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Fabrication of New Nanocomposites (PMMA-SPO-PS-TiC) and Studying Their Structural and Electrical Properties for Humidity Sensors

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ABSTRACT

Samples have been prepared by adding Titanium carbide nanoparticles to the Poly (methyl methacrylate) and Ethylene-alpha olefin co-polymer (SPO) and Polystyrene (PS) with different weight percentages (o, 2, 4, 6 and 8) wt%. The FTIR analysis, electrical, dielectric, and structural properties have been studied.The dielectric loss and The dielectric constant decrease with increasing of Titanium carbide (TiC) nanoparticles. The A.C electrical conductivity increases with increasing of Titanium carbide (TiC) concentrations and frequency. The D.C electrical conductivity increases with increasing of Titanium carbide (TiC) concentration and temperature. The Activation energy decreases with increasing of Titanium carbide (TiC) nanoparticles. The Humidity sensor application showed that the electrical resistance of (PMMA-SPO-PS-TiC) nanocomposites decreases with increase the Humidity.

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1. INTRODUCTION

Transition metal carbides are important materials because they possess some desired properties such as thermal stability, corrosion, and wear resistance, electronic, magnetic, and catalytic characteristics. Among them, titanium carbide (TiC), tungsten carbide (WC), and niobium carbide (NbC) are three kinds of important transition metal carbides, which are applied as cutting tools, ceramics, and wear resistance materials. titanium carbide has a good thermal conductivity and high thermal shock resistance, as well as high abrasion resistance. Titanium carbide powders are ofen used for manufacturing cutting tools, aerospace materials, grinding wheels, abrasive-resistant materials, polishing paste, and magnetic recording heads, as well as crucibles for smelting metals. Titanium carbide is commercially produced from the reduction of titania by carbon in a temperature range between1700 C and 2100 C [1]. Poly (methyl methacrylate) (PMMA) is one of the earliest and best known polymers. PMMA was seen as a replacement for glass in a variety of applications and is currently used extensively in glazing applications. The material is one of the hardest polymers, and is rigid, glassclear with glossy finish and good weather resistance. PMMA is naturally transparent and colorless. The transmission for visible light is very high. Polymeric composites of PMMA are known for their importance in technical applications [2]. Polystyrene (PS) is amorphous polymer with bulky side groups. General purposes PS are hard, rigid, and transparent at room temperature and glass like thermoplastic material which can be soften and distort under heat. It is soluble in aromatic hydrocarbon solvents, cyclohexane and chlorinated hydrocarbons [3].In this study we use Ethylene-alpha olefin copolymer (SPO), this polymer was discovered in 1991. The SPO having monomer units derived from ethylene and monomer units derived from an alpha olefin of 3 to 20 carbon atoms, a density of 906 to 970 kg/m^3,an activation energy of flow of 50 to 100 kJ/mol,a molecular weight distribution of 5.5 to 12 [4]. Humidity monitoring is a necessary activity in many industry fields. Measurement of humidity is of great importance in chemical and medical industries such as respiration monitoring. In addition, humidity sensing is essential in civil and aerospace engineering. It is frequently monitored in giant structures such as planes and bridges to control the possible risk of leakage due to corrosion. Furthermore, it affects product quality and the health of workers in the food industry. Therefore, it has been the focus of research for decades and a great variety of humidity sensors; resistive, capacitive, optical and thermal conductivity have been proposed and examined. In a humidity sensor, low response time, high sensitivity, repeatability, reversibility and noise immunity are required [5].

2. RESEARCH METHOD

(PMMA-SPO-PS-TiC) nanocomposites have been prepared by adding Titanium carbide nanoparticles to 70% Poly (methyl methacrylate) and 20% Ethylene-alpha olefin co-polymer (SPO) and 10% Polystyrene(PS) in 40 mL of pure benzene, by using magnetic stirrer for 70 min in 1250 ^{o}C. The Titanium carbide nanoparticles was add to the mixture by different concentrations (0, 2, 4, 6, and 8) wt%. FTIR spectra were examiend in wavenumber range (500–4000) cm^{-1} by FTIR (Bruker company, German origin, type vertex-70). The D.C electrical properties of nanocomposites were measured by by using the Keithley electrometer type 2400 source mater. The dielectric properties of samples examined with frequency range from 100 Hz to 5×10^{6} Hz by using LCR meter type (HIOKI 3532-50 LCR HI TESTER). The humidity sensor application of (PMMA-SPO-PS-TiC) nanocomposites was investigated. The sample was placed in box and the water vapor was used as a source of humidity. The control network monitored and controlled variations in humidity. The electrical resistance for different humidity range (30–90)% was measured by using the Keithley electrometer type2400 source mater. The D.C electrical conductivity of nanocomposites calculated for a regular body with a section has along the length (*L*), a constant area (*A*) and electrical resistance (*R*) by using the relation [6]:

$$\sigma_{dc} = \frac{1}{\rho} = \frac{L}{R\,A} \tag{1}$$

The activation energy can be calculated by [7]:

$$\sigma_{dc} = \sigma_{\circ} \exp\left(\frac{-E_{act}}{K_B T}\right) \tag{2}$$

Where σ is electrical conductivity at T temperature, σ_0 is electrical conductivity at 0K, KB is Boltzmann constant and Eact is activation energy. The dielectric constant έ calculates by [8]:

$$C_p = \frac{\varepsilon' \varepsilon_{\circ} A}{d} \tag{3}$$

Where Cp is capacitance, d is sample thickness, A is surface area the dielectric loss $\varepsilon^n$is [9]:

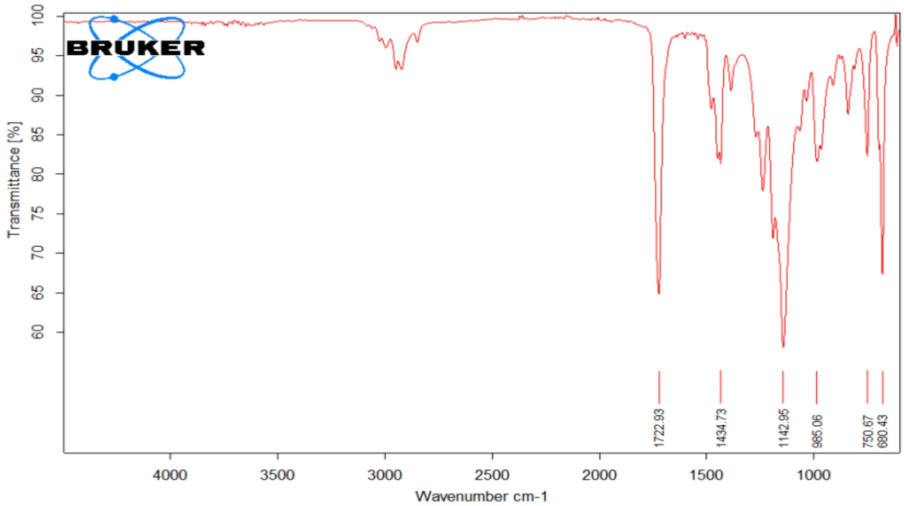
$$\tan\delta = \frac{I_p}{I_q} = \frac{\varepsilon''}{\varepsilon'} \tag{4}$$

Where tanδ is a loss factor. The AC conductivity σac calculates by [10]:

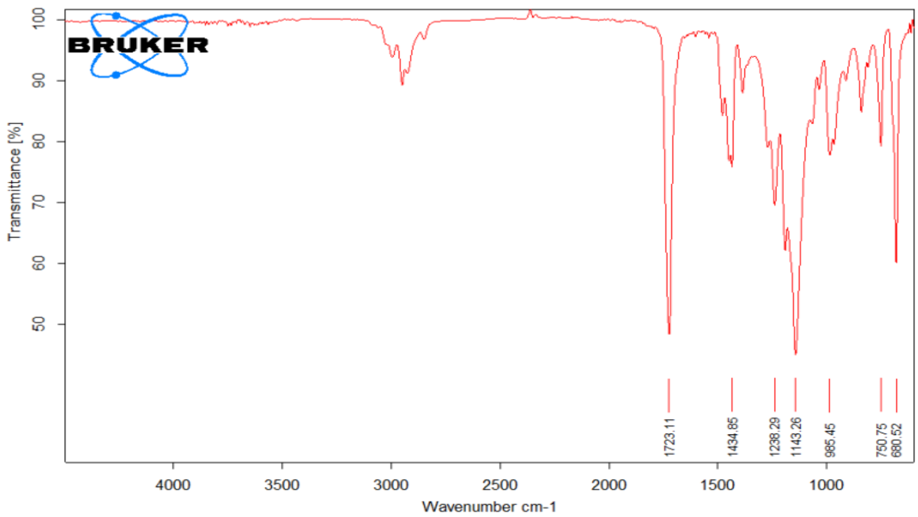
$$\sigma_{A.C} = \omega \varepsilon'' \varepsilon_{\circ} \tag{5}$$

3. RESULTS AND ANALYSIS

The FTIR spectra of (PMMA-SPO-PS-TiC) nanocomposites is shown in Figure 1. From the figure it can seen that the broad bands at around (3000) cm^{-1} are observed due to –OH groups. The absorbent peak at around (1723) cm^{-1} have been attributed to the C=O stretching mode. Asymmetric stretching and scissoring bending vibrations of CH2 group are appeared at around (1434) cm^{-1} [11].


BRUKER
Transmittance [%]
100
95
90
85
80
75
70
65
60
1722.93
1434.73
1142.95
985.06
750.67
680.43
4000
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

(a)


BRUKER
Transmittance [%]
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90
80
70
60
50
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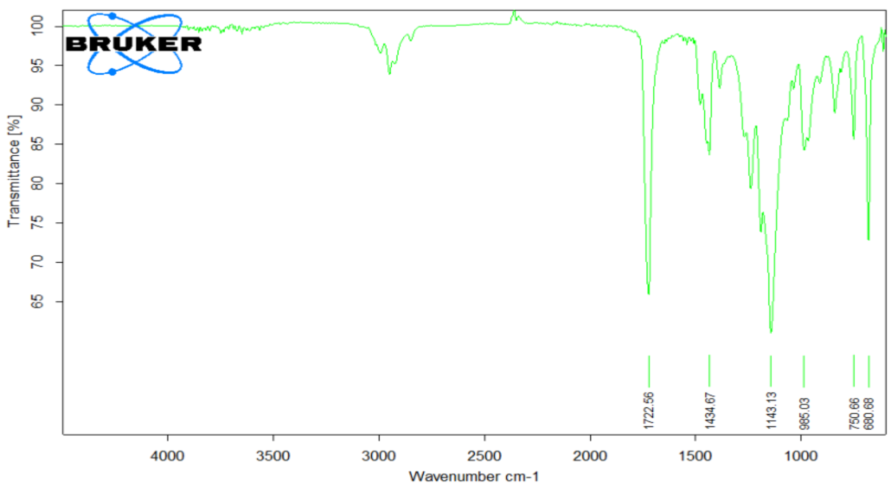
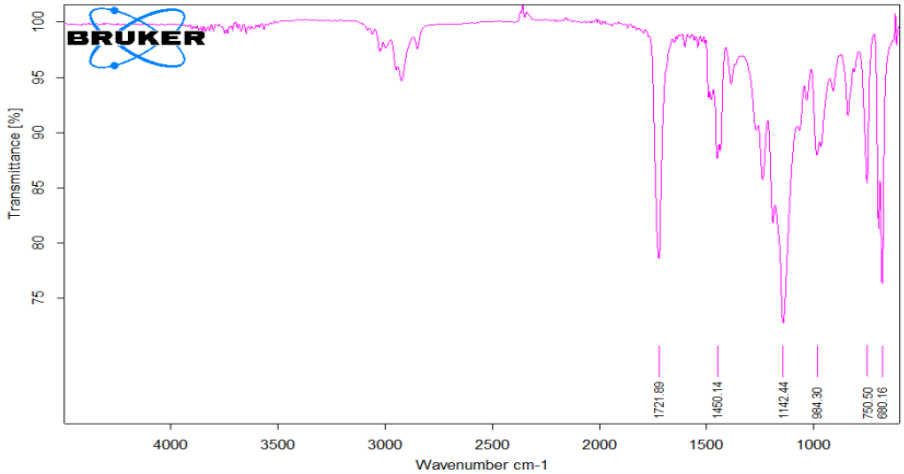
1434.85
1238.29
1143.26
985.45
750.75
680.52
4000
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

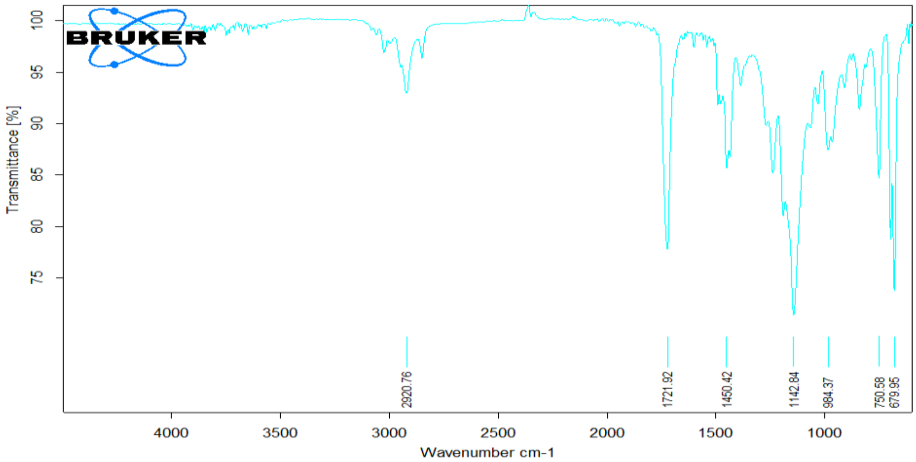
(b)


BRUKER
Transmittance [%]
100
95
90
85
80
75
70
65
1722.56
1434.67
1143.13
985.03
750.66
680.68
4000
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

(c)



(d)



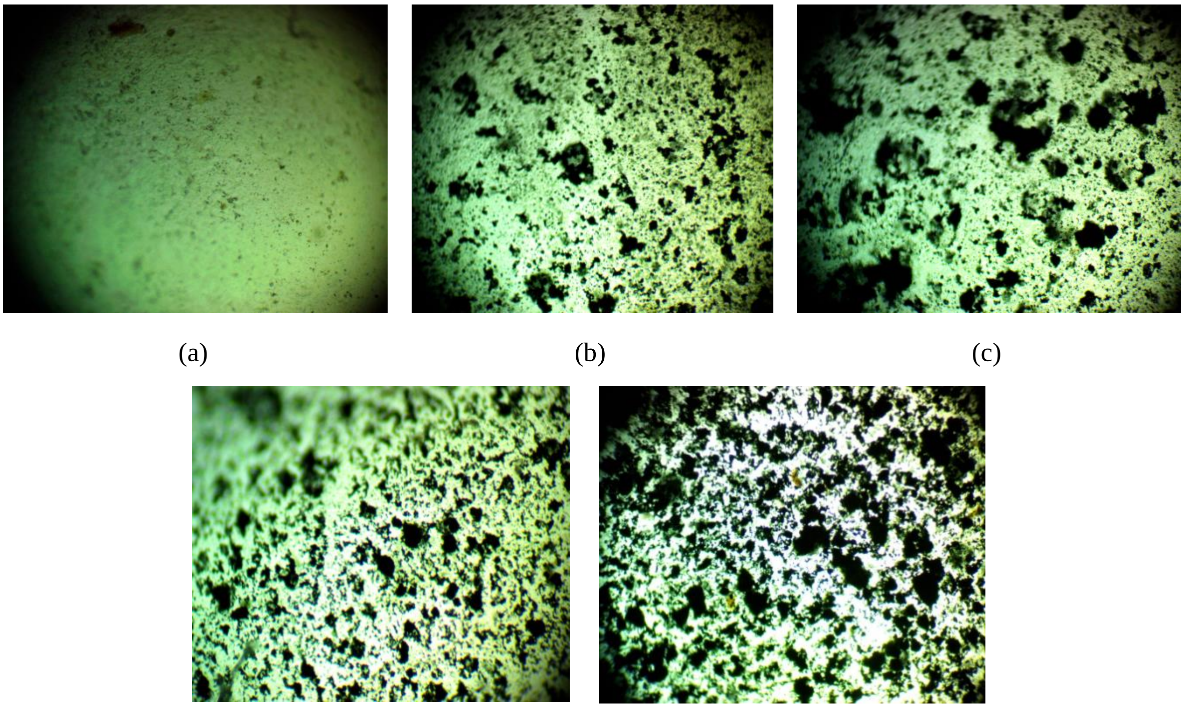
(e)

Figure 1. FTIR spectra for (PMMA-SPO-PS-TiC) nanocomposites. (A) Pure blend, (B) 2 wt.% TiC, (C) 4 wt.% TiC, (D) 6 wt.% TiC, (E) 8 wt.% TiC

Figure 2 shows the images of (PMMA-SPO-PS-TiC) nanocomposites films taken at magnification power (10×).When increasing proportions of TiC nanoparticles in the nanocomposites form a continuous network inside the polymers. This network allows charge carriers to pass through polymer [5].

Figure 3 shows the electrical conductivity increase with increasing of TiC nanoparticles due to increase the number of free charge carriers [5]. Figure 4 shows the electrical conductivity increases with increasing of temperature due to increase the charge carriers in the conduction band [12]. Figure 5 shows the relation between Lnσs and the inverse absolute temperature for (PMMA-SPO-PS-TiC) nanocomposites. The activation energy calculates by (2). Figure 6 shows By increasing the TiC nanoparticle concentrations, the activation energy decreases for (PMMA-SPO-PS-TiC) nanocomposites due to create a local energy levels in the band gap which act as traps for the charges [13].

In Figure 7 it is clear that the dielectric constant increases with increasing of TiC nanoparticles. This attributed to the formation of a continuous network of TiC nanoparticles inside the nanocomposite [14]. Figure (8) shows the dielectric constant values decrease with increasing applied flied frequency due to decrease the space charge polarization [15].



(a) (b) (c)

(d) (e)

Figure 2. Photomicrographs (×10) for (PMMA-SPO-PS-TiC) nanocomposites:(a) blend (b) 2 wt.% TiC (c) 4 wt.% TiC (d) 6 wt.% TiC (e) 8 wt.% TiC

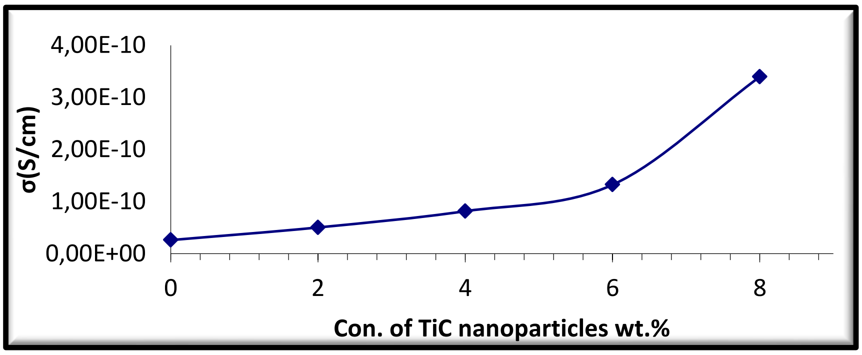


Figure 3. Variation of D.C electrical conductivity with (TiC) nanoparticles wt.% concentration for (PMMA-SPO-PS-TiC) nanocomposites at $30^{o}C$

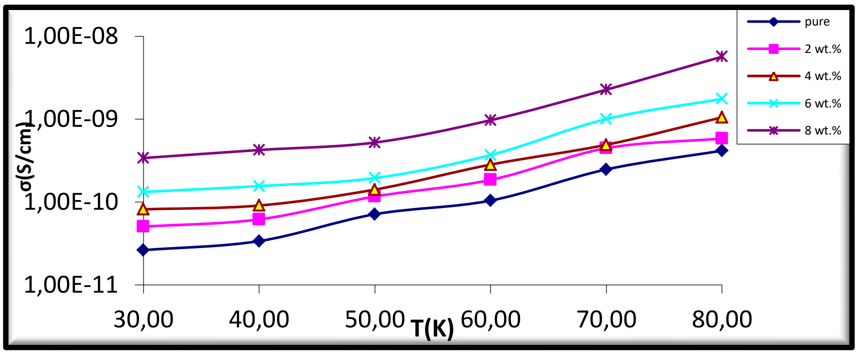


Figure 5. Variation of Ln D.C electrical conductivity with inverse absolute temperature for (PMMA-SPO-PS-TiC) nanocomposites

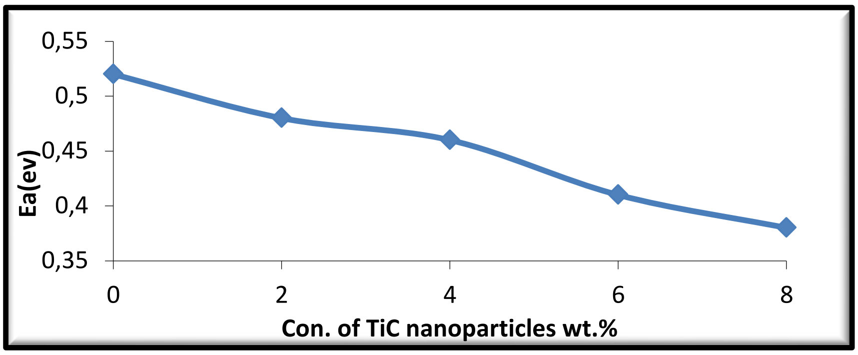


Figure 6. Variation activation energy for D.C electrical conductivity with concentration of TiC nanoparticles wt.% for (PMMA-SPO-PS-TiC) nanocomposites

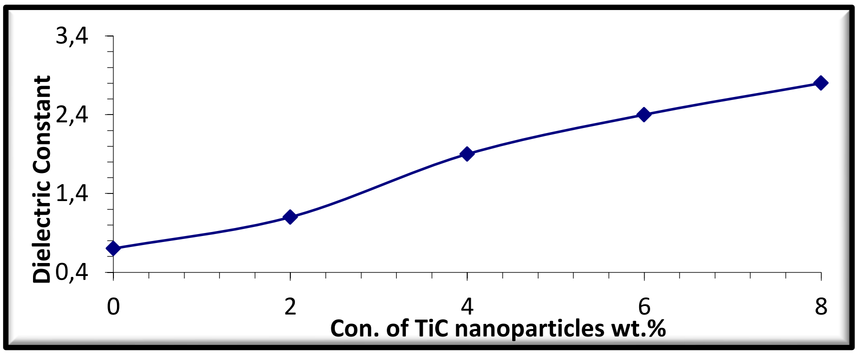


Figure 7. Variation of dielectric constant with concentration of TiC nanoparticles wt.% at 100 Hz for (PMMA-SPO-PS-TiC) nanocomposites

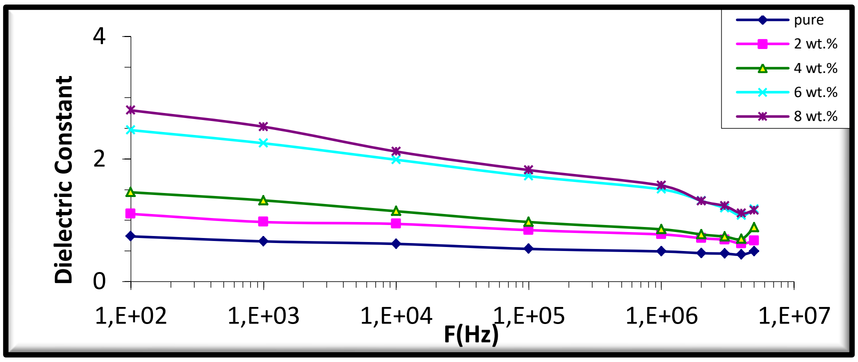


Figure 8. Variation of the dielectric constant of of (PMMA-SPO-PS-TiC) nanocomposites with frequency

In Figure 9 the dielectric loss increases with increasing of concentration of TiC nanoparticles due to increase the numbers of charge carries [12]. Figure 10 shows the dielectric loss with the frequency of (PMMA-SPO-PS-TiC) nanocomposites at room temperature.It is clear from the figure that dielectric loss decreases with frequency. The larger value of dielectric loss at low frequency could be due to the mobile charges within the polymer backbone [16].

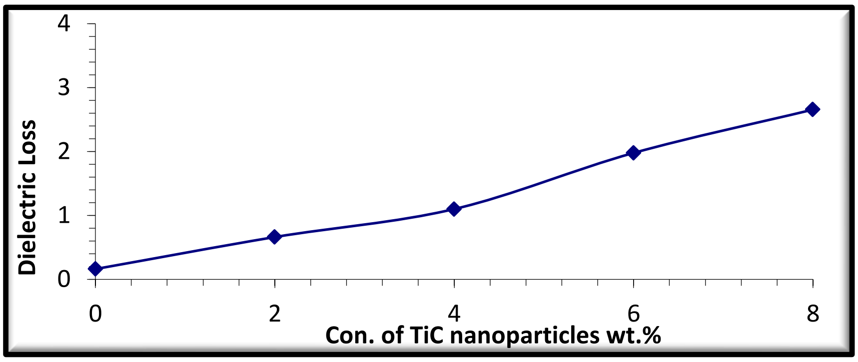


Figure 9. Variation of Dielectric loss with concentration of TiC nanoparticles at 100Hz for (PMMA-SPO-PS-TiC) nanocomposites

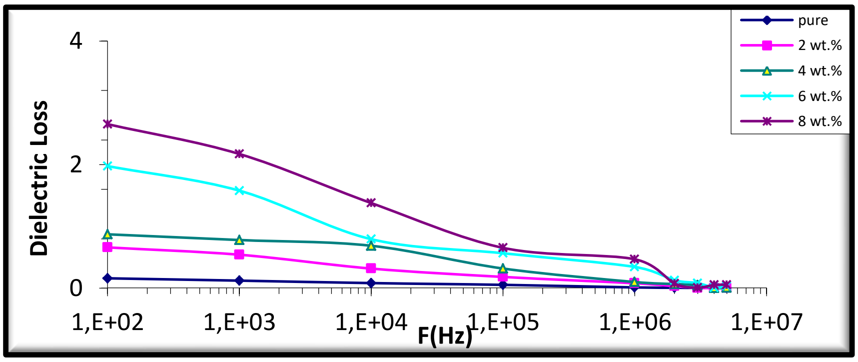


Figure 10. Variation of the dielectric loss with frequency for (PMMA-SPO-PS-TiC) nanocomposites

Figure 11 shows the A.C conductivity is increasing with increase the TiC nanoparticles. This increase due to increase the charge carriers, and the A.C conductivity increases considerably with the increase of frequency due to the motion of charge carriers by hopping process and the excitation of charge carriers to upper states in the conduction band [17].

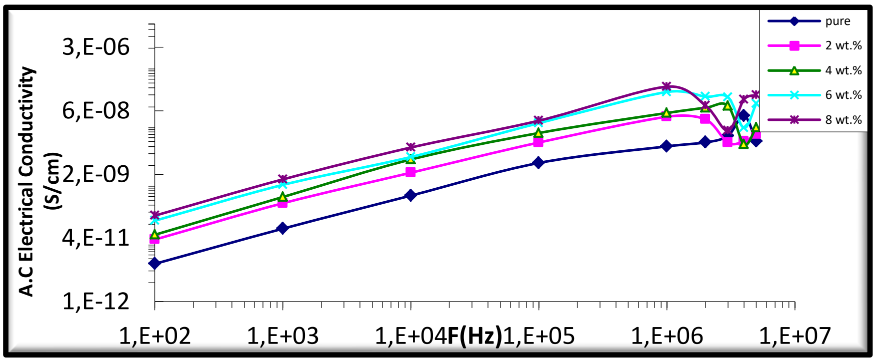


Figure 11. Variation of A.C electrical conductivity with frequency for (PMMA-SPO-PS-TiC) nanocomposites

Figure 12 shows the measured results of the humidity sensor. In this measurement, the temperature kept constant at room temperature. The experimental results showed that the humidity sensor almost had no humidity hysteresis, the resistance of the sensor decreased as humidity increased. It is universally suggested that protons and hydroxide ions are quickly diffused due to surface collision or self-ionization of water molecules, and this leads to initial separation of (H+, OH-) ions Due to the amphoteric nature of water, and hence auto ionization reaction of water vapour on a surface, a H2O molecule loses nucleus of one of its hydrogen(H+) atoms to become a hydroxide ion (OH). the increase in density of H+ in the nanocomposites leads to decrease the electrical resistance [18].

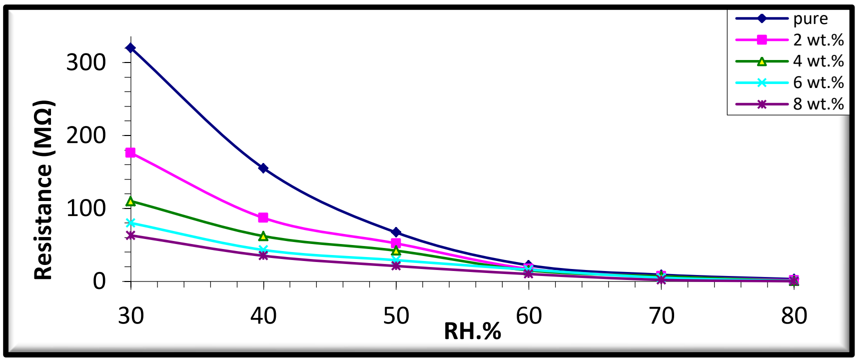


Figure 12. Variation of electrical resistance with Humidity (RH%) for (PMMA-SPO-PS-TiC) nanocomposites

4. CONCLUSIONS

a. D.C electrical conductivity for (PMMA-SPO-PS-TiC) nanocomposites increases with increasing of temperature and Titanium carbide (TiC) nanoparticles concentration.
b. Activation energy, The dielectric loss and The dielectric constant of (PMMA-SPO-PS-TiC) nanocomposites decrease with increasing of Titanium carbide (TiC) nanoparticles concentration.
c. The dielectric loss and The dielectric constant of (PMMA-SPO-PS-TiC) nanocomposites decrease with increasing of frequency.
d. The A.C electrical conductivity of (PMMA-SPO-PS-TiC) nanocomposites increases with increasing of frequency(F) and concentrations of Titanium carbide (TiC)nanoparticles .
e. The (PMMA-SPO-PS-TiC) nanocomposites have high sensitivity for Humidity

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