MEASUREMENT OF BULK CHARGE IN DIELECTRIC MATERIALS IRRADIATED BY ELECTRON BEAM IN VACUUM ENVIRONMENT

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Abstract

Bulk charge accumulation in thin dielectric materials under electron beam irradiation in vacuum environment was observed using newly developed measurement system. Recently, some accidents in spacecraft due to the charging up of electric potential have been reported. Some of them are caused by surface discharge normally happens in plasma environment. Some others seem to be caused by discharge due to and an accumulation of charge in bulk of materials at relatively higher altitude environment. Surface charge is usually measured using surface potential meter. However, there had been no useful method to measure the bulk charge in the materials. Therefore, we have been developing the bulk charge measurement system. We have already succeeded in measuring the bulk charge distribution in thick sample under electron beam irradiation in air atmosphere. However, to simulate the actual spacecraft in condition of high altitude space environment, it is necessary to carry out the measurement for thin materials in vacuum environment. Therefore, we have developed an improved measurement system applicable to a thin sample in vacuum environment. Using the improved system, we carried out the measurement of bulk charge distributions in 180 and 50 μm thick Kapton® and PET film under electron beam irradiation in vacuum of ca 10^{-6} Pa. In this report, some typical measurement results are introduced following the explanation of brief measurement principle.

Introduction

The spacecraft flying in GEO is always exposed to plasma and/or radioactive-rays such as α−, β− and γ−rays. In such condition, dielectric materials like cover glasses of solar battery or thermal blankets are charged up. Especially in GEO, they are expected to be irradiated by high-energy electron beam. In the case of high-energy electron beam irradiation, the electrons are injected into the bulk of dielectric materials and they accumulate in them. Because there are no basic data based on practical experiments, it seems difficult to simulate the accumulation and relaxation process of injected charge in dielectric materials. In other words,

it is difficult to expect when and how an accident of ESD caused by accumulated charge will happen on spacecraft. Therefore, we need to measure the charge distribution in the bulk of dielectric materials. We have been developing a system for measuring such a charge distribution in dielectric materials using, so-called, PIPWP (Piezo-induced pressure wave propagation) method.

Principle of PIPWP Method

The principle of PIPWP method is shown in Figure 1. By applying a pulse electric field to the piezo-device, a pulsive pressure wave is generated. When the acoustic wave propagates through the charged sample, the position of charge shifts slightly. The movement of the charge induces the change of surface charge on the electrode. Therefore, the displacement current flows the external circuit due to the change of induced charge on the electrodes. Since the displacement current flows when the acoustic pulse passes through the charge layer, we can observe the charge distribution by measuring the external current. A detail of the principle is described elsewhere [1].

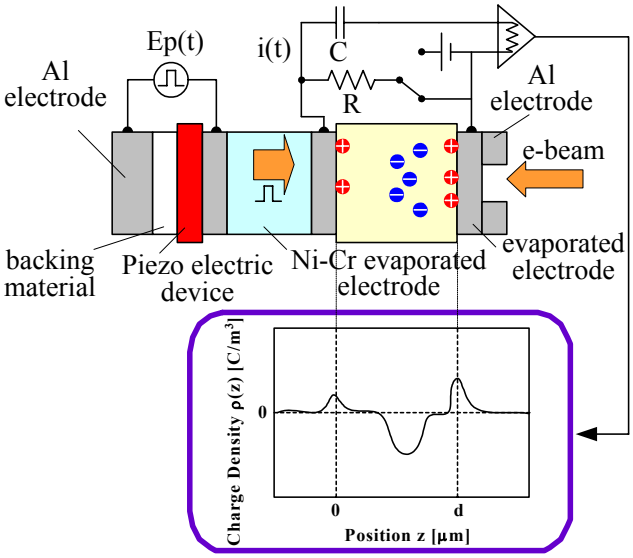

Figure 1. The principle of PIPWP method

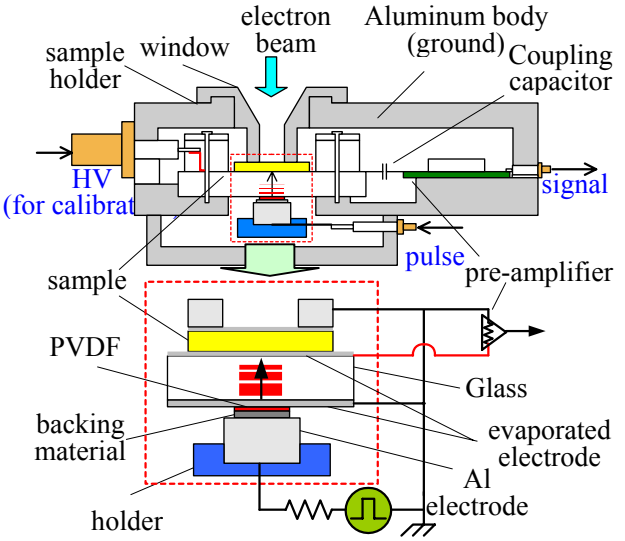

Figure 2. Diagram of the measurement apparatus

Measurement Apparatus

Diagram of the measurement apparatus is shown in Figure 2. [2] And Figure 3 shows Picture of the measurement apparatus. The apparatus have a window for the irradiation of the radioactive rays to the sample as shown in fig.2. The room for the sample should be completely shielded to reduce the noise from outside. Therefore the sample has an evaporated aluminum electrode on the topside surface, and it is connected tightly to the grounded flange of the window. To obtain the electric signal from the bottom side of the sample, a glass plate is inserted between the sample and the piezo-electric device. This glass plate is used to isolate the bottom side of the sample from the grounded level. As the aluminum electrode is evaporated on the bottom side of the glass plate for the shielding, the sample is completely covered by the grounded shield. The glass plate also has an evaporated electrode on the topside surface and it is connected to the detecting amplifier.

To generate a pressure wave, a pulse voltage is applied to the piezo-devise. The resolution of the apparatus depends on thickness of piezo-devise and the pulse width. In the experiment for measurement of Kapton® with 180 μm thickness, the PVDF film with 9 μm thick and 500ns width pulse were used as the piezo-devise and pulse voltage, respectively. To measure a thin film, we needed to improve the resolution of the measurement. Therefore, in the case of measurement for PET with 50 μm thickness, PVDF film with 4 μm thick and 1ns width pulse were used.

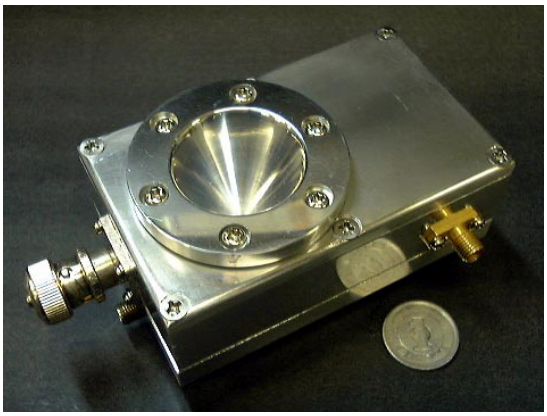

Figure 3. Picture of the measurement apparatus

Figure 4. Picture of SIRENE

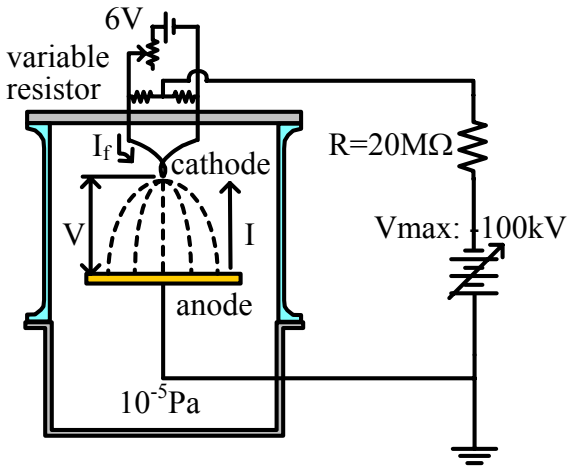

Figure 5. Picture and diagram of the small test chamber

Electron Beam Irradiation System

In this experiment, two types of electron beam chambers were used. One is a named SIRENE in ONERA (Office National d'Etudes et de Recherches Aerospatiales), shown in Fig. 4. The range of acceleration energy and flux of electron beam in SIRENE are 10-400 kV and 0-2 nA, respectively. Another is small test chamber, shown in Figure 5, with dc high voltage generator up to 100 keV.

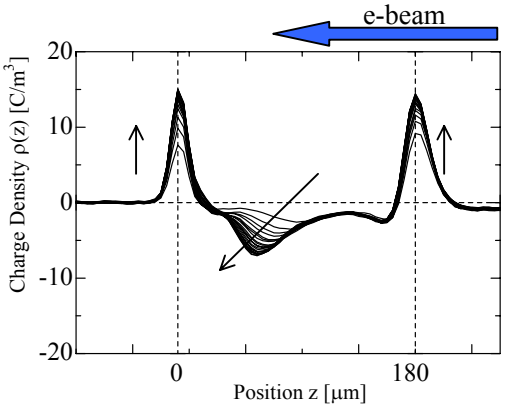

Figure 6. The Charge Density (under irradiation)

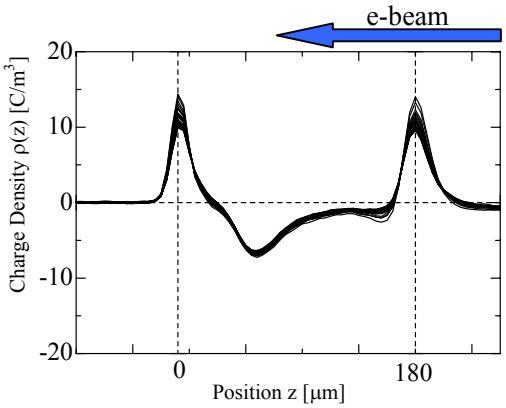

Figure 7. The Charge Density (after irradiation)

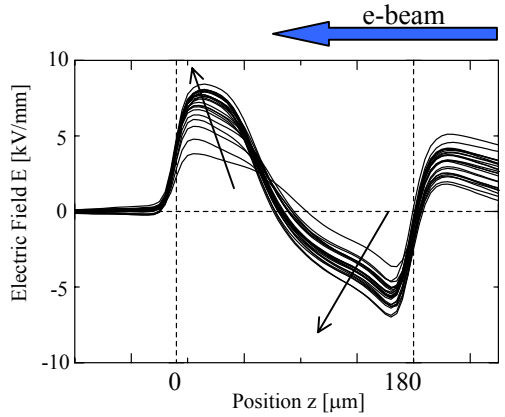

Figure 8. The Electric Field (under irradiation)

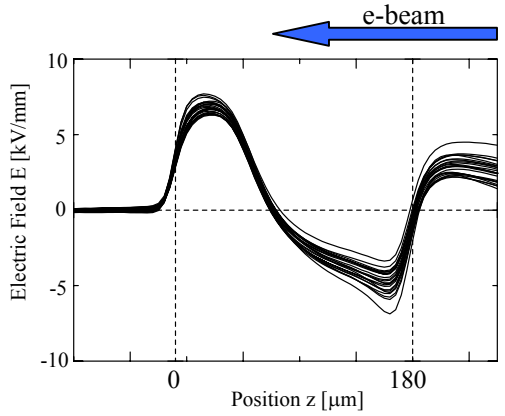

Figure 9. The Electric Field (after irradiation)

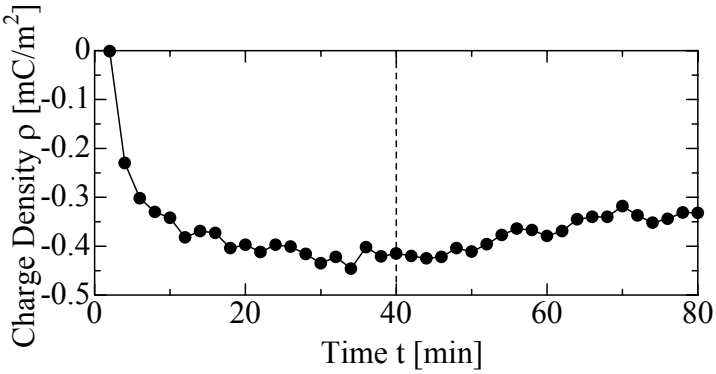

Figure 10. Amount of total charge (under and after irradiation)

Results and Discussion

Electron beam irradiated Kapton® of 180 μm thick

Figures 6 and 7 show the changes of charge distributions in 180 μm thick Kapton® under and after electron beam irradiation with acceleration energy of 125 keV in vacuum. This experiment was carried out using SIRENE. In these figures, the charge distributions of every 2 minutes are described. The electron beam is irradiated from right hand side in the Figs. As shown in Fig. 6, the negative charge gradually increases with increase of the irradiation time.

The peak of the negative charge is located around 120 μm from the irradiation surface described in right side in the figure. After irradiation, it is found that almost no changes are observed in this time range. Figures 8 and 9 show the electric field distributions that are obtained by integral calculation from the charge distributions shown in Figs. 6 and 7. As shown in Fig. 8, during e-beam irradiation, the electric field gradually increases with increase of the negative charge distribution. On the other hand, the electric field is stable after the irradiation as shown in Fig. 9. These results show the accumulated negative charge in Kapton® film may remains in the bulk for long time. Figure 10 shows the change of total amount of accumulated charge in Kapton® film under and after irradiation. The total amount of charge rapidly increases immediately after beginning of the irradiation. However, the change of it becomes stable soon and seems to be saturated. After irradiation, the amount of charge seems to keep the maximum value

Electron beam irradiated PET of 50 μm thick

Figures 11 and 12 show the changes of charge distribution in 50 μm thick PET film under and after electron beam irradiation with acceleration energy of 40 keV in vacuum. This experiment was carried out using small test chamber. As shown in Fig. 11, the negative charge gradually increases with increase of the irradiation time. In these results, the distributions of every 1 minute are described. It is clear that the injected electrons increases rapidly near the opposite electrode as shown in Fig. 11. The peak of the negative charge is located around 41 μm from the irradiation surface described in right side in the figure. After irradiation, it is found that the charge distribution gradually decreases as shown in Fig. 12. Figures 13 and 14 show the electric field distributions calculated using the space charge distributions shown in Figs. 11 and 12. As shown in Fig. 13, during e-beam irradiation, the electric field gradually increases with increase of the negative charge distribution. The maximum electric field finally becomes 100 kV/mm. After irradiation, the electric field distribution gradually decreases. Figure 15 shows the change of total amount of charge accumulated in PET film under and after irradiation. It is found that the total amount of charge gradually increases in irradiation process. After irradiation, however, it quickly decreases in this time range.

Since it is difficult to compare the results obtained from different samples, we do not mention the physical meaning of the results. However, it is clear that the developed measurement system seems to be useful for analysis of interaction between electron beam and dielectric materials.

Conclusion

We develop a measurement system of charge distribution in dielectric materials during electron beam irradiation in vacuum atmosphere. Using this system, we observed the change of charge distributions in Kapton® and PET films under and after electron beam irradiation. The developed measurement system seems to be useful for analysis of interaction between electron beam and dielectric materials.

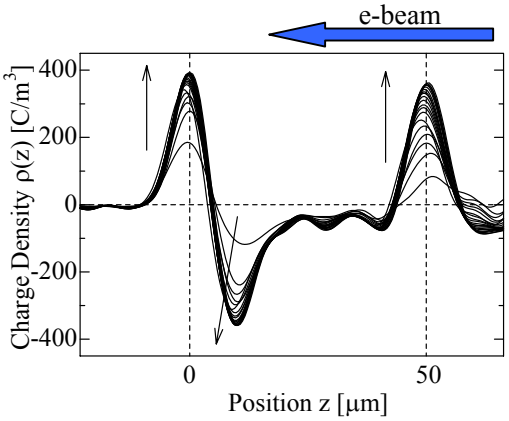

Figure 11 The Charge Density (under irradiation)

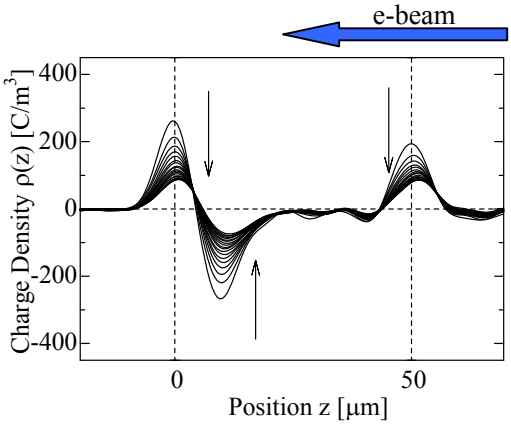

Figure 12 The Charge Density (after irradiation)

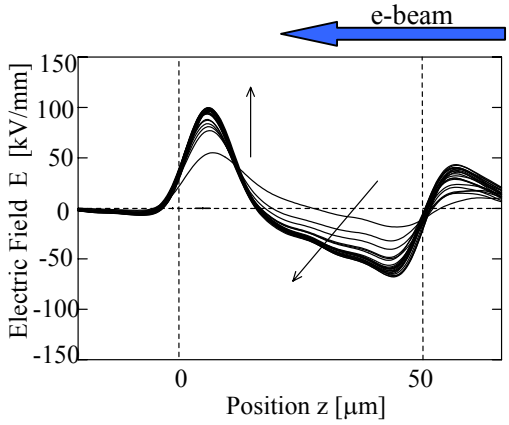

Figure 13 The Electric Field (under irradiation)

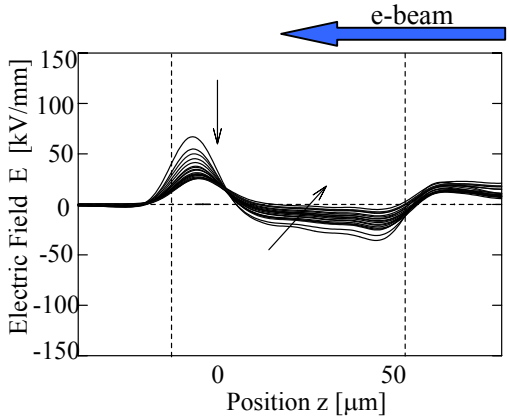

Figure 14 The Electric Field (after irradiation)

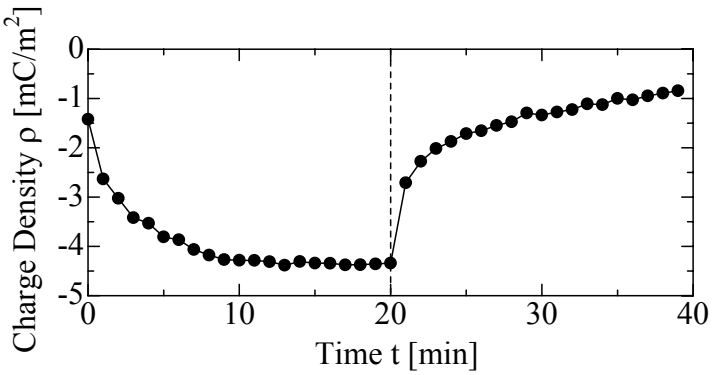

Figure 15. Amount of total charge (under and after irradiation)

References

1. T.Takada, Y.Tanaka, N.Adatchi, X.Qin "Comparison between the PEA Method and the PWP Method for Space Charge Measurement in Solid Dielectrics'' IEEE Transactions on Dielectrics and Electrical Insulation Vol.5, No.6

2. Y.Tanaka, R.Watanabe, N.Tomita and T.Takada "Measurement techniques for charging in bulk of insulating materials irradiated by radioactive rays'' 7th Spacecraft Charging Technology Conference, 2001