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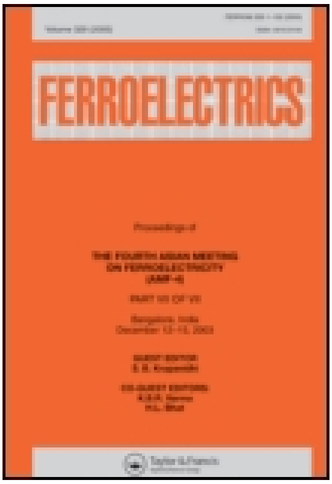

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The Influence of Cu and Mg Dopant on the Microwave Properties of PVC

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The effect of Cu and Mg doping at Polyvinyl Chloride (PVC) site on the the dielectric properties of $(PVC)_{1-x}M_x$ *in powder form with various M and x in powder form is investigated [*$M = Cu$ *and Mg &* $(0.00 < x < 0.20]$*. The permittivity* ε' *and the loss factor* ε'' *at 11.01 GHz and room temprature of PVC in pure form as well as with some conducting impurities are measured. It is found that the permittivity* ε' *and the loss factor* ε'' *are increaseing with doping content. These values are found to be higher in Mg doped samples as compared to Cu doped samples. Similar behaviour is also reported for the conductivity and relaxation time which are calculated for the considered samples. Our results are discussed in terms of parameters atomic structure, density and random distribution.*

1. Introduction

Microwave processing is a field of intersting importance and is receiving more attention particularly in processing materials with a broad range of compositions, sizes and shapes [1–3]. In recent years microwave processing research and development have been expanded into many new areas such as ceramics, polymers, composites and chemicals [4–7]. The real and imaginary parts of the complex permittivity are parameters describe the behaviour of a dielectric material under the influence of a microwave field. Both affect the power absorbed and the half-power depth. They describe well how microwaves penetrate and propagate through an absorbing material, and influence the volumetric heating of agiven material [8]. Guided wave transmission technique is the method for measuring the dielelectric properties of materials in the microwave range frequencies.

Polyvinyl chloride (PVC) is used in many areas of manufacturing , and have naturally found application in the construction of electronic devices. As the operating frequencies of these devices continue to increase, designers need accurate data of electromagnetic properties of these materials. There is asizable body of data in the technical literature about the electromagnetic properties of PVC ; but most of those results focus on sheats form rather than powder form [10–14]. Dielectric properties of solids in the form of powders may be useful in understanding the structural behavior of particles in an alternating field. These studies may also be used to formulate models for predicting the dielectric properties of

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*Corresponding author. E-mail: drswalha@hotmail.com packed beds. Many solid electrolyets are used as the major component in the preparation of binary and ternary compounds. The dielectric constant and the conductivity of such solids in the particulate form are of importance for the behavioural study of these compounds.

In the above background, we chose to doing our measurements on powder materials rather than with solid, for two reasons. First, powder compacts have acceptability in technological work and such compacts are easy to fabricate. Particular beds are finding applications in heavy electrical industry and the dielectric properties of such beds are gaining importance these days. Second, there is need for an accurate and convenient technique to measure the dielectric properties of solids in the form of the powder. In the present study, we propose a method to measure the dielectric constant of PVC in powder form and with impurities at different microwave frequency and the results obtained are discussed in details.

2. Theory of Calculation

The dielectric constant is a measure of the polarizability of a material. When an electric field is impressed on a material with intrinsic, microscopic dipoles, the dipoles will realign so as to modify the total electric field .That is the total electric field will now be the sum of the impressed electric field and the electric field of the dipoles. This is generally expressed through the constitutive relation:

$$\vec{D} = \varepsilon_r \varepsilon_o \vec{E} \tag{1}$$

One of Maxwell's equations in time-harmonic form is:

$$\vec{\nabla} \times \vec{H} = \vec{J} + j\omega\varepsilon_r\varepsilon_o\vec{E}. \tag{2}$$

Where $\vec{J} = \sigma\vec{E}$ in eq. (2) is the conduction current. Combining eqs. (1) and (2) results in the definition of an effective complex relative permittivity ε^*

$$\vec{\nabla} \times \vec{H} = j\omega\varepsilon^*\varepsilon_o\vec{E} \tag{3}$$

Where:

$$\varepsilon^* = \varepsilon' - j\varepsilon'' = \varepsilon_r - j\left(\frac{\sigma}{\varepsilon_o\omega}\right)$$

The ratio $\frac{\varepsilon''}{\varepsilon'}$ is commonly referred to as the loss tangent , this quantity is an indicator how will the material will absorb the microwaves.

When the dielectric material of a complex permittivity ε^* filled in a rectangular waveguide and the waveguide is operating in the TE_{10} mode (TE_{10} mode is the transverse electric mode with one half cycle in the direction of the width of the guide and constant along the direction of the height of the guide) , the propagation constant in the material can be written as

$$\gamma_d = \alpha_d + j\beta_d = j\frac{2\pi}{\lambda_o}\left[\varepsilon^* - \left(\frac{\lambda_o}{\lambda_c}\right)^2\right]^{\frac{1}{2}} \tag{4}$$

Where α d is the attenuation introduced by the unit length of the dielectric material (*Nepers/m*), β d is the phase shift introduced by the unit length of the dielectric material (*radian/m*), λ_o is the wavelength in free space and λ c is the cutoff wavelength of the wave guide. The complex permittivity ($\varepsilon^* = \varepsilon' - j\varepsilon''$) is not a directly measurable quantity, it is necessary to relate ε^* to the physically measurable parameters in the experiments.

Substituting ($\varepsilon^* = \varepsilon' - j\varepsilon''$) in equation (4) and separating real and imaginary parts, we get :

$$\varepsilon' = \left(\frac{\lambda_o}{2\pi}\right)^2 \left[\left(\frac{2\pi}{\lambda_c}\right)^2 - \left(\alpha_d^2 - \beta_d^2\right)\right] \tag{5}$$

$$\varepsilon'' = \left(\frac{\lambda_o}{2\pi}\right)^2 (2\alpha_d \beta_d) \tag{6}$$

Where $\beta_d = \frac{2\pi}{\lambda_d}$, (λ_d is the guide wavelength when it is filled with the dielectric medium). Therefore eqs. (5) and (6) can be written as:

$$\varepsilon' = \left(\frac{\lambda_o}{\lambda_c}\right)^2 + \left(\frac{\lambda_o}{\lambda_d}\right)^2 \left[1 - \left(\frac{\alpha_d}{\beta_d}\right)^2\right] \tag{7}$$

$$\varepsilon'' = \frac{1}{\pi}\left(\frac{\lambda_o}{\lambda_d}\right)^2 (\alpha_d \beta_d) \tag{8}$$

Equations (7) and (8) can be employed to obtain the values of ε' and ε''. The main quantities to be measured experimentally are λ_d and α_d for the sample in which ε' and ε'' values are to be obtained.

The behaviour of the powder in the pure form as well as with metalic impurities can also be understood by examining the relaxation behaviour of the sample subjected to the electromagnetic fields at microwave frequencies.The relaxation time τ can be obtained from the permittivity ε' and the loss factor $\varepsilon''$by employing the relation:

$$\tau = \frac{\varepsilon''}{\omega\varepsilon'}$$

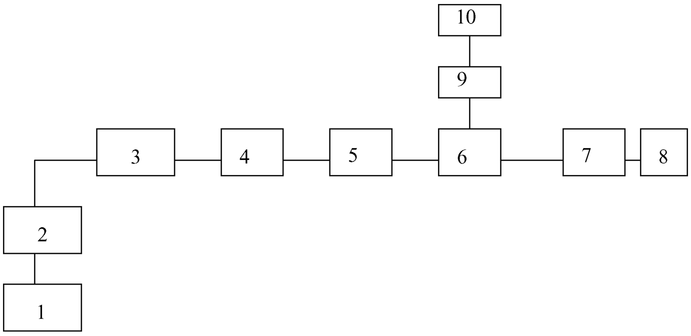
and the value of conductivity σ from the relation:

$$\sigma = \omega\varepsilon_o\varepsilon''$$

3. Experimental Results and Discussion

The samples of the system $(PVC)_{1-x}$ Mx with various M and x, [M = Cu and Mg and x = 0.00, 0.025, 0.05, 0.10, 0.15 and 0.20] are prepeared as follows; stoichiometric proportion of high purity starting materials, PVC, Cu and Mg with appropriate amount suitable for each sample are weighted. The resulting powder are mixed and grounded many times to obtain homogenous powders. The experimental arrangement proposed for these measurements is shown schemahically in Fig. 1. The sample in the form of powder is filled in the dielectric cavity. Microwave power is obtained from a microwave sourse and is allowed to form standing waves in the slotted waveguide section, after being reflected from the short circuit plunger in the dielectric cell.

Figure (2) shows that the permittivity ε' for pure PVC powder is 1.454; and the value of ε' systematically increases with the increasing doses of conducting powder either Cu or Mg. However, the pattern of variation in the case of two impurities is quite different.



1 – *Gunn Power Supply*
2 – *Gunn Oscillator*
3 – *Isolator*
4 – *Attenuator*
5 – *Frequency Meter*
6 – *Slotted Waveguide*
7 – *Dielectric Cell*
8 – *Short Circuit Plunger*
9 – *Detector*
10 – *Indicator*

Figure 1. Experimental Set-Up.

This obvious difference is more clearly demonstrated as shown in the figure. It can be seen from the figure that the behavior of PVC powder with increasing the precentage of Cu as impurity shows a sharp variation from pure PVC to addition of five percent copper impurity. For higher impurities, the increase in permittivity value with increasing percentage of Cu is nearly linear, and appears to approach higher values at very high concentrations of Cu powder.

In the case of PVC powder with Mg powder the variation of permittivity ε' with increasing percentages of Mg powder simulates an exponential rise. Moreover the permittivity

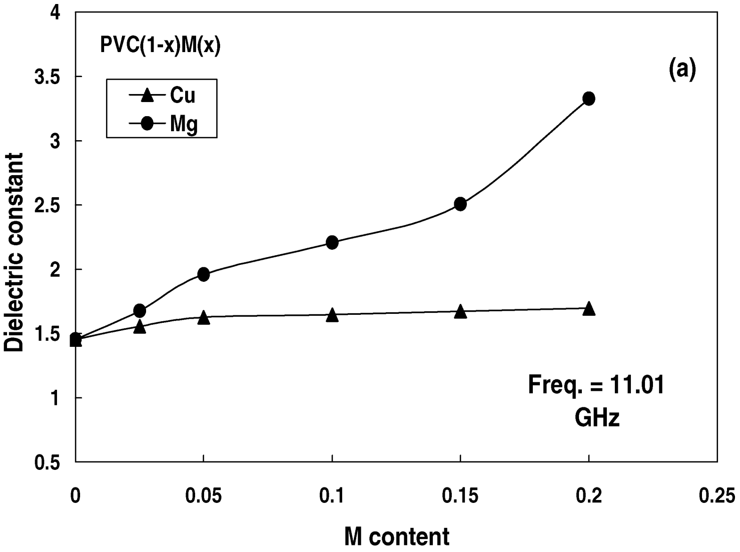


Figure 2. Dielectric constant versus doping content for PVC in powder form at 11.01 GHz.

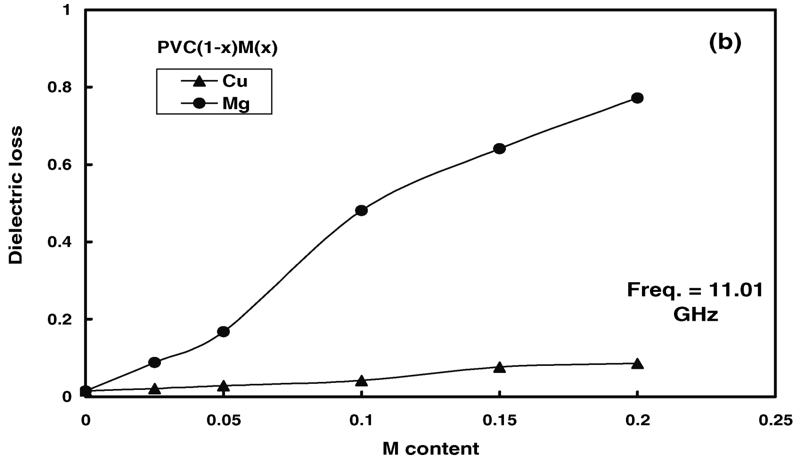


Figure 3. Dielectric loss versus doping content for PVC in powder form at 11.01 GHz.

value of PVC powder doping by Mg powder as an impurity is more than PVC powder doping by Cu powder in the same percentage.

The increase in the permittivity values of dielectric in the powder form and in the presence of small percentage of conducting media is understodable. The conducting media is expected to absorb the electromagnetic energy resulting in damping of the dipolar motion of the dielectric media, this must result into higher values of ε'.

The loss factor ε'' shown in Fig. (3) for the PVC powder with Cu and Mg podwer as impurities at the operating frequency 11.01 GHz shows that the values in both cases increase with increasing the doping percentage of conducting media in the dielectric medium. This behaviour is expected with more and more conducting centres avaliable in the medium.

The loss of electromagnetic energy passing through the medium should increase. It is interested to note that the two trends are entirely different, Cu has an electrical conductivity more than two times of electrical conductivity of Mg , and one should expect that the behaviour of PVC powder in presence of Cu powder must exhibit a steep rise in loss, where as the presence of Mg powder as impurity in PVC powder should shows a relatively slow rise in loss with increasing percentage of Mg. But such an expectation is not confirmed as shown in fig. (3). It is found that PVC powder in presence of Mg powder under similar conditions shows qualitatively the same trend, but quantitively the loss increase more steeply in presence of Mg impurities than that of Cu.

This is probably that due to the fact that the absorption of the microwave energy in a dielectric medium with conducting centres does not only depend on the electrical conductivity of the conducting centres but also on the atomic structure, density and the form of their random distribution.

The conductivity of the pure PVC powder and its mixtures with different concentrations of Cu and Mg at 11.01 GHz is shown in Fig. (4), and this shows similar behaviour as shown in Fig. (3). Obviously the conductivity in oscillating field is different from the conductivity in the d.c field. The present calculation shows that the relaxation time τ for pure PVC powder used in the present investigation is 1.53 × 10–13 sec., which is very much comparable to the values of 10–13 sec. reported by Blatt for silica [15]. All the data relating to the considered investigation are listed in Table (1a) and (1b).

Table 1

(a): Dielectric constant, dielectric loss, conductivity and relaxation time for pure and Cu doped PVC

Cu doping	Dielectric constant	Dielectric loss	Conductivity	Relaxation time
0.00	1.454	0.1054	0.009	1.53 × 10–13
0.025	1.556	0.0211	0.012	2.11 × 10–13
0.05	1.627	0.0286	0.018	2.54 × 10–13
0.10	1.647	0.0423	0.026	3.71 × 10–13
0.15	1.674	0.0770	0.047	6.65 × 10–13
0.20	1.697	0.0862	0.053	7.34 × 10–13

(b): Dielectric constant, dielectric loss, conductivity and relaxation time for pure and Mg doped PVC

Mg doping	Dielectric constant	Dielectric loss	Conductivity	Relaxation time
0.00	1.454	0.0154	0.009	1.5 × 10–13
0.025	1.677	0.089	0.049	1.35 × 10–13
0.05	1.959	0.168	0.103	1.24 × 10–13
0.10	2.207	0.481	0.294	3.15 × 10–12
0.15	2.507	0.641	0.392	3.69 × 10–12
0.20	3.327	0.772	0.472	3.34 × 10–12

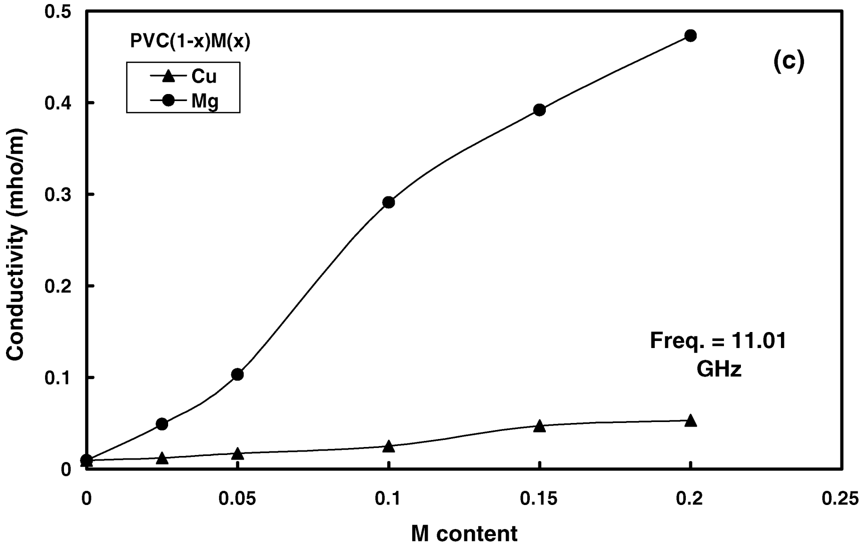


Figure 4. Microwave conductivity versus doping content for PVC in powder form at 11.01 GHz.

4. Conclusion

The dielectric properties of pure and doped PVC in powder form are investigated. We have shown that the dielectric properties of pure PVC in powder form are improved by the doping content. These improvements are higher in Mg doped PVC samples than Cu. The atomic structure, density and random distribution are playing a major contribution in the PVC dielelectric properties.

Acknowledgments

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