2000 Conference on Electrical Insulation and Dielectric Phenomena

Space Charge Behavior near LDPE / LDPE Interface

Teruyoshi Mizutani, Kenta Shinmura, Kazue Kaneko, Tatsuo Mori,
*Mitsugu Ishioka and **Tatsuya Nagata
Nagoya University, *Japan Polychem Co., **Chubu Electric Power Co.

Abstract : We investigated the space charge behavior near the interface between different low-density polyethylene (LDPE). Charge carriers were mainly injected from the semiconductive electrode in a specimen of Al/LDPE/LDPE/semiconductive layer and they moved through the interface to the counter Al electrode. Charge carriers moving from a lower density LDPE to a higher density one were accumulated near the interface to form space charge, while there was no space charge accumulation for carriers moving in the opposite direction. The mobilities of charge carriers were estimated from the change in space charge profile with time. Charge carriers are more mobile in the lower density LDPE than in the higher density one. Positive carriers were more mobile in LDPE than negative ones. The interface between different LDPE's greatly affected space charge behavior and discharging currents.

Keywords: space charge, LDPE, interface, mobility

1. INTRODUCTION

Polyethylene is widely used as insulating materials for power cables. Recently, much attentions have been paid to the developments of extruded DC power cables and prefabricated joints [1]. Many papers have been published on space charge in low-density polyethylene (LDPE) and cross-linked polyethylene (XLPE) and also on charge dynamics near the interface between solid dielectrics [2,3]. However, space charge behavior and charge dynamics are very complicated and sensitive to various factors such as physical/chemical structures of LDPE, additives, interfacial conditions, applied field, temperature, and so on. They have not been well understood yet. More research works on space charge behavior in LDPE and its interface are required to develop high performance DC cables and prefabricated cable joints.

We reported the space charge behavior and DC currents in three-layered LDPE [4]. The interface between different LDPE's greatly affected space charge behavior and discharging currents. But the thickness of the middle layer was too thin to discuss the effect of the interface in detail. In this paper, space charge dynamics in LDPE and near the interface between LDPE's of different densities have been studied. The results of space charge have been discussed compared with the results of DC conduction.

2. EXPERIMENTAL

2.1 Samples

We used LDPE-R (70 μm thick), LDPE-A (70 μm thick) and two kinds of two-layered LDPEs (140 μm thick) films. They are nominally free from additives. The physical properties of LDPE-R and LDPE-A are listed in Table 1. LDPE-R has a higher density than LDPE-A. We used the Al/semiconductive (SC) electrode system to investigate the effect of electrode material on space charge behavior. The configurations of two-layered LDPE films are shown in Table 2.

2.2 Space charge and current measurements

We measured space charge distributions and DC currents in LDPE. Both measurements were carried out at room temperature (23 °C).

As shown in Fig. 1, space charge distributions were measured with the pulsed electro-acoustic (PEA) method [3]. Positive and negative DC voltages were applied to the SC electrode and the Al electrode was connected to the ground. In this paper, "positive (negative) polarity" means that positive (negative) voltage was applied to the SC electrode. DC field of 50 MVm^{-1} was applied to the specimen for 90 min and then the electrodes were short-circuited for 30 min.

To measure DC current under the same conditions as space charge measurements, we used the upper electrode unit of the PEA setup as shown in Fig. 2.

3. RESULT AND DISCUSSION

3.1 Space charge distributions

3.1.1 Single-layer LDPE

Table 1 Physical properties of LDPE-R and LDPE-A

Sample	Melting point (°C)	Density (g/cm^3)
LDPE-R	116.1	0.9243
LDPE-A	108.4	0.9172

Table 2 Structure of two-layered LDPE

Sample	Electrode system
LDPE-RA	Al / LDPE-R / LDPE-A / SC
LDPE-AR	Al / LDPE-A / LDPE-R / SC

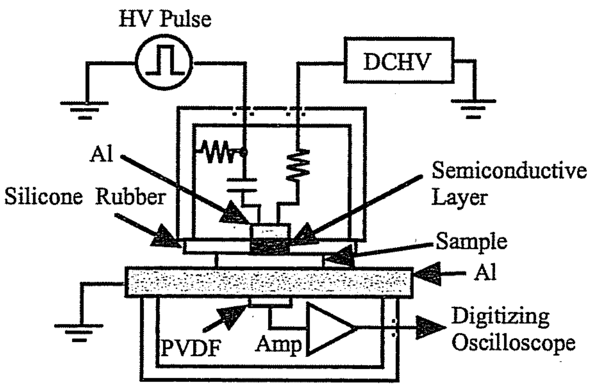

Fig. 1 Setup for space charge measurement (PEA method)

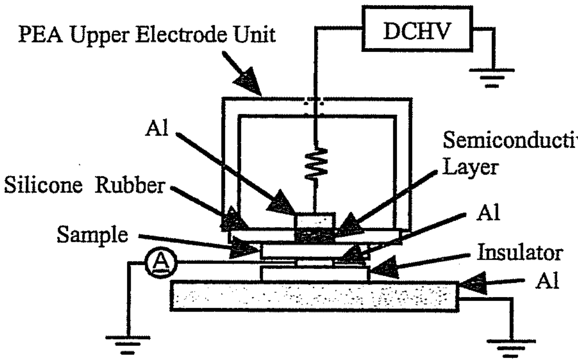

Fig. 2 Setup for DC current measurement

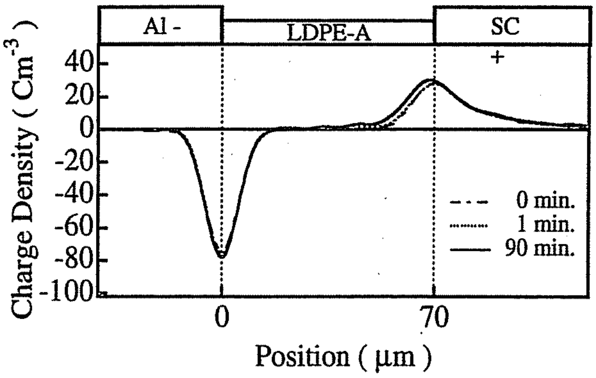

Fig. 3 Space charge distributions in LDPE-A (50 MVm^{-1}, 23 °C)

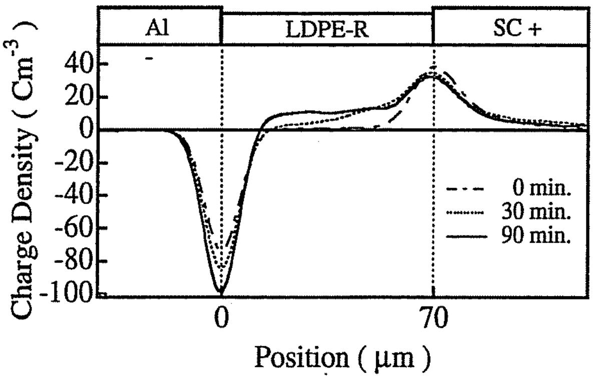

Fig. 4 Space charge distributions in LDPE-R (50 MVm^{-1}, 23 °C)

Figure 3 shows the space charge distributions in LDPE-A single-layer film at 50 MVm^{-1}. For the positive polarity, where a positive voltage is applied to the SC electrode, positive carriers are injected from the SC anode to form space charge near the anode. They arrive at the counter Al electrode in about 1 min after the field application. There was little space charge in the bulk.

Figure 4 shows the space charge distributions in LDPE-R single-layer film at 50 MVm^{-1}. For the positive polarity, positive carriers are injected from the SC anode to form space charge near the anode. They arrive at the counter Al electrode in about 30 min after the field application. Positive space charge was uniformly distributed in the bulk.

These results suggest that the mobility of space charge in lower density LDPE-A is higher than that in higher density LDPE-R and that the amounts of space charge in lower density LDPE-A is larger than that in higher density LDPE-R. They also suggest that carriers are more easily injected from the SC electrode than the Al electrode.

3.1.2 LDPE-RA

Figure 5 shows the space charge distributions in the two-layered film LDPE-RA at 50 MVm^{-1}. For the positive polarity, positive carriers are injected from the SC anode and they move in LDPE-A. They are accumulated near the interface between LDPE-A and LDPE-R which we call A/R interface from now on. Then, they move into LDPE-R layer.

On the other hand, for the negative polarity, negative space charge is accumulated near the SC anode and moves into the bulk. Positive space charge is also accumulated near the Al electrode. At 90 min, small negative carriers are accumulated near A/R interface.

These results suggest that space charge is accumulated near the interface when it moves from high mobility layer to low mobility layer.

3.1.3 LDPE-AR

Figure 6 shows the space charge distributions in two-layered film LDPE-AR at 50 MVm^{-1}. For the positive polarity, positive homo space charge is accumulated near the SC electrode at about 10 min after applying DC field. This positive space charge gradually moves into the bulk and arrives at R/A interface. Near R/A interface, the amount of space charge decreases and space charge is little accumulated in LDPE-A layer.

This result suggests that space charge is not accumulated near the interface when it moves from

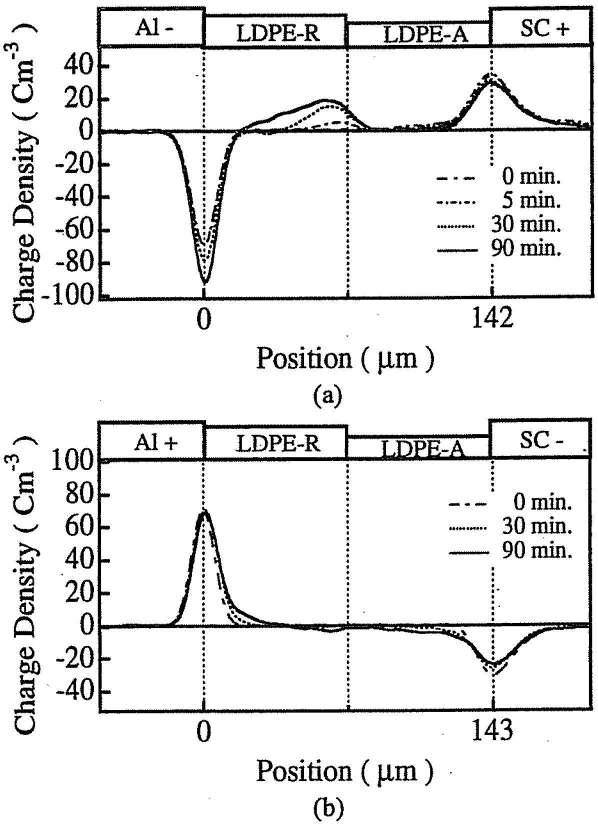

Fig. 5 Space charge distributions in LDPE-RA for positive polarity (a) and negative polarity (b) (50 MVm-1, 23 °C)

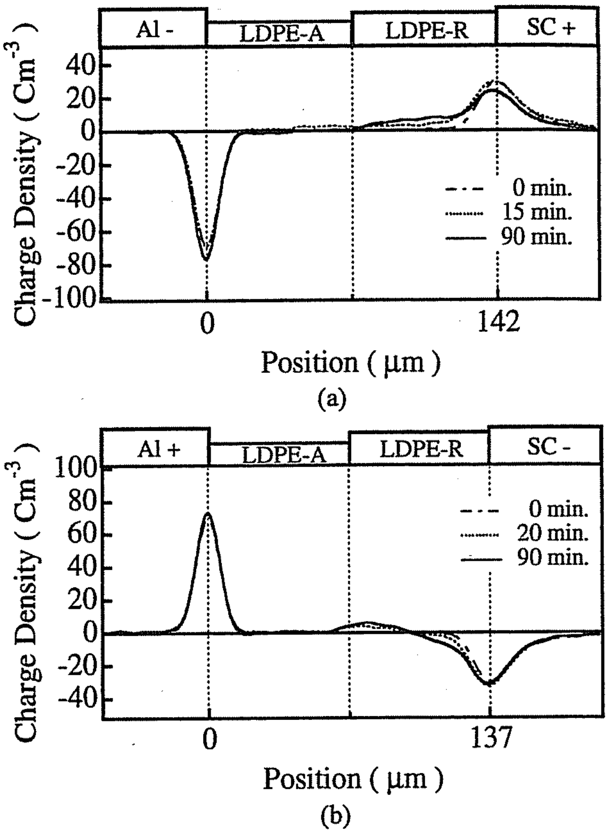

Fig. 6 Space charge distributions in LDPE-AR for positive polarity (a) and negative polarity (b) (50 MVm-1, 23 °C)

low mobility layer to high mobility layer.

On the other hand, for the negative polarity, positive space charge is accumulated near A/R interface in about 10 min after applying DC field. Later, negative carries injected from SC cathode gradually move into the bulk. These results suggest that positive carriers injected from the Al anode are accumulated near A/R interface because of their high mobility in LDPE-A.

3.2 DC current

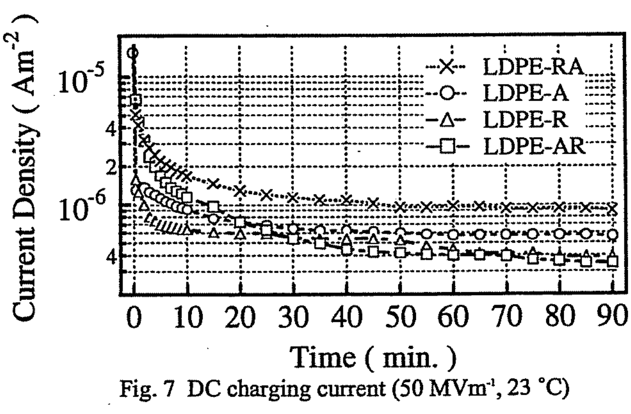

Fig. 7 DC charging current (50 MVm-1, 23 °C)

Figure 7 shows DC charging currents for positive polarity at 50 MVm-1. LDPE-RA and LDPE-A show larger charging currents than LDPE-R and LDPE-AR. It suggests that carriers are more mobile in low density LDPE-A than LDPE-R and that they are easily injected from the SC electrode. However, the two-layered LDPE's show larger discharging current than the single layer LDPE's as shown in Fig. 8.

Figure 9 shows the space charge distributions in LDPE-A and LDPE-R after the short-circuit for positive polarity. In LDPE-R, space charge is almost uniformly

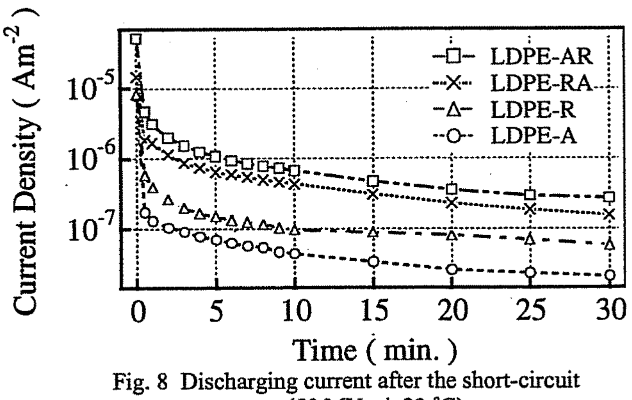

Fig. 8 Discharging current after the short-circuit (50 MVm-1, 23 °C)

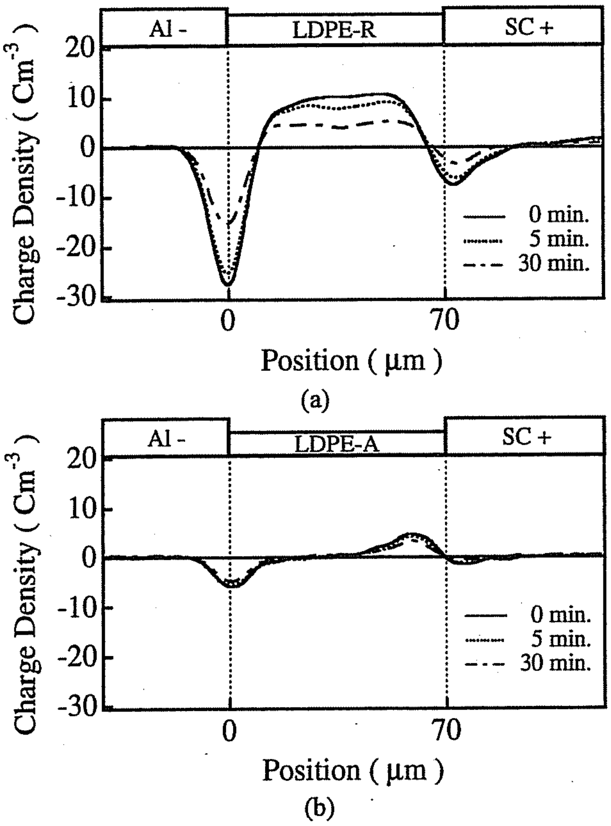

Fig. 9 Space charge distributions in LDPE-R (a) and LDPE-A (b) after the short-circuit (50 MVm^{-1}, 23 °C)

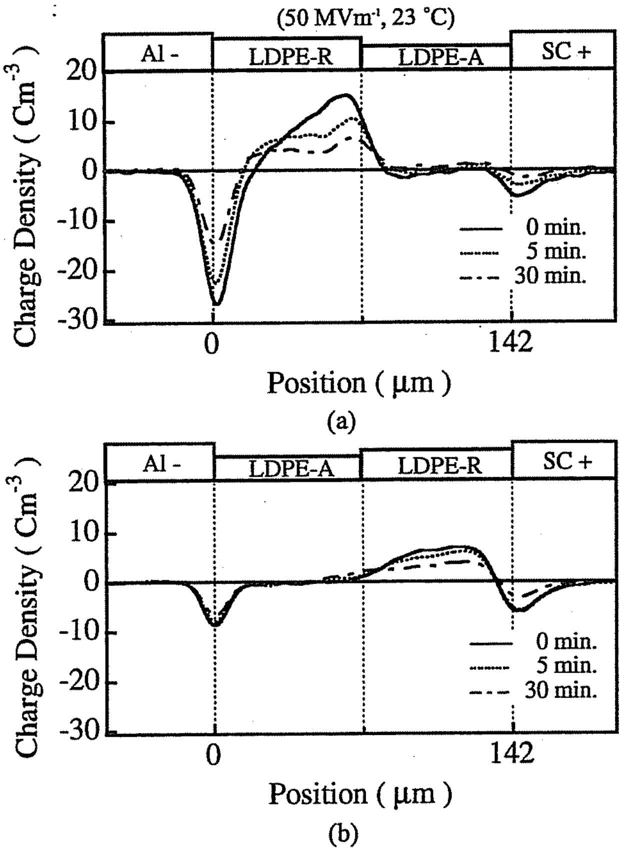

Fig. 10 Space charge distributions in LDPE-RA (a) and LDPE-AR (b) after the short-circuit (50 MVm^{-1}, 23 °C)

distributed in the bulk. Space charge in LDPE-R will move towards both electrodes and as a result the discharging current is expected to be small because of the cancellation of currents. In LDPE-A, there is little space charge near the SC electrode. LDPE-R has larger discharging current than LDPE-A because of a high density of space charge in LDPE-R.

Figure 10 shows the space charge distributions in LDPE-RA and LDPE-AR after the short-circuit. For these samples, space charge is distributed in the side of the Al and SC electrodes, respectively. In LDPE-RA, most space charge accumulated near A/R interface moves to the SC electrode after the short-circuit. On the other hand, in LDPE-AR, space charge is accumulated near the SC electrode and most space charge moves to the SC electrode. These charge movements cause the large discharging currents.

4. CONCLUSIONS

We investigated space charge behavior and DC currents in two-layered LDPE and discussed the effects of LDPE/LDPE interface on space charge behavior and DC currents. The main conclusions obtained are as follows.

(1) Both positive and negative carriers are mainly injected from the semiconductive electrode. They form space charge near the LDPE/LDPE interface in LDPE-RA and near the semiconductive electrode in LDPE-AR.

(2) Both positive and negative charges are more mobile in LDPE of a lower density.

(3) The interface between different LDPE's greatly affects space charge behavior and discharging currents.

5. REFERENCES

[1] M. Fukawa, T. Kawai, Y. Okano, S. Sakuma, A. Asai, M. Kanaoka and H. Yamauchi: "Development of 500 kV XLPE Cables and Accessories for Long Distance Underground Transmission Line," IEEE Trans. on Power Delivery, Vol. 11, pp. 627-634, 1999.

[2] T. Mizutani: " Space Charge Measurement Techniques and Space Charge in Polyethylene," IEEE Trans. on Diel. Electr. Insul., Vol. 1, pp. 923-933, 1994.

[3] T. Takada: "Acoustic and Optical Methods for Measuring Electric Charge Distributions in Dielectrics," IEEE Trans. on Diel. Electr. Insul., Vol. 5, pp. 519-547, 1999.

[4] T. Mizutani, K. Shinmura, K. Kaneko, T. Mori, M. Ishioka and T. Nagata: "Space Charge Behaviors near the Interface between Different Low-Density Polyethylene," Proc. 6th ICPADM, pp. 59-62 (Xi'an, June 21-26, 2000).