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Fabrication of New Nanocomposites (PS-SPO-Ag) and Studying their Structural and Electrical Properties for Pressure Sensors

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Abstract: (PS-SPO-Ag) nanocomposites prepared by adding silver nanoparticles to the Polystyrene (PS) and ethylene alpha olefin copolymer (SPO) with different percentages (0, 3, 6, 9 and 12) wt.% . The AC electrical conductivity (σ_{ac}) increases with increasing of silver (Ag) concentrations and Frequency (F). The DC electrical conductivity (σ_{dc}) increases with increasing of silver (Ag) concentrations and Temperature (T).The dielectric loss and the dielectric constant ($\acute{\varepsilon}$) decrease with increasing of silver (Ag) nanoparticles. The activation energy (E_{act}) decreases with increasing of silver (Ag) nanoparticles. The pressure sensors application showed that the electrical resistance of (PS-SPO-Ag) nanocomposites decreases with increasethe pressure.

Key words: Silver, nanocomposites, electrical properties, ethylene-alpha olefin, sensors, conductivity (σ_{dc})

INTRODUCTION

Polymers form a very important class of materials without which the life seems very difficult. They are all around us in everyday. Nowadays the enormous use of polymer materials is attributed to their extraordinary combination of properties, low weight and ease of processing. However, for improvement of some properties such as thermal and mechanical stability, large numbers of additives were added to polymeric matrix and formed polymer matrix composite. In recent years, notes when we add nanoparticles (particles between 1 and 100 nm in size) into polymers leads to dramatic changes in optical and electrical properties of the polymer and that's give us a materials have a new properties called nanocomposites (Rudko *et al*., 2015). The nanocomposites are solid materials that have multiple phase domains and at least one of these domains has a nanoscale structure. These are high performance materials that exhibit unusual property combinations and unique design possibilities and are thought of as the materials of the 21st. The improvement of the properties by the addition of particles can be achieved when adequately good interaction between the nanoparticles and the matrix and good dispersion of particles within the matrix. In nanocomposites, covalent bonds, ionic bonds, vander Waals forces, hydrogen bonding could exist between the matrix and filler components (Camargo *et al*., 2009). Sensor technology is one of the widely used technologies for applications in the industry and medicine. It can be used to measure pressure, temperature, quality and amount of energy and to monitor health. Pressure is one of the most important physical quantities in our environment. Pressure is a significant parameter in such varied disciplines as thermodynamics, aerodynamics, acoustics, fluid mechanics, soil mechanics and biophysics. Pressure enters into the control and operation of manufacturing units that are automated or operated by human operators. All these activities require instrument chains in which the first element is the pressure sensor (Al-Saygh *et al*., 2017).

MATERIALS AND METHODS

Computational details: Polymers nanocomposites have been prepared by adding silver nanoparticles to 90% Polystyrene (PS) and 10% ethylene alpha olefin copolymer (SPO) in 40 mL of pure benzene by using magnetic stirrer for 60 min in 130°C. FTIR spectra were examiend in wavenumber range (500-4000 cm^{-1}) by FTIR (Bruker company, German origin, type Vertex-70). The DC 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-5×106 Hz by using LCR meter type (HIOKI 3532-50 LCR HI Tester). The pressure sensors application of nanocomposites investigated by measuring the resistance between 2 electrodes on the top and bottom of the sample for different pressures range (80-200) bar. The electrical conductivity σ_{dc} is (Kadham *et al*., 2018):

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$$\sigma_{dc} = \frac{1}{\rho} = \frac{L}{RA} \quad (1)$$

Where:

A = A guard electrode effective area
R = A resistance
L = Average thickness

The activation energy can be calculated by Khaleel (2004):

$$\sigma_{dc} = \sigma_{o} \exp\left(\frac{-E_{act}}{K_{B} T}\right) \quad (2)$$

Where:

σ = Electrical conductivity at T temperature
σ_o = Electrical conductivity at 0K
K_B = Boltzmann constant and E_{act} is activation energy

The dielectric constant έ calculates by Habeeb *et al.* (2017):

$$C_p = \frac{\varepsilon' \varepsilon_{o} A}{d} \quad (3)$$

Where:

C_p = Capacitance
d = Sample thickness
A = Surface area

The dielectric loss ε'' is (Hashim and Hadi, 2018a, b):

$$\tan\delta = \frac{I_p}{I_q} = \frac{\varepsilon''}{\varepsilon'} \quad (4)$$

where, tan δ = a loss factor. The AC conductivity σ_{ac} calculates by Hashim and Hadi (2018a, b):

$$\sigma_{A.c} = \omega \varepsilon'' \varepsilon_{o} \quad (5)$$

RESULTS AND DISCUSSION

The FTIR spectra of (PS-SPO-Ag) nanocomposites is shown in Fig. 1. From the figure the broad bands at around (3000) cm^{-1} is assigned to the stretching vibration of hydroxyl group (OH). Asymmetric stretching and scissoring bending vibrations of CH_2 group are appeared at around (1500) cm^{-1} (Habeeb and Hamza, 2017).

Figure 2 shows the images of (PS-SPO-Ag) nanocomposites films taken for samples of different concentrations at magnification power (10×). When increasing proportions of silver nanoparticles in films Polystyrene (PS) and ethylene-alpha olefin co-polymer (SPO) when the concentration reaches to 12 wt.% for (PS-SPO-Ag) nanocomposites, the nanoparticles form a continuous network inside the polymers. This network contain paths inside the nanocomposites and allows charge carriers to pass through the paths (Rabee and Hashim, 2011).

Figure 3 shows the DC surface electrical conductivity $\sigma_{dc}(\Omega.cm)^{-1}$ with concentration of Ag nanoparticles at a temperature of 30°C. Figure 3 shows that the electrical conductivity is increasing with increase the concentration of Ag nanoparticles due to the Ag nanoparticles are located in separated groups at low concentration but in the high concentration the Ag form a continuous network in the polymers. This network has paths have low electrical resistance (El-Desoky *et al.*, 2017).

Figure 4 shows the relationship between conductivity and temperature. We can see that the electrical conductivity increases with increasing of temperature. The conductivity in nanocomposites like the semiconductors it is increasing with increase the temperature due to increase the charge carriers in the conduction band (Srikanth *et al.*, 2014).

Figure 5 shows the relation between Lnσs and the inverse absolute temperature for (PS-SPO-Ag) nanocomposites. We calculate the activation energy by Eq. 2:

We note in Fig. 6 by increasing the Ag nanoparticle concentrations, the activation energy decreases for (PS-SPO-Ag) nanocomposites due to create a local energy levels in the band gap which act as traps for the charges (AL-Humairi, 2013).

Figure 7 shows the effect of adding the Ag nanoparticles on the dielectric constant at 100 Hz and 30°C. It is clear that, the dielectric constant increases with increasing of concentration of Ag nanoparticles. This attributed to the formation of a continuous network of Ag nanoparticles inside the nanocomposite at high concentrations of Ag nanoparticles and because the increase of C_p for the storage charges. This is in agreement with the results reached by Hamzah *et al.* (2008).

Figure 8 shows the variation of the dielectric constant of (PS-SPO-Ag) nanocomposites with angular frequency. The figure shows that the dielectric constant values decrease with increasing applied flied frequency due to decreasethe space charge polarization and because the dipolar, ionic and electronic polarization (Abbas and Hasan, 2014).

Figure 9 shows the dielectric loss with concentration of Ag nanoparticles at 100 Hz. It is clear that the dielectric

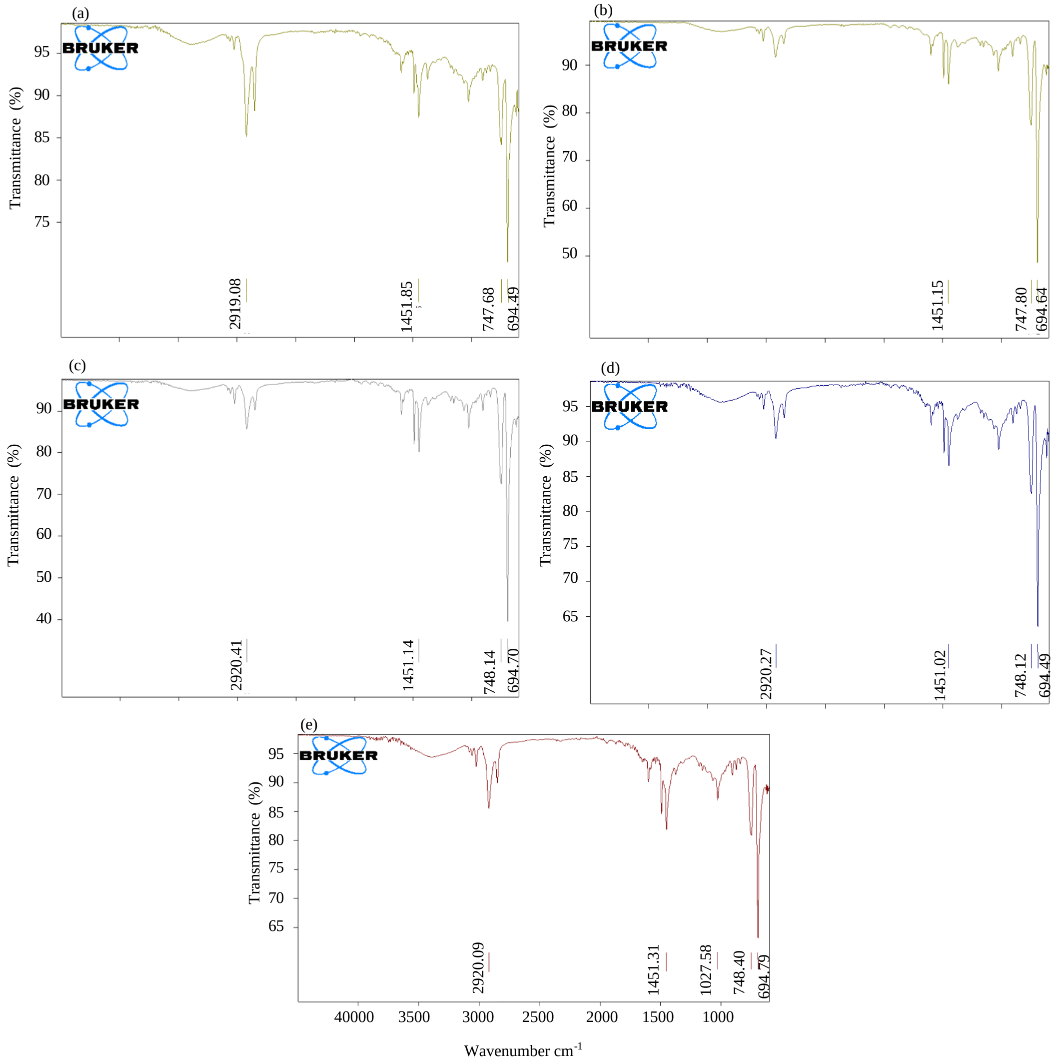

Fig. 1: FTIR spectra for (PS-SPO-Ag) nanocomposites: a) Pure blend; b) 3 wt.% Ag nanoparticles; c) 6 wt.% Ag nanoparticles; d) 9 wt.% Ag nanoparticles and e) 12 wt.% Ag nanoparticles

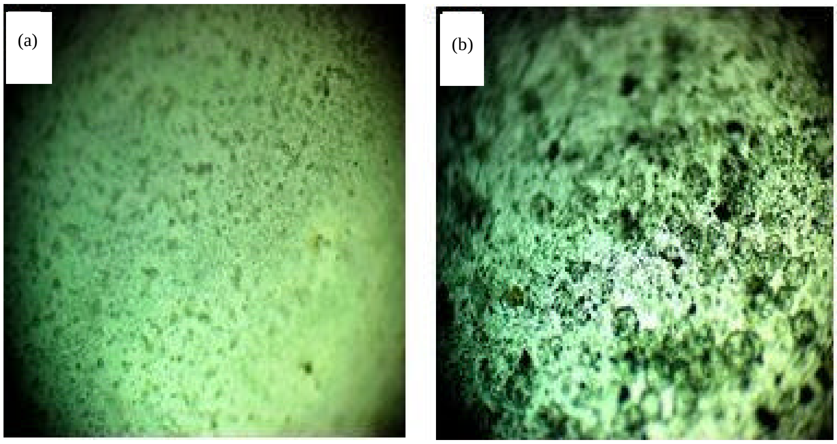

Fig. 2: Continue:

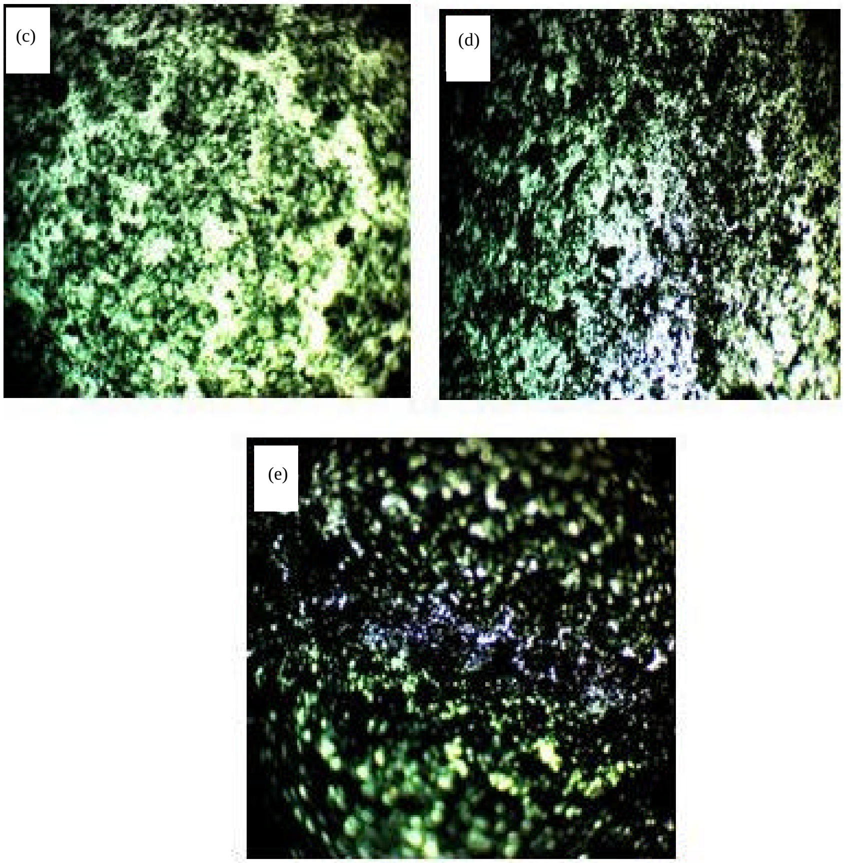

Fig. 2: Photomicrographs (×10) for (PS-SPO-Ag) nanocomposites: a) Blend; b) 3 wt.% Ag nanoparticles; c) 6 wt.% Ag nanoparticles; d) 9 wt.% Ag nanoparticles and e) 12 wt.% Ag nanoparticles

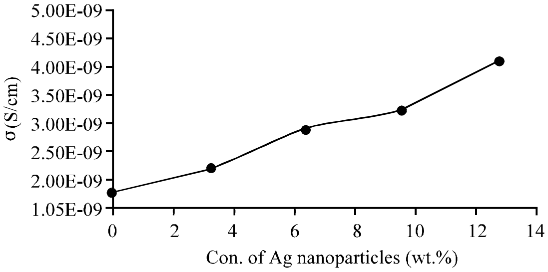

Fig. 3: Variation of DC electrical conductivity with (Ag) nanoparticles wt.% concentration for (PS-SPO-Ag) nanocomposites at 30°C

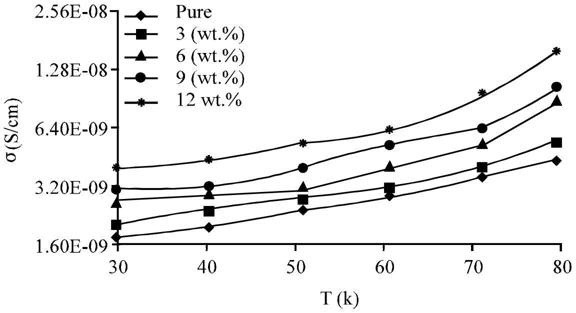

Fig. 4: Variation of DC electrical conductivity with temperature for (PS-SPO-Ag) nanocomposites

loss increases with increasing of the concentration of Ag nanoparticles due to increase the electronic charge (Liang and Tjong, 2008).

Figure 10 shows the dielectric loss with the frequency of (PS-SPO-Ag) 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. When the frequency is increasing to (5 MHz) the dielectric loss is approximately constant due to the mechanisms of other types of polarization that occur at high frequencies (Satapathy *et al*., 2008).

Figure 11 shows the AC conductivity of (PS-SPO-Ag) nanocomposites with Ag concentration at

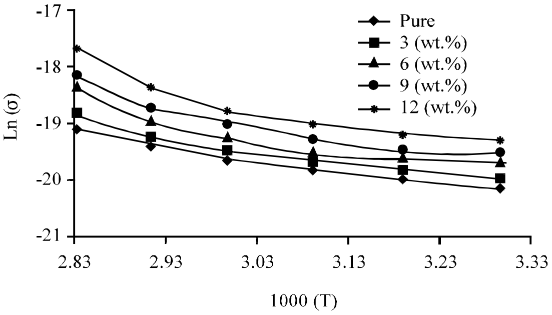

Fig. 5: Variation of Ln DC electrical conductivity with inverse absolute temperature for (PS-SPO-Ag) nanocomposites

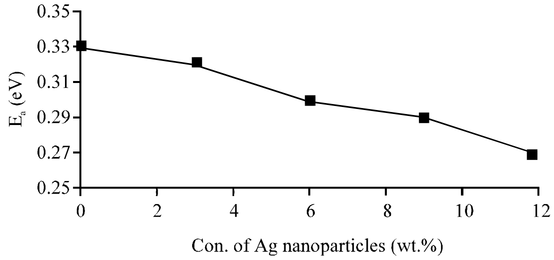

Fig. 6: Variation activation energy for DC electrical conductivity with concentration of Ag nanoparticles wt.% for (PS-SPO-Ag) nanocomposites

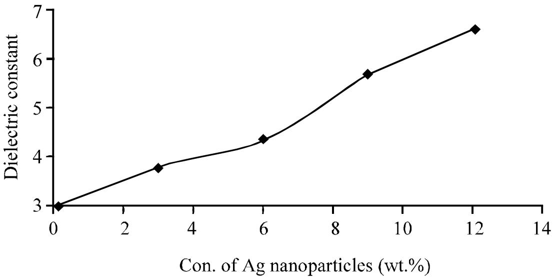

Fig. 7: Variation ofdielectric constant with concentration of silver nanoparticles wt.% at 100 Hz for (PS-SPO-Ag) nanocomposites

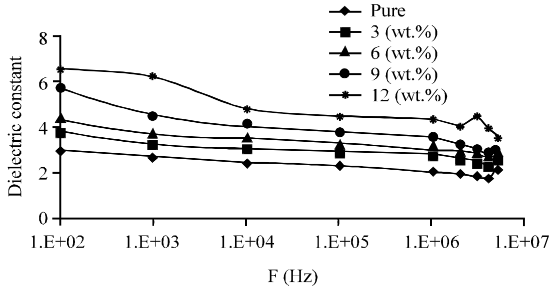

Fig. 8: Variation of the dielectric constant of of (PS-SPO-Ag) nanocomposites with frequency

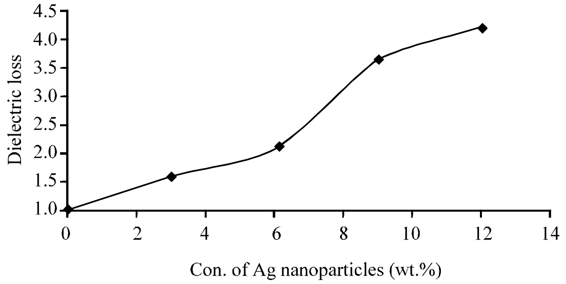

Fig. 9: Variation of dielectric loss with concentration of Ag nanoparticles at 100 Hz for (PS-SPO-Ag) nanocomposites

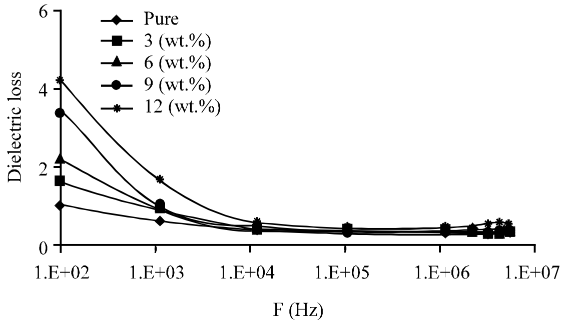

Fig. 10: Variation of the dielectric loss with frequency for (PS-SPO-Ag) nanocomposites

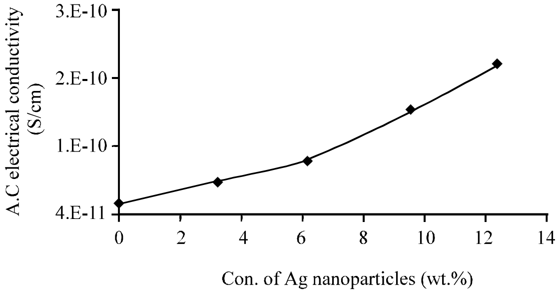

Fig. 11: Variation of AC electrical conductivity with Ag nanoparticles wt.% concentration at 100 Hz for (PS-SPO-Ag) nanocomposites

100 Hz and 30°C. The conductivity is increasing with increase the concentration of Ag nanoparticles. This increase is due to increase the charge carriers (Hashima *et al*., 2018).

Figure 12 shows the variation of the AC conductivity for (PS-SPO-Ag) nanocomposites with frequency. The figure shows that AC 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 (Muheisin, 2009).

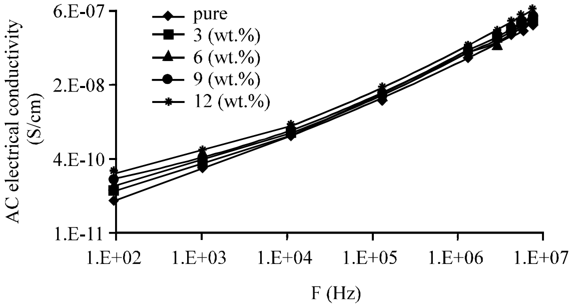

Fig. 12: Variation of AC electrical conductivity with frequency for (PS-SPO-Ag) nanocomposites

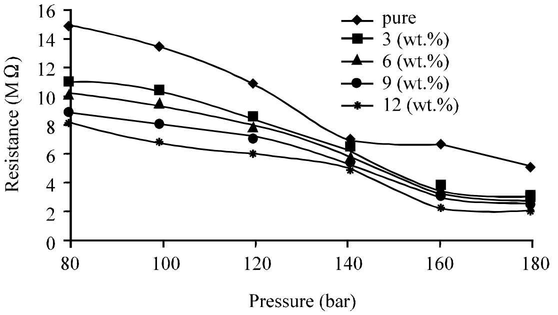

Fig. 13: Variation of electrical resistance with pressure

Figure 13 shows the variation of electrical resistance for (PS-SPO-Ag) nanocomposites with different pressure. From figure, the electrical resistance decreases as the pressure increases. The samples have a crystalline region that has an internal dipole moment. These dipole moments are randomly oriented without any mechanical or electrical poling process and the net dipole moment is zero in this condition. When stress is applied it will change the local dipole distributions and induce an electric field. The induced electric field accumulates the charges at both the top and bottom of the sample (Hashim and Hadi, 2017).

CONCLUSION

DC electrical conductivity (σ_{dc}) for (PS-SPO-Ag) nanocomposites increases with increasing of Temperature (T) and silver (Ag) nanoparticles concentration. Activation Energy (E_{act}) the dielectric loss and the dielectric constant ($\acute{\varepsilon}$) of (PS-SPO-Ag) nanocomposites decrease with increasing of silver (Ag) nanoparticles concentration. The dielectric loss and the dielectric constant ($\acute{\varepsilon}$) of (PS-SPO-Ag) nanocomposites decreases with increasing of Frequency (F). The AC electrical conductivity (σ_{ac}) of (PS-SPO-Ag) nanocomposites increases with increasing of Frequency (F) and concentrations of silver (Ag) nanoparticles. The (PS-SPO-Ag) nanocomposites have high sensitivity for pressure.

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