2003 Annual Report Conference on Electrical Insulation and Dielectric Phenomena

Space charge distribution in low-density polyethylene with blocking layer

T. Hori[1] K. Kaneko[1] T. Mizutani[1] and M. Ishioka[2]
[1] Department of Electrical Engineering, Nagoya University, Japan
[2]Japan Polychem Co. Ltd., Japan

Abstract: Charge carriers injected from the electrode and charge carriers generated in the bulk contribute space charge in low density polyethylene (LDPE). However, it is sometimes difficult to separate their contributions. In this paper, a fluorinated ethylene propylene copolymer (FEP) film was used as a blocking layer. It was effective to separate injected carriers and bulk-generated carriers. The electrode materials used were aluminum and semiconductive (SC) polymer. Charge carriers were mainly injected from the SC electrode into a specimen of Al / LDPE / SC and they formed homo space charge. A blocking FEP film suppressed the carrier injection and it gave information about the behavior of bulk-generated carriers. From these results, we discussed the contributions of injected carriers and bulk carriers to space charge in LDPE.

Introduction

Low-density polyethylene (LDPE) has been widely used as insulating material for electric power cables because of its excellent electrical and mechanical properties. The space charge sometimes affects the breakdown of an insulating material because it enhances a local electric field [1].

However, the space charge behavior is complicated and it depends upon physical / chemical structures of an insulating material, impurities, additives, temperature, applied electric field and so on [2]. There are many obscure things such as types of charge carriers, origins of carrier traps, and effects of electrode on space charge [3].

In the previous paper [4], we reported that homo space charge injected from the SC electrode is dominant in LDPE at room temperature.

In this paper, we investigated the contributions of injected carriers and bulk carriers to space charge by using a blocking layer.

Experimental

Specimens: We used LDPE films. LDPE was polymerized using Ziegler-Natta catalyst. It contains 0.5 wt% of anti-oxidants. The properties of LDPE films used are listed in Table 1. The film thickness is about 100 μm. In addition to the standard electrode system of Al plate / SC, a 25 μm-thick FEP film was inserted between LDPE and the electrode as a blocking layer.

Table 1: Specimen

Sample	Density (g cm^{-3})	Melting point (°C)
LDPE	0.9223	122.6

Space charge measurement: Space charge distributions in LDPE specimens were measured with the PEA method [5] as shown in Fig. 1. The PEA electrode system was put in an oven and its temperature was controlled. The measurements were carried out mainly at room temperature (about 23 °C). A specimen was set in the Al / Semiconductive (SC) electrode system. A positive or negative DC voltage was applied to the SC electrode and the Al electrode was grounded. In this paper, 'positive polarity' and 'negative polarity' mean that positive voltage and negative voltage were applied to the SC electrode, respectively. The DC field of 50 MVm^{-1} was applied to a specimen for 90 minutes and then the electrodes were short-circuited for 30 minutes. When a blocking layer was used, we removed it 5 minutes later after short circuited.

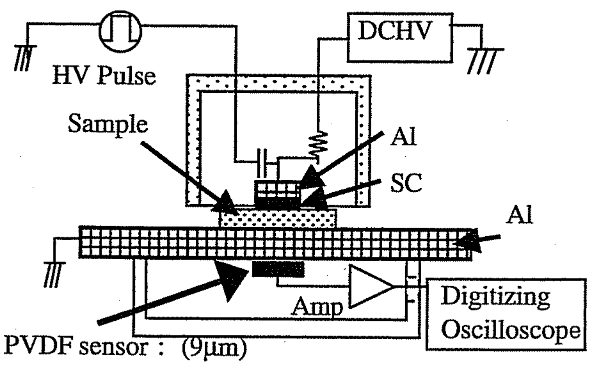
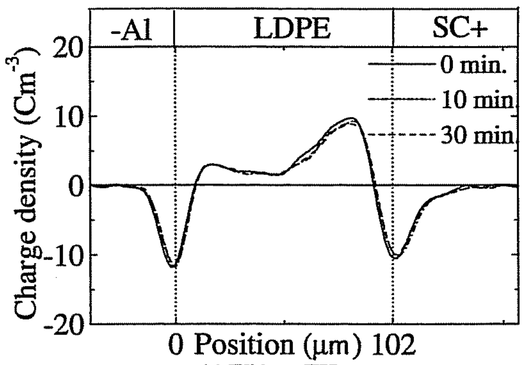


Figure 1: Setup for space charge measurement.

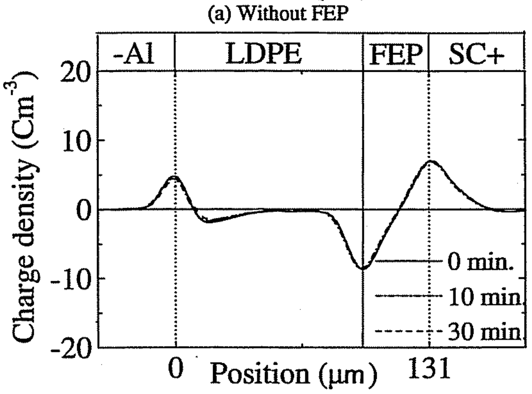
Results and discussion

Positive polarity: The space charge distribution in LDPE without a blocking FEP film is shown in Fig. 2(a). The specimen with a 25 μm-thick FEP film inserted as a blocking layer between LDPE and the SC electrode or the Al electrode had a space charge profile as shown in

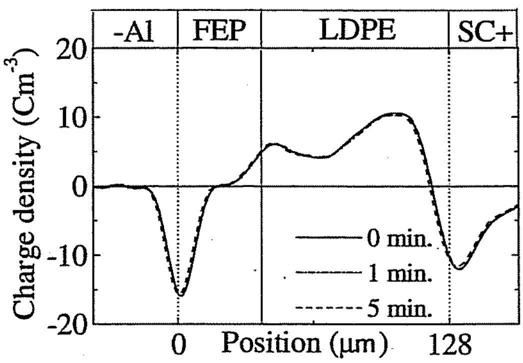
0-7803-7910-1/03/$17.00 ©2003 IEEE



(a) Without FEP



(b) Blocking FEP next to the SC anode



(c) Blocking FEP next to the Al cathode

Figure 2: Space charge distributions under short-circuit after the application of +50MV/m (Positive polarity) for 90 min.

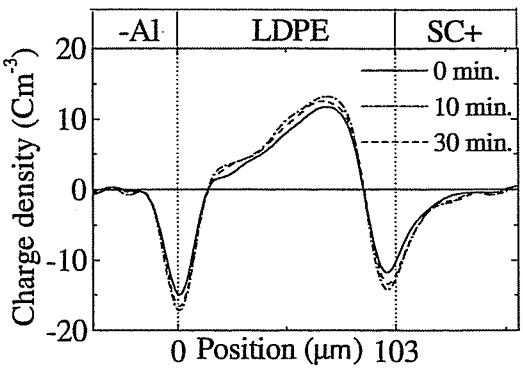


Figure 3: Space charge distributions after removing FEP from Al side

Fig. 2 (b) or (c). The space charge distributions were measured under the short-circuit after a DC field of +50 MV/m was applied to the SC electrode for 90 min.

In case of no FEP layer [Fig.2 (a)], the positive hetero space charge is observed near the Al electrode in addition to positive homo space charge near the SC electrode. These are very stable after shortcircuting and hardly decay in 30 minutes. When FEP is inserted between LDPE and the SC electrode [Fig.2 (b)], the injection of positive carriers is suppressed by the blocking FEP film and negative space charge is observed near the interface between FEP and LDPE. When FEP is inserted between LDPE and the Al electrode [Fig.2 (c)], positive carriers injected from the SC anode arrive at the FEP film and they accumulate there to form positive space charge.

Figure 3 shows the space charge distribution in LDPE after removing FEP from Fig. 2(c). Positive space charge in LDPE is very stable at 23 °C.

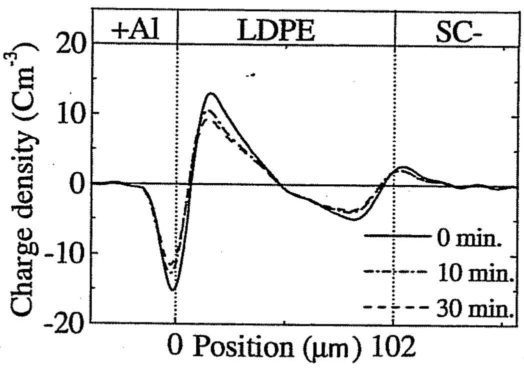
Negative polarity: Figure 4 shows the space charge distributions in LDPE with and without a blocking FEP film for the negative polarity.

In case of no FEP layer [Fig 4 (a)], positive carriers are injected from the Al anode and negative carriers are injected from the SC cathode forming homo space charges near both Al and SC electrodes. It is interesting that the SC electrode can inject positive and negative carriers, while the Al electrode can inject few negative carriers.

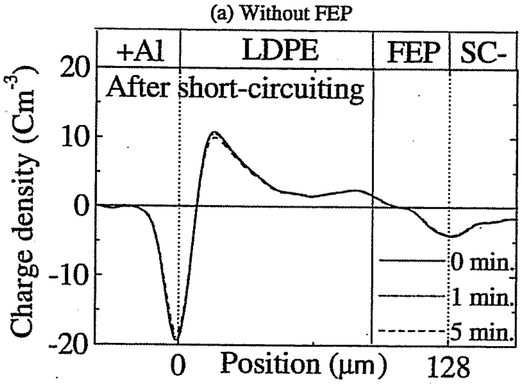
When FEP is inserted between LDPE and the SC electrode [Fig.4 (b)], a blocking FEP film suppresses the injection of negative carriers from the SC cathode and, as a result, only positive space charge is observed in LDPE. Similarly, When FEP is inserted between LDPE and the Al electrode [Fig. 4 (c)], a blocking FEP film suppresses the injection of positive carriers from the Al anode and, as a result, negative space charge is observed near the interface between LDPE and FEP. The negative space charge near the SC cathode is similar to that of Fig. 4(a).

These experiments clearly show the blocking of carrier injection from the electrode by a thin FEP film. They also suggest that charge carriers injected from the electrode play an important role in space charges in LDPE in our experiments.

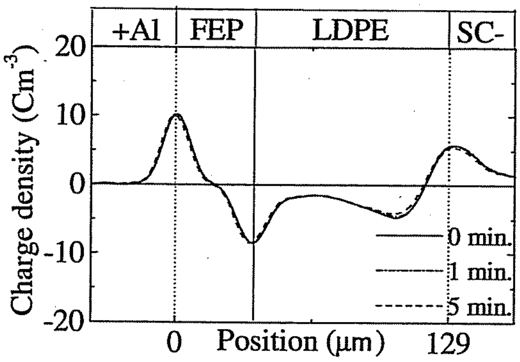
Double blocking: Figure 5 shows the space charge distributions in LDPE with blocking FEP films next to the both Al and SC electrodes at 23 °C and 60 °C. In the double blocking, the charge injection from both elctrodes is suppressed by the blocking layer and the contributions of charge carriers generated in the bulk is observed.



(a) Without FEP



(b) Blocking FEP next to the SC anode



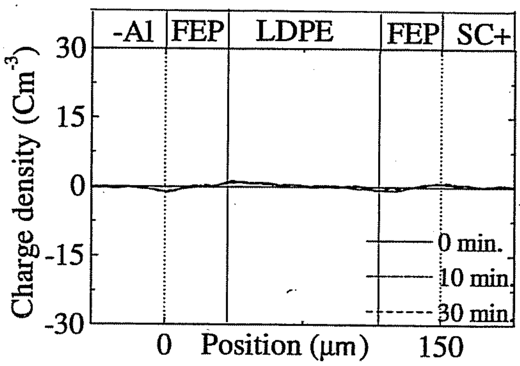
(c) Blocking FEP next to the Al cathode

Figure 4: Space charge distributions under short-circuit after the application of +50MV/m (Negative polarity) for 90 min.

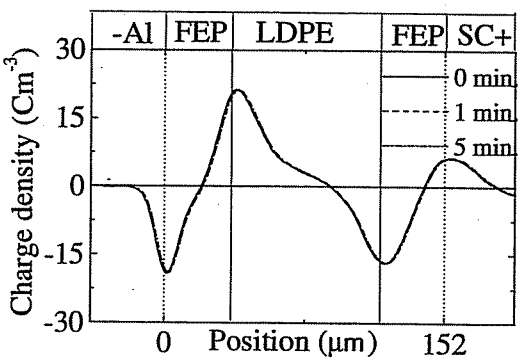
The accumulation of charge is hardly seen at 23 °C [Fig.5 (a)], suggesting almost no cotribution of bulk carriers to space charge at 23 °C.

At 60 °C [Fig.5 (b)], hetero space charges are near both Al and SC electrodes. Their amounts increase with the rise of temperature. The space charge due to charge carriers generated in the bulk depends on temperature.

Figure 6 shows the space charge distribution in LDPE after the removal of a FEP film at 60 °C. The comparison between Fig. 6 and Fig.5 (c) reveals that most hetero space charge is located in the LDPE film but not in FEP. They gradually decay at 60 °C.



(a) 23 °C



(b) 60 °C

Figure 5: Space charge distributions under short-circuit after the application of +50MV/m (Positive polarity) for 90 min.

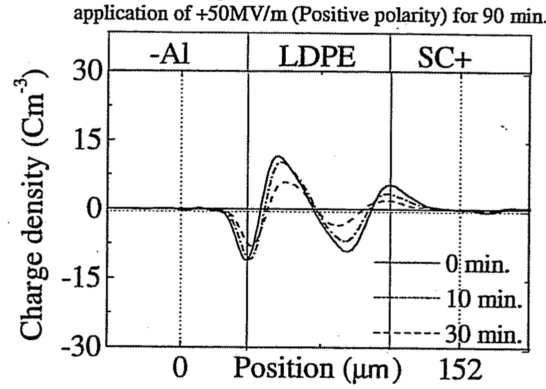


Figure 6: Space charge distributions after the removal FEP film at 60 °C

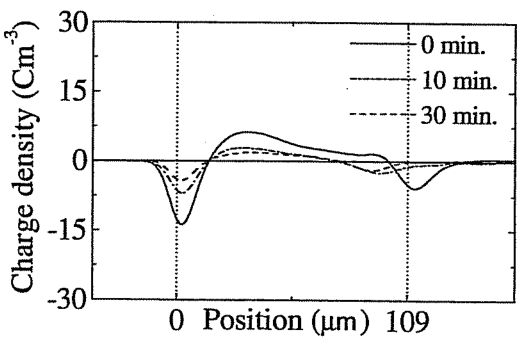


Figure 7: Space charge distributions at 60 °C

Figure 7 shows the space charge distribution in LDPE with no FEP film at 60 °C. This result reveals that the positive space charge is observed near the Al electrode. The comparison between Fig. 6 and Fig.7 suggests that positive charge carriers near the Al electrode are due to charge carriers generated in the bulk at high temperatures.

These results of LDPE with blocking FEP clearly show the contributions of injected carriers and bulk carriers to charge carriers generated in the bulk.

Conclusions

We investigated the space charge by using blocking FEP layer. The main conclusions are as follows.

(1) A FEP film next to the electrode acts as a blocking layer. Space charge behaviors of a LDPE specimen with a blocking FEP film reveal that space charge in LDPE is mainly due to charge injected from the electrode.

(2) The contribution of bulk carriers to space charge was clarified by using a LDPE specimen with blocking FEP next to both electrodes. It depended on temperature.

References

[1] A.Bradwell, R.Cooper and B.Varlow : "Conduction in Polyethylene with Strong Electric Fields and the Effect of Prestressing on the Electric Strength", Proc. IEE, Vol. 118, pp. 247-254 (1971).

[2] T.Mizutani, H.Semi and K.Kaneko : "Space Charge Behavior in Low-Density Polyethylene", IEEE Trans. on DEI, Vol.7, No.4, pp.503-508 (2002).

[3] G. Chen, T. Y. G. Tay, A. E. Davies, Y. Tanaka, T. Takada: "Electrodes and Charge Injection in Low-density Polyethylene", IEEE Trans. Electr. Insul. Vol. 8, pp. 867-873 (2001)

[4] T. Hori, K. Kaneko, T. Mizutani, and M. Ishioka : "Characteristics of Space Charge in Linear Low-Density Polyethylene", IEEJ Trans, Vol.131-A, No.7 (2003) (in print).

[5] T. Maeno, T. Futami, H. Kusibe, T. Takada and C. M. Cooke: "Measurement of spatial charge distribution in thick dielectrics using the pulsed electroacoustic method", IEEE Trans. Electr. Insul. Vol. 23, pp. 433-439 (1988).

Author address: Tetsuya Hori, Department of Electrical Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan Email: tetuya_h@echo.nuee.nagoya-u.ac.jp