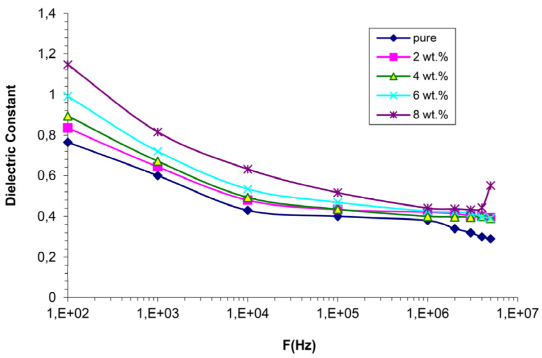


Figure 4. Dielectric constant of PS/SiC/Sb_2O_3 nanocomposites varies with frequency

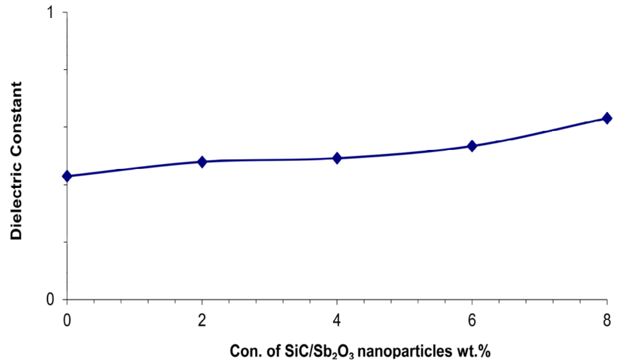


Figure 5. Difference of dielectric constant with concentration of (PS/SiC/Sb_2O_3)

Equation (2) was used to calculate the dielectric loss (ε″) of nanocomposites. Fig. 6 shows the dielectric loss of PS/SiC/Sb_2O_3 nanocomposites with frequency. From this figure it can be seen the dielectric loss is high at lower applied frequencies, but decreases with increasing applied frequencies. This can be attributed to the actuality that as the frequency rises, the space charge polarization contribution decreases [34- 37].

The relationship between SiC and Sb_2O_3 NPs concentration and dielectric loss (ε″) is shown in Fig. 7. As the concentration of NPs rises, the dielectric loss of PS/SiC/Sb_2O_3 NCs also rises, which is related to an increase in charge carriers [38,39].

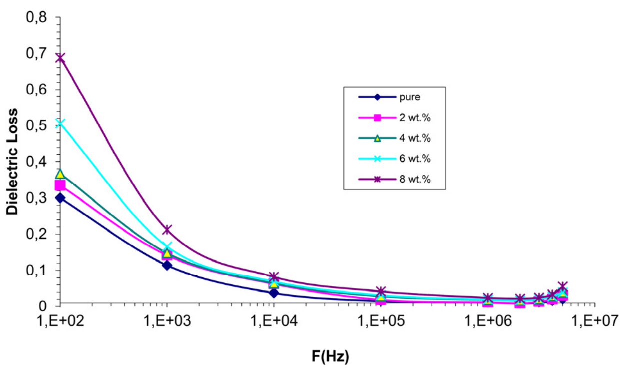


Figure 6. Dielectric loss variation with frequency for (PS/SiC/Sb_2O_3) nanocomposites

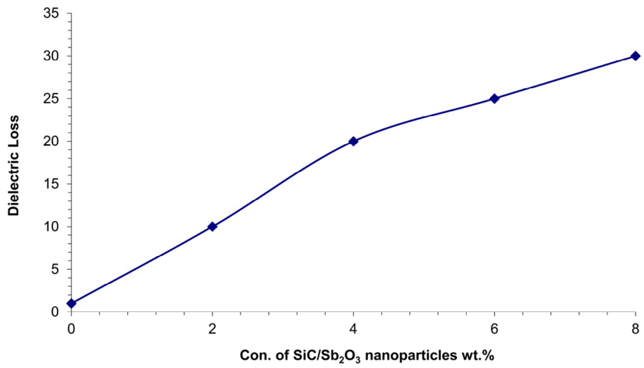


Fig. (7) Difference of dielectric loss for PS/ Sic/Sb_2O_3 NCs with different concentrations of Sic/Sb_2O_3 NPs

The A.C electrical conductivity was calculated from equation (3). Fig. (8) Shows the variation in electrical conductivity of PS/SiC/Sb_2O_3 NCs with frequency. This figure demonstrates that electrical conductivity significantly rises with frequency, which is caused by space charge polarization, which happens at low frequencies, and the hopping process, which causes charge carriers to move. The increase in electrical conductivity is only moderate at high frequencies due to electronic polarization and charge carriers that move through hopping [40, 41].

Table 1. Values of the dielectric constant, dielectric loss and AC electrical conductivity at 100Hz of (PS/SiC/Sb_2O_3) nanocomposites

Con.(wt.)%	Dielectric constant	Dielectric loss	AC electrical conductivity(S/cm)
0	0.43	1	2.08E-10
2	0.479	10	3.47E-10
4	0.492	20	3.56E-10
6	0.534	25	3.86E-10
8	0.63	30	4.56E-10

Fig. 9. shows influence of SiC and Sb_2O_3 NPs on the A.C electrical conductivity of PS/SiC/Sb_2O_3 NCs at 100 Hz. The A.C. electrical conductivity of NCs rises as SiC and Sb_2O_3 NPs concentration rises. Due to the composition of the dopant nanoparticles, there are more charge carriers, which reduces the NCs resistance and boosts electrical conductivity [42,43]. Table (1) shows the values of dielectric constant, dielectric loss and A.C electrical conductivity at 100 Hz.

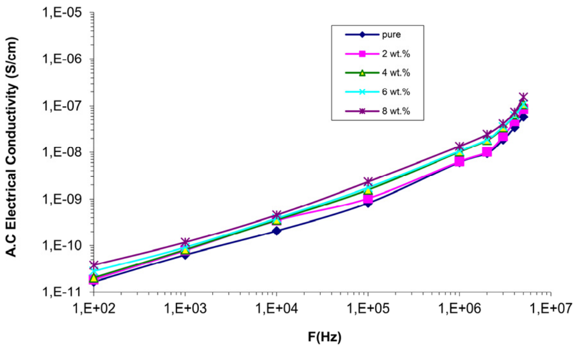


Figure 8. Difference of A.C electrical conductivity with frequency for PS/SiC/Sb_2O_3 NCs

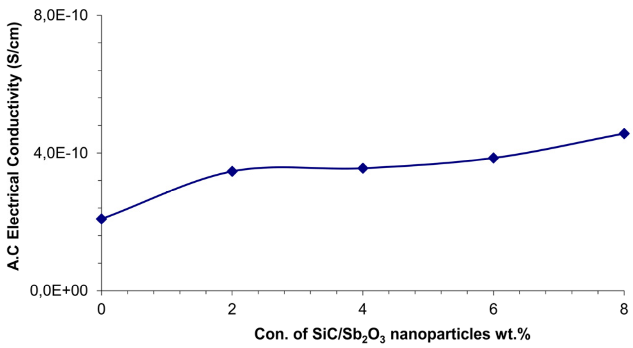


Figure 9. Difference of A.C electrical conductivity with (Sic/Sb_2O_3) NPs for (PS/SiC/Sb_2O_3) NCs

4. CONCLUSSION

In this work, the solution casting technique was used to prepare (PS/SiC/Sb_2O_3) NCs films. The surface morphology of the (PS/SiC/Sb_2O_3) nanocomposites films is shown by scanning electron microscopy (FE-SEM) confirmed that the good distribution of the SiC and Sb_2O_3 NPs into the polymer polystyrene matrix. The optical microscope (OM) proven the morphological of nanocomposite that confirmed that the polystyrene is exceptionally miscible, as seen by its finer form and smooth, homogeneous surface, while the additive concentration SiC and Sb_2O_3 NPs are well distributed on the surface of the polymer blend films. The Fourier transformation spectroscopy (FTIR) confirmed the additive SiC and Sb_2O_3 NPs caused physical interaction with polymer matrix. The dielectric constant and dielectric loss of PS/SiC/Sb_2O_3 decreased with increasing of frequency and increased with increasing concentration of SiC/Sb_2O_3 nanoparticles. The A.C. electrical conductivity of Ps/SiC/Sb_2O_3 NCs increase with increasing of frequency and concentration of SiC/Sb_2O_3 nanoparticles. These characteristics can be applied to films in a variety of electrical applications.

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ПОКРАЩЕННЯ СТРУКТУРНИХ І ДІЕЛЕКТРИЧНИХ ВЛАСТИВОСТЕЙ НАНОСТРУКТУР PS/SiC/Sb_2O_3 ДЛЯ ПРИСТРОЇВ НАНОЕЛЕКТРОНІКИ

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У поточному дослідженні нанокомпозити PS/SiC/Sb_2O_3 були виготовлені методом лиття з розчину з різними концентраціями наночастинок Sb_2O_3 (0,2,4,6,8) % мас. Досліджено структурні та діелектричні властивості нанокомпозитів (PS/SiC/ Sb_2O_3). Повний емісійний скануючий електронний мікроскоп (FE-SEM), який використовується для дослідження поверхні нанокомпозиту. FE-SEM підтвердив хороший розподіл НЧ SiC і Sb_2O_3 в полімерній матриці. Під оптичним мікроскопом (OM) було перевірено морфологію нанокомпозиту, що довело, що полістирол є винятково змішуваним, як видно з його більш тонкої форми та гладкої однорідної поверхні, тоді як концентрація добавок SiC та Sb_2O_3 NPs добре розподілена на поверхні полімерного плівки нанокомпозиту. Інфрачервоною Фур'є спектроскопія (FTIR) досліджено структуру нанокомпозиту та отримана інформація про коливальні властивості молекул. З FTIR додавання SiC і Sb_2O_3 NP викликало взаємодію з полімерною матрицею. За допомогою FTIR доведено, що існує фізична взаємодія між полістиролом і наночастинками SiC і Sb_2O_3. Відповідно до електричних властивостей змінного струму діелектрична проникність і діелектричні втрати НК зменшуються зі збільшенням частоти прикладеного електричного поля та збільшуються зі збільшенням концентрації наночастинок SiC/Sb_2O_3, тоді як електропровідність змінного струму зростає зі збільшенням частоти та концентрації НЧ SiC/Sb_2O_3. Результати структурних та електричних характеристик показують, що нанокомпозити PS/SiC/Sb_2O_3 можуть бути використані для різних електронних пристроїв.

Ключові слова: *нанокомпозити; полістирол; наночастинки SiC і Sb_2O_3; електричні властивості для змінного струму*