Pramāṇa, Vol. 4, No. 6, 1975, pp 271-275. © Printed in India.

Polarization in FEP-fluorocarbon

M R BHIDAY and MISS S RAO
Department of Physics, University of Poona, Poona 411007

MS received 15 July 1974; in final form 2 April 1975

Abstract. Absorption of polarization in fluorocarbon foil electrets has been studied under different conditions. The mode of surface charge decay of thermo- and radio-electrets has been explained by the mechanism of polarization trapping in electrets.

Keywords. FEP-fluorocarbon; thermoelectret; radioelectret.

1. Introduction

A number of materials have been used to produce electrets. The results, however, differ due to the intrinsic anisotropic behaviour of polarization. Thermoelectrets have been investigated over a number of parameters; comparatively little importance has been given to radioelectrets, although photoelectrets are being extensively studied (Gross 1964). Thermoelectrets of foils of fluorocarbon and their use in microphones were first reported by Sessler and West (1968). Thermoelectrets are difficult to prepare and require longer times. Certain amount of strain is there over the film and a consequent loss of transparency. This paper reports the behaviour of foil electrets of fluorocarbon polarized with gamma rays. These are superior to their thermal counterparts, retain the physical properties, and give both hetero and homo-charges with long lives; furthermore, they are easy to prepare, and give useful information about the mechanism of polarization. A new method of repeated polarization is suggested for getting longer life high homo charge electrets. The paper also gives a generalised equation to describe the charge decay of the electret. The foil electrets of fluorocarbon will find greater applications in the electret microphones if prepared by this new technique.

2. Experimental technique

Discs of 9 cm diameter were cut from commercially available sheets of FEP fluorocarbon with thickness of 0·025 cm. The foil was sandwiched between two plane parallel aluminium electrodes. The diameter of the dielectric was kept larger than those of the electrodes in order to avoid any corona discharge from the edges of the electrodes. For preparing thermoelectrets, the samples were heated in an oven at controlled temperature, for about 2 hr and after reaching a steady state an electric field was applied across the electrodes. The temperature was kept constant for a further period of 2 hr, and then the system allowed to cool to the room temperature in about 6 hr and held at the same temperature for 12 to 14 hr.

Similarly sandwiched samples were irradiated uniformly by gamma rays from a kilocurie ^{60}Co source at an average dose rate of 12 rad/sec, with simultaneous application of the electric field. The dose rate was determined by ferrous sulphate dosimetry (Spinks and Woods, 1963).

The charge density was measured immediately after removing the electric field with a vibrating electrode charge measuring device (Reedyk and Perlman 1968). The signal proportional to the charge density was generated by vibrating an electrode over the charged surface of the dielectric. This was displayed on an oscilloscope after proper amplification and was compensated by a bias voltage applied across the two electrodes of the capacitor.

The bias voltage V_B and the charge density σ_S are given by the relation

$$\sigma_S = \frac{K\epsilon_0 V_B}{d}$$

Where K is the dielectric constant, ϵ_0 the permittivity of free space and 'd' the thickness of the sample. All other parameters remaining constant, the charge density can be calculated by measuring V_B. This is justified as the dielectric constant K of the sample in our experiments did not vary when the sample was made electret, unlike observed by Chatterjee and Bhadra (1955), (table 1).

Several others (Freedman and Rosenthal 1950, Sessler and West 1962, 1968) who employed this method for the charge measurement of electrets, also found it to be very sensitive.

Volume and surface polarization were also measured with the new technique designed by Bhiday *et al* (1973). The electrets were then wrapped inside aluminium foils and kept between heavy steel plates to ensure good contact. These were stored inside desiccators to protect from humidity.

Table 1. Measurement of capacity of thermo- and radio-electret condensers

Remark	Time in days	Capacity of fluorocarbon condenser p.f.	Time in days	Capacity of fluorocarbon condenser p.f.
		Thermo-electret		Radio-electret
Before polarization	0	284·0	0	285·0
After Thermal Polarisation	1	284·0	1	284·0
	2	284·5	2	284·6
	3	284·6	3	285·0
	4	284·4	4	285·0
	5	284·6	5	285·0
	6	284·0	6	284·5
	7	284·4	7	284·5

3. Results

The properties of radioelectrets of fluorocarbon are compared with those of thermoelectrets of the same material. The latter were studied at two temperatures 130° C and 230° C (figure 1). The quantity of heterocharge was larger in the electrets polarized at 230° C, showing more dielectric absorption. The electric field was varied from 8 kV/cm to 80 kV/cm keeping the forming temperature at 230° C. The amount of heterocharge increased by increasing the field strength. Low fields yielded pure heterocharge electrets which remained stable for more than a year. Fields above 50 kV/cm yielded net homocharges having negligible rates of decay after about 12 to 14 days of preparation.

In a similar set of experiments carried out with thermal energy replaced by gamma radiations, the variation of the electric fields from 40 kV/cm to 100 kV/cm was similar to those of thermoelectrets (figure 2). Low fields yielded heterocharge electrets while high fields gave net homocharge electrets. The electrets prepared at 60 kV/cm and 70 kV/cm showed reversal from the heterocharge to homocharge. This phenomenon is very interesting as it was seen to be absent in most other substances (melinex, perspex, mica and carnauba wax) prepared similarly by Bhiday *et al* (1973). The hetero as well as homocharges attained a constancy after about 12 to 14 days of their preparation, as in the thermal counterpart. A state of saturation of polarization was reached above a field of 80 kV/cm.

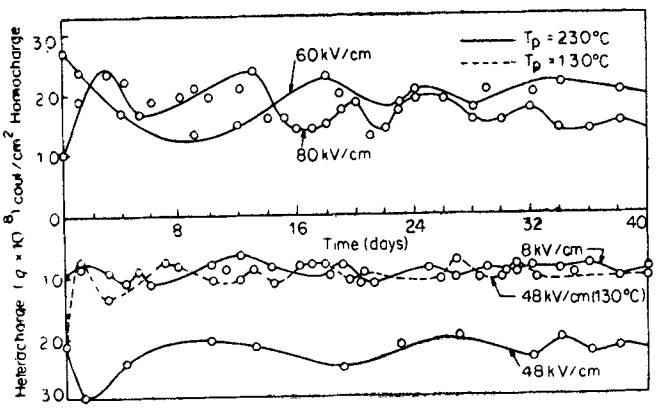

Figure 1. Charge decay of thermo-electrets of fluorocarbon.

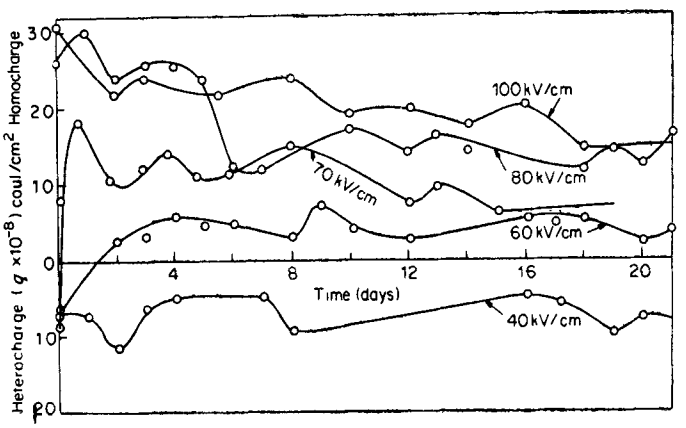

Figure 2. Charge decay of radio-electrets of fluorocarbon.

A new technique of polarization was adopted in which the electret was repolarized after it started decaying slowly. This kind of repolarization by repeated irradiation under an electric field gave a longer stability of polarization. Figure 3 shows the charge decay of a single electret for a span of 80 days, which was polarised three times after which a stable condition was reached. The final charge density was higher in such an electret.

The mode of charge decay of these radio and thermoelectrets were analyzed and a generalized equation was formulated. The decay was accompanied by more than one exponential, depending upon the state of polarization of the electret. Relative charge densities q_t/q_0 (where q_t is the charge density at time 't' and q_0 is the maximum initial charge density) is given by

$$\frac{q_t}{q_0} = A_0 e^{-a_0 t}\,\theta\,(t_1 - t)\,\theta\,(t - 0) + A_1 e^{-a_1 t}\,\theta\,(t_2 - t)\,\theta\,(t - t_1)\ldots$$
$$+ A_2 e^{-a_2 t}\,\theta\,(t_3 - t)\,\theta\,(t - t_2) + \cdots$$

or we can write it as

$$\frac{q_t}{q_0} = \sum_{i=0 \text{ to } n} A_i e^{-a_i t}\,\theta\,(t_{i+1} - t)\,\theta\,(t - t_i).$$

Where A_i and a_i are constants, t_i represents the time at which the rates of decay is changed and the next relaxation time starts playing its part. The function $\theta\,(x)$ is defined by

$$\theta\,(x) = 0 \quad \text{where} \quad x < 0$$
$$\theta\,(x) = 1 \quad \text{where} \quad x > 0$$

$\theta\,(x)$ is not defined for the points of intersections where $\theta\,(x) = 0$; the equation then can be written as

$$q_t/q_0 = A_i e^{-a_i t}$$

i represents the order of intersection.

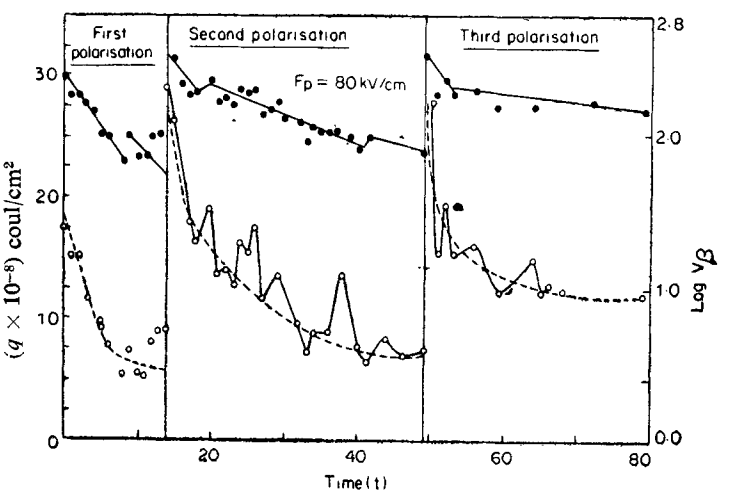

Figure 3. Charge decay of a radio-electret which was repolarized by repeated irradiation.

4. Discussion

The results described in this paper on the polarization characteristics of fluorocarbon films give a useful comparison between thermo- and radio-electrets of the foil. The results obtained by varying the polarizing field strength and temperature help us to predict conditions of polarization for producing stable thermo- and radio-electrets. Latour (1971) has similarly predicted the critical polarizing field and temperature of formation for thermoelectrets of polar polymers.

The interest lies in the result that the homocharge as well as the heterocharge in the electrets of this substance attain a constant value for a very long time (more than one year). Although the magnitude of surface charge density, when compared with that observed in foils of melinex and mica (Bhiday *et al* 1972) was low, the decay was negligible and the charge density was found to remain unaltered for two years after its preparation. Thin foils of fluorocarbon can, thus, be used in microphones where the charge stability is an important factor.

The dipole orientation has so far been held responsible for the heterocharge. The presence of heterocharge even in radioelectrets of FEP and its reversal into homocharge, could not be the effect of dipole orientation. This can be better understood by the trapping mechanism of polarization. Charge centres can be trapped in at different energy levels as a consequence of the passage of the ionizing radiations. The depth and number of these traps can be measured by the method of thermal glow peak analysis (Perlman 1971).

The small irregularities observed in the charge decay of the electrets, are possibly due to either improper shielding or charge domains inside the material. The former was minimized by keeping the electret pressed between short circuited aluminium foils. The electrets were exposed for a very short time ($\sim$ 30 sec) during which the charge was measured with a dynamic electrode dissectible capacitor. There were no chances of breakdown inside the dielectric electrode air gap, as the vibrating electrode does not touch the dielectric surface. The latter, therefore, seems to be the more probable reason for the fluctuations in the charge decay characteristics. This is also supported by the different exponentials present in the equation governing the charge decay of these electrets.

References

Bhiday M R, Rao S and Gupta U 1972 *Charge storage in foils*, a paper presented in the Indo-Soviet Symposium on Solid State Physics, Bangalore.

Bhiday M R, Gupta U, Ranade M and Rao S 1973 *Pramāṇa* **1** 235

Chatterjee S D and Bhadra T C 1955 *Phys. Rev.* **98** 1728

Freedman L A, Rosenthal L A 1950 *Rev. Sci. Instrum.* **21** 896

Gross B 1964 *Charge storage in Solid Dielectrics*, Elsevier Publishing Co., Amsterdam

Latour M 1971 *Hebd. Sean. Sci. B (France)* **272** 469

Perlman M M 1971 *J. Appl. Phys.* **42** 2645

Reedyk C W and Perlman M M 1968 *J. Electrochem. Soc.* **115** 45

Sessler G M and West J E 1962 *J. Accoust. Soc. Am.* **34** 1787

Sessler G M and West J E 1968 *J. Elect. Chem. Soc.* **115** 836

Spinks J W T and Woods R J 1963 *Radiation Chemistry*, John Wiley & Sons, Inc., New York, p. 106.