EFFECT OF TEMPERATURE OF PREPARATION ON SEALING WAX THERMOELECTRET CHARGE

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Thermoelectrets of sealing wax have been prepared at different temperatures and fixed polarizing field, the electrode materials always being the same. Surface charge measurements have been carried out on the anode side of each thermoelectret. Surface charge characteristics are discussed in terms of barrier and bulk polarization generated by the trapping of less-mobile carriers. The results of these studies suggest that the less-mobile charge carriers in the case of sealing wax are holes.

1. Introduction

Since the discovery of the thermoelectret by Eguchi [1], the theories of the thermoelectret state have been modified as a result of the revealed existence of the thermoelectret effect in new classes of substances. Mixtures of organic and inorganic substances [2] may offer such a new class of substances, among which belong sealing waxes manufactured in India. The sealing wax selected for studying the thermoelectret effect was found by *X*-ray analysis to contain rosin as the amorphous organic constituent and barytes ($BaSO_4$) and titanium dioxide (TiO_2) as inorganic crystalline constituents [3].

Studies on the effect of temperature of preparation on the sealing wax thermoelectret charge were undertaken in view of the dependence of thermoelectret charge on temperature of preparation [4–7]. The effect of temperature of preparation on thermoelectret charge has been reported in the case of carnauba wax by Froiman and Fridkin [8] and Bhadra [9] and in the case of plastics by Wieder and Kaufman [10]. Polovikov [11] observed in the case of ebonite that at lower temperatures the heterocharge predominates and the homocharge is induced only at higher temperatures.

2. Experimental

Sealing wax thermoelectrets have been prepared in an electret cassette designed and preparated locally at the workshop using a method developed in this laboratory for sealing wax [12]. Thermolectrets were preserved by short circuiting with tin foil and keeping them between cotton pads inside a desiccator.

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The electrostatic induction method using a Lindemann electrometer was used for measuring the surface charge of thermoelectrets. The method used is essentially the lifted electrode method described by Gross [7].

Five series of thermoelectrets were prepared by varying the temperature of preparation in steps of 10°C between 30°C or 40°C and 90°C and keeping the polarizing field constant at 0, 5, 10, 15 and 20 kV/cm. The upper limit of the temperature is set at 90°C, as preliminary studies showed that the maximum permissible temperature to which the wax can be heated without decomposition is 95°C. The thickness of the thermoelectrets was fixed at 1 mm for the 15 and 20 kV/cm fields and 2 mm for the 0, 5, and 10 kV/cm fields. Each thermoelectret was subjected to the polarizing field for a total of 9 hrs. This time included 3 hrs of heating in a thermostat and 6 hrs of cooling. The metal electrodes used for all the thermoelectrets was tin foil.

The designation of the thermoelectrects as shown in the figures points to the mode of preparation as regards temperature of preparation and polarizing field. For example, the thermoelectret $30E_{10}$ is the one prepared at 30°C and polarizing field of 10 kV/cm. The number to the left of the capital letter E (which stands for the word electret) signifies the temperature of preparation and the right-hand subscript gives the strength of polarizing field in kV/cm.

3. Results and discussion

The surface charge of the thermoelectrets was measured immediately after a polarizing time of 9 hrs, the electret being, preserved by short circuiting and keeping it in low-humidity conditions during the measurements. The surface charge of the anode side of each thermoelectret was measured every 24 hrs for 30 days.

The decay curves of a representative series are shown in Fig. 1. The general nature of the decay curves of different series of thermoelectrets is similar to that shown in Fig. 1 and shows that changes in surface charge density with time are irregular in the initial stages of decay. The rate of decay of surface charge density becomes quite slow at about the twentieth day and the charge becomes more or less stable.

The initially observed charge in most of the thermoelectrets is homocharge. The heterocharge which does sometimes appear at first is found to decay very rapidly.

The results of investigations of the variations of surface charge density with temperature are presented in Fig. 2. A general study of these curves shows that the maximum surface density of the final charge is not a function of temperature alone, but is dependent on the value of field strength as well. At field strengths of 10, 15 and 20 kV/cm the maximum charge is observed at 80, 60 and 40°C, respectively.

The decay curves in the case of thermoelectrets prepared without applying an electric field are quite irregular as regards the value and polarity of the charge on the surface. There is no indication of any volume polarization, and the charge on the surface appears to be a surface effect only.

Results on electrical conductivity [13] show there may be volume-generated charge carriers at fields greater than 15 kV/cm in the temperature region beyond 70°C. This is

further confirmed by a power law between current and voltage reported for higher temperatures.

The activation energy as found from electrical conductivity measurements [13] favours electron injection from the electrode. The trapping of these charge carriers in the

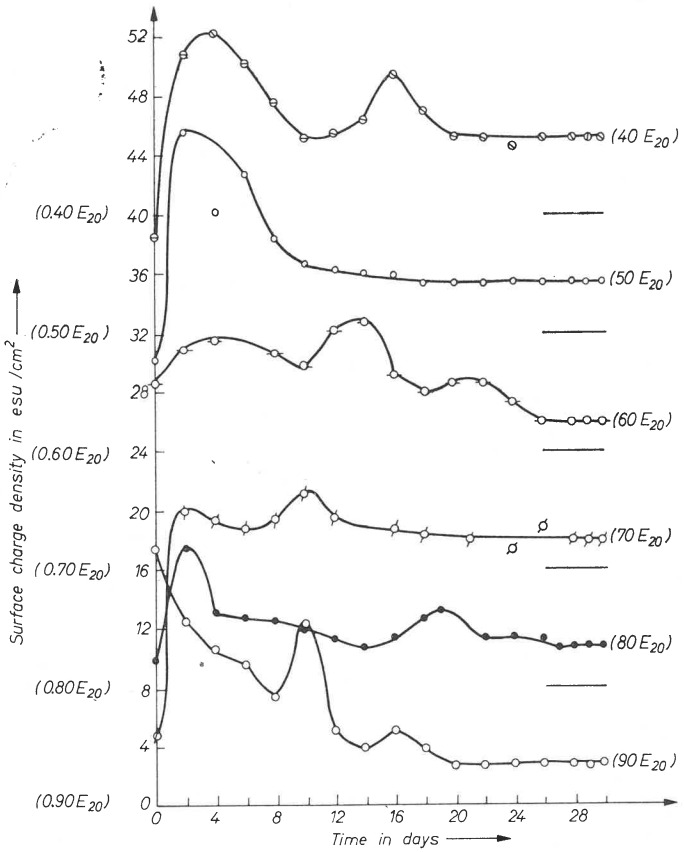

Fig. 1. Decay mode of sealing wax thermoelectrets prepared with 20 kV/cm polarizing field at different temperatures

bulk and their accumulation at the barrier at lower temperatures may give rise to an inhomogeneous charge distribution both in the bulk and at the barrier.

At higher temperatures the easier phase presented by the bulk will let most of the mobile bulk-generated carriers to reach the electrodes. The more mobile charge carriers may be discharged and the less mobile ones may accumulate and get trapped. This gives rise to barrier polarization, which may extend into the layer near the surface of the sample [14].

The present results of the surface charge density measurements on the anode side of the specimen can be explained in terms of trapping of charge carriers generated at the electrodes and in the bulk. Depending on the field and temperature conditions of polariz-

ation, the surface charge density will correspond to the internal field produced by both types of trapped charges. At lower temperatures the polarization will be confined to the barrier layers, since these barrier layers (mainly consisting of electrons injected from the electrodes) will reduce the effective field in the bulk. The reduced effective field in the bulk

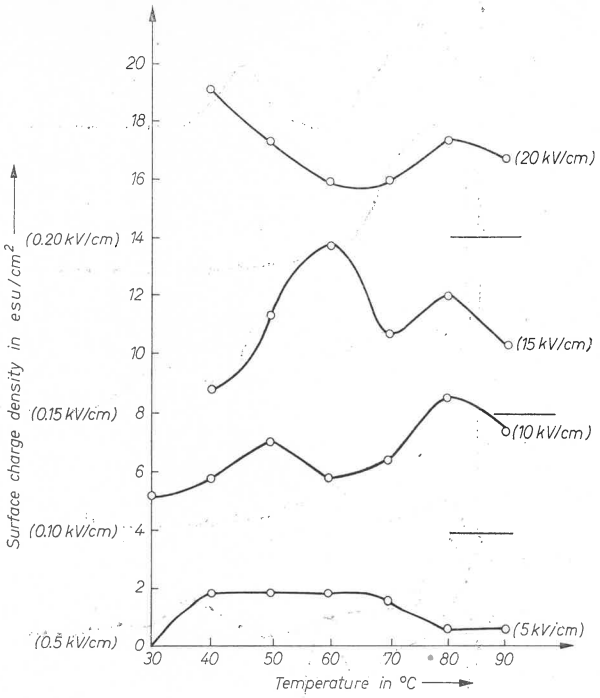

Fig. 2. Variation of final charge of sealing wax thermoelectrets with temperature at different field strengths

will increase trapping probabilities for the bulk carriers. The trapped charge carriers in the bulk may be of both signs, giving rise to fields corresponding to heterocharge and homocharge. If we assume holes to be carriers of lower mobility for sealing wax, then the bulk polarization is primarily due to holes trapped in the bulk.

This mechanism seems to be in agreement with the initial charge density observed in the case of samples polarized at higher temperatures. Higher temperature will produce large volume-generated charge carriers, and the current mainly consists of majority bulk-generated carriers. The more mobile carriers, whether injected from the electrodes or generated in the bulk, will be discharged at the electrodes, leaving only the inhomogeneously distributed and trapped less mobile carriers in the bulk. These trapped charge carriers will produce a field corresponding to homocharge density on the surface.

The decay mechanism of the surface charge density will be controlled by the cross-section and depth of the trapping sites for both types of charge carriers. The decay of heterocharge is rather abrupt, which seems to be in agreement with the finding that barrier polarization mainly consists of electrons trapped near the surface of the specimen.

Such surface states have been reported to be present in inorganic materials. Similar results have been reported recently in naphtalene and were interpreted in terms of barrier and bulk polarization, generated on account of the trapping of less mobile charge carriers [15].

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