Effect of Anti-Oxidants on Space Charge in Low-Density Polyethylene

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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 [1]. Many papers have been published on space charge in low-density polyethylene (LDPE) and cross-linked polyethylene (XLPE) [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 effects of these factors on space charge behavior are required to develop high performance DC cables. In this paper, we investigated the effect of anti-oxidants on space charge behavior and DC current in LDPE.

EXPERIMENTAL

Samples

We used four kinds of LDPE films, LDPE-0, LDPE-15, LDPE-30 and LDPE-60 (100 μm thick). The film density of these LDPE is 0.920 gcm^{-3}. LDPE-0 has no additives. LDPE-15, LDPE-30, and LDPE-60 have 15, 30, 60 wt% anti-oxidant respectively. We used 4,4'-thio-bis(3-methyl-6-t-butyl phenol) as anti-oxidant. Fig. 1 shows the chemical structure of the anti-oxidant.

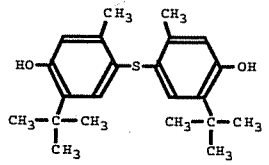

Fig. 1 Chemical structure of anti-oxidant

Space charge and current measurements

We measured space charge distributions and DC currents in LDPE. Both measurements were carried out at room temperature (about 23 •C), 40 •C and 60 •C.

As shown in Fig. 2, space charge distributions were measured with the pulsed electro-acoustic (PEA) method [3]. We used the Al/semiconductive (SC) electrode system. Positive or negative DC voltage was 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. 3.

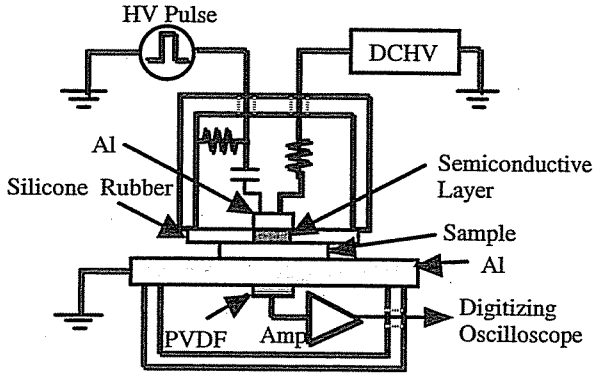

Fig. 2 Setup for space charge measurement (PEA method)

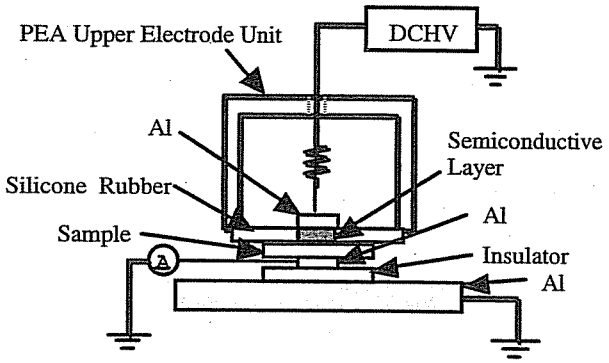

Fig. 3 Setup for DC current measurement

RESULT AND DISCUSSION

Space charge distributions

Effect of anti-oxidant (at room temperature) Fig. 4 shows the space charge distributions in LDPE-0, LDPE-30 and LDPE-60 at 50 MVm^{-1} for the positive polarity at room temperature. For LDPE-0 (Fig. 4-(a)), positive carriers are injected from the SC anode to form space charge near the anode. Negative carriers also form space charge is dominant after 60 min. There was little near the Al electrode in about 20 min. However, positive positive space charge in the bulk.

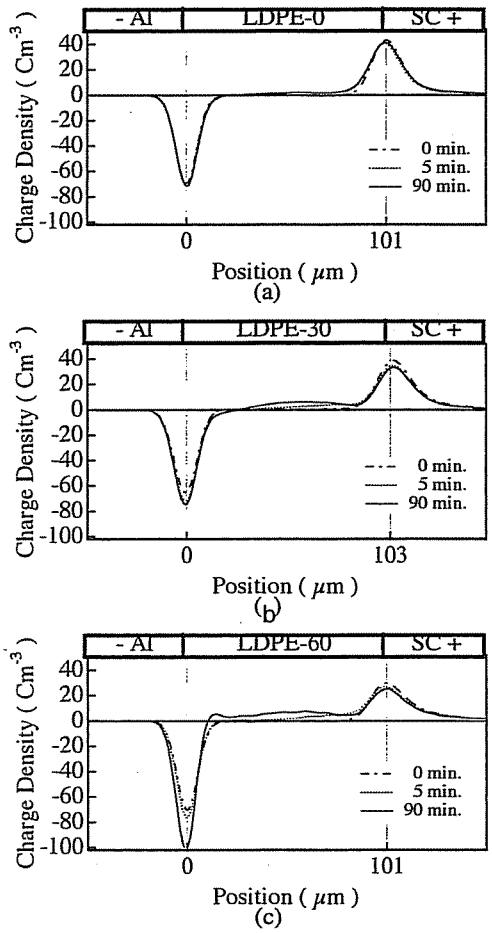

Fig. 4 Space charge distributions in LDPE-0 (a), LDPE-30 (b) and LDPE-60 (c) for positive polarity (50 MVm^{-1}, 23 °C)

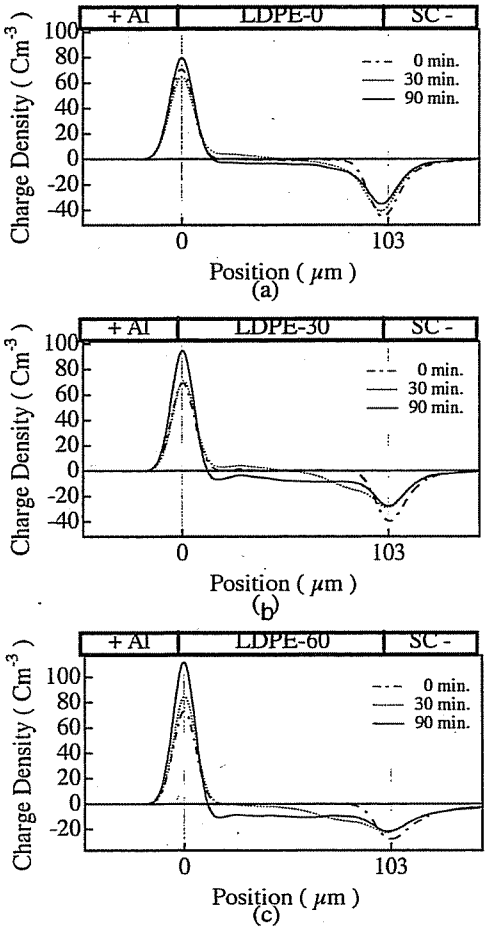

Fig. 6 Space charge distributions in LDPE-0 (a), LDPE-30 (b) and LDPE-60 (c) for negative polarity (50 MVm^{-1}, 23 °C)

For LDPE-30 (Fig. 4-(b)), positive carriers are injected from the SC anode to form space charge near the anode. They arrive at the counter Al electrode in about 20 min. after the field application. Positive space charge is accumulated in the bulk. Small negative space charge is also observed near the Al cathode.

For LDPE-60 (Fig. 4-(c)), positive carriers are injected from the SC anode to form space charge. But, negative space charge is not observed near the Al cathode. Positive carriers injected from the SC anode move through the bulk and form hetero space charge near the counter Al cathode.

As shown in Fig. 4, the amount of positive space charge increases with anti-oxidant content. We calculated the amount of positive space charge at 90 min. Fig. 5 shows the charge density versus anti-oxidant content characteristics.

These results suggest that positive carriers are easily injected from the SC electrode and that the mobility of positive space charge is higher than that of negative one [4,5].

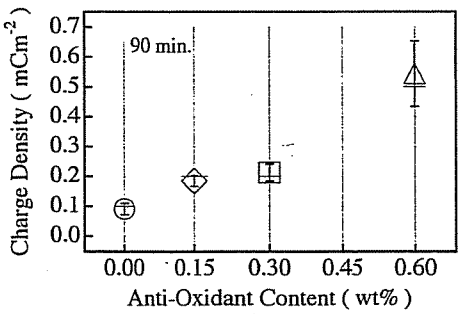

Fig. 5 Charge density vs anti-oxidant content for positive polarity (50 MVm^{-1}, 23 °C)

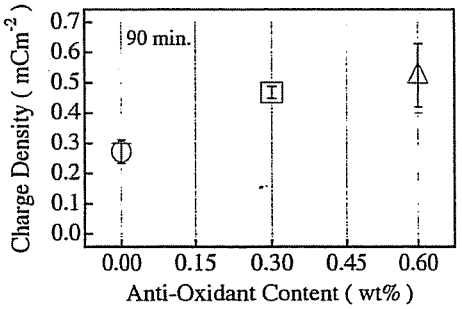

Fig. 7 Charge density vs anti-oxidant content for negative polarity (50 MVm^{-1}, 23 °C)

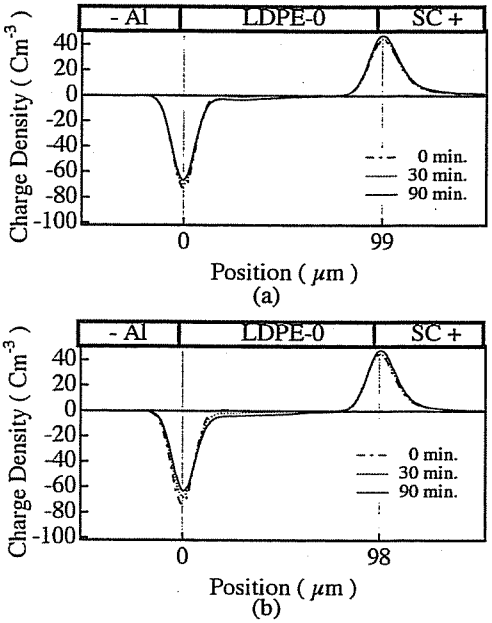

Fig. 8 Space charge distributions in LDPE-0 for positive polarity at 40 °C (a) and 60 °C (b) (50 MVm^{-1})

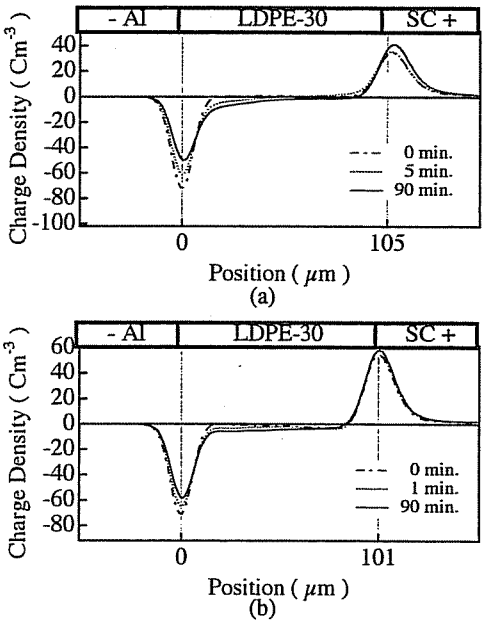

Fig. 9 Space charge distributions in LDPE-30 for positive polarity at 40 °C (a) and 60 °C (b) (50 MVm^{-1})

Fig. 6 shows the space charge distributions in LDPE-0, LDPE-30 and LDPE-60 at 50 MVm^{-1} for the negative polarity at room temperature. For each LDPE, positive carriers injected from the Al anode move through the bulk in 1 min. After 5 min., negative space charge is formed near the SC cathode. It moves into the bulk and cancels the positive space charge. However, the space charge distribution 90 min. after the DC voltage application depends upon the anti-oxidant content. LDPE-0 shows a negative homo space charge near the SC cathode. On the other hand, LDPE-30 and LDPE-60 have negative hetero space charge near the Al anode.

Negative hetero charge in LDPE-60 is more remarkable than that in LDPE-30. We calculated the amount of negative space charge at 90 min. and plotted them as a function of the anti-oxidant content in Fig. 7. Negative space charge also increases with anti-oxidant content in the same way as the positive polarity (Fig. 5).

Temperature dependence Fig. 8 shows the space charge distributions in LDPE-0 at 50 MVm^{-1} for the positive polarity at 40 °C and 60 °C. At both temperatures, positive space charge is not observed and small negative space charge is accumulated near the Al

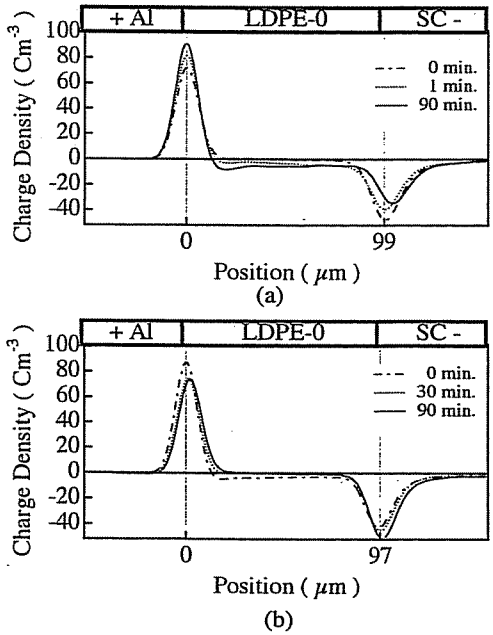

Fig. 10 Space charge distributions in LDPE-0 for negative polarity at 40 °C (a) and 60 °C (b) (50 MVm^{-1})

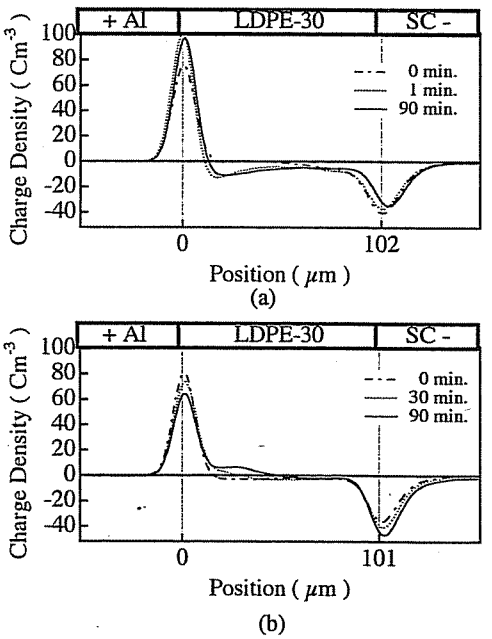

Fig. 11 Space charge distributions in LDPE-30 for negative polarity at 40 °C (a) and 60 °C (b) (50 MVm^{-1})

cathode. These results suggest that carrier transport is thermally activated and that negative carriers staying near the Al cathode at room temperature move further into the bulk as temperature rises.

Fig. 9 shows the space charge distributions in LDPE-30 at 50 MVm^{-1} for the positive polarity at 40 •C and 60 •C. At both temperatures, positive space charge is not observed and negative space charge is accumulated near the Al cathode. The amount of space charge is larger in LDPE-30 than in LDPE-0.

Fig. 10 shows the space charge distributions in LDPE-0 at 50 MVm^{-1} for the negative polarity at 40 •C and 60 •C. At 40 •C (Fig. 10-(a)), negative space charge is formed near the SC cathode in 1 min. and accumulated near the counter Al anode as hetero charge in 3 min. At 60 •C (Fig. 10-(b)), negative space charge is formed in the bulk soon after the voltage application and then decreases. A little positive space charge is accumulated near the Al anode in 90 min.

Fig. 11 shows the space charge distributions in LDPE-30 at 50 MVm-1 for the negative polarity at 40 •C and 60 •C. At 40 •C (Fig. 11-(a)), negative space charge injected from the SC cathode is accumulated near the counter Al anode as hetero charge in 1 min. At 60 •C (Fig. 11-(b)), negative space charge is formed in the bulk soon after the voltage application, but it is gradually surpassed by positive charge injected from the Al anode. The amount of space charge in LDPE-30 is larger than that in LDPE-0.

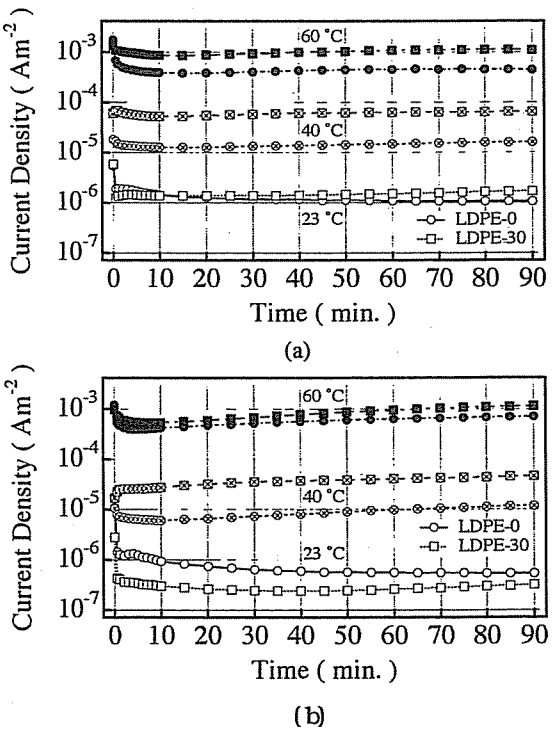

Fig. 12 DC charging current for positive polarity (a) and negative polarity (b) (50 MV/m)

For both polarities, anti-oxidants tend to enhance space charge accumulation. This suggests that anti-oxidants enhance the carrier injection and/or transport.

DC current

Fig. 12 shows DC charging currents at 50 MVm^{-1}. At high temperature, charging current gradually increases with time. This may suggest a slow rise of sample temperature by Joule heating. As shown in Fig. 12, LDPE-30 has a larger charging current than LDPE-0 at each temperature, except for the negative polarity at 23 •C. These results also suggest the enhancement of carrier injection or transport by anti-oxidant. But the result that the charging current is larger in LDPE-0 than in LDPE-30 at 23 •C is still under consideration.

CONCLUSION

We investigated space charge behaviors and DC currents in LDPE with anti-oxidant and discussed the effects of anti-oxidant on them. The main conclusions obtained are as follows.

(1) The amount of space charge increases with anti-oxidant content.

(2) At 40 •C and 60 •C, charging current is larger in LDPE with anti-oxidant than in LDPE without anti-oxidant.

(3) Anti-oxidants enhance charge injection from the electrodes and/or charge transport.

REFERENCES

[1] F. Ruter, J. L. Parpal and S. G. Swingler: "A Review of HVDC Extruded Cable Systems", CIGRE 2000 paper P2-03, 2000.

[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, H. Semi, K. Kaneko: "Space Charge Behavior in Low-Density Polyethylene", IEEE Trans. on Diel. Electr. Insul., Vol. 7, No. 4, pp. 503-508, 2000.

[5] T. Mizutani, K. Shinmura, K. Kaneko, T. Mori, M. Ishioka and T. Nagata: "Space Charge Behavior near LDPE/LDPE Interface", Annual report IEEE Conf. Electr. Insul. Dielectr. Phenomena, pp. 800-803, 2000.