

Stabilization of negative charge in polystyrene foils by corona charging at elevated temperatures

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Abstract : A study of thermally stimulated charge decay (TSCD) measurements in conjunction with that of short circuit thermally stimulated currents (TSCs) was undertaken in unilaterally metallized 25 μm thick polystyrene samples. The samples have been negatively corona charged with corona voltage of 9 kV at different temperatures (40–100°C) and the charge stability of such samples is investigated using the above two methods. It has been found that the charge stability of negative charge increased when the charging is made at elevated temperatures. This has been considered to be due to the localization of charge carriers in deep traps at higher charging temperature.

Keywords : Corona charging, polystyrene, negative charge stabilization

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1. Introduction

Numerous publications in recent years indicated the rapid growth of interest in gaining insight into the charge storage and transport processes in polymer electrets by means of techniques based on thermal stimulation [1,2]. The use of polymers in electrical industry has increased remarkably over the few years and the information on charge storage properties of such polymers is of interest for several industrial applications [3].

The charging and discharging behaviour of polystyrene (PS) has been studied by number of authors [4–6]. However, the results obtained have been interpreted differently. In the recent past, H von Seggern and J E West [7] reported a technique for stabilizing electronic charge in Teflon FEP which is based on corona charging through a regulating grid at elevated temperature. Such technique for charge stabilization in other insulating polymers is considered to be interesting.

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The possible combination of the techniques based on the thermal stimulation for studying the charge storage and charge transport with others, such as, surface charge density measurements have been exploited to investigate the processes responsible for charge carrier trapping in various polymers and to determine the various parameters associated with these processes [8]. Presently we report the results of the studies of thermally stimulated charge decay (TSCD) and thermally stimulated current (TSC) in polystyrene with the view to have a better insight into the mechanisms responsible for charge storage and release in polymer. Various trap parameters have also been evaluated

2. Experimental details

The isothermal immersion technique was utilized for preparing samples. The solution was prepared in a glass beaker by dissolving 5 gm polystyrene in 100 ml of chemically pure benzene. The solution was kept for 24 h to get a homogeneous and transparent solution. The solution thus prepared was then poured onto an optically cleaned glass plate floating on mercury. The solvent was allowed to evaporate in an oven at 40°C for 12 h to yield the desired samples. This was followed by room temperature outgassing at 10^{-5} torr for a further period of 12 h to remove any residual solvent. Samples thus obtained, were uniformly smooth and could be easily peeled from the glass surface.

Polystyrene (PS) samples of thickness about 25 microns were obtained. One surface of the preconditioned samples so prepared was then vacuum aluminized over central circular area of 3.6 cm diameter. The samples were corona charged negatively through a grid on the non-metallized face with corona voltage (V_p) of 9 kV and grid potential (V_g) of -600 V at different temperatures (40 to 100°C). The charging of the sample with its metallized face grounded against the heating plate was carried out by exposure to corona point discharge situated between a grid electrode (metal mesh) at a distance of 3.5 cm from the upper face of the heating plate and oriented perpendicular to it. The grid was mounted 0.5 cm above the heating plate supporting the sample. The samples preheated to the desired temperature were subjected to corona-charging for 240 sec and then were quickly cooled back to room temperature (30°C).

Thermally stimulated charge decay (TSCD) measurements were made using field-compensation technique [9] and TSCs were monitored at a heating rate of 3°C/min by short-circuiting the sample through 610-C Keithley Electrometer.

3. Results and discussion

Surface potential dependence on charging time measured after 40 sec of charging at various charging temperatures has been found to be independent of charging time at each charging temperature. However, the surface potential values have been found to decrease with increasing charging temperature. Such observations are in agreement with that reported [7]

(for Teflon FEP which has been considered to be due to constant current flowing through the sample.

The charge decay curves of samples charged at various temperatures with corona voltage of 9 kV are shown in Figure 1. It is noted that the temperature at which the charge begins to decay and also the temperature at which the charge reduces to half of its initial value (half-value temperature), practically remains the same for electrets charged at and below 70°C. However, both these two temperatures for electrets charged above 70°C increases with charging temperature. These characteristics indicate the distribution of traps in energy in the sample and suggest that the injected electrons are trapped at different trapping levels. The observed increase in half-value temperature for samples charged at higher temperature indicate that the high charging temperature favours energetically deeper trapping of electrons in the sample [10].

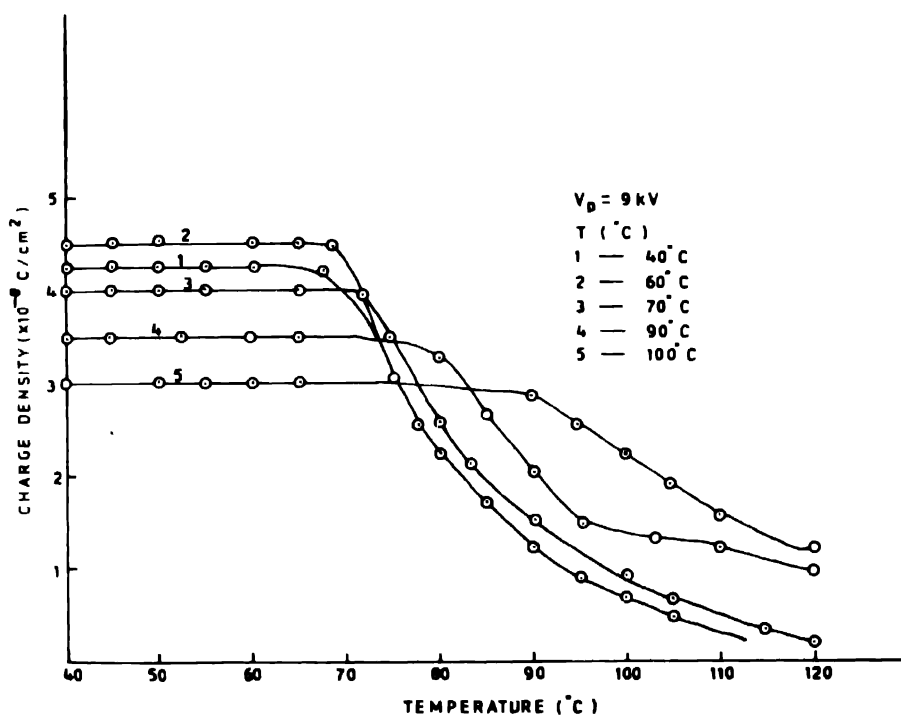


Figure 1. Thermally stimulated charge decay (TSCD) of negatively charged polystyrene foil electrets

The electrons deeply trapped in the bulk of the electret are supposed to remain immobile during the decay run, and are expected to slow down the drift of charge carriers detrapped from shallow traps. Thus the charge decay rate becomes sufficiently slow for electrets polarized at high temperatures at which trapping of charge carriers in deep traps is favoured [11].

It has been shown that in the case of fast retrapping, the sum of the mean depth \bar{r}_n of the injected charge and the mean depth \bar{r}_p (measured from the rear electrode) of the compensation charge is given by [12,13]

$$\frac{\bar{r}}{L} = \frac{1}{(1 + |\sigma|/|Q|)}, \quad (1)$$

where $\bar{r} = \bar{r}_n + \bar{r}_p$, is the total depth and L is the sample thickness.

The \bar{r}/L values determined soon after the completion of polarization for electret polarized under different polarizing conditions are shown in Table 1. It is noted that the value of \bar{r}/L increases with T_p . It indicates that under higher temperature conditions the charge is continuously transferred into the bulk of the sample due to trap filling with increasing charge density.

Table 1. TSC parameters.

Corona voltage (kv)	Poling temperature (°C)	Activation energy (eV) (U)	Released charge (Q) (C/cm^2)	Relative penetration depth \bar{r}/L	Trap density (n_0) (cm^{-3})	Mobility (μ) ($cm^2V^{-1}sec^{-1}$)
	40	0.65	4.3×10^{-11}	0.01	5.3×10^{15}	0.47×10^{-12}
	60	0.78	2.2×10^{-10}	0.04	12.8×10^{14}	1.90×10^{-12}
9	90	0.85	1.5×10^{-9}	0.05	11.1×10^{14}	2.20×10^{-12}
	100	0.94	2.1×10^{-9}	0.07	6.0×10^{14}	3.60×10^{-12}

With the view to further verify, the trapping of charge carriers at different trapping levels and to study the effect of thermal aging on charge stability of PS electrets, a two-stage TSCD study was performed (Figure 2). The sample charged at 90°C with corona voltage of 9 kV was heated upto 90°C and then was cooled back to room temperature. It was then again heated with the charge left after the first run. It is seen that the charge remains constant upto a higher temperature during the second run. The shift of the onset of the charge decay towards higher temperature shows the increased charge stability by thermal aging. Such behaviour can be understood in terms of detrapping of electrons from shallow traps during the first run leaving the electrons only in deep traps [8,12]. These deeply trapped electrons then persist upto a higher temperature during the second run.

TSC thermograms of samples charged at different temperatures with corona voltage of 9 kV are shown in Figure 3. It is noted that there is a single trap distribution with TSC peak located at about 80°C for electrets charged at temperatures below 70°C. Moreover, there is no appreciable shift in peak positions. This is in agreement with the results obtained from TSCD study, shown in Figure 1. The electrets charged at and above 70°C are characterized with two peaks, one of them being located at about 80°C and the other at higher temperature (high-temperature peak). The high temperature peak shifts to higher

temperatures (from 100–120°C) and increase in magnitude with increase in charging temperature. These characteristics demonstrate that at low charging temperature, trapping

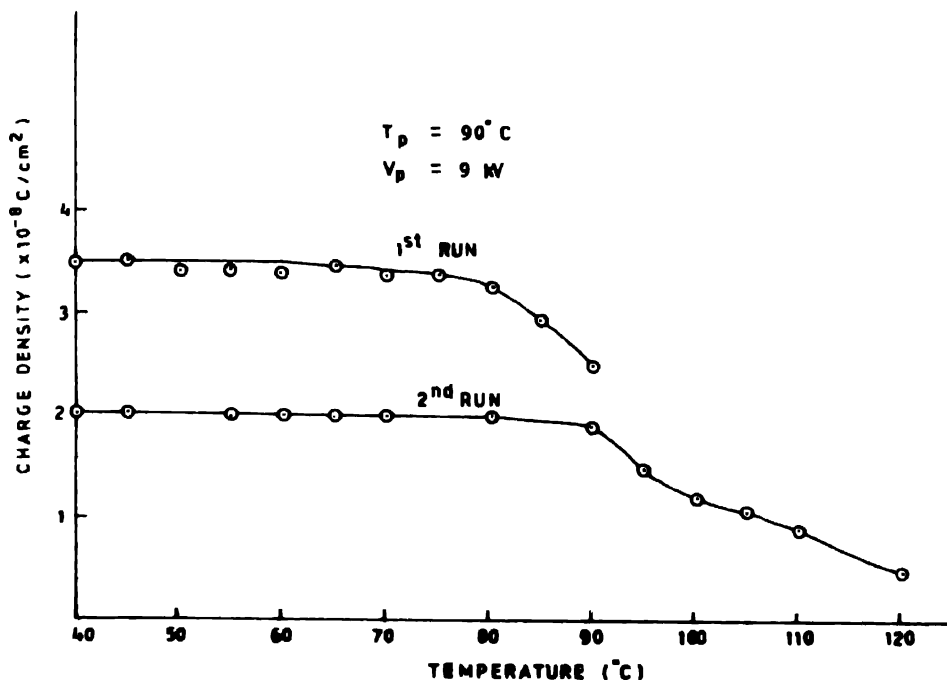


Figure 2. Two stage thermally stimulated discharge of polystyrene foil electret.

takes place only in shallow traps. However, a considerable amount of charge is trapped in deeper traps at higher charging temperature. The shift of high temperature peak from 100 to 120°C indicates a distribution of trapping levels for this peak and shows that charge is trapped in deeper traps as the charging temperature increases. The activation energy, determined from the initial rise of such peaks, (shown in Table 1) which correspond to the shallowest inactive levels (not contributing to the charge motion) support this conclusion. As shown in Table 1, the charge under these peaks increases with increasing charging temperature.

The absence of high temperature peak and the appearance of only low temperature peak for samples charged at low charging temperature may be related to the surface/near surface trap discharging. From the calculated values of penetration depth [8] (Table 1), for samples charged at different temperatures. We may conclude that the charge carriers in the case of samples charged at low temperatures are localized in the near surface region, and the traps located in this region are energetically shallow traps. The penetration depths at higher temperature indicate that the high temperature peak is due to the detrapping of charge carriers from the traps which are located deeper in the bulk. The appearance of weak lower temperature peak in such cases can be understood in terms of active and inactive traps under given charging conditions. As explained by von Seggern and West [7], the

number of active (contributing to charge motion) trapping levels increases with increasing charging temperature while the number of inactive levels which are energetically deeper, decreases. These inactive levels store the charge delivered by corona.

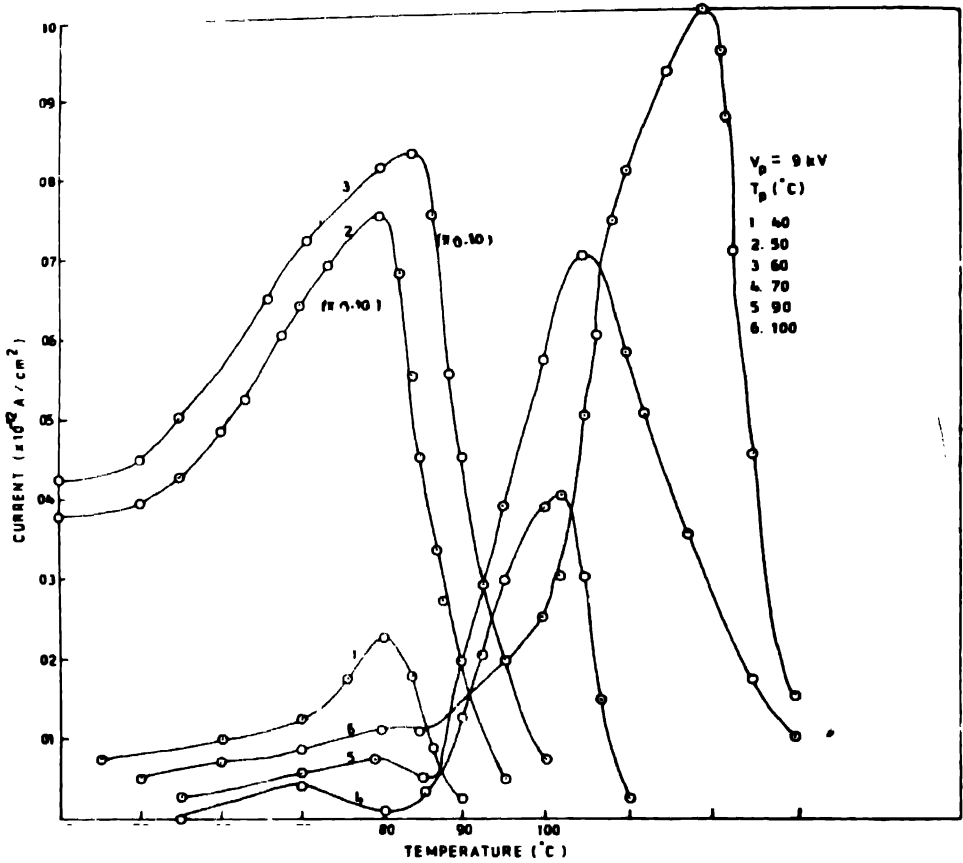


Figure 3. Thermally stimulated currents (TSCs) of negatively charged polystyrene foil electrets.

The retrapping times [7] (t_R) at room temperature for negatively charged samples and the activation energy for the observed peaks can be calculated with the experimental parameters from Figure 3 using the following relation

$$t_R > t_c \exp \left[\frac{U}{R} \left(\frac{1}{T_R} - \frac{1}{T_c} \right) \right], \quad (2)$$

where U is the activation energy. T_R is room temperature, T_c is charging temperature and t_c is charging time. These retrapping times (Table 2) are a lower limit of electret life time.

The maximum total trap density [13,14] for different charging temperature have been calculated and are found to decrease with charging temperature. These values are in agreement with those reported earlier [15-17].

A pronounced effect of trapping on mobility is expected under steady state condition in materials subjected to fast retrapping.

Table 2. Estimated lower limit of the lifetime at room temperature T_R of an electret charged at T_c

Charging temperature T_c (°C)	Charging time T_c (sec)	Retrapping time $t_R >$
40	300	9.8 h
60	300	23.4 h
90	300	438 h
100	300	670 h

The trap modulated mobility values at the TSC peak temperature evaluated from the condition [8] for the current maximum, which yields

$$\mu = \frac{h\epsilon U}{2kT^2\rho}, \quad (3)$$

where h is the heating rate, U is the activation energy, ρ is a total charge density. This yields the mobility values (Table 1). The order 10^{-12} for the carrier mobility indicates that the mobility is modulated by the traps. The lower value of the mobility further shows the excellent charge storage capability of the polymer which supports the lower limit of the electret life-time estimated in the present case.

Conduction in polymers is explained not on the basis of band theory but in terms of the existence of mobility edge. Charge carrier is free to move only when it possesses a certain value of mobility. If the charge carrier is near the bottom of conduction band, it is in the extended delocalized state and requires no thermal activation. However, if it is in the localized trapped state, it requires thermal activation and mobility increases with the increase in temperature.

4. Conclusion

Various results of present study indicate the presence of traps distributed in energy in PS, and suggest that the trapping of injected electrons in deep traps is favoured for electrets charged at higher temperatures. Stabilization of negative charge in PS increases markedly by corona charging at elevated temperatures. Further on the basis of the various experimental findings, it has been concluded that the charges are subjected to fast retrapping in this polymer. The mobility values obtained in the present polymer are well within the limits of measured mobilities in polymers [18,19].

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