DIELECTRIC PROPERTIES OF THE CONDUCTING POLYMERS BASED ON NR, NBR USING TWO POINT METHOD AT MICROWAVE FREQUENCIES

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Abstract-Based on NR, NBR methods and using two point technique, the Dielectric properties of the conducting elastomer composites based were measured at microwave frequencies in the X band (7-13 GHz) frequency using . The absolute value of the dielectric constant, absorption coefficient and AC conductivity of the conducting polymers prepared are greater than the polymers prepared by gum vulcanizates. Heating coefficient and skin depth PPy and fibre coated PPy (F-PPy) dielelctrics decreases. For NPFp5, LNPFp3 and BP3 the Dielectric constants obtained are 37, 57.5 and 44 respectively. At 10.8 GHz maximum AC conductivity of 6.9 S/m was obtained by the CEC for NPFp5.

I. INTRODUCTION

Microwave properties of conductive polymers plays a vital role in the applications like coating in electronic equipment, coating in reflector antennas, frequency selective surfaces, microchip antennas, EMI materials etc. [1-3].

Understanding the transport mechanism in conducting polymers and absorbing materials have encouraged the study of dielectric properties at micro wave frequencies. Conducting polymers gives some specific characteristics in microwave frequencies. Conducting polymers are good absorbers at microwave frequecies and exhibts technological lead when compared to inorganic electromagnetic absorbing materials and can be used for making microwave absorbers in space applications. The intrinsic conductivity of conjugated polymers leads to high levels of dielectric constant. Many absorbing materials based on conducting polymers have been developed to work at microwave frequencies. In recent years electromagnetic wave absorbing materials used in gigahertz (GHz) range developed with the development of radar detection, GHz microwave communication etc.

Conducting polymers and their composites are good shielding materials. Polypyrrole powders have included in thermoplastics, plastics with silicon and fluroplastics. Fibers and textiles coated with PPy are reported to yield high shielding effectiveness.

All dielectric materials are characterized by their dielectric parameters such as dielectric constant, conductivity and dielectric loss factor. These parameters differ with frequency, temperature, pressure etc.

II. MICROWAVE CHARACTERISTICS

A. Experimental method to find the Dielectric constant using Two Point Method

The dielectric constant $(\in')$ and dielectric loss $(\in'')$ of the Coducting polymers were measured in the range of 7.2 GHz to 12 GHz microwave frequencies using microwave benches and employing the two-point method. The reflex Klystron and Gunn diode were used to generate microwave frequencies, respectively. The experimental set up is shown in fig 1.1.

The sample holders for frequency measurements were fabricated from the standard wave guides. The one end of the sample holder is connected with metallic flange and other end was carefully shorted..

First, with no dielectric in the short-circuited line, the position of the first minimum DR in the slotted line was measured (Figure 4.6). Now the Conducting polymer sample of certain length $(l\in)$ was placed in the sample holder, such that the sample touches the short-circuited end. Then the position of the first minimum D on the slotted line and the corresponding VSWR, r were measured (Figure 4.7). The   VSWR was measured using a VSWR

meter which in turn is connected a PC. For the measurement of VSWR, the VSWR meter was connected and the amplitude modulation using pin diode was applied to the microwave signal set up. This procedure was repeated for another conducting polymer sample of same sample length (l'∈). The block diagram of flange connection is as shown in the fig. 1.2
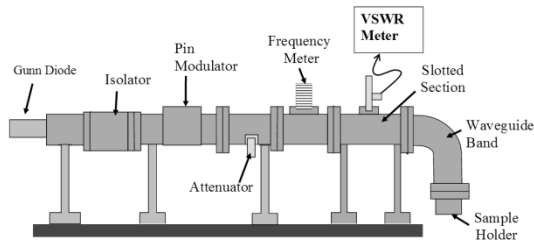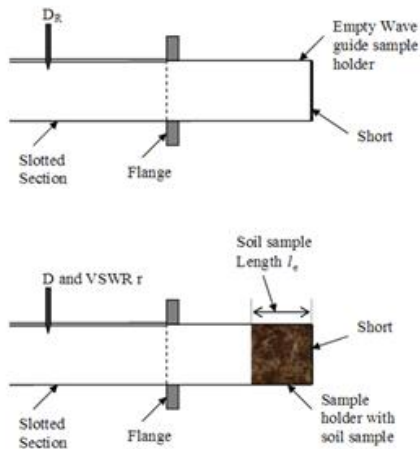

Fig. 1.1 Experimental setup of Microwave Bench

Fig 1.2 Block diagram of flange connection

The propagation constant (in the empty wave-guide) is calculated as

$$k = \frac{2\pi}{\lambda_g}$$

Where, λ_g =2x (distance between successive minima with empty short circuited wave- guide sample holder)

The value of λ_g is calculated using the formula

$$\left(\frac{1}{\lambda_0}\right)^2 = \left(\frac{1}{\lambda_g}\right)^2 + \left(\frac{1}{\lambda_c}\right)^2$$

Using the above formula the various parameters are calculated

Dielectric constant: $\epsilon'r = \dfrac{\left(\frac{a}{c}\right)^2 \left(\frac{\beta\in l\in}{l\in}\right)^2 + 1}{\left(\frac{2a}{\lambda_g}\right)^2 + 1}$

Where 'a' is the wave guide dimension, λ_c is twice the waveguide dimension (= 4.582) and λ_o is the ratio of velocity and frequency of microwave(=3.03).

Loss Tangent (Tan δ): Tan $\delta = \left(\frac{(\Delta Xs - \Delta X)}{\epsilon' d}\right) \left(\frac{\lambda_0}{\lambda_g}\right)^2$

Where

ΔXs = Width at twice minimum or maximum with sample

ΔX = Width at twice minimum or maximum without sample

iii. Loss Factor (ε''): ε''= ε' Tan δ

Absorption Coefficient (α) = $\dfrac{\varepsilon_r'' f}{n c}$

A.C conductivity σ = $2\pi f \varepsilon_0 \varepsilon_r''$

Dielectric Heating Coefficient, J = $\dfrac{1}{\varepsilon_r \tan \delta}$

Skin depth, d = $\dfrac{1}{\alpha}$

III. RESULTS AND DISCUSSION

A.Natural Rubber (NR) based CECs

a. Dielectric Constant

The changes in dielectric constant (ε') of the three series of CECs in X band frequency are shown in fig. 1.3. Greater the polarizability, the greater is the dielectric constant of the material. The frequency dependence can be explained as follows: Below frequencies of 1 KHz all polarization mechanisms – electronic, ionic and dipolar – contribute to dielectric constant. The prepared composites are a heterogeneous mixture of conducting polypyrrole separated by highly resistive rubber matrix. The dielectric constant of these heterogeneous, conducting composites exists mainly due to space charge polarization along with intrinsic electric dipole polarization. Polypyrrole which is doped will have permanent electric dipoles. So orientation polarization is likely to contribute to the dielectric constant. Of these polarizations, dipolar and space charge are more frequency-dependent. It has been shown that ε' is approximately constant with applied frequency for NP series. Therefore in these, electronic and ionic polarization mechanisms contribute to ε' . But for NPFp and NFp series, PPy coated fibers contribute high conducting regionsm which leads an increase in space charge polarization. The practical decrease in ε' with increasing frequency may be attributed to the decrease in space charge polarization with increasing frequency. This action is similar with Maxwell-Wagner space charge polarization. As the frequency of field increases, space charge polarization decreases and hence dielectric constant too decreases. As the frequency is increased, the time required for the space charge to be polarized is delayed makes a decrease in dielectric constant with frequency.

There is an increase in ε' with PPy loading and Fibre loaded PPy. Due to an increase in conducting regions there is an increase in ε'. According to Koops, the dielectric

constant is inversely proportional to the square root of electrical resistivity. With loading the DC conductivity of NR based composites increases. For NPFp5 a dielectric constant of 35 is obtained at 9.3 GHz frequency. Fig.1.3(i) shows a sudden increase in ε' at higher concentrations of PPy. This is because at large concentrations, the trend of conductivity chain formation increases with the aggregation of the PPy particles network, while at lower concentration, the PPy particles are widely dispersed through the polymeric matrix. So it is clear that dielectric constant of NR matrix gets highly modified by doping of PPy and Fibre loaded PPy and the necessary dielectric constant can be obtained by varying their concentrations.
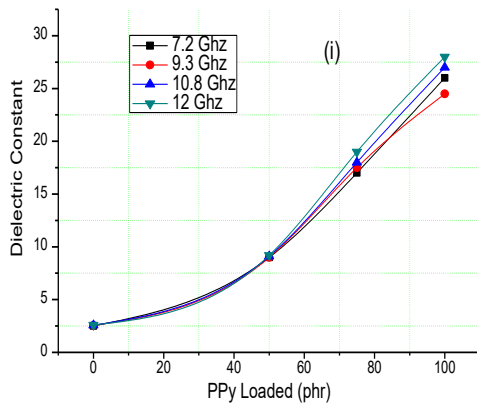

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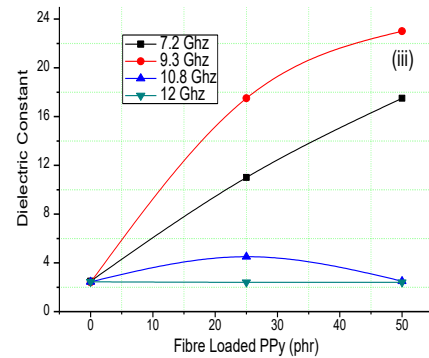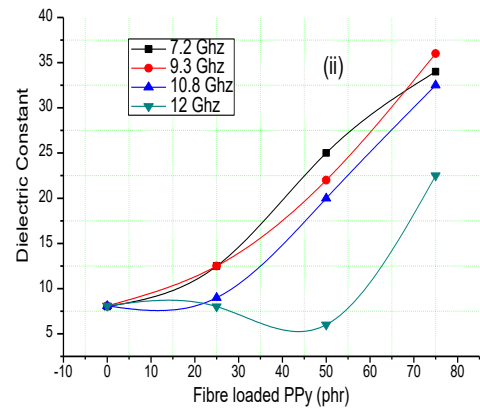
Fig.1.3 Changes in dielectric constant with loading of (i)NP, (ii)NPFp and (iii)NFp series

b. Dielectric loss

At dielectric relaxation region with the application of external field, the polarization acquires a component out of phase and the displacement current in phase, ensuing in thermal dissipation of energy. The dielectric loss (ε") is a quantify of energy dissipated in the dielectric in unit time when an electric field is applied. The increase in dielectric loss is due to mobility of charge carriers. In the conducting polymers the conductivity of a composite increases and thereby the dielectric constant, they can also give high dielectric loss. So ε" tends to be more in materials with large ε' value. In heterogeneous dielectrics due to accumulation of virtual charges of two media having different dielectric constant, ε'1 and ε'2, and conductivities σ1 and σ2, lead to space charge polarization. While for NP, NPFp and NFp series of composites, a charge build up can occur at the macroscopic interface due to differences in conductivity and dielectric constant. This accumulation of charge leads to dielectric loss. This space charge loss depends on the weakly polar material present, as well as on

the geometrical shape of its dispersion. Here NR as a second phase, with a different dielectric constant and conductivity, contributes to the space charge polarization and hence a high dielectric loss is observed for the prepared conducting polymer composites. Loading dependence of ε" of PPy filled and Fibre loaded PPy filled with NR composites in X band frequencies are depicted in fig.1.4. Dielectric loss is found to increase with PPy loading and Fibre loaded PPy due to improved mobility of charge carriers. Increase in frequency too increases dielectric loss. The values of ε" in the low frequency range is due to contribution of both interfacial polarization and conductivity while the increase in ε" at higher content of conducting polymer is mainly due to the increase in the electrical conductivity. Dielectric loss at X band is due to the free charge motion within the material. The NR gum compound offers a low dielectric loss (0.02) while dielectric loss as high as 33 by NPFp5 at a frequency 10.8GHz.
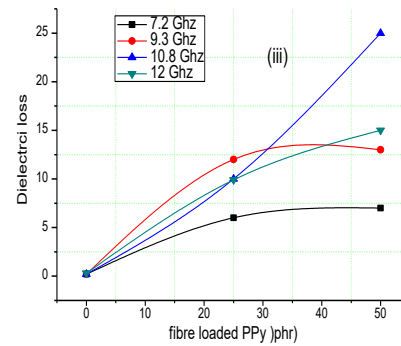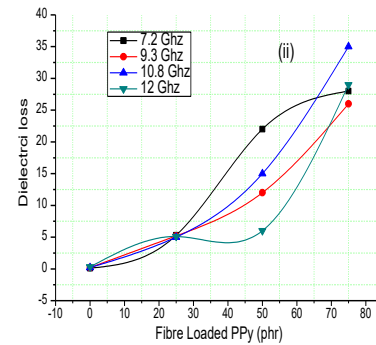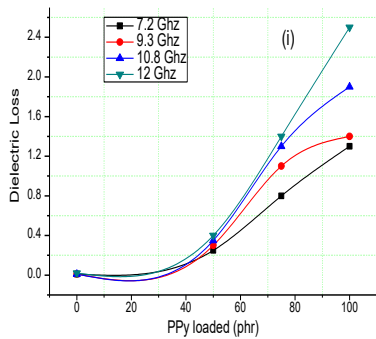

Fig. 1.4 Changes in dielectric loss with loading of (i)NP, (ii)NPFp and (iii)NFp series

c. AC conductivity

The microwave conductivity is a function of dielectric loss and hence the fig.1.5, showing the change in the AC conductivity (S/m) of composites with PPy and Fibre loaded PPy at different frequencies, has the same nature as that of the dielectric loss factor. Conductivity of the matrix is affected by three parameters namely the intrinsic conductivity, the shape of the filler and surface tension of the matrix. It was estimated that fibrous fillers will yield a threshold at lower loadings, since the former will give many more inter particle contacts. This will be the reason for lower threshold and higher AC conductivity of fiber filled composites. Maximum conductivity 6.9 S/m is obtained for NPFp5 at a frequency 10.8 GHz.

from fig.1.6. It is clear that the absorption coefficient increases with increase in frequency and also with filler loading and maximum absorption coefficient value is obtained for NPFp5 at 7.2 GHz frequency.
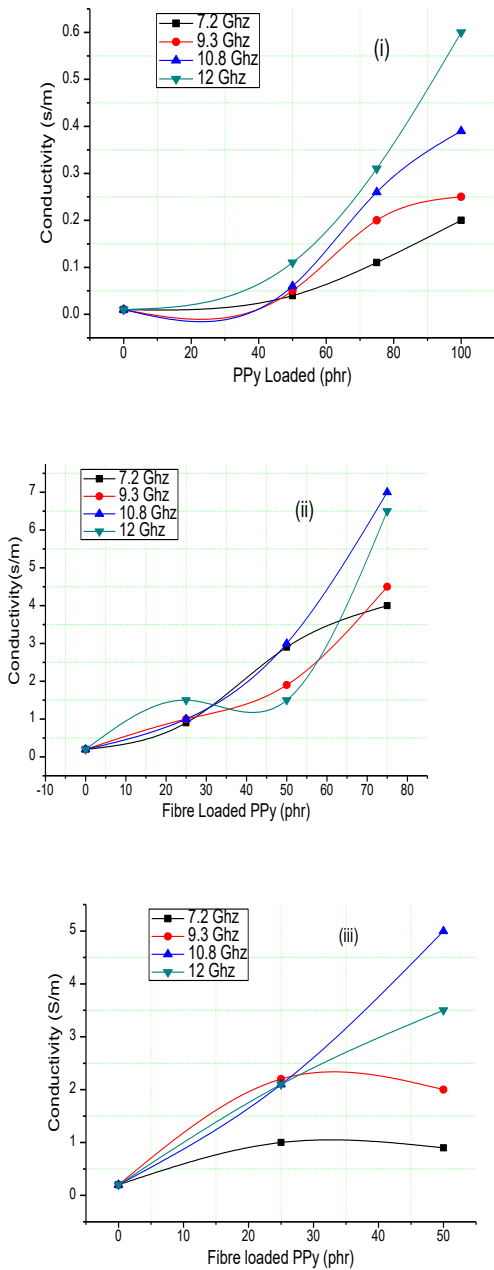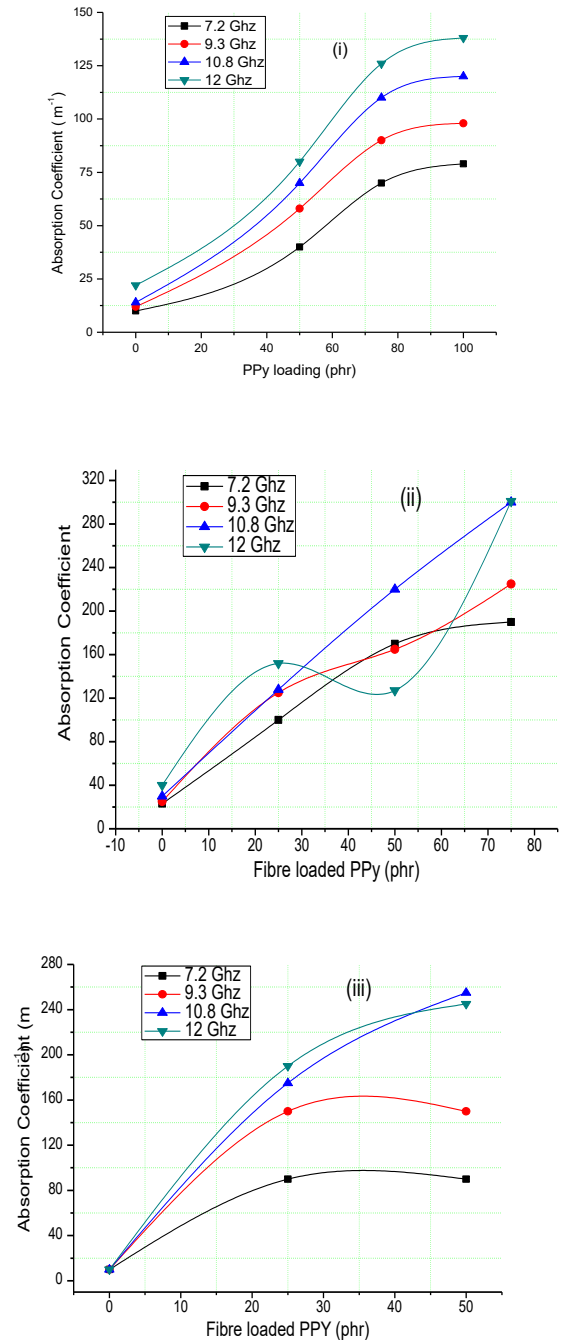

Fig. 1.5 Changes in A. C. conductivity with loading of (i) NP, (ii)NPFp and (iii)NFp series

d. Absorption coefficient

The absorption coefficient is derived from the complex dielectric constant and is a measure of propagation and absorption of electromagnetic waves. Hence the dielectric materials can be classified in terms of this parameter indicating transparency of waves passing through it. The change in absorption coefficient with frequency and filler loading is same as that for AC conductivity as is observed

Fig.1.6 Changes in absorption coefficient with loading of (i) NP, (ii) NPFp and (iii) NFp series

e. Skin depth

Skin depth is also called as the penetration depth. It is basically the effective distance of penetration of an electromagnetic wave into the material when it is applied to a conductor carrying high frequency signals. The self-inductance of the conductor limits the conduction of the signal to its outer shell and the shells thickness is the skin depth which decreases with increase in frequency. It is clear from the fig. 1.7 that skin depth of the conducting polymers decreases with filler loading and the minimum value of skin depth is for the CPC, NPFp5 at 7.2 GHz frequency.
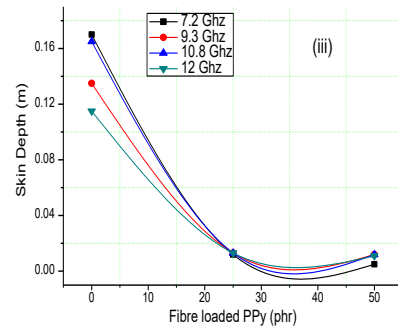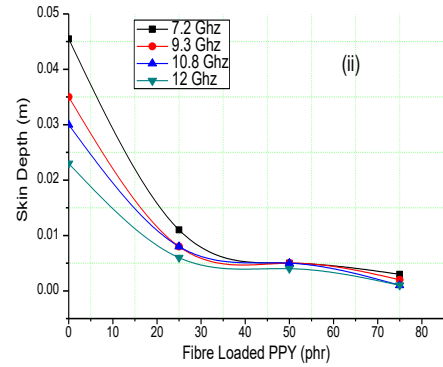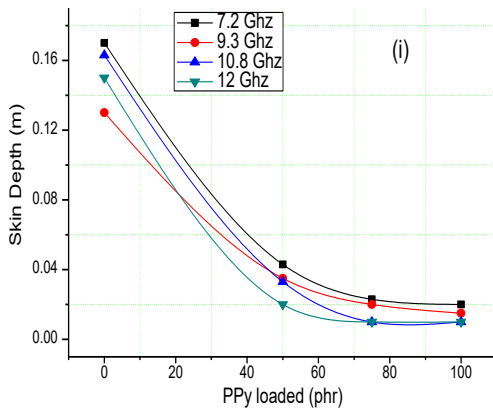

Fig.1.7 Changes in skin depth with loading of (i)NP, (ii)NPFp and (ii)NFp series

f. Dielectric heating coefficient

The changes in dielectric heating coefficient (J) with frequency and with loading is as shown in fig. 1.8. It is observed that the heating coefficient decreases with increase in frequency and also with filler loading. The heat developed is inversely proportional to both frequency and the product of εr and $\tan \delta$. Greater the value of J lesser will be the conducting polymer for dielectric heating purpose. The heat generated in the material comes from the tangent loss, but that loss may not come entirely from the relaxation loss. In the present study J value is found to be the lowest for NPFp5 at 7.2 GHz frequency. At 7.2 GHz the heating coefficient of NR gum vulcanized is 81.5 while the CPC, NPFp5 gives a value as 0.025.
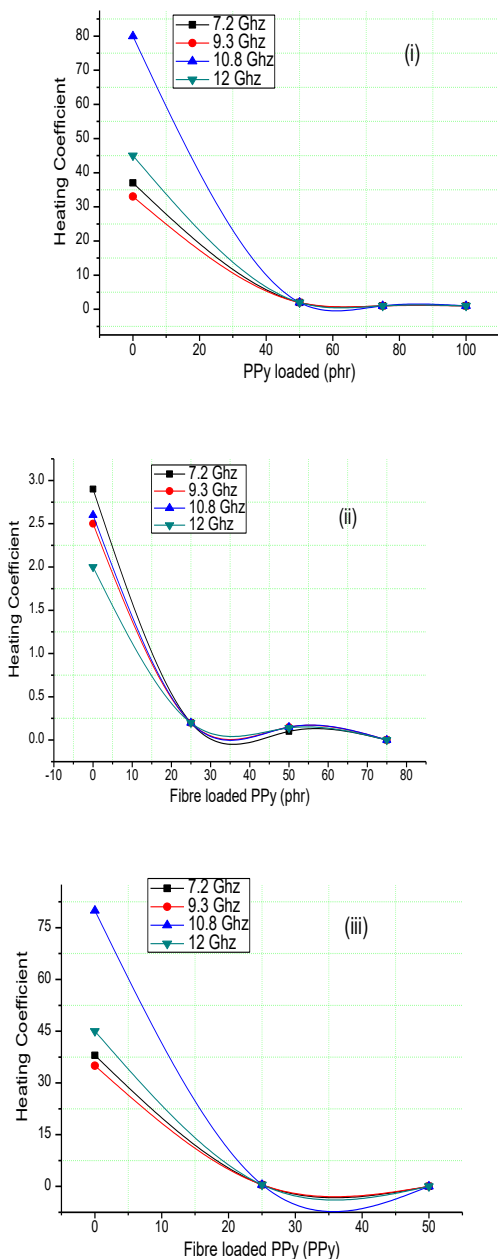
Fig. 1.8 Changes heating coefficient loading of (i)NP, (ii)NPFp and (iii)NFp series

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