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Space Charge Behaviors near the Interface between Different Low-Density Polyethylenes

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Abstract: We investigated the space charge behaviors near the interface between different low-density polyethylenes (LDPE) by using the PEA method. Charge carriers were mainly injected from the semicon electrode in a specimen of Al/LDPE/LDPE/LDPE/semicon and they moved through the interface to the counter Al electrode. Charge carriers moving from LDPE of a lower density to LDPE of a higher one were accumulated near the interface to form space charge, while there was no space charge accumulation for carriers moving in the opposite direction. It suggests that charge carriers are more mobile in LDPE of a lower density.

The mobilities of charge carriers were also estimated from the change in space charge profile with time and positive carriers were more mobile in LDPE than negative ones.

These space charge behaviors were discussed compared with the results of DC conduction.

Keywords: space charge, LDPE, interface, mobility

1. INTRODUCTION

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 LDPE(low-density polyethylene) and XLPE (cross-linked polyethylene) and also on charge dynamics near the interface between solid dielectrics.[2,3] However, space charge behaviors 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 behaviors in LDPE and near its interface are required to develop high performance DC cables and prefabricated cable joints.

In this paper, space charge dynamics in LDPE and also space charge behaviors 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 (100 μm thick), LDPE-A (100 μm thick) and three-layered LDPE-ARA (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. LDPE-ARA has a structure of 20 μm-thick LDPE-R layer sandwiched by two 60 μm-thick LDPE-A layers as shown in Fig. 1. So, the density of the central layer of sample LDPE-ARA is higher than those of the others.

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

Sample	Melting point (°C)	Density (g/cm³)
LDPE-R	116.1	0.9243
LDPE-A	108.4	0.9172

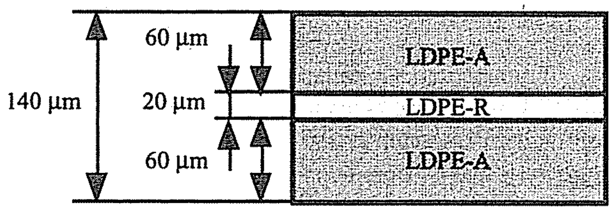

Fig. 1 Structure of three-layered LDPE-ARA

2.2 Space charge and current measurements

We measured space charge distributions and DC currents in LDPE. Space charge distributions were measured with the PEA (Pulsed Electro-Acoustic) method.[3]

We used the Al/semicon electrode system to investigate the dependence of electrode material on space charge behaviors. Positive and negative DC voltages were applied to the semicon electrode and the Al electrode was connected to the ground. In this paper, "positive polarity" means that positive voltage was applied to the semicon electrode and "negative polarity" means that negative voltage was applied to the semicon electrode. DC field of 50 MVm^{-1} was applied for 90 min. and then the electrodes were short-circuited for 30 min.

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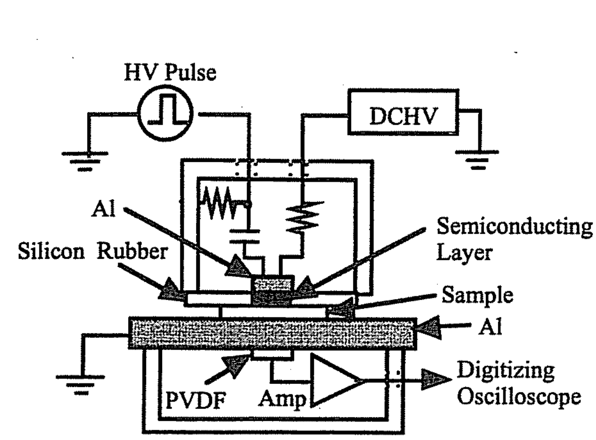


Fig. 2 Setup for space charge measurement (PEA method)

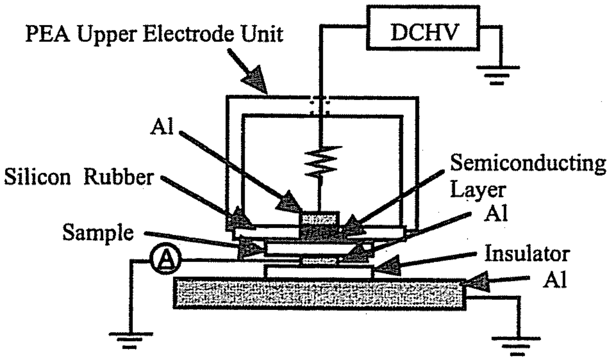


Fig. 3 Setup for DC current measurement

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. 3. Both experiments were measured at room temperature (23 °C).

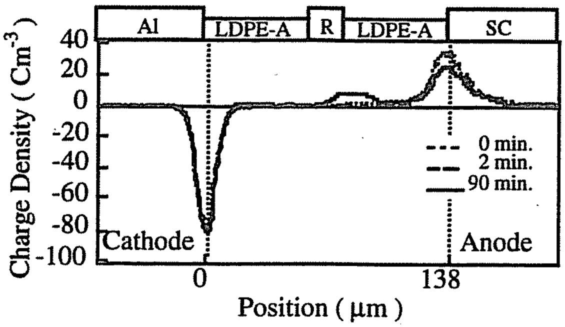
3. RESULT AND DISCUSSION

3.1 Space charge distributions

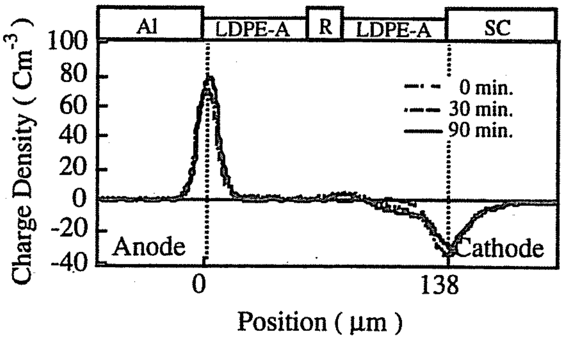
3.1.1 LDPE-ARA

Figure 4 shows the space charge distributions in the three-layered film, LDPE-ARA at the field of 50 MVm^{-1}, room temperature (23 °C). In the positive polarity where a positive voltage is applied to the semicon electrode (Fig. 4 (a)), positive carriers are injected from the semicon anode and they move in LDPE-A. Then, they are accumulated near the interface between LDPE-A and LDPE-R which we call A/R interface from now on.

On the other hand, for the negative polarity where negative voltage is applied to the semicon electrode (Fig. 4 (b)), negative carriers are injected from the semicon electrode and they form negative homo space charge near the semicon cathode. These results suggest that both positive and

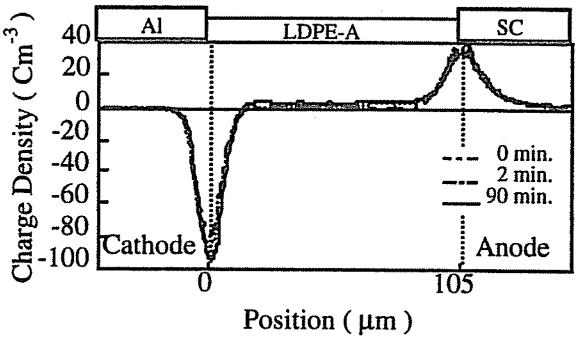


(a)

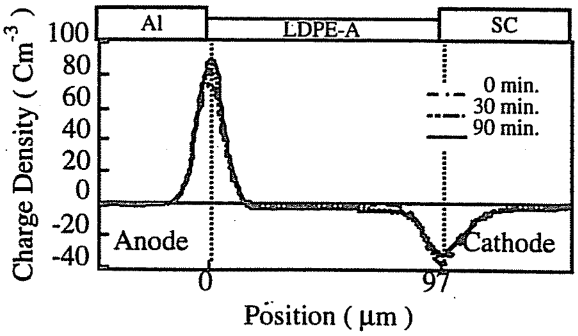


(b)

Fig. 4 Space charge distributions in LDPE-ARA for (a) positive polarity and (b) negative polarity, (50 MVm^{-1}, 23 °C)



(a)



(b)

Fig. 5 Space charge distributions in LDPE-A for (a) positive polarity and (b) negative polarity, (50 MVm^{-1}, 23 °C) negative carriers are more easily injected from the semicon electrode than the Al electrode. They also indicate that the mobility of the positive space charge is higher than that of negative one. One can see a small amount of positive space charge at 30 min. and it disappears at 90 min. (Fig 4 (b)). At the beginning, a small amount of positive carriers injected from the Al anode are accumulated near the interface because of their high mobility, but the positive space charge decreases as slow negative carriers injected from the semicon electrode arrive at the interface.

3.1.2 LDPE-A

Figure 5 shows the space charge distributions in a single-layer film, LDPE-A at the field of 50 MVm^{-1}. For the positive polarity (Fig. 5 (a)), positive carriers are injected from the semicon anode to form space charge near the anode. They arrive at the counter Al electrode in about 15 min.

For the negative polarity (Fig. 5(b)), negative homo space charge is accumulated near the semicon electrode in about 5 min. after applying DC field. This negative space charge gradually moves into the bulk and arrives at the counter Al electrode in about 30 min. These results also suggest that both positive and negative carriers are injected from the semicon electrode to form homo space charge depending on the polarity of applied field and that the mobility of the positive space charge is higher than that of the negative one.

3.2 DC current

Figure 6 shows DC charging currents in LDPE-ARA and LDPE-A at 50 MVm^{-1} (23 °C). Both LDPE-ARA and LDPE-A have almost the same DC currents for both polarities. It indicates that a thin LDPE-R layer (20 μm thick) little affects the DC charging current in LDPE-ARA. However, discharging current after the short-circuit is quite different between LDPE-A and LDPE-ARA as shown in Fig. 7. LDPE-ARA shows a larger discharging current than LDPE-A.

Figure 8 shows the space charge distributions in LDPE-A after the short-circuit. For both polarities, space charge is almost uniformly distributed in the bulk. Uniformly distributed space charge in LDPE-A will move to both electrodes and, as a result, the discharging current is expected to be small because of the cancellation of currents.

Figure 9 shows the space charge distributions in LDPE-ARA after the short-circuit. For both polarities, space charge is distributed in the side of the semicon electrode. In this case, most space charge moves to the semicon electrode and a large discharging current is observed. This is a reason why LDPE-ARA shows a larger discharging current than LDPE-A. Figure 8 also shows that positive space charge decays faster than negative one.

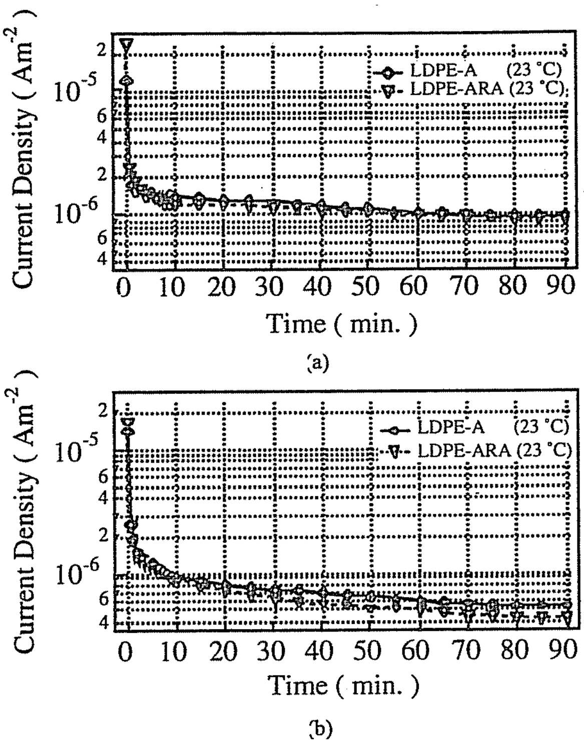


Fig. 6 DC chargingcurrent for (a) positive polarity and (b) negative polarity, (50 MVm^{-1}, 23 °C)

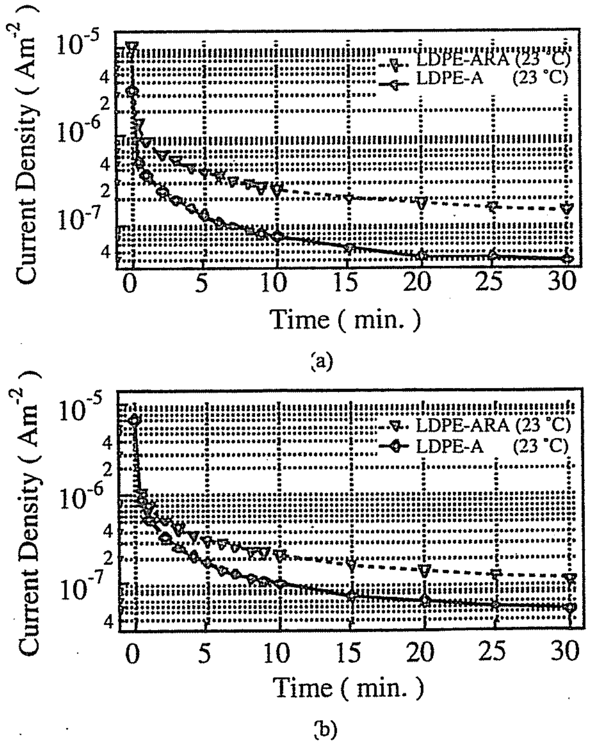


Fig. 7 Discharging current after the short-circuit for (a) positive polarity and (b) negative polarity, (50 MVm^{-1}, 23 °C)

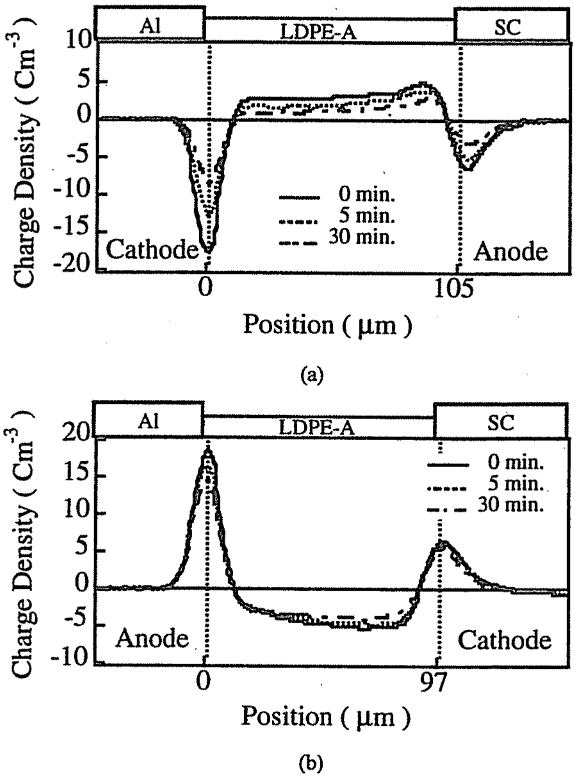


Fig. 8 Space charge distributions in LDPE-A after short-circuiting for (a) positive polarity and (b) negative polarity, (50 MVm^{-1}, 23 °C)

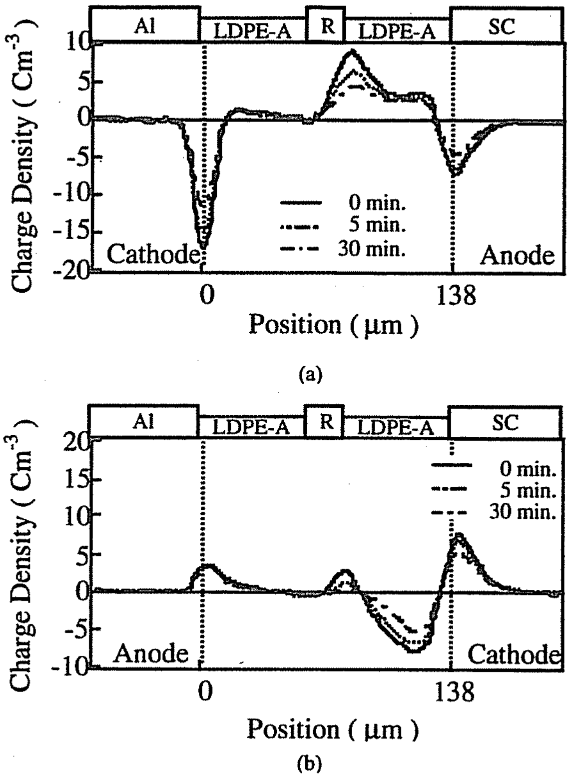


Fig. 9 Space charge distributions in LDPE-ARA after short-circuiting for (a) positive polarity and (b) negative polarity, (50 MVm^{-1}, 23 °C)

4. CONCLUSIONS

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

(1) Both positive and negative carriers are mainly injected from the semicon electrode, depending on the polarity of applied field. They form homo space charge near the LDPE/LDPE interface or near the semicon electrode in LDPE-ARA.

(2) The mobility of positive space charge is higher than that of negative one. 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 behaviors and discharging currents.

5. REFERENCES

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