

STUDY OF THE PLASMA INTERFERENCE WITH HIGH VOLTAGE ELECTRODE ARRAY FOR SPACE POWER APPLICATION

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Abstract

We are studying the problems associated with high voltage power systems in space. Especially we are interested in the potential distribution of the solar array that is resistant to the electrical discharge. We have carried out experiments on the interaction between the high voltage solar array and the ambient plasma. In the experiment, an array of electrodes distributed on the insulation panel was used to simulate the inter-connectors of the solar array. An electrode array without the insulator panel was also used for comparison to study the effect of the insulator. One of major concerns in the usage of the high voltage solar array in space is the arc discharge on the array. Based on the plasma sheath theories, there is a possibility to control or to prevent the discharge by selecting a potential distribution of the electrode array. As the first step to find the potential distribution that is tolerant to the discharge, we measured the distribution of space potential surrounding an array of electrodes and measured the current to the electrodes. This paper presents the experimental results suggesting that we can control the discharge by selecting a proper potential distribution of the high voltage solar array.

1. Introduction

As power consumption of spacecraft increases, power generation at higher voltages and lower currents is required to reduce power loss in the cables and power systems. For kilowatt-class spacecraft, the array voltage near 50 V is currently used. For the International Space Station requiring 100-kilowatt level electric power, power generation more than 100 V is used. Much higher voltages are considered for large commercial satellites and solar power satellites in the future.

Since the inter-connectors of the solar cells are usually exposed to the space environment, the solar array panel interacts strongly with the ambient plasma for the high voltage solar array [1]. The interaction sometimes causes electric discharge and current leak from the cells, resulting in the damage of the solar cells and the associated circuits in the worst case. Especially solar array voltage more than 200 V in the low earth orbit has a potential risk for the electric discharge [2].

One approach to prevent the discharge is to shield the inter-connectors from the ambient plasma, but it is very difficult to maintain the insulation for a long time in space environment, considering the thermal cycle and impact of the meteoroids and debris in orbit.

Another approach is to select the distribution of the array voltage to suppress the discharge. The voltage of the inter-connectors ranges from 0 to the solar array voltage with respect to the body of the satellite. According to the theory of the plasma probe [3][4], the plasma current to the inter-connector strongly depends on the sheath structure surrounding the solar array panel. On the other hand, the sheath structure depends on the distribution of the solar array voltage. It can be possible to design the distribution of the solar array voltage so as to minimize the risk of the electric discharge. Our research aims to get basic data in the laboratory experiments for this approach.

2. Experiment to measure the space potential and the electrode current of the 3×3 multi-electrodes

2.1. Experimental setup

The experimental setup employed in this experiment is shown in Fig.1. A back-diffusion type discharge plasma source is installed at the end of the large space chamber 2.5 m in diameter and 5 m long. Argon gas is used as the working gas for the plasma source. The base pressure is 10^{-5} Pa, but the pressure is 2×10^{-2} Pa during the experiment when the Argon gas is fed. The plasma density in the chamber is $10^5/\text{cm}^3$. The electron temperature was measured as 4 eV. The Debye length is 4.7 cm. A multi-electrode plate and a Langmuir probe are configured at the opposite side of the plasma source. The panel with 10 x 10 multi-electrodes was used in this experiment. The diameter of the electrode is 5

mm and the center-center distance between two adjacent electrodes is 5 cm. An emissive probe is installed on a three-dimensional movable platform. A set of high voltage is applied to the electrodes on the array panel. The current flowing into the electrodes are measured sequentially by a multiplexer and recorded in a data acquisition system.

A filament of a small lamp (6V, 60mA) is used as the electron emitter for the emissive probe. The emissive probe gives an accurate information on the space potential inside the electron sheath [5].

The emissive probe we used in the experiment is shown in Fig.2. The resistance of the voltage detection circuit was 200 M ohms.

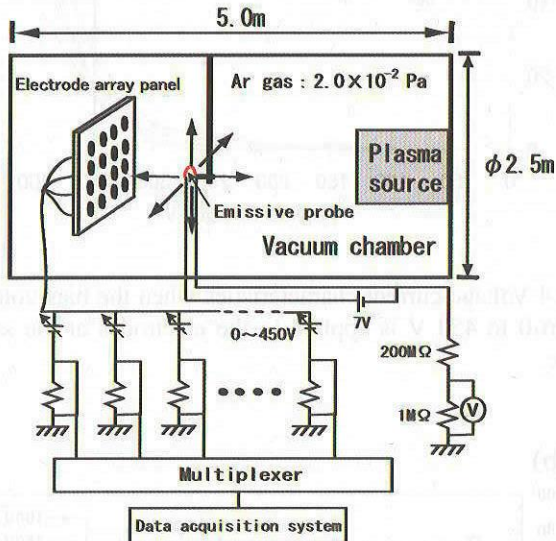


Fig.1 Experimental setup.



Fig.2 Emissive probe.

2.2. Experimental results

In order to clarify the physical process of the current-voltage characteristics for the multi-electrodes, we measured the distribution of the space potential surrounding the array electrodes using the emissive probe in addition to the electrode current. Both arc and glow discharges were observed on the array depending on the plasma density and applied voltage, but the data were analyzed only in the parameter range without discharge. A 3 x 3 electrodes array in a part of the 10 x 10 electrodes array was used for this experiment. Other electrodes were floating to the ground in this experiment. Figure 3 shows the electron current to each electrode when the bias voltage from 0 to 450 V was separately applied to the electrodes in the plasma of $10^5/\text{cm}^3$. The electron current flowing into each electrode is almost same below 200 V. Figure 4 shows voltage-current characteristics when the bias voltage from 0 to 450 V was applied to the electrodes at the same time. This is remarkably different from the characteristics in Fig.3. The increase of the electrode current is suppressed in the voltage region below 300 V but the electrode current exponentially increases above 300 V. Each electrode current at 400 V is almost ten times larger than that at 300V. However, the electrode current is almost constant in the voltage region from 400 V to 450 V.

The spatial distribution of the space potential from 2 cm to 10 cm in front of the electrode array biased from 100 V to 450 V is shown in Figs.5(a), (b) and (c). In these figures, z is the distance from the plate and x is the position parallel to the plate as shown in Fig.5(d). These figures provide the information on the shape and size of the sheath structure in front of the panel. For the voltage below 300 V, the potential distribution at 2 cm from the panel has the peaks corresponding to each electrode, but is rather flat above 300 V. The potential distribution at 5 cm is smoother than that

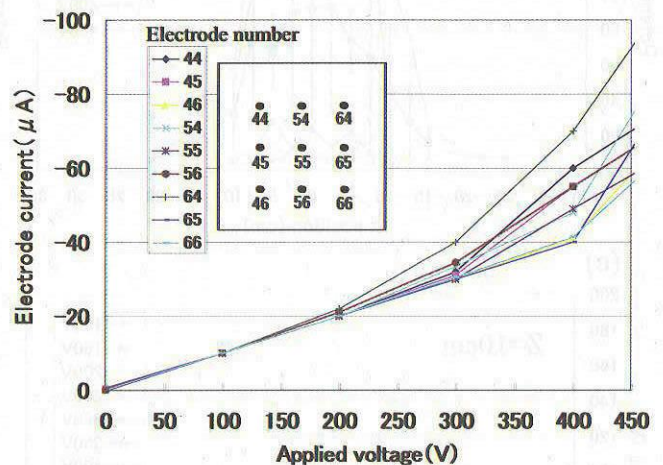


Fig.3 Voltage-current characteristics when the bias voltage from 0 to 450 V is separately applied to each electrode.

at 2 cm. For the voltage below 300 V, the profile of the space potential at 10 cm is almost the background level. The space potential at 400 V is about ten times larger than that at 300 V. The peaks of the space potential at 2 cm are almost same for 400 V and 450 V. On the other hand, the space potential at 5 cm and 10 cm increase until 400 V, and decrease above 400 V.

The sheath structure for the multi-electrodes is discussed more in detail in another paper [6]. The experimental results suggest that the growth of the sheath of the electrode array is different from that of the single electrode by the interaction of the sheath surrounding each electrode. Based on the measurement of the space potential for the multi-electrodes, the difference of the voltage-current characteristics in Figs.3 and 4 can be explained by the growth of the sheath. As shown in Fig.4, we find a very interesting effect that the electrode current steeply increase above 300V and the electrode current is almost constant when the applied voltage is changed from 400 V to 450 V.

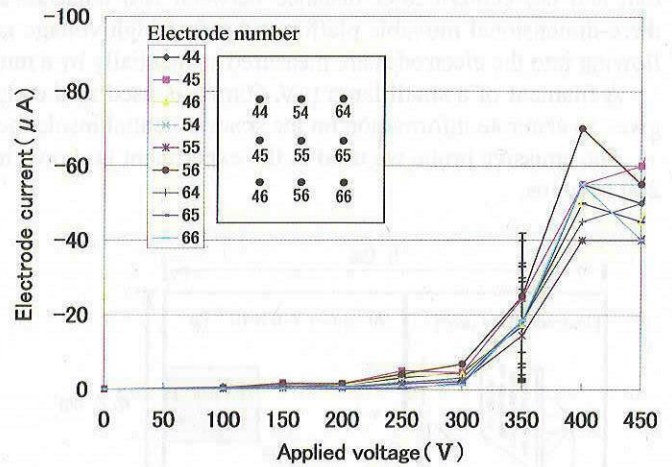


Fig.4 Voltage-current characteristics when the bias voltage from 0 to 450 V is applied to the electrodes at the same time.

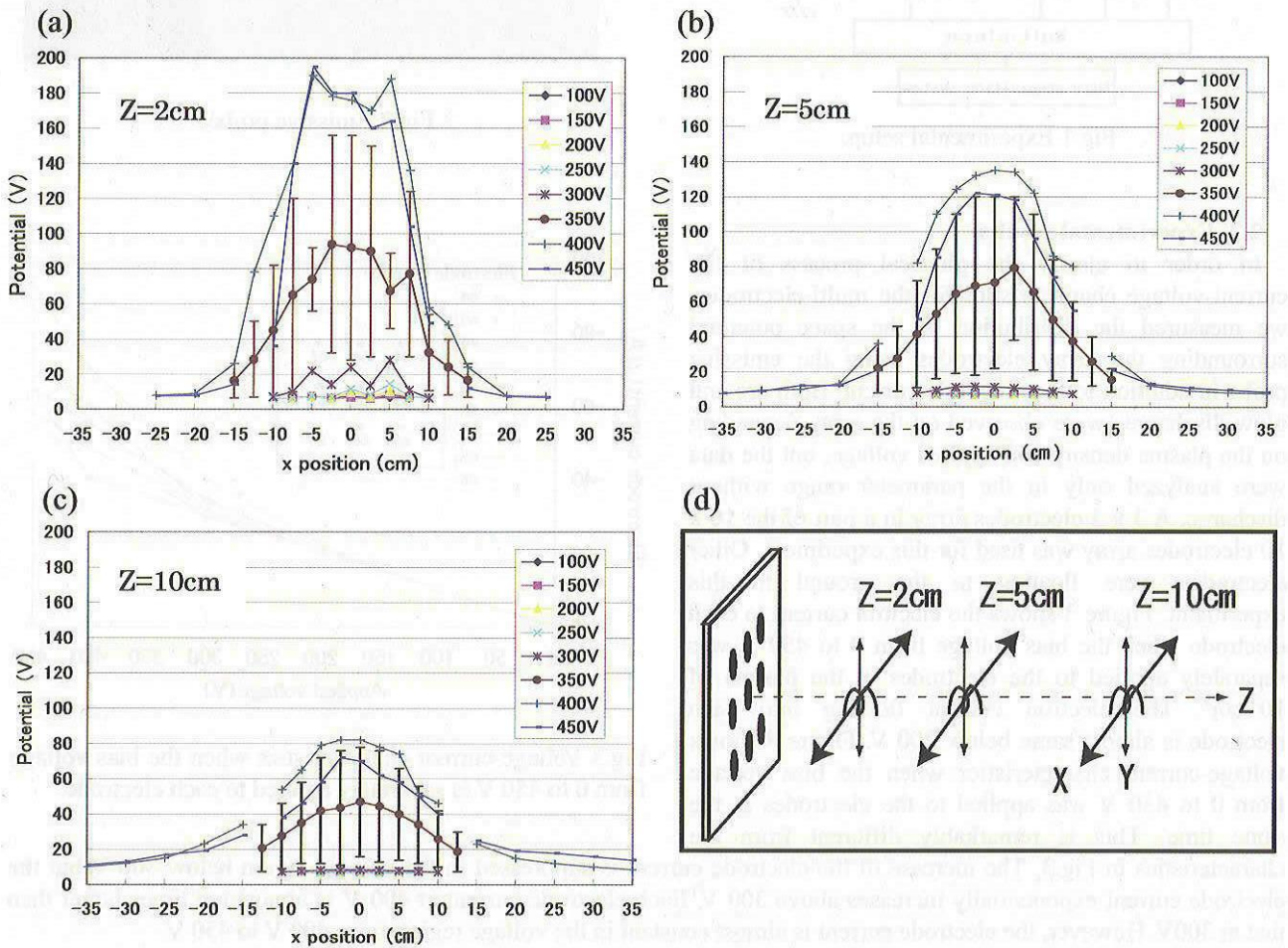


Fig.5 (a), (b), and (c) show the profile of space potential for the electrode array biased from 100 V to 450 V. (a) at 2 cm in front of the electrode array. (b) at 5 cm. (c) at 10 cm. (d) illustrates the definition of the axis. z is the distance from the plate. The x-y plane is parallel to the plate.

3. Experiment to study the influence of the insulator

3.1. Experimental setup

Figure 6 shows the experimental setup employed in this experiment. A magnetic-field-diffusion type discharge plasma source is installed in the space chamber 1m in diameter and 1.8m long. The working gas for the plasma source is Argon gas. The base pressure is 10^{-4} Pa, but the pressure is 4×10^{-2} Pa during the experiment when the Argon gas is fed. The plasma density in the chamber is $10^5/\text{cm}^3$. The electron temperature was measured as 2 eV. The Debye length is 2.4 cm. A multi-electrode plate and a Langmuir probe are configured at the opposite side of the plasma source. Two types of panel with 3×3 multi-electrodes, as shown in Figs.7 and 8, are used in this experiment. Figure 7 shows the lattice-shaped array to eliminate the effect of the insulator. Another electrode array shown in Fig.8 has the Kapton insulator surrounding electrodes which are the same distributed as those in Fig.7. The diameter of the electrode is 5 mm and the center-center distance between the two adjacent electrodes is 5 cm. A set of high voltage is applied to the electrodes on the panel.

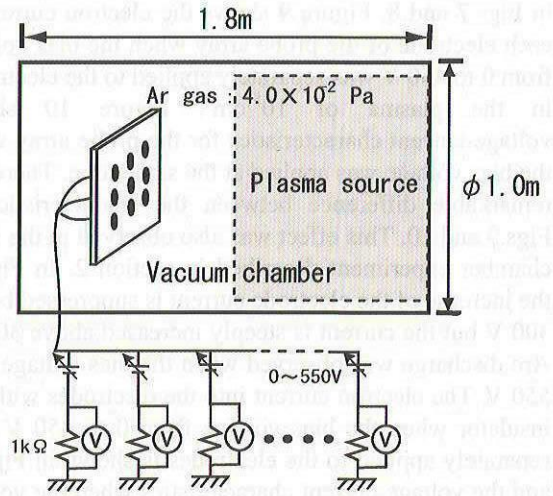


Fig.6 Experimental setup.

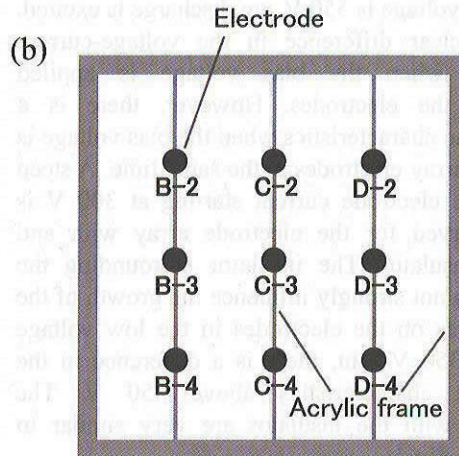
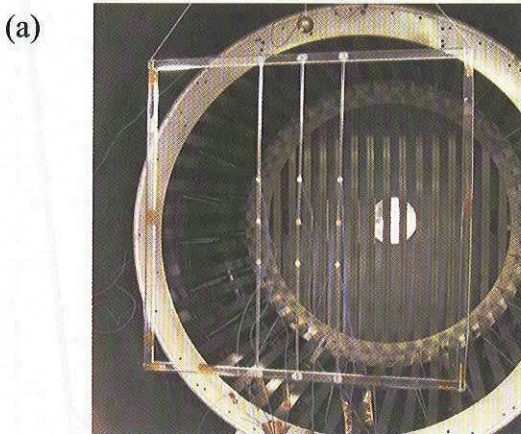


Fig.7 (a) the lattice-shaped array to eliminate the effect of the insulator. (b) distribution of the electrodes.

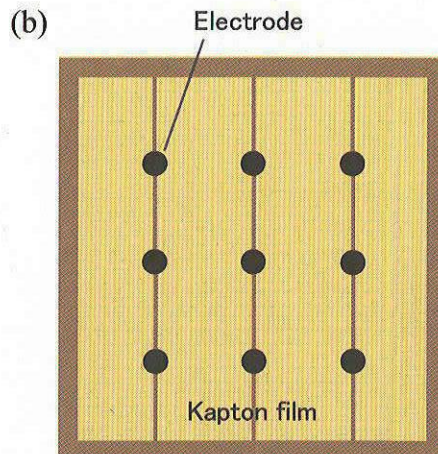
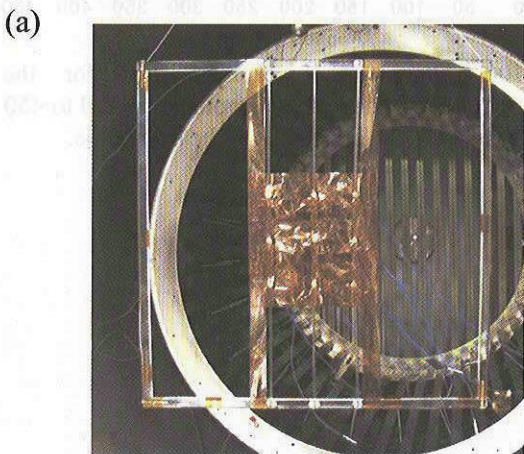


Fig.8 (a) electrode array with insulator. (b) distribution of the electrodes which are the same as those of Fig.7.

3.2. Experimental results

To study the influence of the insulator, we measured the current into the two types of electrode array shown in Figs.7 and 8. Figure 9 shows the electron current to each electrode of the probe array when the bias voltage from 0 to 450 V was separately applied to the electrodes in the plasma of $10^5/\text{cm}^3$. Figure 10 shows voltage-current characteristics for the probe array when the bias voltage was applied at the same time. There is a remarkable difference between the characteristics in Figs.9 and 10. This effect was also observed in the large chamber experiment described in section 2. In Fig.10, the increase of the electrode current is suppressed below 300 V but the current is steeply increased above 300 V. Arc discharge was observed when the bias voltage was 550 V. The electron current into the electrodes with the insulator when the bias voltage from 0 to 450 V was separately applied to the electrodes is shown in Fig.11, and the voltage-current characteristics when the voltage was applied at the same time to the electrodes are shown in Fig.12. The electrode current is almost constant in the voltage region from 350 V to 400 V. When the bias voltage is 550 V, arc discharge is excited. There is no clear difference in the voltage-current characteristics when the bias voltage is applied separately to the electrodes. However, there is a difference in the characteristics when the bias voltage is applied to the array electrodes at the same time. A steep increase of the electrode current starting at 300 V is similarly observed for the electrode array with and without the insulator. The insulator surrounding the electrodes does not strongly influence the growth of the sheath structures on the electrodes in the low voltage region below 350 V. But, there is a difference in the voltage-current characteristics above 350 V. The characteristics with the insulator are very similar to those shown in Fig.4.

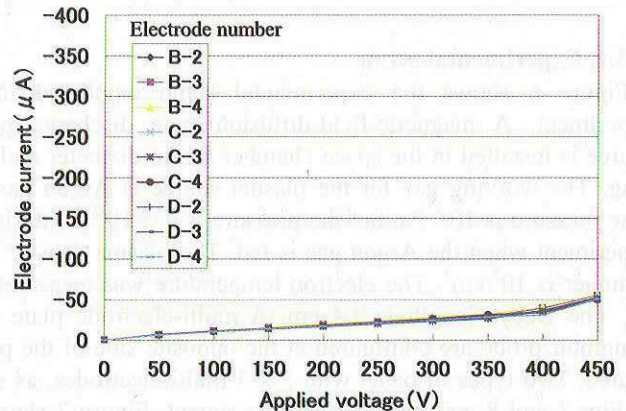


Fig.9 Voltage-current characteristics for the probe array when the bias voltage from 0 to 450 V is separately applied to the each electrode.

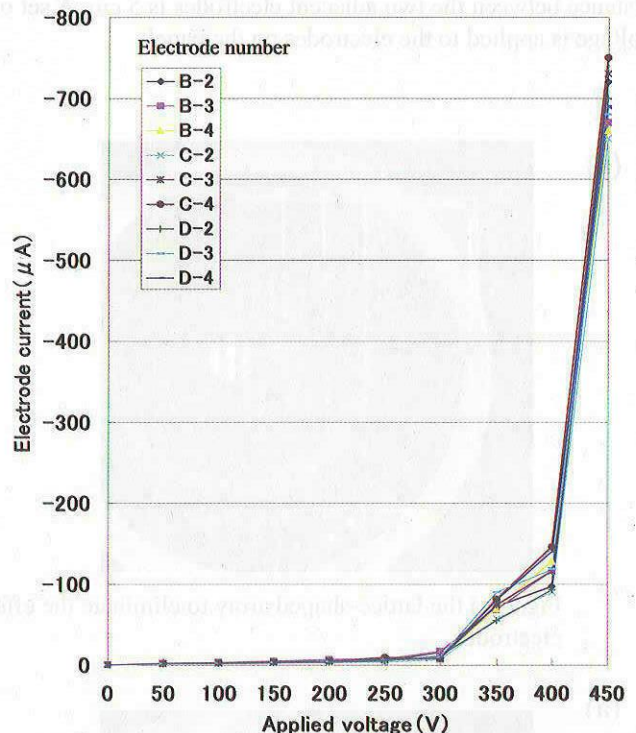


Fig.10 Voltage-current characteristics for the electrode array when the bias voltage from 0 to 450 V is applied to the electrodes at the same time.

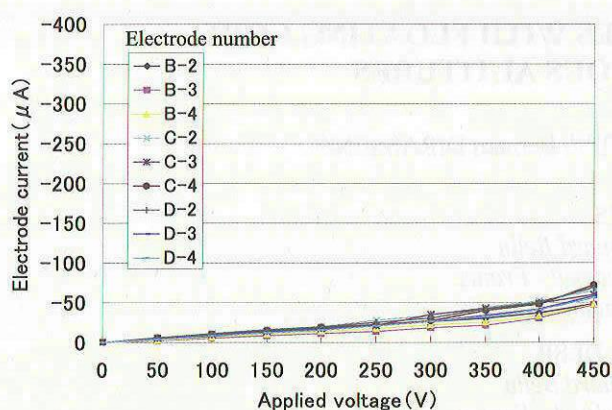


Fig.11 Voltage-current characteristics for the electrode array with insulator when the bias voltage from 0 to 450 V is separately applied to the each electrode.

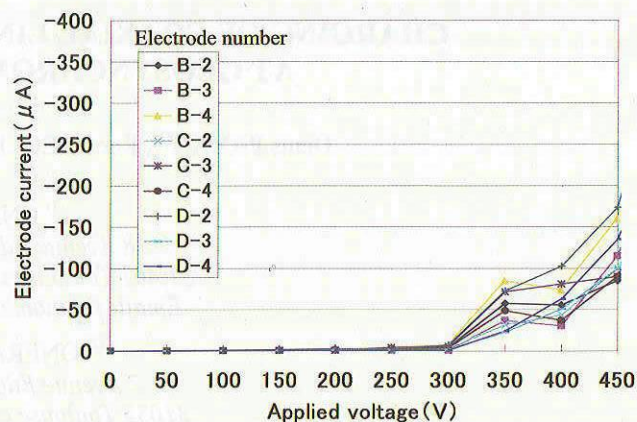


Fig.12 Voltage-current characteristics for the electrode array with insulator when the bias voltage from 0 to 450 V is applied to the electrodes at the same time.

Conclusion

The experiment to measure the distribution of electrode current and space potential surrounding an array of electrodes has been conducted for the study on the interaction between the high voltage solar array and the ionospheric plasma. This experimental result suggests that the configuration of the electron sheath on the array changed as the applied voltage to the electrodes increased differently from single electrode. The electron current flowing into each electrode changed with the growth of the sheath structure. This indicates that the electron current to the electrode can be controlled by changing the potential distribution of the array electrodes.

For the investigation on the influence of the insulator, we conducted another experiment to measure the current of the electrode array with and without the insulation film. The insulator surrounding the electrodes does not strongly influence the voltage-current characteristics in the voltage region below 350 V. But a clear difference is found in the characteristics for the voltage above 350 V. The mechanism for the difference will be studied in the next step experiment.

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