# OBSERVATION OF INTERNAL CHARGE BEHAVIOR IN ELECTRON BEAM IRRADIATED POLYMERS USING ACOUSIC METHOD

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## Abstract

Bulk charge accumulation in polymers 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 the electric potential have been reported. Some of them seem to be caused by discharge due to the charge accumulation in bulk of insulating materials at relatively higher altitude environment. However, there had been no useful method to measure the bulk charge in materials. On the other hand, we had developed the bulk charge measurement system for the polymeric insulation materials used in insulating materials of power cable. Therefore, we have applied this system to the polymers used in spacecraft. Using the improved system, we have observed internal charge behavior in Kapton® and PTFE films under electron beam irradiation in vacuum condition. It was found that an amount of accumulated charge in PTFE was much larger than that in Kapton®.

## Introduction

The spacecraft flying in GEO is always exposed to plasma and radioactive-rays such as α-, β- and γ-rays. In such condition, multilayer insulation materials are charged up. In the case of high-energy electron beam irradiation, electrons are injected into the bulk of polymers and they accumulate in them for long time. Sometimes the charge accumulation causes to the discharge with serious damage to the electric devices. Because there are no basic data based on the practical experiments, it seems to be difficult to simulate the accumulation and the relaxation process of the injected charge in polymers. In other words, it is difficult to expect when and how an accident of electrostatic discharge (ESD) caused by accumulated charge will happen on the spacecraft. Therefore, it is necessary to observe the internal charge behavior in an electron beam irradiated polymers. We have been developing a system for measuring such a charge distribution in polymers using, so-called, PIPWP (Piezo-induced pressure wave propagation) method [1]. Using this system, we measured the charge distributions in Kapton® and PTFE irradiated by electron beam to investigate the influence of charged particles on polymers.

## Principle of PIPWP Method

A schematic diagram for the principle of the PIPWP method is shown in Figure 1. An electric pulse voltage is applied to a piezo-electric transducer to generate a pulsive pressure wave. The pressure wave propagates through a charged sample, and then a position of charge shifts slightly. The movement of the charge induces the change of surface charge on electrods. Therefore, the displacement current flows through an external circuit due to the change of induced charge on the electrodes. Since the displacement current flows when the pressure wave passes through the charge layer, we can observe the charge distribution by measuring the time dependent signal of the external current. A detail of the principle is described elsewhere [1].

## Measurement Apparatus

A picture and a schematic diagram of the measurement apparatus are shown in Fig.2. The apparatus has the window for the irradiation of the radioactive rays to the sample. The sample is completely covered by the grounded shield to reduce the external electric noise. The glass plate has an evaporated electrode on the topside surface and it is connected to the detecting amplifier. To obtain the electric signal from the bottom side of the sample, a glass plate is inserted between the sample and the piezo-electric transducer. In other words, this glass plate is used to isolate the bottom side of the sample from the grounded level. To generate a pressure wave, a pulse voltage is applied to the piezo-electric transducer. In this experiment, the PVDF film with 4μm thick was used as the acoustic pulse generator. The pressure wave generated at the piezo-electric transducer propagates through the glass layer and then it arrives at the sample [2].

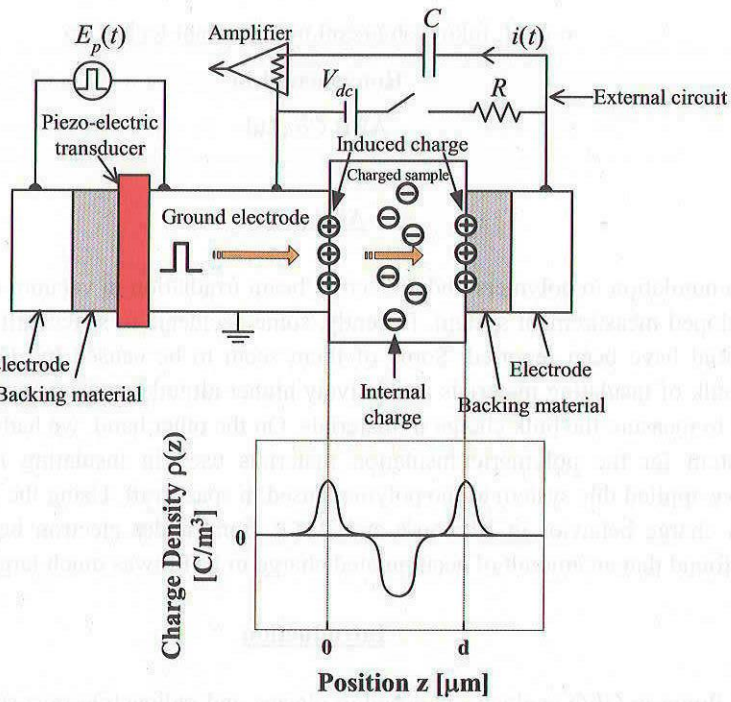


Figure 1. A schematic diagram for the principle of PIPWP method

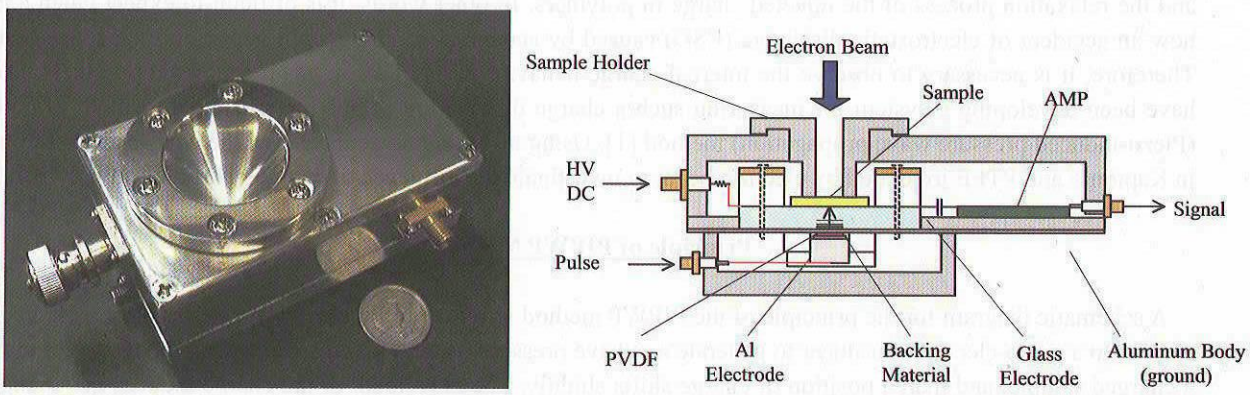


Figure 2. Picture and schematic diagram of the measurement apparatus

## Electron Beam Irradiation System

Figure 3 shows a picture and a schematic diagram of the electron beam irradiation system. The electron beam irradiation was carried out using a filament applied by the dc high voltage power supply in the vacuum condition of about $10^{-5}$ Pa. The sample is irradiated by the electron beam from the upper part of the measurement apparatus in the chamber [3].

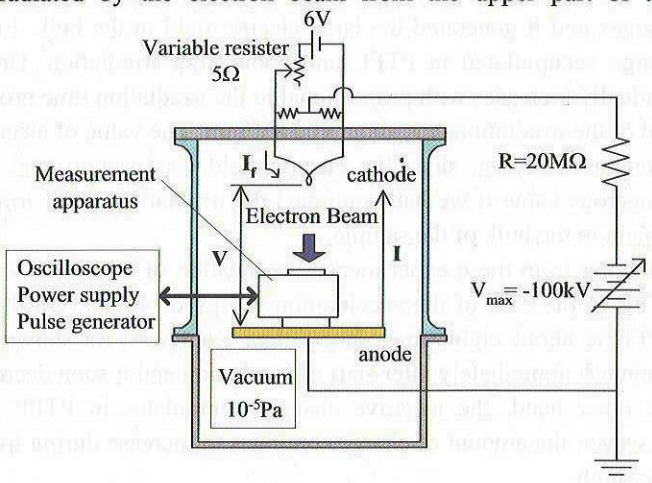


Figure 3. Picture and schematic diagram of the electron beam irradiation system

## Experimental Procedure

The samples used in the experiments are Polyimide (Kapton®) and PTFE with thicknesses of 50 and 42 μm, respectively. The samples were irradiated by the electron beam in vacuum with acceleration energy of 40 keV. The current density of the electron beam was about 80 nA/cm$^2$. The measurement was carried out with intervals of 30 seconds for 20 minutes during electron beam irradiation. After the irradiation, the decay process of the charge distribution was also measured under the short circuit condition with intervals of 30 seconds for 20 minutes.

## Results and Discussion

### Electron beam irradiated Kapton® film

Figures 4 and 5 show the charge and the electric field distributions in Kapton®, respectively. These figures show the results under irradiation and after irradiation in vacuum. In these figures, the distributions of every 30 seconds are described. The samples are irradiated by the electron beam from right hand side in the figures. As shown in Fig. 4a, the peak of the negative charge is located at about 10 μm from the irradiation surface. While the sample was continued to be irradiated by the electron beam, it was observed that the negative charge gradually decreases. After irradiation, as shown in Fig. 4b, there was no remarkable amount of charge remained in the bulk. Figures 5a and 5b show the electric field distributions calculated using the space charge distributions shown in Figs. 4a and 4b. As shown in Fig. 5a, during electron beam irradiation, the electric field gradually decreases with decrease of the negative charge distribution as shown in Fig. 4a. The maximum electric field was 25kV/mm which was observed just after the beginning of the irradiation. After irradiation, the value of the electric field was very small. Figure 6 shows the time dependent total amount of charge accumulated in Kapton® under and after irradiation. The total amount of charge means the total amount of negative charge accumulated by electron beam irradiation. It is found that the negative charge accumulates immediately under the electron beam irradiation, then it gradually decreases even when the irradiation goes on.

### Electron beam irradiated PTFE film

Figures 7 and 8 show the charge and the electric field distributions in PTFE, respectively. These figures show the results under irradiation and after irradiation in vacuum, respectively. The negative charge peak appeared at the depth of about 10 μm from the irradiation surface as shown in Fig. 7a. The peak finally reaches about -750

$C/m^3$. The electric field distributions shown in Figs. 8a and 8b were calculated using the charge distributions shown in Figs. 7a and 7b. As shown in Fig. 8a, the electric field gradually increases with increase of the amount of negative charge accumulation during electron beam irradiation. The maximum electric field intensity finally exceeded the value of 400 kV/mm. After irradiation, the charge and the electric field distributions gradually decrease. However, even 20 minutes after end of the irradiation, there still remained a large amount of negative charges and it generated the large electric field in the bulk. Figure 9 shows the change of the total amount of charge accumulated in PTFE under and after irradiation. Under the irradiation, the total amount of charge gradually increases with proportional to the irradiation time progress. The maximum electric field just before the end of the irradiation was about 400 kV/mm. The value of electric field is not so high compared with the electric strength. However, since the electric field was proportional to the irradiation time, it must soon become a dangerous value if we had continued the irradiation. After irradiation, a large amount of the injected electrons remain in the bulk of the sample.

Judging from these experiments, the location of the negative charge peak is almost the same in Kapton® and PTFE in the case of the acceleration energy of 40keV. On the other hand, the peak of the negative charge in PTFE is about eight times larger than Kapton®. As shown in Fig. 6, the negative charge accumulates in Kapton® immediately after start of irradiation and it soon decrease even under the electron beam irradiation. On the other hand, the negative charge accumulates in PTFE more slowly during electron beam irradiation. However, the amount of charge continues to increase during irradiation and emphasize the internal electric field very high.

## Conclusions

We developed a measurement system which is capable to measure the bulk charge in polymers in vacuum condition. To investigate the influence of the charged particle irradiation on the materials of spacecraft, we irradiated the electron beam to Kapton® and PTFE films and we observed the charge accumulation profiles in the bulk of them using the developed PIPWP system. It is found that the amount of the accumulated charge in PTFE is much larger than that in Kapton®. After irradiation, a large amount of charge remains in PTFE while that in Kapton® soon disappears. Since the electric field in PTFE generated by the accumulated electrons is very large, it must be danger if it is used as the insulating material of spacecraft.

## 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 Trans. DEI, Vol.5, No.6, pp.944-951, 1998

[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, p.411-416, 2001

[3] N.Osawa, S.Takahashi, Y.Tanaka, T.Takada, R.Watanabe and N.Tomita "Measurement of bulk charge in dielectric materials irradiated by electron beam in vacuum environment" 8th Spacecraft Charging Technology Conference, 2004

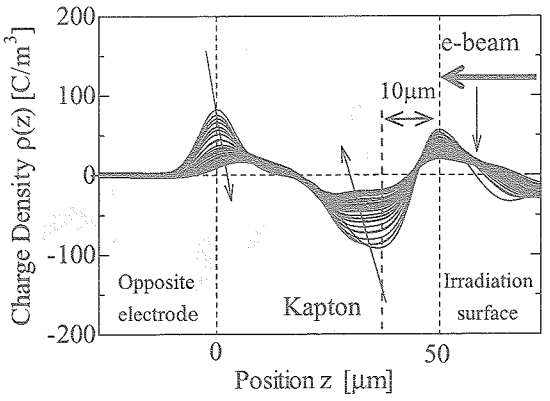


Figure 4a. Charge distribution in Kapton® under irradiation with 40 keV, 80 nA/cm$^2$

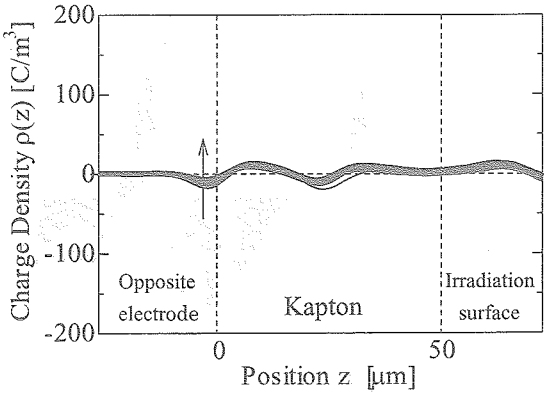


Figure 4b. Charge distribution in Kapton® after irradiation with 40 keV, 80 nA/cm$^2$

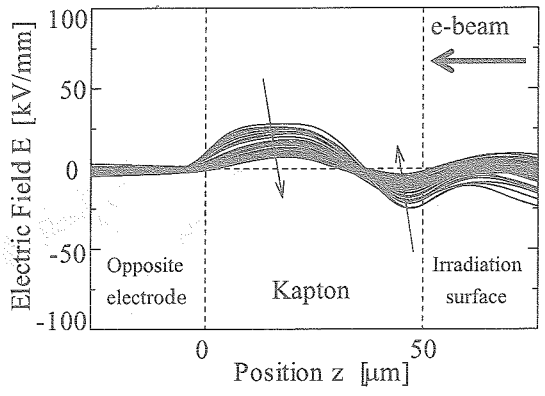


Figure 5a. Electric field distribution in Kapton® under irradiation with 40 keV, 80 nA/cm$^2$

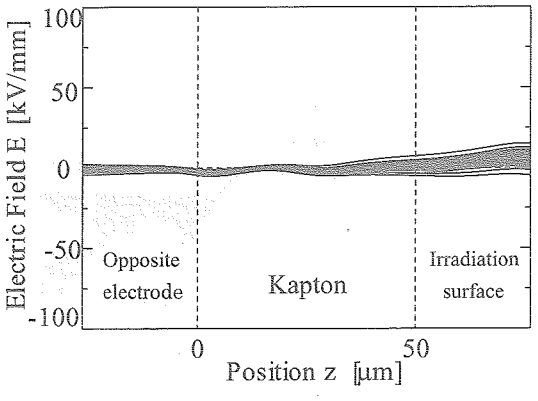


Figure 5b. Electric field distribution in Kapton® after irradiation with 40 keV, 80 nA/cm$^2$

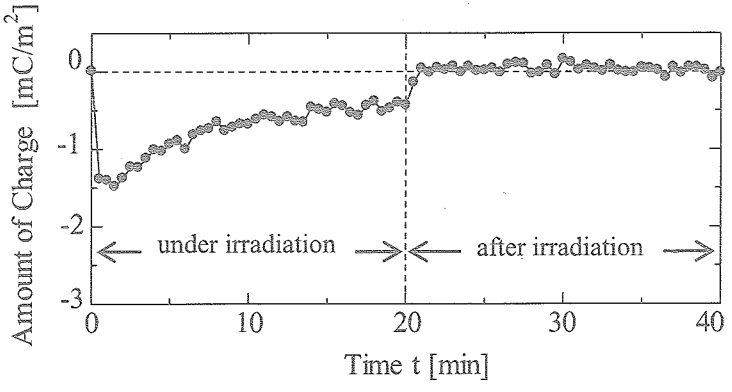


Figure 6. Amount of total charge in Kapton® irradiated with 40 keV, 80 nA/cm$^2$ (under and after irradiation )

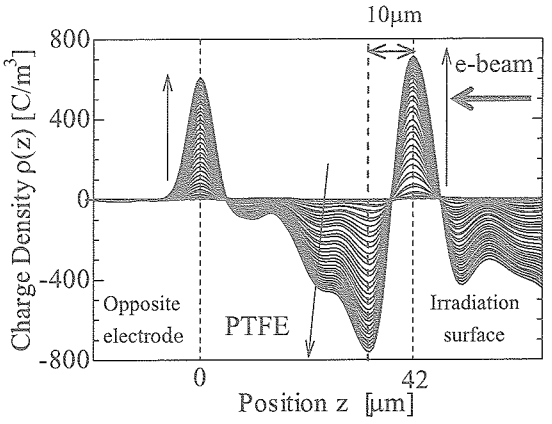


Figure 7a. Charge distribution in PTFE under irradiation with 40 keV, 80 nA/cm$^2$

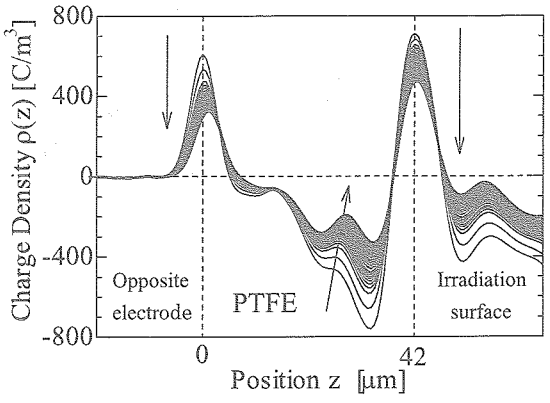


Figure 7b. Charge distribution in PTFE after irradiation with 40 keV, 80 nA/cm$^2$

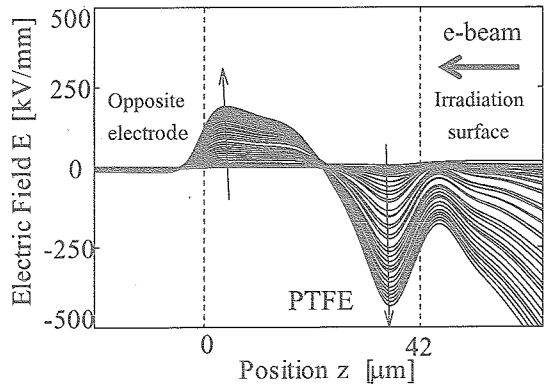


Figure 8a. Electric field distribution in PTFE under irradiation with 40 keV, 80 nA/cm$^2$

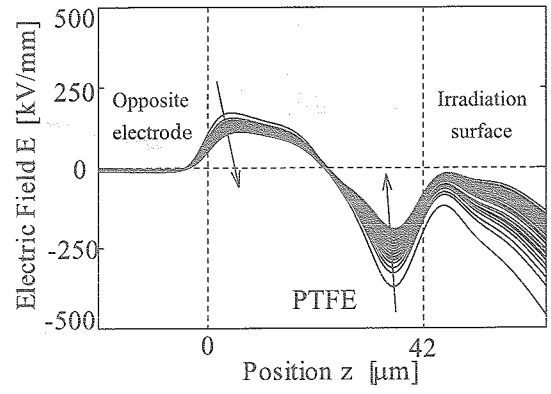


Figure 8b. Electric field distribution in PTFE after irradiation with 40 keV, 80 nA/cm$^2$

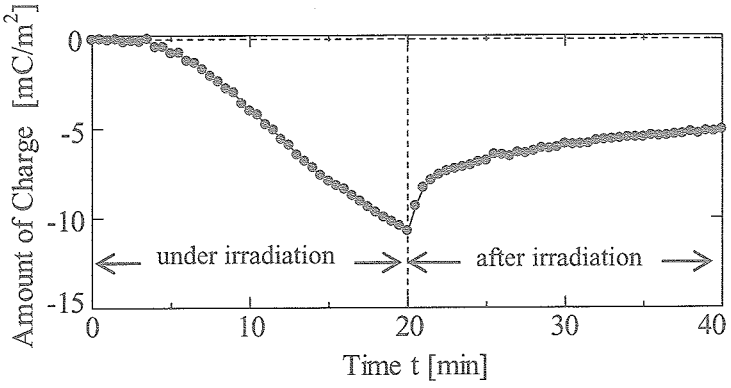


Figure 9. Amount of total charge in PTFE irradiated with 40 keV, 80 nA/cm$^2$ (under and after irradiation )