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Gamma Irradiation Effects on Electrets*

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Carnauba wax electrets were irradiated with gamma rays from a Co^{60} source. Doses varied between 0 and 5 megaroentgen (Mr). After irradiation the polarization of the electrets was determined by reheating them in short circuit and measuring the released charge. This charge was found to decrease roughly exponentially with dose, with a decay constant of the order of 1 Mr. A background effect due to Compton polarization is described.

I. INTRODUCTION

An electret is a dielectric containing a "frozen-in" electric charge.[1] The charge is associated with a volume polarization though it is not clear whether this is a dipolar or an ionic effect. The "frozen-in" charge can be released by reheating of the sample; the release is accompanied by a depolarization current.[2] The current integral is a measure of the charge. It has been conjectured at an early stage that depolarization might also be brought about by x-ray or gamma-ray irradiation. However, so far no definite quantitative evidence is available since all measurements were influenced by the ionization of the air outside the electret. Recently, Myazdrikov[3] has described a dosimeter for penetrating radiation based on the depolarization of electrets by gamma rays; in addition to a theoretical treatment he refers to some experimental results. But again the effect of the radiation on the volume polarization is neglected against the compensation of the surface charge due to saturation currents in the air above a free surface of the electret. The quantity measured is the surface charge as given by an induction plate method. According to our experience this is not a measure for the volume polarization of the electret. In the following, depolarization experiments are described which give the decrease of the "frozen-in" charge as a function of gamma-ray dose.

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[1] B. Gross, Phys. Rev. **67**, 253 (1945).

[2] B. Gross, J. Chem. Phys. **17**, 866 (1949).

[3] O. A. Myazdrikov, Atomnaya Energ. **8**, 64 (1960); Kernenergie **3**, 687 (1961); see also T. L. Wolfson and T. C. Dyment, Health Physics **7**, 36 (1961).

II. EXPERIMENTAL

The material used for the manufacture of the electrets was prime yellow carnauba wax. A series of disk-shaped samples was prepared. Dimensions were: thickness 2 cm, diameter 6 cm. Aquadag electrodes were applied to the top and bottom surfaces of each sample. Samples were polarized in the solid state. For this purpose they were heated to 70°C; after temperature equilibrium had been reached, a polarizing voltage of 10 kv was applied. The temperature was kept constant for 2 hr and then slowly lowered during the course of 3 hr. When it had fallen to 44°C, samples were short circuited and kept in this condition for 10 days at room temperature of about 30°C. Subsequently they were carried from Rio de Janeiro to Washington and irradiated in the Naval Research Laboratory Co^{60} irradiation facility.[4] This consists of a hollow metal cylinder surrounded at its middle section by six Co^{60} sources with a total source strength of 8500 C. The dose rate at the center of the cylinder is 3.88×10^4 r/min. At a distance of 2 in. from the center in an axial direction it has decreased by 15% and at a distance of 2 in. in a radial direction it has decreased by 6%. Values given below refer to doses at the center. Different doses were obtained by changing the time of irradiation. For each irradiation intended to produce a given dose, two samples, one polarized and the other a nonpolarized blank, were sandwiched together, placed in a copper cylinder, and irradiated. Samples were then shipped back to Brazil. One to two months later each sample was reheated in a suitable capacitor already described in reference 2. The temperature was increased during 80 min from 30° to 75°C and subsequently kept con-

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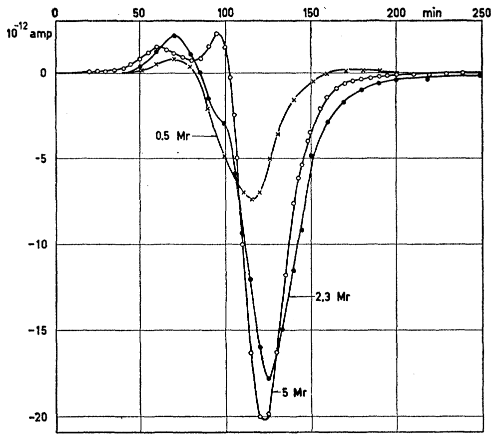

FIG. 1. Currents during heating of nonpolarized irradiated samples for different doses.

stant at this value for 6 hr. During this period short-circuit currents were measured. Current-time curves were numerically integrated. The charge remaining after irradiation with a given dose was then obtained as the current integral obtained for the sample irradiated with that dose. One sample underwent the same electrical and heat treatment as the others and was also shipped to Washington and back to Brazil, but was not irradiated. Measured under identical conditions as the others, the charge recovered from it gave the reference value for zero dosage.

It is important to ascertain that the temperature increase caused by the irradiation is too small to produce significant charge release. Measurements of the specific heat of the wax gave the value of 0.6 cal/g. An absorbed dose of 1 Mrad corresponds to an absorbed energy of 2.4 cal/g. Assuming adiabatic conditions, the maximum temperature increase at the end of the irradiation period would be 4°C. This would be quite irrelevant for the actually observed effect.

III. BACKGROUND EFFECT

Previous observations have shown that irradiation of dielectrics by gamma rays can produce by itself polarization and space-charge effects.[5] The gamma-ray polarization is also released by heating of the irradiated dielectric. Depolarization currents under these conditions have been found (a) when irradiation has been nonisotropic or (b) when during the heating process a temperature gradient existed across the dielectric. The effect has been attributed to the trapping of Compton electrons which accompanies the absorption of the primary radiation in highly insulating dielectrics. It has also been observed in the present experiments. This is shown by Fig. 1 which gives the results obtained with the nonpolarized blanks irradiated together with the polarized samples. Currents up to 2×10^{-12} amp were observed; the released charge appears to reach saturation for a dose of approximately 2 Mr. Current reversals are observed, the general character of the currents being similar to that observed during previous measurements with electron-irradiated dielectrics.[6] The direction of the currents is given as negative because they are opposite to those observed with the polarized samples. In the present case the cause is probably found in a slight temperature gradient in the heating system. The phenomenon is quite interesting and a more extensive investigation is now being undertaken. But for the purpose of the present work this is essentially a background effect which has to be considered in the interpretation of the results obtained with the polarized samples. Currents and charges obtained with the latter are much higher, except of course at radiation doses high enough to destroy practically the electrical polarization. Therefore the effect is actually of second order.

IV. RESULTS OF MEASUREMENTS

The results of measurements with the electrically-polarized samples are shown by the curves of Fig. 2. They show the depolarization currents as a function of time during reheating, for samples irradiated with different doses between 0 and 5 Mr. The currents have the shape familiar from previous experiments with electrets.[1,2] But the amplitudes of the currents obviously decrease with increasing radiation dose. Irradiation with 2 Mr reduces the current to a small fraction of that observed with the polarized nonirradiated reference sample. Currents for 5 Mr are mostly in the negative direction and both the 2-Mr and the 5-Mr curves show irregularities and current reversals. A similar behavior is found in the curves of Fig. 1 referring to the nonpolarized samples. These irregularities are therefore attributed to the previously discussed background effect.

Values of the released charge were obtained by numerical integration of the curves of Fig. 2. The distor-

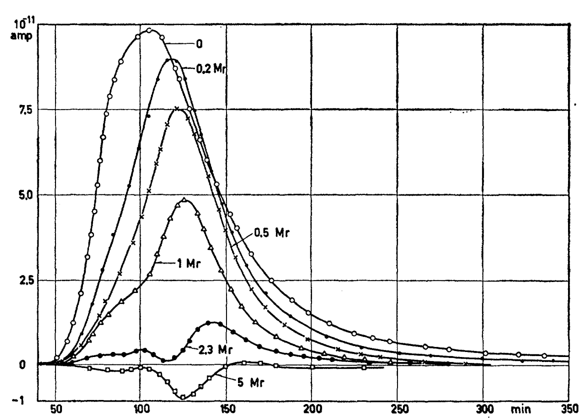

FIG. 2. Currents during reheating of polarized irradiated samples for different doses.

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[6] B. Gross, Phys. Rev. **107**, 368 (1957).

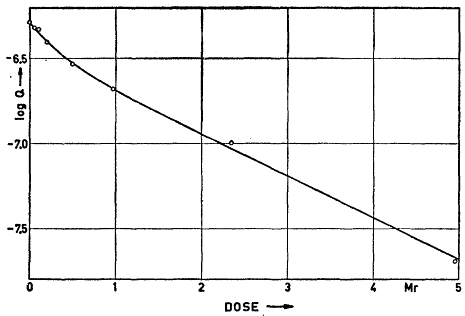

FIG. 3. Released charge as a function of dose.

tion due to the background effect has been taken into account by integrating also the curves of Fig. 1 and and subtracting charge values thus obtained from the corresponding values of Fig. 2. The correction becomes significant only with 2 Mr and above. The charge obtained for the nonirradiated sample was 5.22×10^{-7} coul; the sample irradiated with 1 Mr gave 1.91×10^{-7} coul. This corresponds to approximately $1/e$ of the reference value. Figure 3 shows the logarithm of the released charge (in coul) or polarization as a function of the dose (in Mr). Polarization decreases with increasing dosage approximately according to an exponential function.

Since irradiation was made with constant dose rate, exposure dose is proportional to irradiation time, 1 Mr corresponding to 34.2 min; exposure dose is also proportional to absorbed dose, 1 r being approximately equivalent to 1 rad or 100 erg/g. Therefore, Fig. 3 indicates also the decrease of polarization with irradiation time and absorbed dose. It was not possible yet to perform experiments with different dose rates.

The mechanism of the effect is not yet clear. To understand it fully the nature of the polarization of the electret must be known. In the presence of a space-charge polarization, irradiation-induced conductance could, under the influence of the space-charge field, result in internal currents over macroscopic distances leading to a compensation of the space charge. However, recent measurements by the authors to be discussed in a following paper, made with the use of a dissectioning method, have now proved the existence of a uniform volume polarization. Since a dipole effect is usually ruled out, this is likely to be due to an ionic effect of the type envisaged by Gerson and Rohrbaugh.[7] However, whatever the cause, depolarization must then be due to a mechanism acting locally. It might be caused through the release of trapped charges, increase of carrier concentration, production of pseudodipoles as discussed by Myazdrikov,[3] or similar effects.

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[7] H. Gerson and J. H. Rohrbaugh, J. Chem. Phys. **23**, 2381 (1955).