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Effect of applied voltage on transient current of filled and unfilled epoxy resin

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Abstract: Electrical properties of unfilled and ZnO-filled epoxy polymer are investigated by temporal spectroscopy. Transient current analysis indicates that relaxation time decreases with increasing applied voltage and adding ZnO nanoparticles, due to an increase of charge carriers mobility. Moreover, adding ZnO nanoparticles to polymer epoxy matrix enhances the dielectric function parameter (s). This parameter gives information on the expected conduction mechanisms. In the other hand, the depolarization current was simulated to determine the equivalent circuit. We obtain an equivalent circuit consisting of 3 R-C parallel branches. We note that ZnO loading causes a fall in the capacities values, and an increase in resistances of nanocomposite. This resistive behavior can be explained by an increase of interactions and bond formation between ZnO nanoparticles and epoxy polymer chains.

Keywords: dielectric properties, relaxation time, conduction mechanism, equivalent circuit

1. Introduction

Polymer nanocomposites have been a very important subject for optical, mechanical, magnetic, optoelectronic, dielectrics and electrical insulation applications [1]. PDC (Polarization, depolarization current) measurement is dielectric testing method based in time domain. When an electric field is applied to a dielectric material between two plane parallel electrodes, it causes charges motions, which manifests as a current flow in the external circuit. This technique can provide information about dielectric parameters. In addition the simulation of measured currents leads to determine equivalent circuit [2].

3. Results and Discussion

a. Polarization currents

Fig. 1 shows an increase of the polarization current with increasing applied field, since the mobility and the amount of carriers depend on applied field [3]. In the other hand the magnitude of polarization current of nanocomposite is higher than that of neat epoxy (Fig. 1 b) This can be discussed on the base of interfacial polarization (MWS) [4].

Polarization current in bilogarithmique scale presents 3 regions (Fig 1 (b)):

Region (I) current follows an exponential law:

$$I = I_0 + A \exp(-t/\tau)$$

Where A is a pre-exponential factor, τ is the polarization time.

As seen in Fig.2 relaxation time decreases with increasing applied voltage and adding ZnO nanoparticles. This is due to an increase of charge carriers mobility.

In region (II), current follows Curie’s low:

$$I(t) = B\, t^{-s}$$

Where t is the time, A is a temperature dependent factor and s is dielectric function parameter (0<s< 2).

From the evolution of dielectric function parameter (s) vs the applied field (fig.3) we can conclude, the possible conduction mechanisms [5]:

- Dipolar orientation
- Injection of charges with trapping
- Tunnel effect
- Jump conduction
- Space charges limited Conduction

b. Depolarization current:

The equivalent circuit is determined by modeling the depolarization current by the following equation.

$$I_{dép} = \sum_{i=1}^{n} A_i e^{-t/\tau_i}$$

Where the individual exponential corresponds to an R-C branch with the corresponding time constants $\tau_i = R_i C_i$

Fig. 4 shows the measured and simulated depolarization currents with the constituent exponential components for neat epoxy and epoxy/ZnO nanocomposite vs applied field. The obtained circuit consists of 3 R-C parallel branches as presented in Fig.5. R, C values and the computed parameters (τ_i, A_i) are gathered in Table 1.

Table 1 shows an increase of resistivity and a decrease of capacity with adding ZnO nanoparticles. This phenomenon can be explained by an increase of interactions and hydrogen bond formation between ZnO nanoparticles and polymer chains. These results matches well with IR and Raman results already discussed [6]

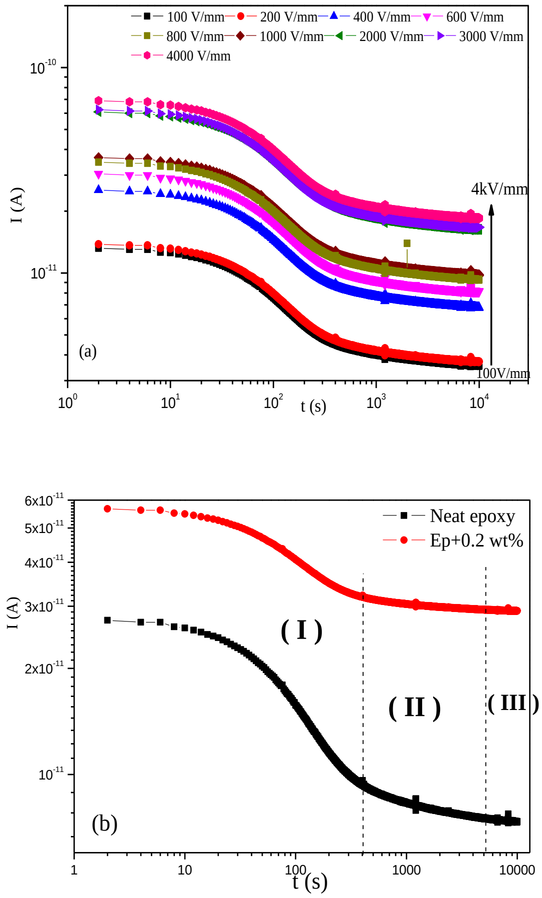

***Fig1.* Polarization current** (a) **of polymer matrix vs time and applied field (b) of 0.2 wt% ZnO/epoxy nanocomposite vs time at applied field of 1kV**

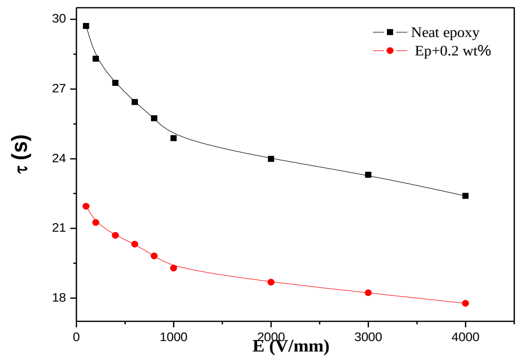

***Fig2.* Polarization time of polymer matrix and 0.2 wt% ZnO/epoxy nanocomposite vs applied field**

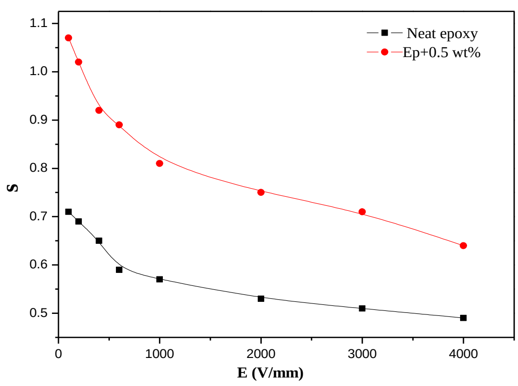

Fig3. **Variation of the exponent s of polymer matrix and 0.2 wt% ZnO/epoxy nanocomposites vs applied field**

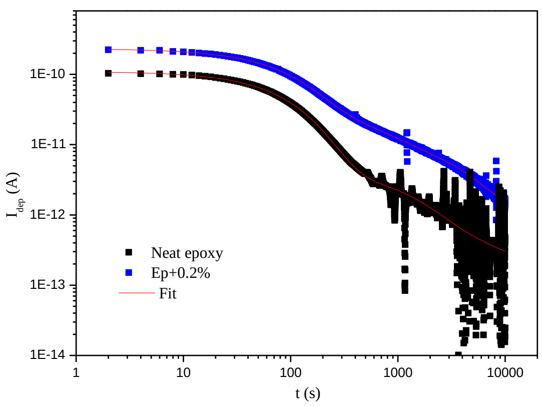

Fig4. **Depolarization current of neat epoxy and 0.2 wt% ZnO/epoxy nanocomposite vs time at 1 kV/mm**

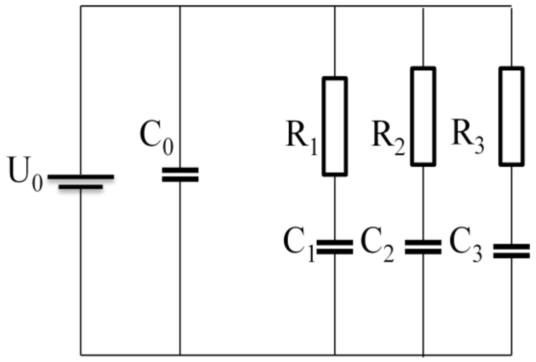

Fig5. **Equivalent circuit of ZnO/epoxy nanocomposite**

Samples	**Branches**	**$A_{1,2,3}$**	**$\tau_{1,2,3}$(s)**	**$R_{1,2,3}(\Omega)$**	**$C_{1,2,3}$(F)**
Neat epoxy	1	2,34 x10^{-11}	457,37	4,27 x10^{13}	1,07 x 10^{-11}
	2	1,93 x10^{-10}	90,21	5,18 x10^{12}	1,74 x10^{-11}
	3	1,17 x10^{-11}	2987,27	8,24 x10^{13}	3,62 x10^{-11}
Ep+0.2%	1	3,51x10-12	1128,78	3,21 x10^{14}	3,51 x10-12
	2	1,04x10-11	91,91	9,61 x10^{12}	9,56 x10-12
	3	6,88x10-12	5000	1,25 x10^{15}	4 x10-12

Table 1: obtained characters of equivalent circuit

3. **Materials and methods**

Epoxy/ZnO hybrid nanocomposites (EP-ZnO-HNCs) are prepared by direct dispersion of commercial ZnO nanoparticles in epoxy matrix.

For transient currents measurements, DC voltage (100 V, 200 V, 400 V, 600 V, 800 V, 1kV, 2kV, 3kV and 4 kV) is applied to EP-ZnO-HNC for 3h and the polarization current is recorded as a function of time. Then the applied voltage is removed and the depolarization current is recorded.

4. Conclusions:

Transient current analysis indicates that the increase of the charge mobility causes a decrease of time relaxation whereas increase of the resistance originates from the increase of interaction and bond formation between ZnO nanoparticles and polymer chains. In addition several conduction mechanisms can simultaneously exist in epoxy polymer and ZnO/epoxy nanocomposite. All results are correlated and demonstrate that adding ZnO nanoparticles in epoxy matrix improves its insulation properties.

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