Dielectric Properties and AC Conductivity of Doped Poly Furfuryl alcohol with Crystal Violet

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Abstract: Dielectric properties such such as relative permittivity dielectric constant ε′ , dielectric loss ε″ and dissipation factor tanδ of doped poly Furfuryl alcohol (PFA) with different doping ratios of crystal violet (0.01, 0.03, 0.05, 0.07, 0.1)% wt as function of temperature in the range (30-100) ˚C and frequency in the range (100Hz-1MHz). The experimental results showed that ε′, ε″ and tanδ increased with increasing temperature, and is due to greater freedom of movement of the dipole molecular chains within polymer at high temperature. The value of ε′ decreased with increasing frequency, which indicates that the major contribution to the polarization comes from orientation polarization. Ac. Conductivity σac and impedance (Z) of doping polymer behaviors as function of frequency and temperature have also been investigated.

Keyword: Dielectric properties, poly Furfuryl alcohol, crystal violet, ac conductivity.

1. Introduction

Dielectrics are materials that do not conduct electricity, essentially functioning as insulators. When exposed to an electric field, the electric charges in a dielectric material, including permanent and induced electric dipoles, can be moved, thus polarizing the material [1].

The ability of the dielectric materials to store energy is attributed to the polarization, and there are several molecular mechanisms associated with this polarization, including: electronic polarization, ionic polarization, molecular (dipole) polarization and interfacial (space-charge) polarization.

The dielectric constant of polymeric materials depends on the contribution of electronic, atomic, interfacial and dipole polarization. In this work the, the dielectric parameters were calculated from measurements of the capacity (Cp) for Al/polymer/Al system, as well as the study real and imaginary parts of dissipation factor and the impedance Z. The reason for studying these parameters is in order to Knowing relaxation processes that occur in solid state of polymers in different ranges of frequencies or temperatures [1,2].

2. Experiment

2.1 Materials

The materials tested in this study were Furfuryl alcohol, dimethyl formamide, Sulfuric acid and crystal violet.

2.2 Prepration of poly Furfuryl alcohol (PFA)

PFA has been prepared from the distillated liquid monomer FA (25 ml) via drops of acid catalysis H2SO4 (1M) and heated at 60°C for 1 hour to yield viscose colored polymer [3-6].

2.3 Doping of PFA

Doping PFA with dye crystal violet is carried out by adding the weighed dye to the appropriate weight of polymer (1g) then the mixture was dissolved in dimethyl formamide DMF after the prepared directly to give a polymer / dye system containing (0.01, 0.03, 0.05, 0.07 and 0.1) g wt% of doping reagent Crystal violet [7]. The mixture was stirred well for 15 minutes to guarantee that the homogenous distribution of dye in the polymer matrix.

2.4 Characterization and measurements

Dielectric properties of doping PFA was investigated using RLC meter (Fluke PM6306), on frequency range of (100Hz-1kHz), RLC meter (Fluke PM6303A) was measuring capacity and dielectric loss properties at different temperatures (30-100) ˚C.

The dielectric permittivity ε′ were calculated in conformity with the relation [8]:

$$C = \varepsilon_o \ \varepsilon' A / d \qquad (1)$$

Where ε_o is the permittivity of the free space (ε_o= 8.8×10-12 F/m), d is the separation between the capacitor electrodes, A is the area of the electrodes.

The dielectric loss ε″ are given by the relation [9]:

$$\varepsilon'' = \varepsilon' \ \tan\delta \qquad (2)$$

AC. Conductivity σ_{ac} was calculated according to the relation [9]:

$$\sigma_{ac} = \varepsilon_{\circ} \ \omega \ \varepsilon'' \qquad (3)$$

where ω is an angular frequency given by:

$$\omega = 2\pi f \qquad (4)$$

where f is frequency.

3. Results and Discussion

Figure (1) shows the variation of the dielectric permittivity ε′ of pure PFA with different ratios A as a function of temperature in the range (303 – 373)K at a constant

frequency (1 kHz) for different doping ratios. It can be seen that, permittivity increases as the temperature increases. The dielectric response of the composites may be related to the segmental mobility of polymer which increases with increasing temperature; this mechanism should lead to increase the dielectric constant due to greater freedom of movement of the dipole molecular chains within the polymer at high temperatures [8].

Figures (2) shows the relationship between dielectric permittivity ε′ and frequency (f) for the range (100 Hz – 1 MHz) of pure PFA with different ratios at (298) k. It is evident from the figures that ε′ Decreases with increasing frequency at fixed temperature and it is the expected behavior in most dielectric materials due to the orientation polarization and interfacial polarization which appears more effective at low frequency . In other means, all the dipole groups in the polymers molecular chains can orient themselves at low frequency. Due to the dielectric relaxation which involves the orientation and interfacial polarization, at higher frequencies the rotational motion of the polar molecules of dielectric is not sufficiently rapid for the attainment of equilibrium with the field ,hence dielectric constant seems to be decreasing with increased frequency, until reaches to a constant value depending on the fact that beyond a certain frequency of electric field the electron exchange does not follow the alternating field [10,11].

Figures (3) and (4) illustrate the variation of dielectric loss ε'' and loss tangent $\tan\delta$ as a function of temperature in the range (303 – 373)K at a constant frequency (1 kHz) for PFA with different doping ratios. It is noticed that both ε'' & $\tan\delta$ are increased in general as doping ratios or temperature increase. The increase in ε'' & $\tan\delta$ with increasing of doping ratios is attributed to the interfacial polarization, while that caused by increasing temperature may be related to the increase of segmental mobility and ionic conductivity. Since the rise in temperature (and the consequence drop in viscosity) exerts an effect on the amount of the losses due to the friction of the rotating dipoles, the degree of dipole orientation increases as well as ionic conduction increases due to the thermal dissociation of molecule [12].

Figure (5) shows the relationship between dielectric loss ε'' and frequency for all weight ratios at (298) K. It is apparent from both figures that dielectric loss ε'' increases initially with increased frequency. This kind of frequency dependency is called dielectric relaxation, being characterized by a relaxation time τ or relaxation frequency f_o corresponding to $\Delta\varepsilon/2$. This relaxation shifts to lower frequencies with the increasing of doping ratio. It clear that, the values of dielectric loss increase gradually with increasing the frequency to reach the highest value (maximum value). The

increase in dielectric loss may be related to a.c conductivity (σac) which depends on the number of charge carriers, relaxation time and frequency domain when the temperature is constant, after which the dielectric loss begins to decrease gradually. This is due to the relaxation processes which were influenced by the interfacial polarization effect. This result is attributed to the different interface structures between dyes and polymers [13,14].

Figure (6) shows the relationship between dissipation factor (tanδ) and frequency for different ratios of doping at room temperature. It is apparent from figure that dielectric tanδ increases initially with increased frequency for pure PFA with doping. The increases in tanδ may be related to a.c conductivity (σac) which depends on the number of charge carriers, relaxation time and frequency domain when the temperature is constant, after that the dielectric loss begins to decrease gradually. This is may be due to the relaxation processes which were influenced by the interfacial polarization effect [15].

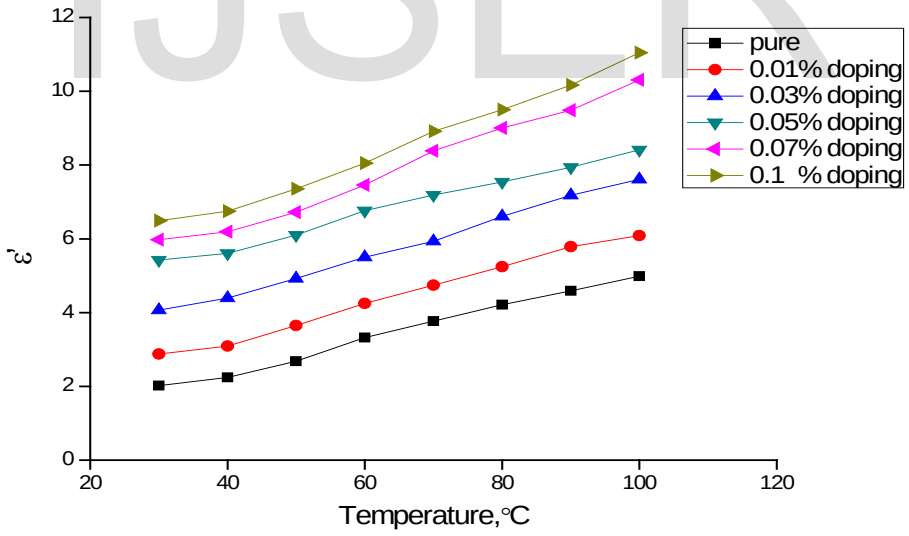
Figure (7) shows the variation of σ_{ac} as a function of temperature in the range (303 - 373)K at a constant frequency (1 kHz) for PFA with different doping ratios. It can be seen that the ac conductivity increases with the increasing of doping ratios for the same temperature circumstances, as well as, the σac for all cases increases as the temperature increases. The influence of temperature on σac can be explained by considering the mobility of the charge carriers responsible for hopping. As the temperature increases the mobility of hopping ions in polymers, which arises as a causal inevitably product during the synthesis processes, also increases thereby increasing the conductivity. The electrons which are involved in hopping are responsible for electronic polarization in these composites [16]. A.C conductivity is also related to the polymer segmental mobility and increases dramatically with increasing temperature.

Figure (8) shows the relationship between ac electrical conductivity σ_{ac} and frequency for all ratios of doping at room temperature. The ac conductivity from both figures increases linearly with increased frequency to ($3.3*10^{-5}$ S/cm) for the PFA (0.1%) doping respectively, and this is a natural behavior for doping polymers due to increase free charge moving with increased frequency,. So, the current flow increases and causes lastly increment in ac conductivity. This increase in ac conductivity may be

related to the interfacial polarization and electrical conduction .Similar trend and explanation were for another system [17].

Figure (9) shows the variation of impedance as a function of temperature in the range (303 – 373)K at a constant frequency (1 kHz) for PFA with different doping ratios. It can be seen that the impedance decreases with the increasing of both temperature and doping ratios due to the increased interfacial polarization. The impedance Z decreases with the temperature rise which is accompanied by clear dips near (80-100 ℃) for all cases in which doping were added. This decrease in Z may relate to the increased mobility of segmental molecules as the temperature increased [18].

Figure (10) shows the relationship between impedance Z and frequency for all ratios of doping at (298) K. As can be seen, there is an exponential decrease in the impedance with increased frequency. This result can be attributed to the increase in ac electrical conductivity σ_{ac} with increased frequency, therefor Z decreases until reaching a fixed and very small value. The same trend was observed with another system by Psarras et al [18].



Figure(1):Temperature dependence of dielectric constant at (1kHz) frequency for PFA with different doping .

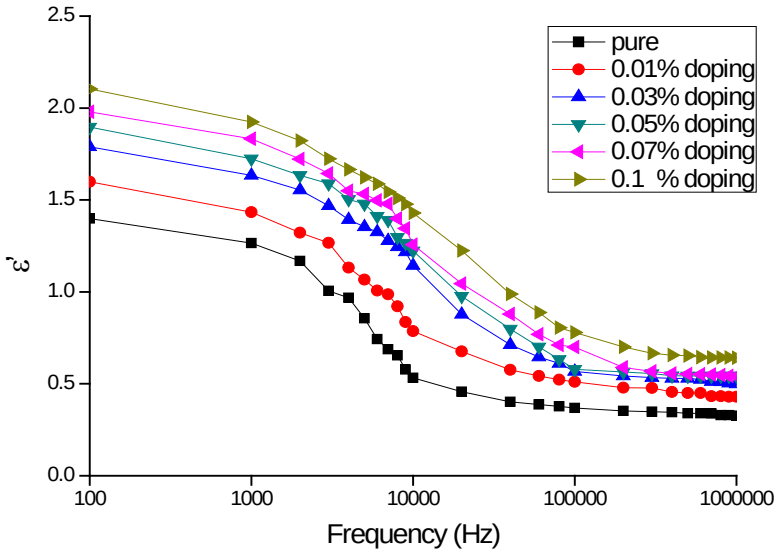


Figure (2): Variation of dielectric constant ε´ with frequency for PFA with different ratios at (298 K).

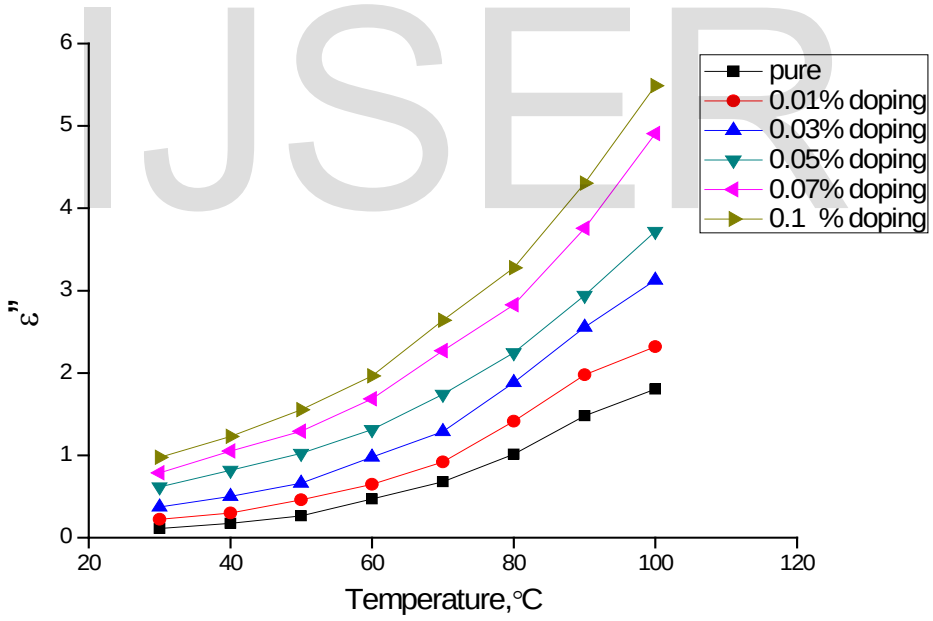


Figure (3): Temperature dependence of dielectric loss at (1kHz) frequency for PFA with different doping.

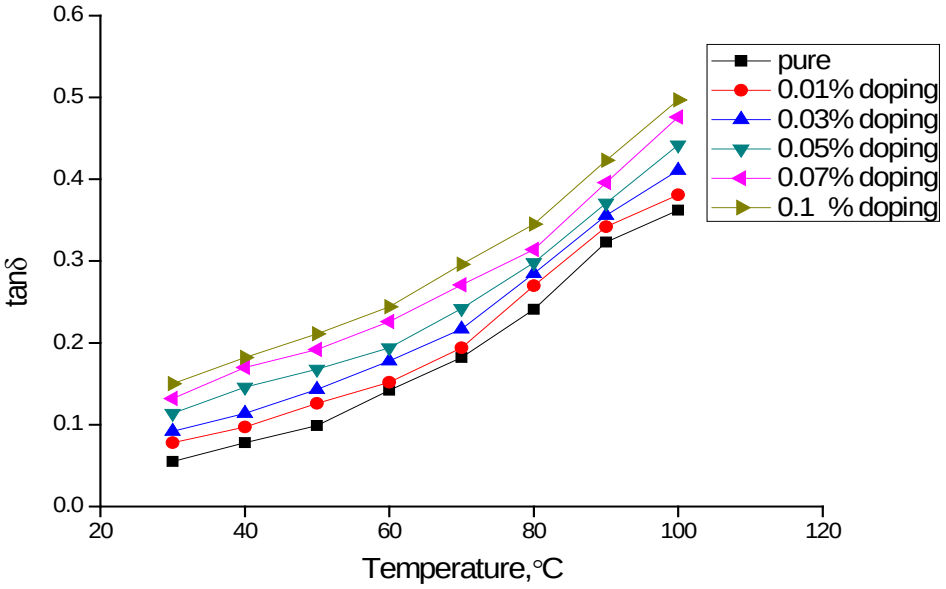


Figure (4): Temperature dependence of dielectric tan δ at (1kHz) frequency for PFA different doping .

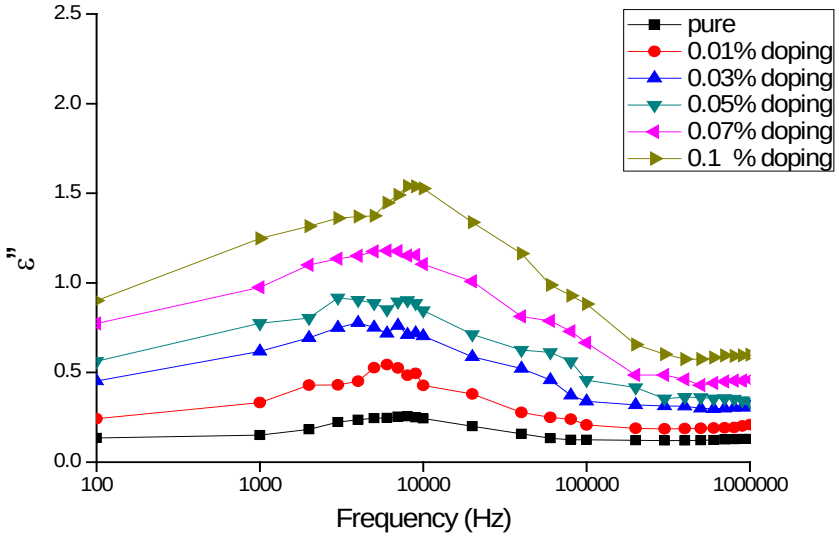


Figure (5): Variation of dielectric loss ε̋ with frequency for PFA with different ratios at (298K).

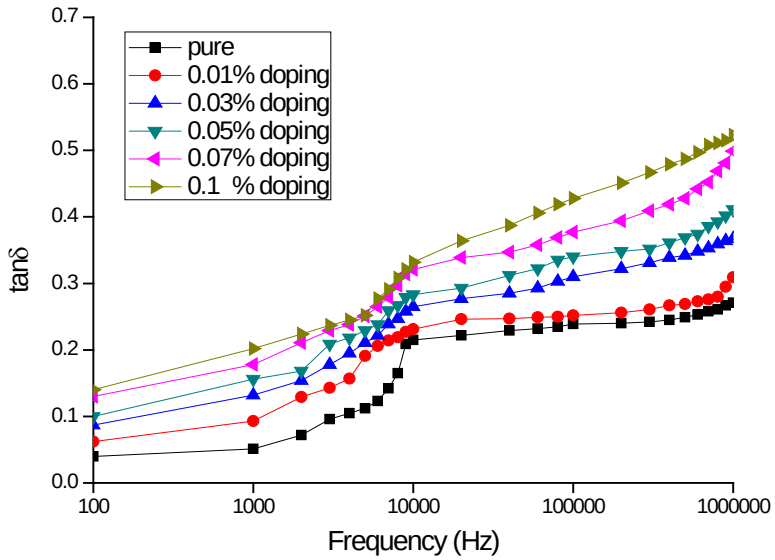


Figure (6): Wavelength Variation of tan δ with frequency for PFA with different ratios at (298 K).

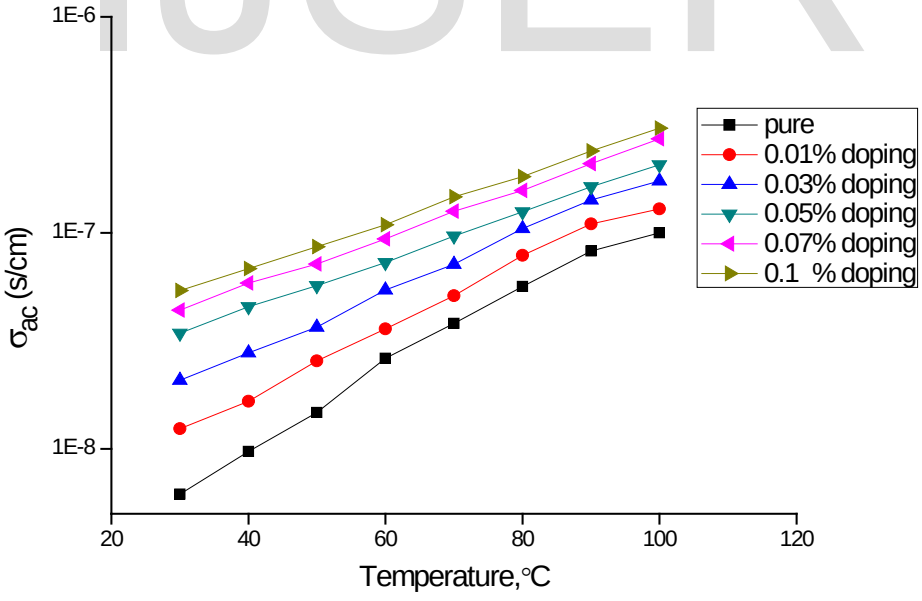


Figure (7): The variation of ac conductivity σ_{ac} with temperature at (1kHz) for PFA different doping .

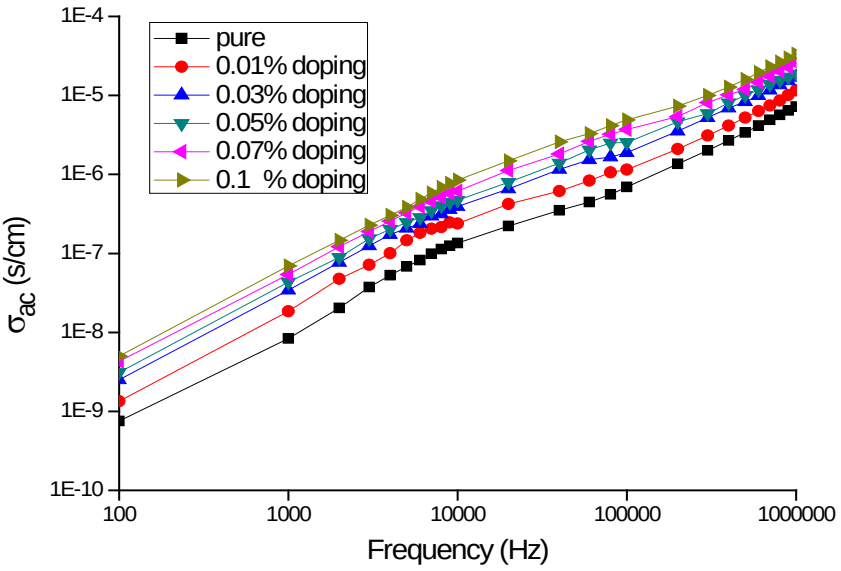


Figure (8): Variation of conductivity σ_{ac} with frequency for PFA with different ratios at (298 K).

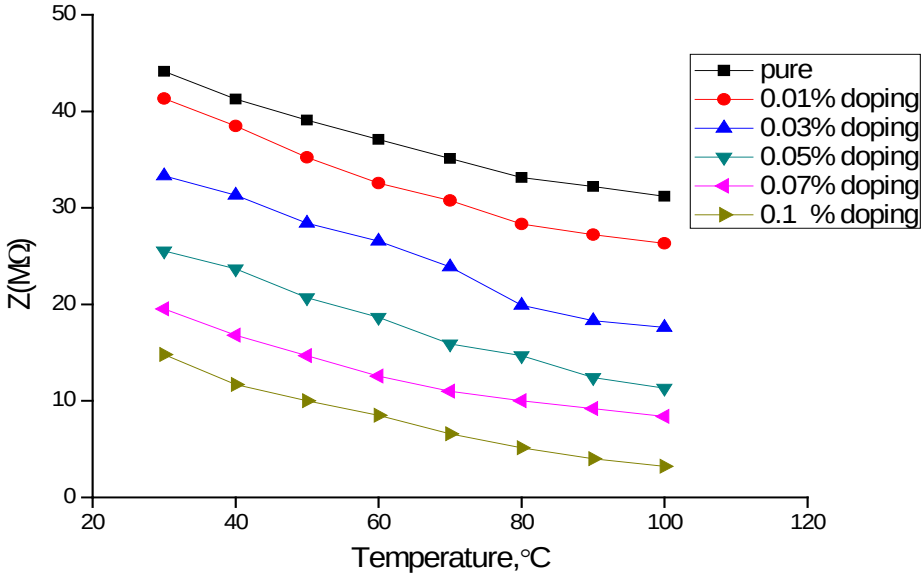


Figure (9): Variation of impedance Z with temperature for PFA at different doping.

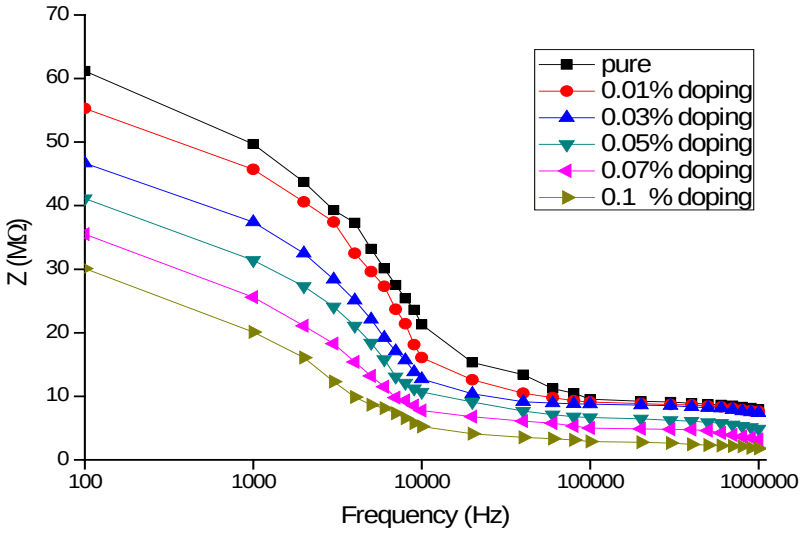


Figure (10): Variation of impedance Z with frequency for PFA with different ratios at (298 K).

Conclusion

Frequency and temperature dependence of dielectric constant ε′ , dielectric loss ε″ and dissipation factor tanδ in doping PFA has been investigated in the frequency rang 100Hz-1kHz and temperature range (30-100) ˚C. the experimental results indicate that ε′, ε″ and tanδ increase with increasing doping ratios and temperature is attributed to the interfacial polarization and segmental mobility of the polymer molecules , the permittivity decreases with increasing frequency, while ε″ and tanδ increase with increasing frequency. The ac conductivity for all doping ratios increase with increasing temperature and frequency. The impedance Z decrease with increase temperature and frequency.

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