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Synthesis and Characterization of Carbon Nanotubes -Polystyrene Composites

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Abstract

Effects of carbon nanotubes on Electrical and optical properties of polystyrene has been investigated. Samples of polystyrene with carbon nanotubes appeared by using casting technique. Results showed that the D.C electrical conductivity increases with increase the weight percentages of carbon nanotubes. The dielectric properties were measured in the frequency range from (1-10)MHz at room temperature The experimental results showed that the dielectric constant, dielectric loss, AC electrical conductivity are changed with change the concentration of additional carbon nanotubes and frequency of applied electrical field. . The optical properties measured in the wavelength from (400-1000)nm. The results showed that the absorption coefficient, extinction coefficient, refractive index and real and imaginary parts of dielectric constants are increasing with increase the weight percentage of carbon nanotubes.

Keywords: Carbon nanotubes, polystyrene, electrical properties, Optical properties.

Introduction

Polymeric composites based on carbon nanotubes (CNTs) are of great interest in both academic and technological areas due to their ability to combine the remarkable properties of CNTs, such as extremely high electrical and thermal conductivity, low density, high tensile strength, and Young's modulus, etc., with the versatility, processability, and mechanical properties of polymers[1]. The characteristic properties of metal nanoparticles an nanocomposites have been the subject of study for a long time because of their unique optical, thermal, mechanical, electronic and electrical properties. Plasmon resonance allows for the enhancement and manipulation of local electromagnetic fields at nanoparticle surface due to surface effects and as a result of these singular optical features, noble metal nanoparticles stimulate great interest for implementation in photonics, biotechnology and space applications[2]. One advantage of nanoparticles, as polymer additives appear to have is that compared to traditional additives, loading requirements are quite low. Microsized particles used as reinforcing agents scatter light, thus reducing light transmittance and optical clarity. Efficient nanoparticle dispersion combined with good polymer–particle interfacial adhesion eliminates scattering and allows the exciting possibility of developing strong yet transparent films, coatings and membranes[3]. Carbon nanotube (CNT) based composites are increasingly being reviewed as a realistic alternative to conventional smart materials, largely due to the superior electrical properties. Recently, great interest has been generated in building highly sensitive strain sensors with these new composites[4].G.D. Liang[5], in (2008) studied the electrical properties of the PS-Carbon nanofiber composites at the percolation threshold. They found that both the electrical conductivity and the dielectric constant increase at an additive concentration of 1.7 vol.%. They indicated that the electrical conductivity is dependent on temperature at this concentration of the additive.

Experiment

The materials used in this study are polystyrene and carbon nanotubes. The weight percentages of carbon nanotubes are (0,3,6 and 9)wt.%. The samples were prepared using casting technique thickness ranged between (72-84)μm. The resistivity was measured at room temperature using Keithly electrometer type (616C) .The volume electrical conductivity σ_v defined by :

$$\sigma_v = \frac{1}{\rho_v} = \frac{L}{RA} \quad (1)$$

Where :

A = guard electrode effective area.

R = volume resistance (Ohm) .

L = average thickness of sample (cm) .

The dielectric properties of PS-CNTs composites were measured using (Agilent impedance analyzer 6500B).

In the frequency(f) range (1-10) MHz at room temperature. The measured capacitance, C(w) was used to calculate the dielectric constant ,έ(w) using the following expression:

$$\acute{\varepsilon}(w) = C(w)\frac{d}{\varepsilon_o A} \quad (2)$$

Where d is sample thickness and A is surface area of the sample . whereas for dielectric loss ε"(w):

$$\varepsilon''(w) = \acute{\varepsilon}(w) \times \tan\delta(w) \quad (3)$$

Where tanδ(w) is dissipation factor . The AC conductivity σ_{ac} Can be calculated by the following equation :

$$\sigma_{ac}(w) = \varepsilon_o w \varepsilon'' \quad (4)$$

The transmission & absorption spectra of PS-CNTs composites have been recording in the length range (400-1000) nm using UV-2400 PC spectrophotometer.

Results and Discussion

Figure(1) shows the variation of electrical conductivity of polystyrene composites with increasing carbon nanotubes content. The general theory to explain the conduction mechanism of fibers or particle-filled polymer composites is the "theory of conductive paths [6]. To obtain electrically conductive composites the carbon nanotubes aggregates have to arrange themselves in continuous paths where the conductive elements are either in direct contact or can move electrons via hopping or tunneling mechanisms[7].

Figure 1: Variation of D.C electrical conductivity with Carbon nanotube wt. % concentration.

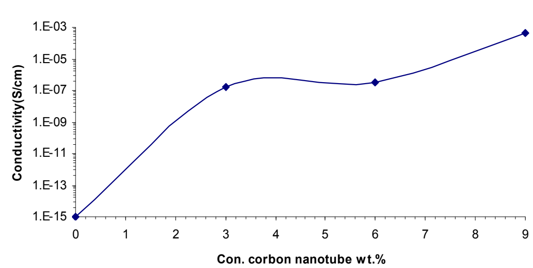
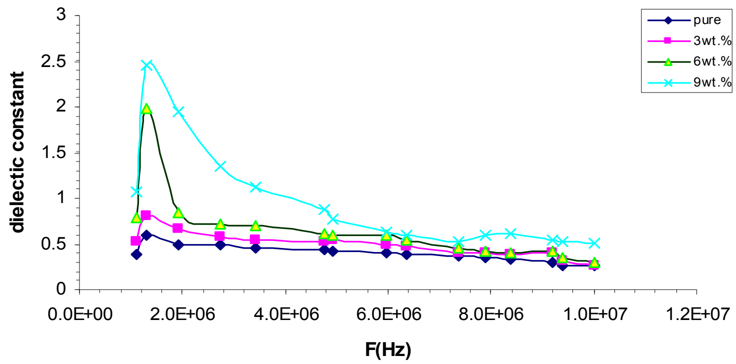


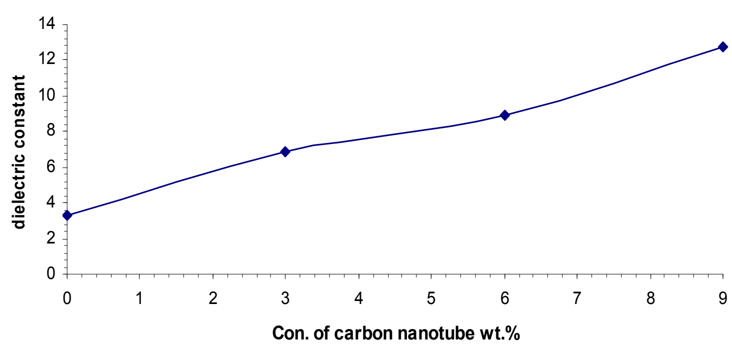
Figure (2) show the variation of the dielectric constant of PS-CNTs composite with frequency for different filler concentration.

Figure 2: Variation dielectric constant with frequency for (PS-CNTs) composite.



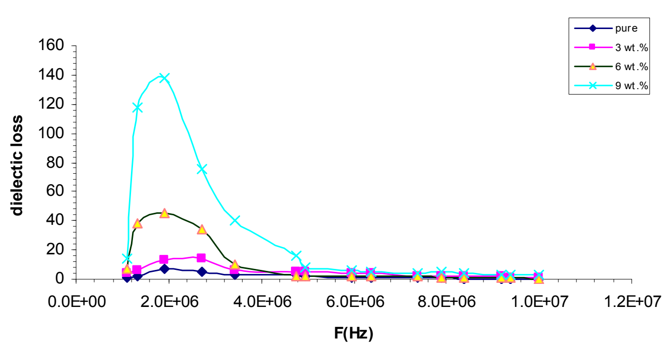
The dielectric constant decreases with increasing of frequency, this may be attributed to the tendency of dipoles, the high value of dielectric constant at low frequency might be due to the interfacial effect. At low carbon nanotubes concentration, the dielectric values are low, characteristics of dielectric behaviour, and increasing the carbon nanotubes concentration caused an increase in the average number of concentrations among the conductive particles. At high concentrations of carbon nanotubes the dielectric constant is due to formation of a continuous network of carbon nanotubes particles through the composite[8] .

Figure 3: Variation dielectric constant with carbon nanotube concentration for (PS-CNTs) composite.



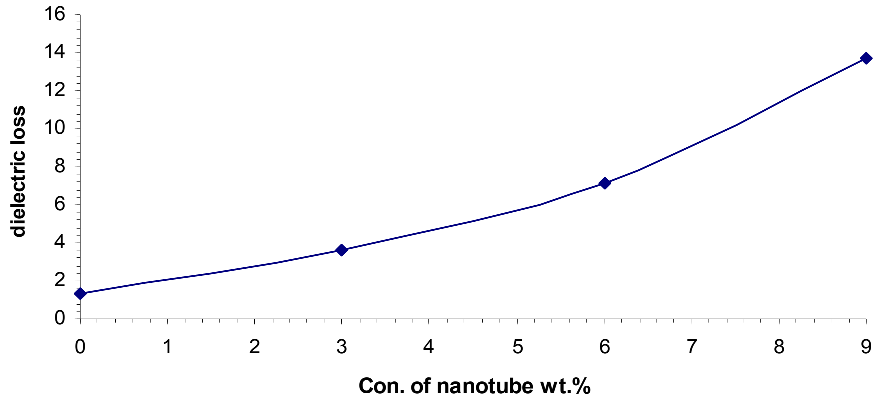
The variation of dielectric loss with frequency for (PS- CNTs) composites at different concentration of dopants is as depicted in figure (4).

Figure 4: Variation dielectric loss with frequency for (PS-CNTs) composite.



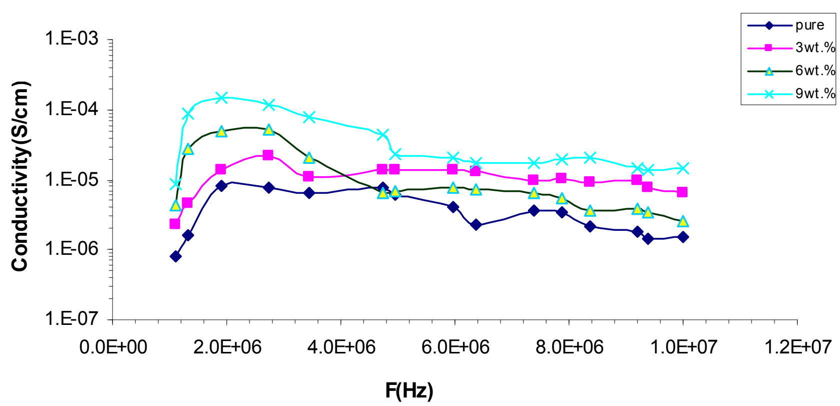
It is clear from the graph that dielectric loss decreases with increasing the frequency. The larger value of dielectric loss at low frequency could be due to the mobile charges within the polymer backbone. The higher value of dielectric loss for the higher concentration of dopant can be understood in terms of electrical conductivity, which is associated with the dielectric loss as shown in figure (5)[9,10].

Figure 5: Variation dielectric losss with carbon nanotube concentration for (PS-CNTs) composite.



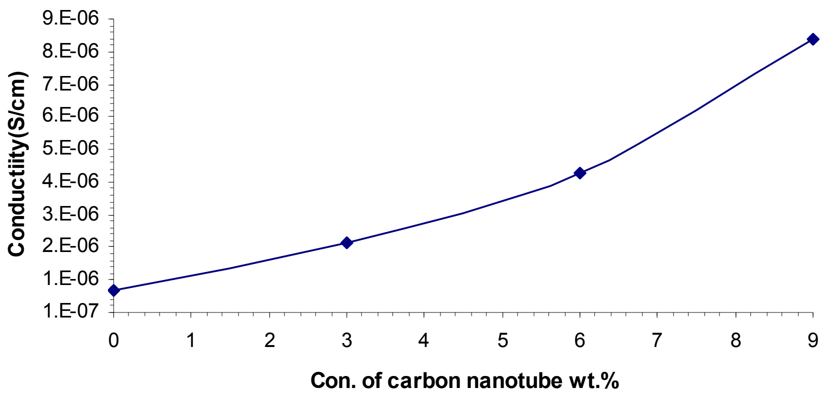
The behaviour of A.C conductivity of PS- CNTs composite for various concentration of the filler as a function of frequency at room temperature is show in figure(6).

Figure 6: Variation A.C. electrical conductivity with frequency for (PS-CNTs) composite.



The A.C conductivity response to the applied field frequency at low and intermediate range is flat, and at high frequency range there is a transition region where the response starts to bent downward. The bending region is shifted towards the frequency value as the concentration of filler increases. For specimens of high filler content the behaviour of A.C conductivity can be determined by conductive pathways of conductive network which formed as a result of infinite clusters formation. The flat response of A.C conductivity at these frequency ranges can be attributed to the fact that electrons will not have trouble traveling over large distances within these infinite clusters before it just hop to other clusters. This can be justified by the fact that most conductors give a flat response in the same frequency ranges[11].At lower concentrations of the filler the A.C electrical conductivity of the composite increases slightly; while at higher concentrations the conductivity increases sharply where the composite becomes a conductive substance as shown in figure (7).

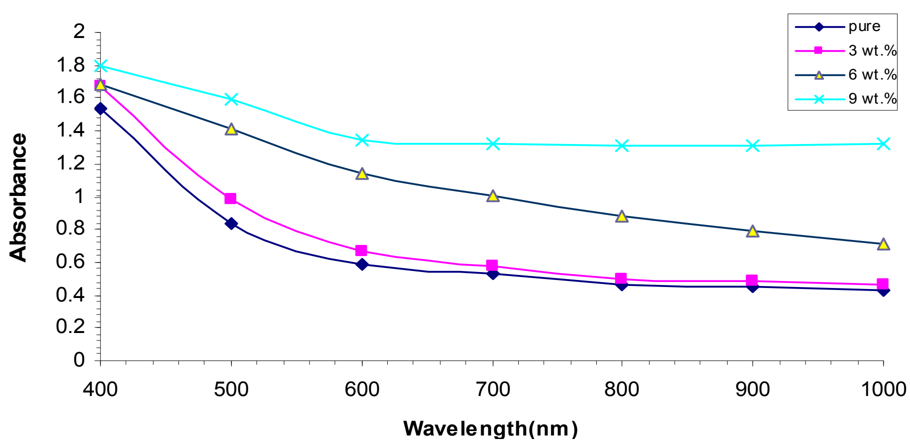
Figure 7: Variation A.C electrical conductivity with carbon nanotube concentration for (PS-CNTs) composite.



At high filler content, the a mount of the interconnecting networks is increased and the contact resistance between the fibers is decreased, and hence a good electron conduction is achieved resulting in transformation of the polymer insulator to a conductive polymer composite[12] .

The optical absorbance as a function of the wavelength of the incident light for PS-CNTs composites of various filler contents is shown in figure (8) . The figure shows that the intensity of the peak increased as a result of filler addition but no shift in the peak position, i.e. adding different amounts of filler to pure polymer do not change the chemical structure of the material but new physical mixture is formed.

Figure 8: Optical Absorbance for (PS-CNTs) composite with various wavelength



The absorption coefficient (α) was calculated in the fundamental absorption region from the following equation[13]:

$$\alpha = 2.303\frac{A}{d}. \tag{5}$$

Where : A is absorbance and d is the thickness of sample.

Figure (9) shows the relationship between the absorption coefficient and photon energy of the PS-CNTs composites. We note the change in the absorption coefficient is small at low energies, this is indicates, that the possibility of electronic transitions is a few. While at high energy , the change of absorption coefficient is large this is indicates the large. Probability of electronic transitions are the absorption edge of the region. The results showed that the values of absorption coefficient of the PS-CNTs composites less than $10^4 cm^{-1}$ which indicates to the indirect electronic transition[14]. The variations of extinction coefficient (k=αλ/4π) with wave length for (PS-CNTs) composite as shown in figure(10) . The extinction coefficient increases with increasing of CNTs concentration. This behavior of extinction coefficient ascribed according to high absorption coefficient. [15].

Figure 9: The relationship between the absorption coefficient and photon energy of the (PS-CNTs) composites

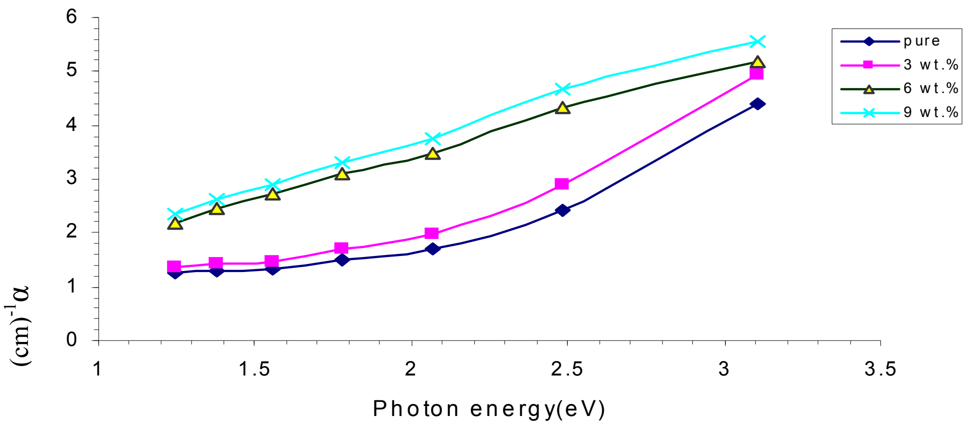
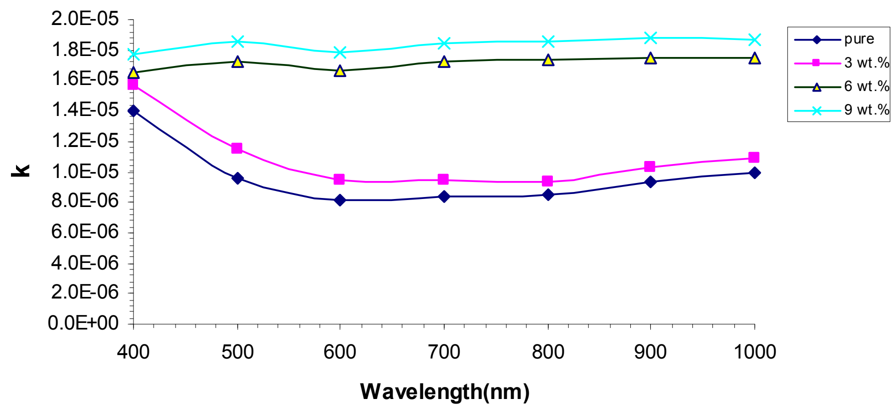
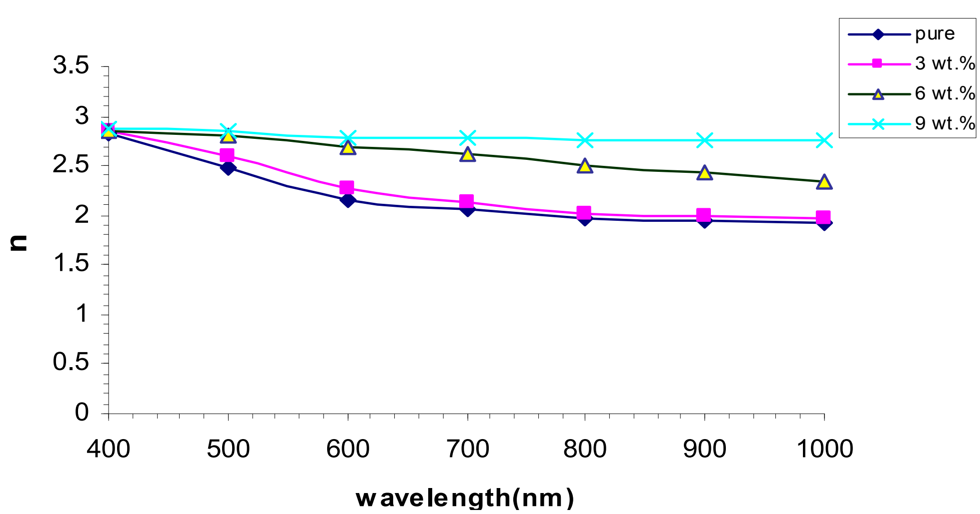


Figure 10: Extinction coefficient for (PS-CNTs) composite with various wavelength



Figure(11) shows the variation of the refractive index($n = \frac{1+\sqrt{R}}{1-\sqrt{R}}$) of composites a function of wavelength. The refractive index increase as a result of filler addition, this behaviour can be attributed to the increasing of the packing density as a result of filler content.

Figure 11: Refractive index for (PS-CNTs) composite with various wavelength



Figures(12,13) show the variation of real and imaginary parts of dielectric constants ($\varepsilon_1 = n^2 - k^2$ and $\varepsilon_2 = 2nk$) of (PS-CNTs) composites .It is concluded that the variation of ε_1 mainly depends on (n^2) because of small values of (k^2), while ε_2 mainly depends on the (k) values which are related to the variation of absorption coefficients[15].

Figure 12: Real part of dielectric constant for (PS-CNTs) composite with various wavelength

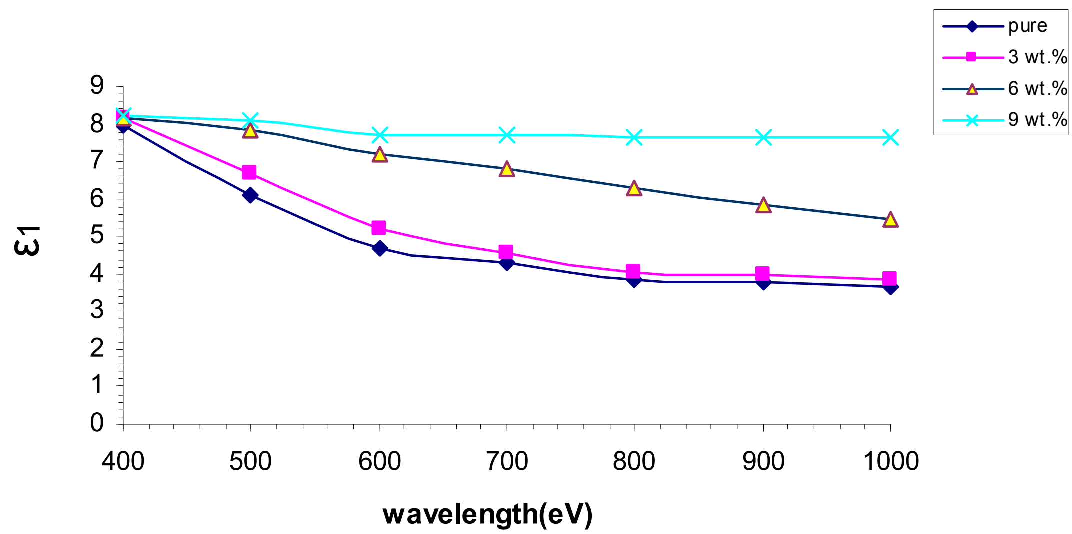
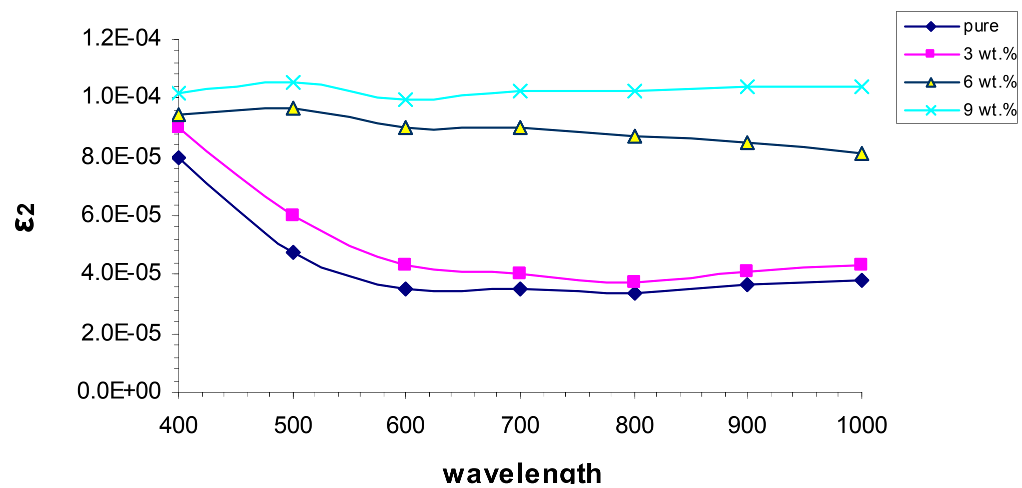


Figure 13: Imaginary part of dielectric constant for (PS-CNTs) composite with various wavelength



Conclusions

1. The D.C electrical conductivity of the polystyrene increases by increasing the carbon nanotubes concentrations.
2. The dielectric constant decreases with increase the frequency and increases with increase the CNTs wt.% content .
3. The dielectric loss decreases with increase the frequency and increases with increase the CNTs wt.% content.
4. The A.C electrical conductivity of composites is increasing with increasing frequency of applied electrical field and CNTs wt.% content.
5. The absorption coefficient, extinction coefficient, refractive index and real and imaginary parts of dielectric constants are increasing with increase the CNTs wt.% content.

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