Charging Characteristics of Cover Glass on Solar Cell Due to Electron Beam Irradiation

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Abstract—Solar arrays of a spacecraft are exposed to space plasma. Space plasma induces electrostatic charging on the solar array and the charging is possible to cause electrostatic discharge (ESD). It is pointed out that the ESD may trigger sustained arcing discharge on the array. So, it is important to investigate the charging characteristics of solar cell’s cover glass as an insulating material on solar array under space plasma condition.

In order to investigate the characteristics, we used a low energy electron beam irradiation method. Electron beam with various energies lower than 10 keV was irradiated to a cover glass or a cover glass adhered with silicone RTV on a metal plate. The surface potential and the bulk current during electron irradiation were measured and the decay of the surface potential after electron irradiation was also measured for long time. From these experimental results, the volume resistivity and secondary electron emission properties were discussed.

The influence of the illumination of vacuum ultra-violet light on the charge-up of the cover glass was also investigated and discussed.

Keywords—cover glass; electron beam irradiation; surface potential; volume resistivity; UV illumination

I. INTRODUCTION

Spacecraft charging problems appeared about 30 years ago [1]. After that, researches and developments for the spacecraft charging technology were extensively conducted [2, 3, 4]. As the results, satellite systems reliable to the spacecraft charging have been developed and operated in space. In these R&D’s for the spacecraft charging technology, the protection against the surface charging on satellites was the main subject. However, in 1997 TEMPO-2 satellite was troubled on the geostationary orbit [5]. The electric power of the satellite was supplied in 100 V. From the investigation of the accident, the possibility of arcing discharge at the high voltage terminal between the solar cell strings was pointed out [6]. Since then investigations have been conducted in order to make the arcing discharge mechanism leading to detrimental failure of satellites clear [7]. However, it seems that the mechanism to progress from charge-up to discharge initiation causing arcing discharge is not yet clear.

From these viewpoints, we intended to make the mechanism clear by investigating charging characteristics of solar cell’s cover glass as one of insulating materials by means of electron beam irradiation method and to reflect the results to the solar array design for future high-power satellites. As a first step of our investigation, solar cell’s cover glass for space use was used as a sample. We conducted the electron beam irradiation experiments which measured the surface potential of the cover glass under various condition and the possibility of the ESD occurrence was investigated.

This paper describes the experimental results and the discussion.

II. EXPERIMENTAL PROCEDURE

A. Samples

Figure 1 shows the sample configurations for the cover glass. The cover glass tested was 0.5 mm thick CMX of the size of 65 x 50 mm². Thin AR layer was formed on the front surface of the cover glass. One sample shown in Fig.1(a) was used in order to evaluate the characteristic of the cover glass itself. So, thin aluminum layer was deposited on the rear surface of the glass and the cover glass was adhered on a 1 mm thick aluminum plate with conductive Ag paste. Another sample shown in Fig.1(b) imitated the cover glass adhered on a solar cell. Adhesives between the cover glass and the 1 mm thick aluminum plate was an insulating silicone RTV (Dow Corning Toray, SE 9186 clear) which is not for space use. The thickness of the silicone RTV was adjusted to 0.1 mm.

B. Experimental Procedure

Figure 2 shows the experimental setup for electron beam irradiation. After setting one sample shown in Fig.1 in the vacuum chamber, the chamber was evacuated to the pressure lower than 1.3x10⁻⁴ Pa by a rotary pump and a turbo-molecular pump. Under the pressure condition, electron beam was irradiated to the sample with the energy E (keV) and the current density J₀ (nA/cm²) for 60 minutes.
The surface potential of the sample during and after electron beam irradiation was measured with a non-contacting electrostatic voltmeter (TREK, 341B) by moving the probe (TREK, 3451E) over the sample keeping the distance of 3-5 mm from the sample surface. The current through the bulk of the sample was also measured with a pen recorder (Yokokawa, LR-8100) having the internal resistance of 1 MΩ.

In this experiment, the beam energy $E$ lower than 7 keV was used. In the case of the electron irradiation with $E$ lower than 5 keV, the electron acceleration potential was -5 kV constant, and the sample holder was biased to the negative potential $V_b$ (kV) by a DC power supply (Kikusui Electronics, PAD 1K-0.2L). By this way, the energy of the electrons irradiated to the sample became $E = 5 + V_b$. In the case of $E < 5$ keV, however, no bulk current was measured. Besides, the beam current density $J_b$ was adjusted at the electron energy $E = 5$ keV. After the adjustment of $J_b$, the sample was biased by negative potential $V_b$ and then the electron beam irradiation was started.

The sample was set between two 1 mm thick aluminum plates. The aluminum plate is the size of 100 x 100 mm². To the aluminum plate on the electron irradiation side, the rectangular aperture of the size of 50 x 36 mm² was open. So the electron beam irradiated area of the sample was 18 cm².

All experiments were carried out at room temperature.

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

A. 0.5 mm Thick CMX Cover Glass

At first, we describe the results of the experiments carried out in order to obtain the properties of 0.5 mm thick CMX cover glass itself.

Figure 3 shows the time dependences of the surface potential and the bulk current during electron irradiation under the condition of $E = 7$ keV and $J_b = 0.10$ nA/cm². The surface potential negatively increased with time and saturated to about -90 V. This value is very low compared with that of an insulating polymer [8]. On the other hand, the bulk current rapidly decreased with time and then became nearly constant. Next Fig.4 is the time dependences of the surface potentials of the cover glass irradiated with various electron energies $E$ lower than 7 keV at $J_b = 0.1nA/cm^2$. In this figure, we can see that in the cases of $E = 5$ keV and 7 keV the negative charging occurred, but in the cases of $E$ lower than 4 keV the cover glass positively charged up and the saturated potential is very high. Figure 5 shows the electron energy dependence of the surface potential of the 0.5 mm thick CMX irradiated with $J_b = 0.1$ nA/cm² for 60 minutes. The saturated surface potential largely depends on the electron energy $E$. And the negative charging occurred in the case of electron irradiation with $E$ higher than 7 keV.
4.5 keV and the positive charging was formed in the case of electron irradiation with $E$ lower than 4.5 keV. It seems that this energy $E = 4.5$ keV is the energy at which secondary electron emission yield becomes one [8].

Next we describe the experimental data obtained from the charge decay characteristics after stopping electron irradiation for 60 minutes. Figure 6 shows examples of the decay of the surface potential of CMX.

In general, the decay of the surface potential $V_s$ of the charged insulator is expressed by the next equation.

$$V_s = V_{s0} \cdot \exp \left( -\frac{t}{\tau} \right),$$  (1)

where $V_{s0}$ is the initial surface potential, $t$ the time after electron beam stopping, and $\tau$ the decay time constant. And $\tau$ is expressed as follows.

$$\tau = \varepsilon_0 \varepsilon_r \cdot \rho_v,$$  (2)

where $\varepsilon_0$ is the permittivity in vacuum ($= 8.9 \times 10^{-12}$ F/m), $\varepsilon_r$ the dielectric constant of the material, and $\rho_v$ the volume resistivity of the material.

In order to obtain the volume resistivity $\rho_v$ of the CMX using the equations (1) and (2), we measured the dielectric constant $\varepsilon_r$ by a LCR meter (Agilent U1733C). We obtained the result that the value of the dielectric constant is $\varepsilon_r = 9$. By the way, the decay shown in Fig.6 was very fast in the time region shorter than about 10 minutes and then became slow. In the negative charging in $E = 7$ keV the surface potential changed to the positive potential at about 50 minutes. So we used the decay time constant $\tau$ obtained from short time region. We calculated the volume resistivity of CMX cover glass from the equation (2) using the $\varepsilon_r = 9$ and the experimentally obtained decay time constant $\tau$. The electron energy dependence of the volume resistivity $\rho_v$ is shown in Fig.7. This figure shows that the volume resistivity is almost constant and the value is about $5 \times 10^{12}$ $\Omega$m irrespective of the electron energy.

**B. 0.5 mm Thick CMX Cover Glass on 0.1 mm Silicone RTV**

Next we explain the experimental results of 0.5 mm thick CMX cover glass on 0.1 mm thick silicone RTV (0.5 mm thick CMX/ Silicone).

Figure 8 shows the time dependences of the surface potential and the bulk current during electron irradiation under the condition of $E = 7$ keV and $J_b = 0.12$ nA/cm$^2$. The surface potential negatively increased with time and saturated to about -4500 V. This saturated potential is very high compared with that of 0.5 mm thick CMX shown in Fig.3(a). The bulk current rapidly decreased with time and then became nearly constant. Next Fig.9 shows the time dependences of the surface potential of the 0.5 mm thick CMX/ Silicone irradiated with various electron energies $E$ lower than 7 keV at $J_b = 0.1$ nA/cm$^2$. In this figure, we can see that in the cases of $E$ higher than 3 keV the negative charging occurred and the saturated surface potential are very high compared with 0.5 mm thick CMX. On the other hand, in the cases of $E$ lower than 2 keV the sample charged up positively but the saturated potential was almost similar to the cases of 0.5 mm thick CMX. Figure 10 shows the electron energy dependence of the surface potential of the
0.5 mm thick CMX/ Silicone irradiated with $J_b = 0.1 \text{ nA/cm}^2$ for 60 minutes. Figure 11 shows examples of the decay of the surface potential of the 0.5 mm thick CMX/ Silicone. We can see that the decay is very slow compared with the case of CMX.

From this figure we calculated the decay time constant. The results are shown as a function of the electron energy in Fig. 12. In this figure, two decay time constants are shown. Short_Term means the time region shorter than 300 minutes and Long_Term means the time region longer than 1000 minutes.
minutes. In Fig.13 we compared the decay time constant of the CMX/Silicone with that of CMX. The decay time constant of the CMX/Silicone is large about double figures. This means the volume resistivity of the silicone RTV is about $10^{14} \Omega \cdot m$.

So the negative charging in 0.5 mm thick CMX/Silicone is controlled by the volume resistivity of the silicone RTV. On the other hand, it seems that positive charging due to electron irradiation with the energy $E$ lower than 2.5 keV is affected by the AR layer coated on the CMX glass.

### C. Influence of Vacuum UV Illumination

We examined the influence of vacuum UV illumination on the charging of the CMX/Silicone due to electron beam irradiation. UV light was irradiated to the sample at an angle of 45 degree. Figure 14 shows the time dependence of the surface potential of 0.5 mm thick CMX/Silicone during electron irradiation. In the case of $E = 4$ keV electron irradiation, the sample was also illuminated with UV light, irradiating with electron beam for 60 minutes. The surface potential was about +300 V constant, although the surface potential in the case of $E = 4$ keV saturated to about -1600 V as shown in Fig.9. This means that a lot of electrons are emitted from the surface due to photo-electron emission effect. On the other hand, in the case of $E = 5$ keV, the illumination of UV light was continued for 30 minutes. After stopping the illumination the surface potential rapidly increased to about -2600 V. This means that photo-electron emission effect ceased at 30 minutes.

### IV. Conclusion

We investigated the charging characteristics of solar cell’s cover glass, 0.5 mm thick CMX which was AR coated, due to electron beam irradiation with the energy lower than 7 keV. The obtained results are as follows.

1. The volume resistivity of the CMX glass was obtained as about $5 \times 10^{12} \Omega \cdot m$ from the charge decay characteristics after electron beam irradiation.

2. The 0.5 mm thick CMX negatively charged up in the case of electron irradiation with the energy higher than 4.5 keV. On the other hand, the CMX positively charged up in the case of the electron energy lower than 4.5 keV. So, it seems that this electron energy, 4.5 keV, is the energy at which secondary electron emission yield becomes one.

3. The 0.5 mm thick CMX adhered with an insulating silicone RTV charged up to higher level than the CMX itself. The characteristic is remarkable in the case of electron irradiation with higher energy. And in the CMX adhered with silicone the electron energy at which secondary electron emission yield becomes one is about 2.5 keV.

4. The negative charging of CMX adhered with silicone RTV due to high energy electron beam irradiation is controlled by the volume resistivity of the silicone RTV. The CMX positively charged up in the case of the electron energy lower than 4.5 keV. So, it seems that this electron energy, 4.5 keV, is the energy at which secondary electron emission yield becomes one.

5. Illumination of UV light during electron beam irradiation largely affected the charging level of the CMX due to photo-electron emission effect.

### References


