Abstract—From our previous work, the difference was observed by the remarkable space charge action by ETFE and FEP which irradiated with the electron beam. Since ETFE and FEP of the same fluoride sample were irradiated with the electron beam, and the space accumulation property under direct-current electric field classified by stage was measured by the PEA method in normal temperature atmospheric pressure after irradiation and this report estimated, it reports.

Keywords—fluoride, electron-beam, space charge accumulation

I. INTRODUCTION

Charge-discharge phenomenon is produced on surface materials of spacecraft, operated on the orbit where many charged particles of electrons and protons are exiting. Therefore, there is a risk of deterioration of a surface insulating material of the spacecraft and operation anomaly. Actually, the number of accident due to discharge phenomenon were reported [1]. So, it is necessary to investigate the electrical characteristics of the insulating materials for design of spacecraft. Therefore, many researches have studied about the charge-discharge phenomenon on various insulating materials. One of the typical research objects is polyimide films as a MLI (Multi layer insulator) and fluoride materials as a OSR (Optical Solar Reflector) and wire harness.

In general, when an insulating material is irradiated by high energy charged particles like electrons or protons, degradations of mechanical and electrical properties of the material are produced due to scission of molecular chains and generation of the defects. Especially, the degradation of electrical properties may affect the charge-discharge characteristics of the irradiated materials.

Now, the aim of our research is to investigate the electric characteristic on the irradiated samples, especially fluoride materials. In this paper, we focused on the space charge accumulation characteristics in the bulk of irradiated materials using Pulsed electro-acoustic (PEA) method. In this report, the space charge accumulating property under the DC step voltage application was investigated after irradiation.
device. The intensity and time distance of detected signal is proportional to the amount of accumulated charges and, position of each accumulated charges, respectively. Hereby it enables to know the space charge distribution. The detail of principle of PEA method were already described in previous literatures. [2][3][4]

The photograph of the equipment using PEA method which are used by us is shown in Figure 2.

III. ELECTRON IRRADIATION SYSTEM

The schematic diagram and photo of the vacuum chamber for electron irradiation is shown in Figure 3.

The degree of in the vacuum chamber can reach up to about \(1.0 \times 10^{-5}\) Pa. The electron beam irradiation was carried out in vacuum atmosphere of approximately \(2.0 \times 10^{-4}\) Pa. Since the top electrode of the chamber is connected to a DC high voltage power supply up to 100 kV, we can control the energy of e-beam up to 100 keV. The sample is irradiated by the electron beam from the upper part of the measurement apparatus in the chamber.

IV. EXPERIMENT PROTOCOL

A. MEASUREMENT SAMPLE

This experiment was carried out using two kinds of fluoride materials, such as ETFE and FEP. The material characteristics of those samples are shown in Table 1.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Density ([g/cm^3])</th>
<th>Thickness ([\mu m])</th>
<th>Molecular architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETFE</td>
<td>1.7</td>
<td>100</td>
<td>([\text{CF} - \mathbb{C}]_n \quad [\text{CF} - \mathbb{C}]_m \quad [\text{CF} - \mathbb{C}]_p )</td>
</tr>
<tr>
<td>FEP</td>
<td>2.2</td>
<td>100</td>
<td>([\text{CF} - \mathbb{C}]_n \quad [\text{CF} - \mathbb{C}]_m \quad [\text{CF} - \mathbb{C}]_p )</td>
</tr>
</tbody>
</table>

B. EXPERIMENT CONDITION

To understand the degradation phenomena, we measured space charge distribution in the bulk of irradiated samples under DC stress. Concerning the irradiation condition, the electrons was irradiated with energy of 60 keV and 40 nA/cm\(^2\) for 20 minutes. We measured space charge distribution immediately after electron irradiation using the PEA method at room temperature and air atmosphere. Concerning applying DC stress, at first, we prepared two kind of DC applying procedures which are as folows;

1. 100 kV/mm for 60 minutes.
2. 20-100 kV/mm for each 30 minutes with the incarnation of 20 kV/mm. The applying procedure is shown in Figure 5.

Before applying the electric field, the short circuit was measured every 5 min. A measurement interval is 5 seconds.

V. RESULT AND DISCUSSION

Two kinds of electron beam irradiated fluoride films, such as ETFE and FEP, used for OSR and insulation materials of wire harness are prepared to comprehend the electric characteristics. For consideration of the electric characteristics, space charge accumulation in those irradiated materials were measured by PEA method.

A. 100 kV/mm application on ETFE and FEP

The space charge distribution measurement under applied electric field 100 kV/mm after the irradiation of the electron beam and the space charge behavior shown in Figure 4 was observed. As shown in Figure 4, there is a remarkable difference of the space charge behavior in spite of the same fluoride material. We consider that in the ETFE, the electron-hole pair generated by the electron beam irradiation has accumulated both positive-negative charges, and in the FEP, the charge injection from an electrode has accumulated the electric charges. Since the high electric field was applied after irradiation, the result of Figure 4 has shown merely a rapid change.

B. 20 -100 kV/mm appliacitn on ETFE

The measurement result of irradiated sample and non-irradiation sample of ETFE are shown in Fig. 5.

From figure 5-(a), we could not observe any significant change in the bulk of non-irradiated sample.

From figure 5-(b), we observed both of positive and negative charges in the bulk of irradiated sample immediate after 20 kV/mm DC application.
Furthermore, when we applied 20 kV/mm to the irradiate sample, induced positive charges were observed at both electrodes. Normally, we observed negative induced charge at the cathode when we applied positive DC electric field. However, from this result, we obtained positive induced charge at cathode. It is considered that the negative induced charge produced due to applying DC field are compensated by the induced charge produced due to the large amount of accumulated negative charges by irradiated electron. And the positive induced charge at cathode gradually decreased and changed to the opposite polarity in the voltage application progress.

Furthermore, when 40 and a 60 kV/mm electric field were applied, the accumulated negative charges in the bulk also decreased in the voltage application progress. It is thought that the reason of the negative charges decrease is due to positive charges injection from the anode.

We considered the charge model of accumulated charge behavior as shown in Figure 5-(c).

In case 1, it is thought that there may be a lot of electron-hole pair in irradiation region. The Holes were drifted from the electron-hole pair generated region toward negative charge accumulated position in the middle of bulk. The negative accumulated charges are compensated by those drifted holes. Furthermore, additional holes are injected from anode to the rack region of holes between the position of accumulated negative charge in bulk and anode.

In case 2, holes are injected and drifted toward accumulated negative charges by applying electric field directly, and those negative charges are compensated by the injected charges.

Figure 4. ETFE after electron irradiation, and the difference in the space charge accumulating property of FEP

Figure 5. The measurement result of a non-irradiated sample and an irradiated sample in ETFE irradiated by an e-beam with the energy of 60 keV and 40 nA/cm² under DC step voltage application
C. 20 -100 kV/mm application on FEP

The measurement result of irradiated sample and non-irradiated sample of FEP are shown in Figure 6.

Concerning the non-irradiated sample, from figure 6-(a), we could not observe any significant change in the bulk of non-irradiated sample. This result is same as non-irradiated ETFE. In the non-irradiated sample, accumulation of the electric charge inside the sample by the charge injection from an electrode, etc. was not observed. From figure 6-(b), we observed only positive charge injection from the anode at the 60 kV/mm application.

From the comparison between the FEP and ETFP results, I think that the most particular difference is whether an electron-hole pair is generated. This may indicate the followings,
(1) The electron hole pairs are not produced
(2) Although electron hole pairs are produced, those are recombined immediate after generation.

However, as the above description is one of prediction, further investigations are required for the phenomena.

VI. CONCLUSION

We measured the space charge distribution in the bulk of fluoride samples irradiated by an electron. From the results, electric property of irradiated samples were changed compared with non-irradiated samples. In particular, the hole-electron pair was produced in the bulk of ETFE by an electron irradiation.

REFERENCES


Figure 6. The measurement result of a non-irradiated sample and an irradiated sample in FEP irradiated by an e-beam with the energy of 60 keV and 40 nA/cm² under DC step voltage application.
13th Space Charging Technology Conference

Space Charge Accumulation Characteristics of Electron Beam Irradiated Insulating Materials under DC High-Electric Stress

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Measurement and Electric Control Laboratory, Tokyo City University
Tokyo, Japan
June. 27, 2014
Spacecraft

Spacecraft is used under the severe environment of a temperature change (From -121 °C to +121 °C)

It is necessary to keep constant a temperature inside the spacecraft

Insulating material

- Multi-layer insulation (MLI) ➞ Polyimide insulating material
- Optical solar reflector (OSR) ➞ Fluoride insulating material

The universe is filled with...

- High energy charged particle
- Plasma
Spacecraft surface is charged up to about \(-10\) kV


<table>
<thead>
<tr>
<th>Material thickness</th>
<th>25 (\mu)m</th>
<th>50 (\mu)m</th>
<th>100 (\mu)m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric field</td>
<td>-400 kV/mm</td>
<td>-200 kV/mm</td>
<td>-100 kV/mm</td>
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There is danger of an electric breakdown

Lead to a spacecraft accident

Electrical properties of insulating materials are very important
Introduction

Spacecraft surface is charged up to about $-10$ kV


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</table>

Viewpoint from space charge distribution

We have investigated the charge action inside a sample using the PEA method

Lead to a spacecraft accident

Electrical properties of insulating materials are very important
We have done space charge distribution measurement of the electron irradiated sample by the Pulsed-Electro Acoustic (PEA) method.

**Step 1**
After electron beam irradiation (*already done*)

**Step 2**
Under electron beam irradiation (*already done*)
   ➡ Imitation of environment

**Step 3**
After electron beam irradiation + DC high voltage application
   ➡ Simulation of surface charging

**GOAL**
Under electron beam irradiation + DC high voltage application
   ➡ Simulation of *real situation* environment + surface charging
Introduction

We have done space charge distribution measurement of the electron irradiated sample by the Pulsed-Electro Acoustic (PEA) method.

**Step 1**
After electron beam irradiation *(already done)*

**Step 2**
Under electron beam irradiation *(already done)*

➡ Imitation of environment

**Step 3**
After electron beam irradiation + DC high voltage application

➡ Simulation of surface charging

**Assumption**

The case that the charged spacecraft surface was irradiated an electron beam.
Principle of the PEA method

The deformation are generated by a pulsed coulomb force
\[ f(t) = \rho e_p(t) \]

Charge signal on DSO

Time [ns]

Charge signal on DSO
**PEA system can obtain the time dependent charge distribution**

- This PEA system can obtain with the time interval of 30 sec.
**Experimental condition**

**Irradiation condition**
- e-beam irradiation
- $E = 60\, \text{keV}$
- $J = 40\, \text{nA/cm}^2$
- ETFE or FEP 100 $\mu\text{m}$ brass

**Measurement condition**
- Irradiation surface
- Anode (SC)
- Cathode (Al)
- Irradiated ETFE or FEP
- Electric field 100 $\text{kV/mm}$

- DC HV: 10 $\text{kV}$
- Measurement of space charge distribution

- Time [min]: 20, 10, 60, 10
**Measurement result**

**Non-irradiated sample**

**ETFE & FEP**

No charge accumulation inside both samples

These are **excellent insulating material**
Measurement result ~ ETFE ~

**Irradiated sample**

- **Space charge**
  Electron-hole pairs generated by the electron beam irradiation

- **Electric field**
  Partial electric field emphasis was observed

**About 1.7 times!!**

Integration
**Measurement result ~ FEP ~**

**Irradiated sample**

- **Space charge distribution**
  Positive charges which are injected from the anode have accumulated inside the bulk

- **Electric field**
  Partial electric field emphasis was observed

**About 1.7 times!!**

![Integration](image)
High electric field was applied after e-beam irradiation

⇒ The result has shown merely a rapid change

In order to investigate the charge action inside a sample, *the electric field rise experiment* was conducted
Experimental condition

**Irradiation condition**
- e-beam irradiation
- $E = 60 \text{ keV}$
- $J = 40 \text{ nA/cm}^2$
- ETFE or FEP
- 100 µm
- brass

**Measurement condition**
- Measurement of space charge distribution (DC step)
- Irradiation surface
  - 20~100 kV/mm
- Anode (SC)
- Cathode (Al)
- Time [min]
  - 20
  - 10
  - 175
- 20 kV/mm
- 40 kV/mm
- 60 kV/mm
- 80 kV/mm
- 100 kV/mm
- short

**Experimental details**
- ETFE or FEP
- Irradiated ETFE or FEP

**Measurement condition**
- 20 kV/mm
- 40 kV/mm
- 60 kV/mm
- 80 kV/mm
- 100 kV/mm

**Experimental setup**
- Anode (SC)
- Cathode (Al)
- Irradiation surface
- Time [min]
  - 20
  - 10
  - 175

**Irradiation conditions**
- $E = 60 \text{ keV}$
- $J = 40 \text{ nA/cm}^2$
Charges accumulation inside the bulk was not observed.

**Irradiated sample**

Accumulation of positive charges was observed by both electrodes.

**How is the variation of electric field?**
Measurement result ~ETFE~

Remarkable electric field emphasis

Over 3 times!!

Spacecraft Charging Technology Conference 2014 - 191 Viewgraph
Measurement result ~ETFE~

Irradiated sample

40, 60 kV/mm
Injection of the positive charges from the anode was observed

we considered the charge model of accumulated charges behavior

Non-irradiated sample

irradiated sample
Measurement result ~ETFE~

After e-beam irradiation

- Accumulation of negative charges inside the sample
- Electron-hole pairs generated

[Diagram showing electric field, position, and time with observations]
Measurement result ~ETFE~

**Applied electric field (40 and 60 kV/mm)**

**Case 1**
Holes were drifted toward negative charge accumulated position
- Holes are injected from the anode

**Case 2**
holes are injected and drifted toward accumulated negative charges directly

Negative charges may have been *decreased* by these phenomena
Charges accumulation inside the bulk was not observed.

**Irradiated sample**

*Only injection* of the positive charge from the anode was observed by raising an electric field.

The injection barrier level on the surface of a sample fell by e-beam irradiation.
**Conclusion**

When applying an electric field to the electron beam irradiated sample

1. **Remarkable space charges accumulation**
2. **Electric field emphasis** (1.7~3 times)

It could lead to *electric breakdown*

**Future**

The experiment under the environment that imitated more realistic space environment

Ex) Under electron beam irradiation + DC high voltage application
Thank you for your attention

If you have a question, please give me the question **slowly & easily**
Contents

investigation of the space charge distribution in the bulk of fluoride samples

Non-irradiated sample
ETFE & FEP
⇒ No charge accumulation inside the bulk

Irradiated sample
ETFE
1. Hole-electron pair was generated by an electron irradiation
2. Holes are injected from the anode
3. Holes were drifted toward negative charge

FEP
Only positive charge injection from the anode
Detail of Samples

Molecular structure

\[
\begin{align*}
F & \quad F \\
C & \quad C \\
F & \quad F
\end{align*}
\]

\[
\begin{align*}
H & \quad H \\
C & \quad C \\
H & \quad H
\end{align*}
\]

\[
\begin{align*}
F & \quad F \\
C & \quad C \\
F & \quad CF_3
\end{align*}
\]

Spacecraft Charging Technology Conference 2014 - 191 Viewgraph
**Principle of the PEA method**

**Pulsed Electro-Acoustic (PEA) method**

Pulsed voltage is applied to a sample

A pressure wave occurs by the small displacement of an electric charge

It changes into an electrical signal by a piezoelectric device

It observes with an oscilloscope

It is detected a "quantity" charge, and exists "where" in a sample (the thickness direction)