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SHORT COMMUNICATION

ROLE OF POLARIZATION AND TENSILE STRENGTH IN THE PROCESS OF ELECTROCHEMICAL ETCHING (ECE)

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Abstract—The effects of dielectric constant and dissipation factor on ECE response at various frequencies was investigated. This study reveals that dipole moment and tensile strength are important parameters on which the tree formation in the ECE process depends.

1. INTRODUCTION

THE ENERGY transferred to an insulating material when subjected to an alternating electrical field is a function not only of field strength across the material and its frequency but also of the physical characteristics of the material—which further depend on the field frequency (Al-Najjar *et al.*, 1979; Somogyi *et al.*, 1979; Sohrabi, 1981; Tommasino *et al.*, 1981). As suggested by Tommasino *et al.* (1981), a possible way to analyse these effects would be to measure the dielectric loss factor, $\epsilon \tan \delta$, as a function of frequency, preferably under the same electrical conditions as those used during electrochemical etching (ECE).

ECE materials studied until now have been polar in nature, i.e. they have dipole moment (μ). The existence of this parameter considerably alters the electrical behaviour of the dielectric. Visualizing the relevance of this study, the dielectric constant ϵ and the dissipation factor $\tan \delta$ have been investigated at various frequencies and their effect on ECE response is discussed. An attempt has also been made to correlate the dipole moment μ with ECE behaviour of the polymeric track detectors such as Lexan polycarbonate (PC), CR-39, cellulose triacetate (CTA), cellulose nitrate (CN) and polyethylene terephthalate (PET).

2. EXPERIMENTAL PROCEDURE

Circular samples of various dielectrics, viz. PC, CR-39, CTA, CN, having approximate area of $0.5\ cm^2$, were used for the determination of ϵ and $\tan \delta$. Silver paste was put on both sides of the samples to make a capacitor and to improve electrical contacts with sample holder. The experiment was carried out in the frequency range from 0.1 to 100 kHz at 25°C using GR Capacitance Bridge type 1615-A which gives a direct reading of capacitance (Cp) and the dissipation factor. The dielectric constant was calculated using the relation, Cp/Co; Co was obtained from the relation, $\epsilon_0 A/d$, where A is the area, d, the thickness of the sample, and ϵ_0, the permittivity of free space. The values of ϵ and $\tan \delta$ thus obtained were plotted vs the log of the frequency.

For the measurement of dipole moment (μ), the polarization current through the sample was measured for an external triangular wave field. From the polarization current the charge on the electrode plates and thus polarization was calculated. From the measurement of polarization current and ϵ (at low frequency), dipole moments were calculated using the Clausius–Mossotti relation:

$$\frac{\epsilon - 1}{\epsilon - 2} = \frac{1}{3\epsilon_0}(\Sigma N_j \alpha_j)$$

where the symbols have their usual meanings.

In a separate experiment, ECE was carried out using dielectric detectors to find out the minimum field strength required for tree initiation.

3. DISCUSSION OF RESULTS AND CONCLUSIONS

The curves shown in Fig. 1 represent variation of ϵ and $\tan \delta$ vs the log of the frequency. It is evident from the figure that ϵ is almost constant in the frequency range 0.1–100 kHz, but $\tan \delta$ is strongly dependent on f and is a maximum around 250 Hz, which supports the results obtained during ECE of PC (Singh and Virk, 1987).

The curves shown in Fig. 2 are plots of ϵ and $\tan \delta$ against $\log f$ for CR-39. The curve of ϵ shows a slight depression at high frequencies. The curve of $\tan \delta$ shows almost no variation until 1 kHz, beyond which it rises linearly. The variation of $\tan \delta$ suggests that in the case of CR-39, a better ECE response is

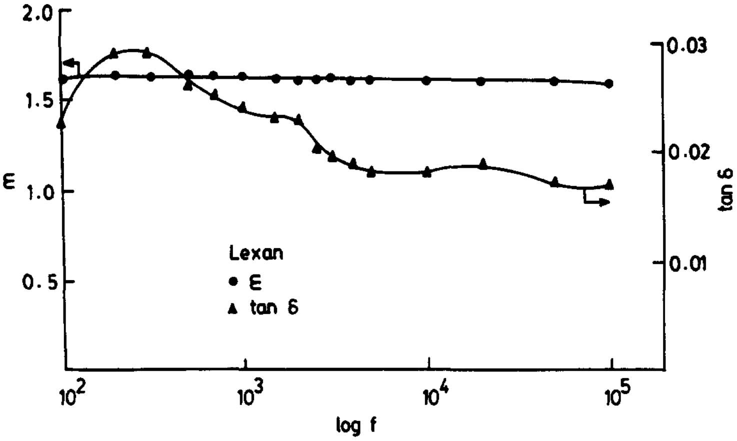

FIG. 1. The dielectric constant and dissipation factor as functions of log f for Lexan.

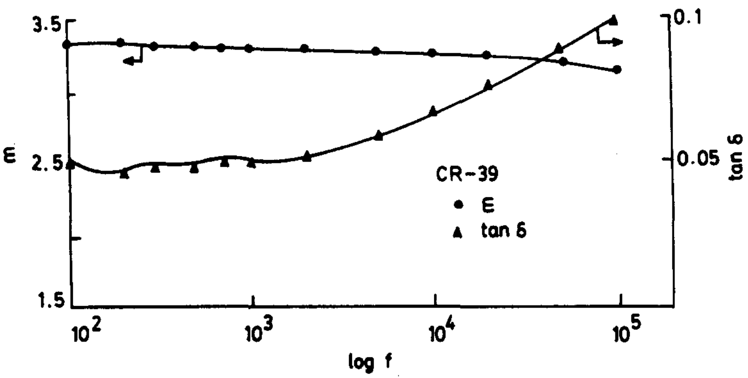

FIG. 2. The dielectric constant and dissipation factor as functions of log f for CR-39.

expected at higher frequencies than at low frequencies. The variation of ϵ and tan δ vs log f is also studied for both CTA and CN. It is observed that both ϵ and tan δ show a decreasing trend with frequency. These variations suggest that to get a better response, ECE should be carried out in a low frequency region.

In the present study, the role of dipole polarization in ECE process is emphasized. Dipole moment is a measure of the extent to which a material will exhibit dipole polarization when placed in an a.c. field. Dipole polarization is absent in non-polar dielectrics such as polyethylene, polystyrene, etc., as there are no polar molecules present in them and their ECE response is the poorest of all of the polymeric materials. Consequently, dielectrics having a high value dipole moment give a better ECE response. It is also observed that a material having a low value dielectric constant gives better ECE results, the only exception being CN.

For electrical treeing, the minimum field strength E_{min} is known as characteristic voltage (Ashcraft *et al.*, 1976). It appears that E_{min} also depends on both dipole moment and tensile strength. The value of E_{min} for CR-39 is 4 kV cm^{-1}, which is expected because of high value of μ. For PC, the value of μ is also high, but E_{min} is only 2.5 kV cm^{-1}, which can be attributed to its low tensile strength. The value of μ for PET is almost half that of CR-39, whereas E_{min} is more than that of CR-39. This anomaly may be explained considering the exceptionally high value of tensile strength for PET. CN has the highest value of μ among the polymers but the value of E_{min} is quite low, which is due to the fact that CN has low value of tensile strength.

The study leads to the following tentative conclusions:

(i) curves of tan δ vs f are helpful in finding the optimum value of frequency for ECE;
(ii) polymeric track detectors for ECE should be polar in nature;
(iii) ECE response of a dielectric is affected collectively by dipole moment, dielectric constant and tensile strength;
(iv) minimum electric field strength required to initiate treeing is a function of both dipole moment and tensile strength.

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