TRANSIENT PHENOMENA OF SPACE CHARGE DISTRIBUTIONS IN POLYPROPYLENE LAMINATED PAPER

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Abstract

In a multilayer insulator made of two or more materials with different dielectric constants and conductivities, internal space charge accumulates at their interfaces. If the local field is increased by the accumulated charge, the electric durability of the insulator should be decreased. In this paper, we describe the space charge accumulation measured when using oil-impregnated PPLP (polypropylene laminated paper) - which consists triple layers; kraft paper, polypropylene (PP), kraft paper - was subjected to a strong dc electric field. The experimental results suggest that internal space charge accumulates at both surfaces of a PP layer and that the electric field in the kraft paper layers disappears.

Introduction

Multilayer insulators are widely used in power apparatus, such as oil-impregnated cables and transformers. In a multilayer insulator made of two or more materials, internal space charge accumulates at their interface when a dc electric field is applied. This polarization, known as Maxwell-Wagner polarization, is related to the electric durability of a multilayer insulator because the local field at the interface may be increased by the polarization. In the work described here we used the pulsed electroacoustic method to measure the internal space charge distribution in polypropylene laminated paper (PPLP) sheets impregnated with different kind of insulating oils.

Space charge accumulation in multilayer insulators

A model of multilayer insulators and an equivalent circuit are shown in Fig. 1, where ε is the dielectric constant and σ is the electric conductivity, respectively. Since the dielectric constant of PP is similar to that of oil-impregnated kraft paper, the polarity at the interface and the amount of charge accumulated there depend on the electric conductivity.

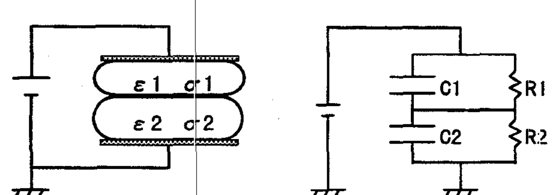

Figure 1 A model and an equivalent circuit of multilayer insulation.

Transient phenomena of space charge distribution in PPLP specimens

Space charge distributions were measured by the pulsed electroacoustic (PEA) method. We developed a high-resolution PEA measurement system (Fig. 2) that can measure the space charge

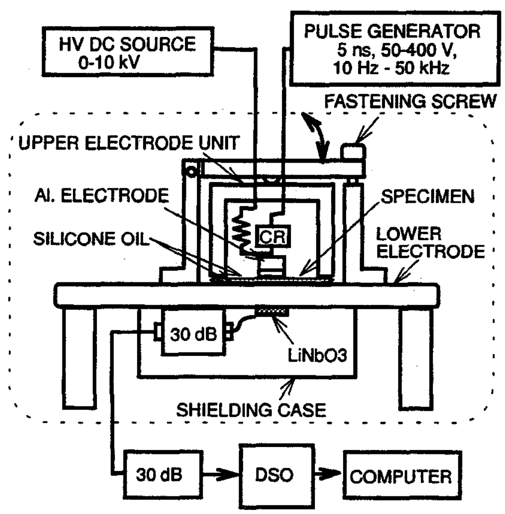

Figure 2 High resolution PEA space charge measurement system.

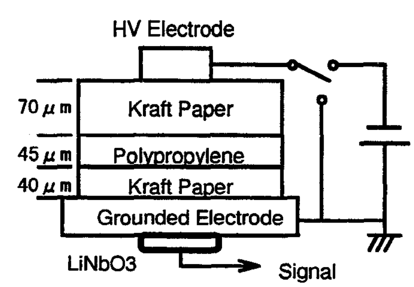

Figure 3 PPLP specimen and a model of dc bias condition.

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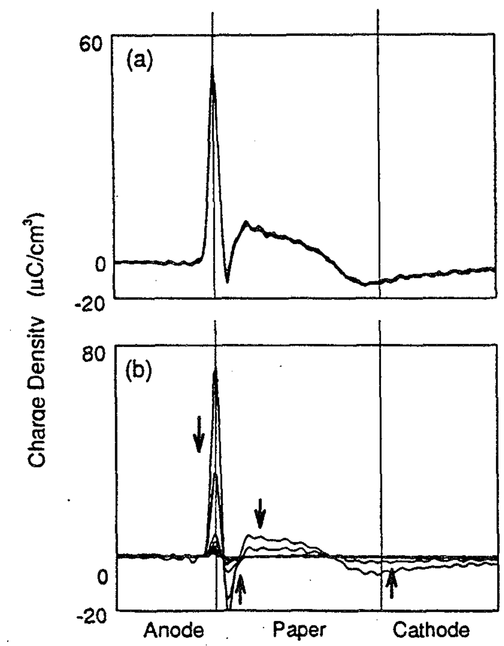

Figure 4. Space charge behavior of mineral-oil-impregnated kraft paper.
(a) Within 3 sec of voltage application.
(b) Within 3 sec of shorting.

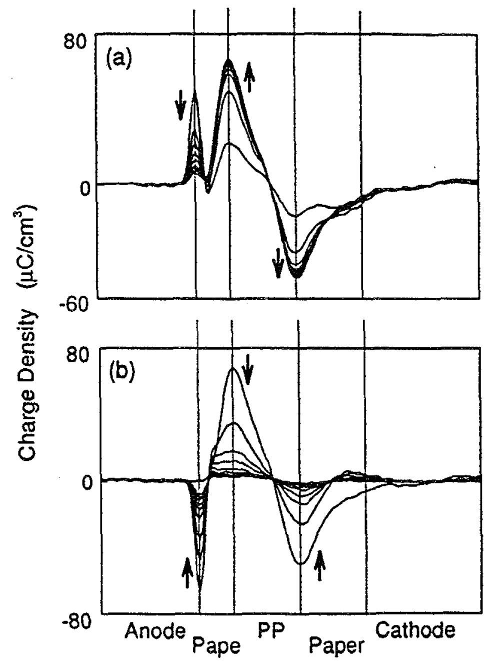

Figure 5. Space charge behavior of mineral-oil-impregnated PPLP.
(a) Within 3 sec of voltage application.
(b) Within 3 sec of shorting.

distribution with a resolution better than 10 μm [1,2].

PPLP films were made by laminating a PP film between two sheets of kraft paper (Fig. 3). Mineral oil, silicone oil and dodecyl benzene were used for insulation oils, and each of the PPLP films was impregnated with one of these oils at 0.1 atm in a vacuum chamber for 30 min. A film of oil-impregnated kraft paper 150 μm thick was used as a comparison specimen.

A dc bias of -5 kV was applied to the oil-impregnated specimen for 1 min., and the space charge was measured from the earth electrode (anode) side. The time dependence of space charge distribution was observed evaluated by measuring the distribution at 0.3-sec intervals for two periods; just after applying the voltage and just after shorting the two electrodes. The upper parts of Figs. 4 to 7 show the space charge behavior for 3 sec just after the voltage application, and the lower parts of figures show the behavior for 3 sec just after shorting.

Figure 4 shows the space charge behavior of the oil-impregnated kraft paper specimen. Just after the voltage application a hetero charge appeared near the anode, and the hetero charge increased after 1 min. Although the space charge near the HV electrode (cathode) was not clearly observed because of the large attenuation of acoustic signal in the kraft paper, a similar hetero charge was observed when a voltage (+5 kV) with the opposite polarity was applied. Since the polarity dependence was not evident in all cases, results obtained when applying -5 kV are given in this paper.

Induced charge appeared at the grounded electrode the instant the electrodes were shorted, and it then decreased with time. Thus the space charge distribution disappeared within 3 sec. This hetero charge behavior may depend on the ions in the insulation oil.

Figure 5 shows the space charge behavior of a mineral oil-impregnated PPLP specimen. The signal layers are, from left to right, the grounded electrode (anode), 40 μm of kraft paper, 45 μm of PP, 70 μm of kraft paper, and the HV electrode (cathode).

Since the electrical conductivity of the kraft paper layer is greater than that of the PP film, positive charge began to accumulate at the interface between them just after the voltage was applied, and then the charge at the anode disappeared within 3 sec. In this case, the electric field exists only in the PP film. When the electrodes were shorted, a charge appeared at the grounded electrode induced by the interfacial charge between the kraft paper and the PP film. The induced charge decreased and disappeared in 3 sec.

Figure 6 shows the space charge behavior of dodecyl-benzene-impregnated PPLP specimen.

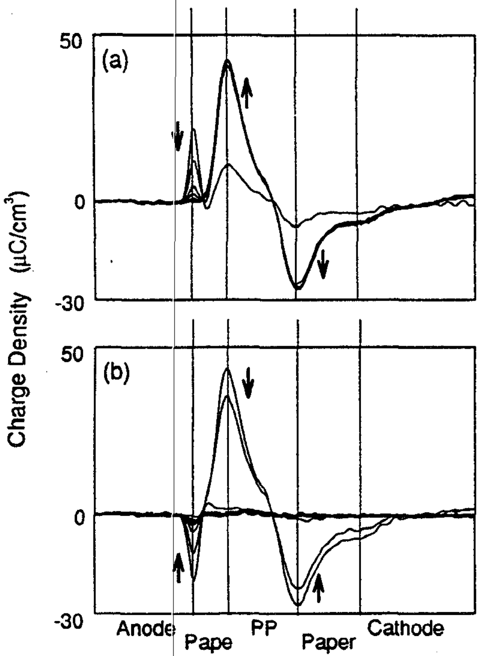

Figure 6. Space charge behavior of dodecyl-benzene- impregnated PPLP.
(a) Within 3 sec of voltage application.
(b) Within 3 sec of shorting.

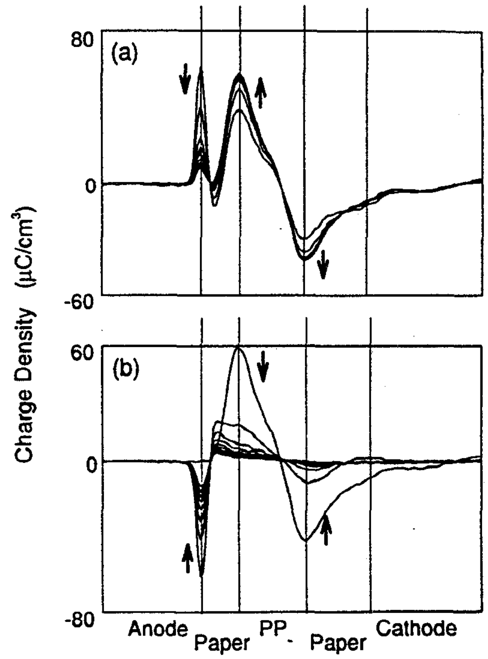

Figure 7. Space charge behavior of silicone-oil-impregnated PPLP.
(a) Within 3 sec of voltage application.
(b) Within 3 sec of shorting.

The space charge distribution is initially the same as that of mineral-oil-impregnated specimen, the change of the charge distribution was twice as faster as the specimen impregnated with mineral oil. This is because the viscosity of dodecyl-benzene, 4.2 cSt, is lower than that of mineral oil, 8.2 cSt, and the mobility of ions must become larger.

As shown in Fig. 7, the space charge behavior of a silicone-oil -impregnated PPLP specimen, was to that of the mineral-oil-impregnated specimen. Although the viscosity of silicone oil, 3000 cSt, is grater than that of mineral oil, 8.2 cSt, the space charge distribution changes at the same speed. This suggests that the ions included in silicone oil are smaller than those included in mineral oil. This possibility should be evaluated in further experiments in which the ions are identified and their clusters sizes are measured.

Ultra fast measurement of charge distributions

This section introduces the transient space charge behavior which was observed by using the rapid detection method. The interval of each output signal depends on the repetition rate of a pulse generator. Since the newly developed pulse generator has a semiconductor switch that can generate pulse train at 50 kHz, the output signal can be obtained every 20 μs. Figure 8 is a two-dimensional image which shows the time dependence of the space charge distribution in PPLP. The sample was kept in the air at room temperature after being impregnated by silicone oil (3000 cSt) and including more than 100 ppm of water. The time dependence of the space charge distribution from just after the voltage application of 5 s, 0.5 s, and 0.05 s are shown in Fig. 8 (a), (b) and (c), respectively. The horizontal axis means t he location in the sample and the perpendicular axis means the time. The charge at the interface which is between the kraft paper and the electrode moves to the interface between the kraft paper and the PP film in 100 ms. These results indicate that the internal charges in this sample can move very fast.

Conclusions

When the behavior of the space charge in oil-impregnated PPLP, a multilayer insulator, was observed under a dc bias voltage, space charge was found to accumulate at both interfaces between the kraft paper and the PP film. This charge accumulates because the internal ions are able to move under the influence of the applied electric field, so the electric field existed only in the PP film. This behavior was obtained in all types of insulation oils, and the velocity of the change in space charge distribution must be related to the viscosity of the oil and to the size of the ion cluster.

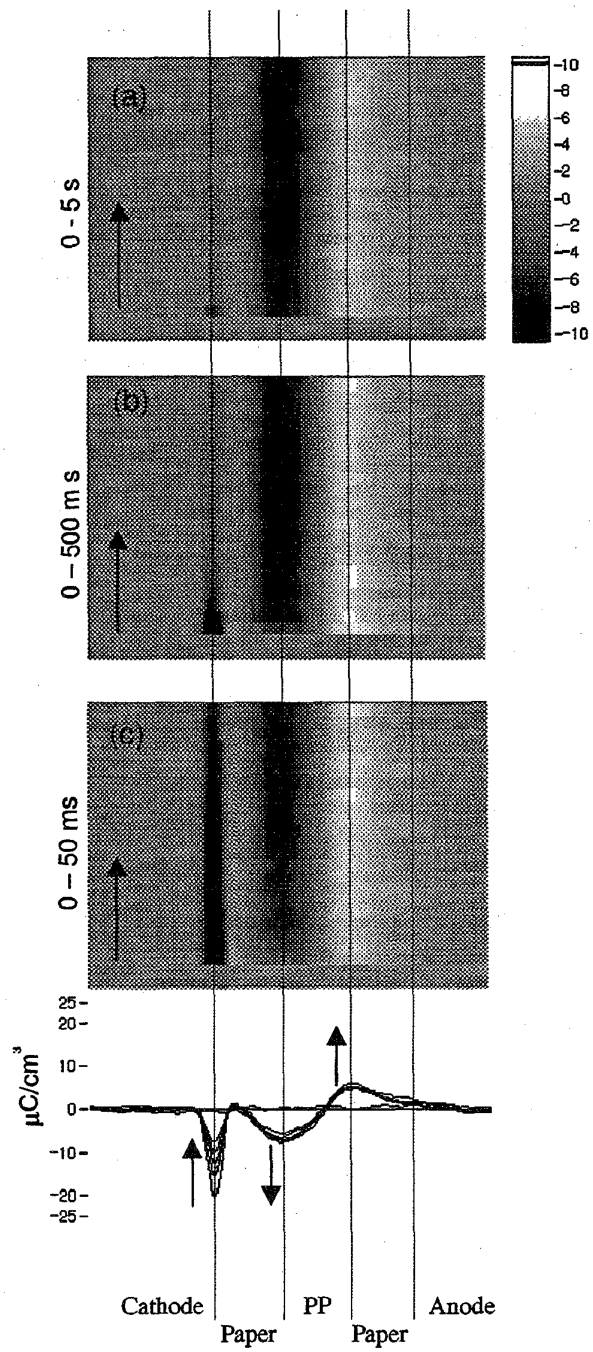

Figure 8 Transient phenomena of charge distribution in silicone oil impregnated PPLP.

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