Preliminary ESD Ground Tests on Meter-Class Solar Panels in Simulated GEO Environments

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Abstract

Preliminary ESD ground tests with two meter-class solar panels were conducted in a simulated GEO environment. The results indicated that the plasma propagation velocity was approximately 10^4 m/s, and the plasma propagation length was greater than 2.8 m. The neutralization current decreased with an increase in the distance from the arc spot.

1. Introduction

In recent years, satellite losses have occurred because of power system failures resulting from spacecraft charging/discharging phenomena [1]–[3]. Hence, electrostatic discharge (ESD) in solar array panels is an important issue related to satellites.

A so-called primary arc might occur at a triple junction on a solar panel if the electric potential of the cell coverglass is higher than that of the spacecraft ground [1]. The plasma generated by the primary arc propagates throughout the solar array and neutralizes the charge stored on the coverglass. Therefore, plasma propagation length and velocity are important for estimating the discharge current waveforms on the solar arrays. ESD ground tests have been conducted in several research institutes to investigate the plasma propagation velocity [4]–[6]. However, the plasma propagation length has not been fully understood. Although the plasma propagation length has been estimated as 3–4 m [7], it has not been confirmed through laboratory experiments because it is difficult to use a large-scale solar panel.

The space plasma chamber used in these experiments is located at the Institute of Space and Astronautical Sciences (ISAS) of the Japan Aerospace Exploration Agency (JAXA). Figure 1 illustrates the space plasma chamber used in this study. The chamber has a diameter of 2.5 m and length of 4 m. Accordingly, the chamber enables us to perform the ESD ground tests with a large solar array panel with a surface area larger than 1 m^2.

Preliminary ESD ground tests using two meter-class solar array panels were conducted in a simulated geosynchronous-earth-orbit (GEO) environment. The tests were designed to investigate the plasma propagation length and velocity. The results of the tests are described herein.

2. Experimental Setup

Figure 2 presents a photograph of the two meter-class solar array panel used in this study. This

Fig. 1. A photograph of the space-plasma chamber in ISAS/JAXA.

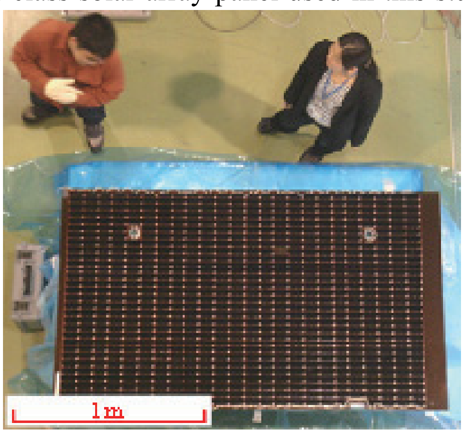


Fig. 2. A photograph of a solar array panel used in this study.

panel consisted of more than 700 solar cells arranged in 24 strings. There were 30–31 cells in a string, which were connected in series by inter-connectors. The panel was 1.77 m long and 1.10 m wide. The solar cell was a triple junction (TJ) cell with a bypass diode. The surface area of the cell was 37 mm × 76 mm. The coverglass thickness was 0.1 mm.

Figure 3 depicts the experimental apparatus. The two panels were placed in a vacuum chamber. Two electron beam guns were mounted at the chamber. These guns were used to simulate GEO environment. These can generate 50 keV electron beams with a maximum current of 200 μA. Two aluminum foils were used to expand the irradiation area of the electron beam. The thickness of the aluminum foils was 100 nm.

Figure 4 illustrates the experimental circuit. The circuit was connected to the solar array via a high voltage feedthrough. A high-voltage power supply biased the panels to a negative potential. The P- and N-electrodes of all the solar cell strings were mutually connected. The current probes were attached to six independent strings among the 48 strings on the panels. These independent strings have been referred to as ST1, ST2, ST3, ST4, ST5, and ST6. Strings ST1 and ST6 were located at both ends of the panels. The distance between the respective strings is indicated in Fig. 4. In addition to ST1–ST6, other strings were bundled together. They have been collectively referred to as ST7. Another current probe was attached to ST7. The current arc that occurred on a string has been referred to as the "arc current." Negative current flows in other strings have been referred to as the "neutralization currents." The bias voltage of the panel was measured using a voltage probe.

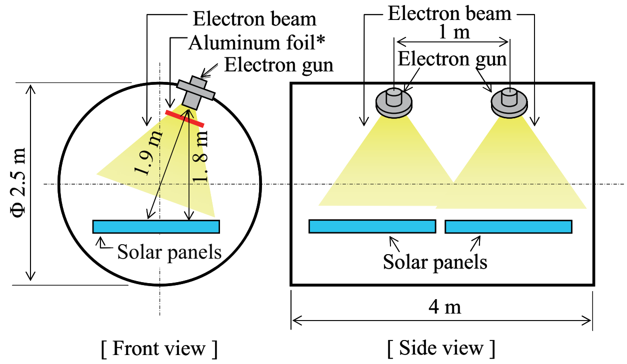
Table 1 presents the experimental conditions. The pressure in the vacuum chamber was maintained at 4.0×10^{-4} Pa. The two solar array panels were biased at –5 kV by a high-voltage supply. The acceleration voltage of the electron guns was fixed at 8.5 kV.

3. Results and Discussion

The confirmed plasma propagation length and velocity based on the neutralization currents

Figure 5 presents the typical current waveforms. The abscissa axis depicts the time; the ordinate axis depicts the current. The time at which the arc discharge started was defined as the null time. Figure 5 depicts the case wherein an arc occurred at ST5. The arc current passing through ST5 lasted approximately 400 μs. The neutralization currents passed through strings ST1–4, and these currents decreased with an increase in the distance from the arc spot. It is noteworthy that the neutralization current passed through ST1 even though ST1 was located as far away as 2.83 m from ST5. The result indicates that the plasma propagation length is inferred to be longer than 2.8 m.

The plasma propagation velocity was calculated based on the test result obtained from Fig. 5. The calculation result is presented in Table 2. The velocity was approximately 10^4 m/s, and it was approximately equal to other research results obtained with small coupon panels [4]–[6].



* Al foil was used to expand the irradiation area of electron beam.

The experimental setup.

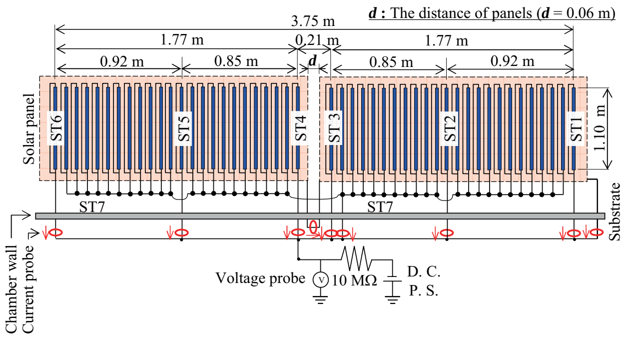


Fig. 4. The experimental circuit used in this study.

Table 1 Experimental conditions.

Pressure	4.0×10^{-4} Pa
Panel bias voltage	-5 kV
The acceleration voltage of electron guns	8.5 kV

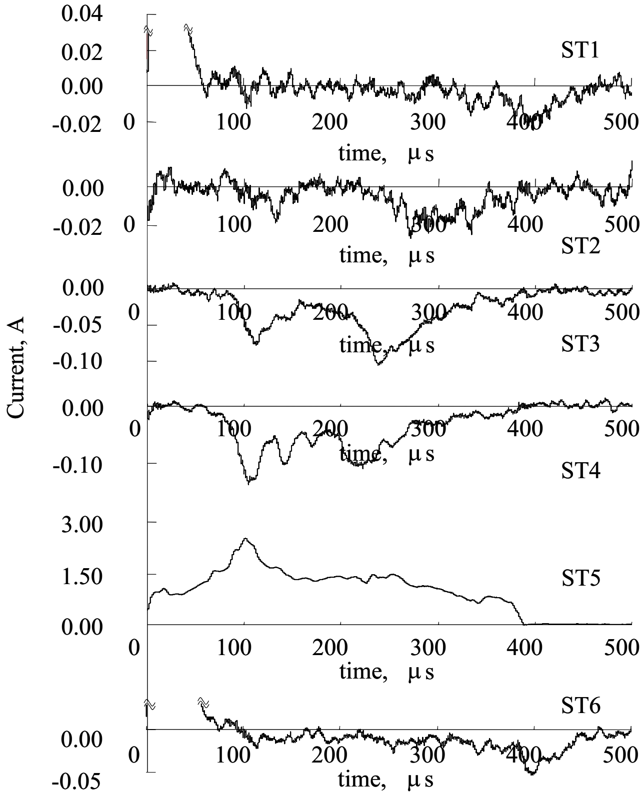


Fig. 5. The typical current waveforms for the arc that occurred at ST5.

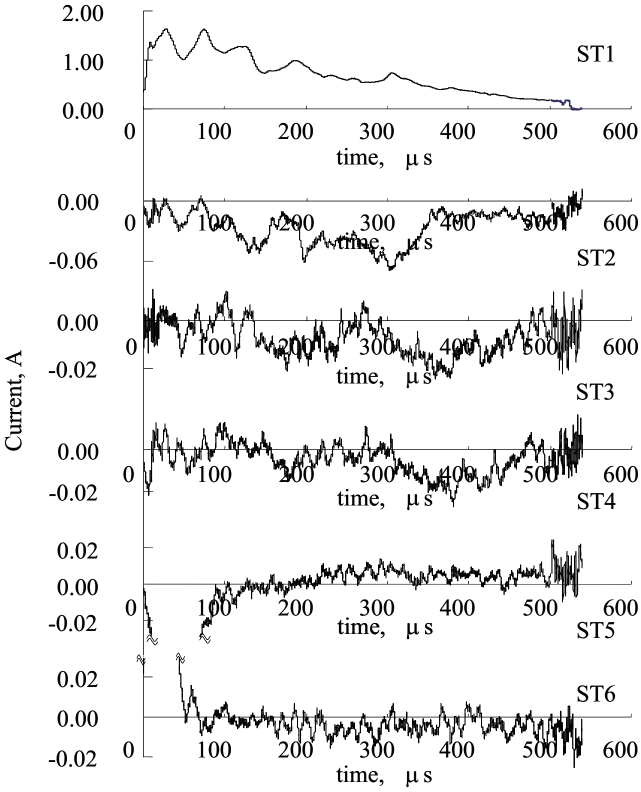


Fig. 6. The typical current waveforms for the arc that occurred at ST1.

Table 2 Plasma propagation velocity.
(Calculated based on the result shown in Fig. 5.)

String	Time of current start*	Distance to ST5+	Plasma propagation velocity
ST3	80 μs	1.06 m	1.3×10^4 m/s
ST4	50 μs	0.85 m	1.7×10^4 m/s

* Time origin is defined as the occurrence of the arc on the panel.
\+ This is the case where an arc occurred at the ST5.

Table 3 Plasma propagation velocity.
(Calculated based on the result shown in Fig. 6.)

String	Time of current start*	Distance to ST1+	Plasma propagation velocity
ST2	60 μs	0.92 m	1.5×10^4 m/s
ST3	130 μs	1.77 m	1.4×10^4 m/s

* Time origin is defined as the occurrence of the arc on the panel.
\+ This is the case where an arc occurred at the ST1.

The presumed plasma propagation length based on the arc current and plasma propagation velocity

Figure 6 depicts other typical current waveforms for an arc that occurred at ST1. Table 3 shows the plasma propagation velocity calculated based on the result illustrated in Fig. 6. The plasma propagation velocity was approximately 10^4 m/s, and it was equal to the result presented in Table 2. Additionally, the arc current passing through ST1 lasted approximately 500 μs. This result indicates the possibility that the plasma had reached ST6. (ST6 was located as far away as 3.75 m from ST1.)

To further clearly research the plasma propagation length, we plan to measure the solar panel surface electric potential before and after discharge.

4. Summary

Preliminary ESD ground tests with two meter-class solar array panels were conducted in a simulated GEO environment. The tests were performed to investigate the plasma propagation length and velocity.

The following is a summary of this study.

1. The plasma propagation velocity was approximately 10^4 m/s.
2. The plasma propagation length was inferred to be over 2.8 m.
3. The neutralization current decreased with the increase in the distance from the arc spot.
4. When an arc occurred on the strings at the edges of the solar panels, the arc current lasted 500 μs. The result indicates the possibility that the plasma propagated through all the panels.

References

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