DISCHARGE CHARACTERS INVESTIGATE OF HIGH-VOLTAGE SOLAR ARRAYS DEPENDED ON PLASMA DENSITY AND TEMPERATURE

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ABSTRACT

The power requirements of large space systems require high voltages to operate economically and more spacecraft will use high-voltage solar arrays. The solar arrays will be processed complex charging effect in Low Earth Orbit plasma environment. Once the solar arrays surface is charged and electrostatic discharge may occur at so-called triple junction where insulator, conductor and plasma meet, and it may trigger secondary discharging phenomenon. This paper study the arcing discharge and secondary discharge of high-voltage solar arrays in LEO-like plasma experimentally, and the discharge characters have been investigate in different destiny ($2.7\times10^{12}m^{-3}$ and $1.2\times10^{12}m^{-3}$) and temperature(1eV and 8eV). The results indicate that the biased-voltage of solar arrays discharge is about 70V in LEO-like plasma. The arcing discharge of high-voltage solar arrays is observed to be more when the plasma density increases, and discharge number have not changed with the plasma temperature increases.

1. INTRODUCTION

In the quest to create lighter and efficient spacecraft, the natural trend is toward higher voltage power systems [1]. To offer more power and reduce resistive losses, space solar arrays have begun employing the bus voltage of more than 100V. The International Space Station (ISS) has a bus voltage of 160V. The bus voltage of Chinese "Tiangong" reached 100V, and subsequent spacelab will be higher.

Plasma in low earth orbit (LEO) is widely known as cold and dense plasma, and the characteristics are high-density (10^{10}-10^{12}m-3) and low energy (0.1-0.3eV). When spacecraft using high voltage solar array running in low earth orbit, high voltage solar will occur electrostatic discharge in the cold and dense plasma, and induce secondary discharge between array strings, making solar cells burned, causing the spacecraft power loss and energy system failure [2].

In order to promote industrial use of low Earth orbit (LEO), such as manufacturing, sightseeing, or power generation, the power of a large LEO platform after the ISS will soon reach the level of megawatts. High-voltage power generation and delivery is a key technology to realize large LEO platforms. At the beginning of space applications of high voltage solar array, many groups has begun to pay attention to electrostatic discharge and secondary discharge of high voltage solar in LEO plasma environment [3-5], carried out a lot of experimental researches to analyse and evaluate the discharge damage, and provided favourable support for high voltage solar array for space applications.

In this paper, we mainly focus on high voltage solar array charging effect in LEO Orbit environment conditions, and analyse the discharged characteristics of the solar array under different plasma temperature and density. The results of discharged characteristics have been used to understand physical mechanism of high-voltage solar array charging effect and create a hybrid solar array design that is expected to function efficiently in LEO charging environments.

2. EXPERIMENTAL PROCEDURE

High-voltage solar array discharged experiment under LEO plasma environment has been carried out by the spacecraft charging effect evaluated facility of Lanzhou Institute of physic. In order to simulate the LEO plasma environment, a plasma source generates Xenon plasma, and the plasma is monitored by the Langmuir probe placed near the solar array, as shown in fig.1. Considered the influence of spacecraft orbital velocity, the Plasma temperature is selected as 1 eV and 8eV in the experiment, and the density is selected as 2.7 x $10^{12}m^{-3}$ and 1.2 x $10^{12}m^{-3}$. The discharge and secondary discharge of high voltage solar array is test mainly by the current probe and high-speed digital storage oscilloscope, and the secondary discharge phenomenon is collected by a CCD camera.

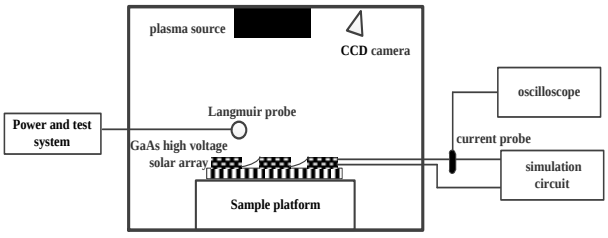


Figure 1. Schematic diagram of experimental setup

In the experiment, a GaAs high voltage solar array is used. The solar cell is divided into two series, and the 2 $\times$ 3 structure is formed by the circuit. As shown in Figure 1, a high voltage solar array simulation circuit is design according to the working mechanism. The stabilized power supply provides the voltage between

the stringed of solar array, and a high voltage power supply bias voltage.

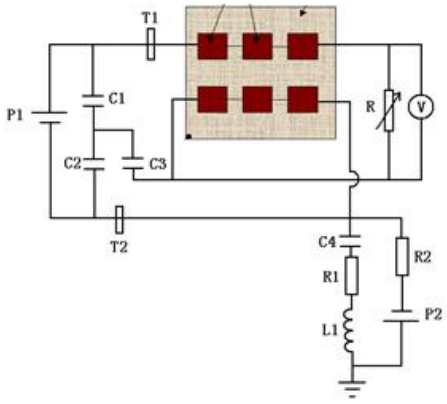


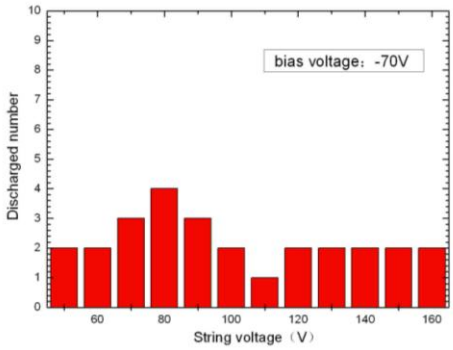
Figure 2. Schematic diagram of high voltage solar array simulation circuit

Among them:
V: voltage meter, monitoring circuit voltage;
T2, T1: the current probe, used to monitor the discharge pulse;
C1, C2, C3: the solar array on the substrate analog capacitor;
C4: the satellite structure on the space of the capacitor;
L1: the inductance of the space of the satellite structure;
R: adjustable resistance;
R2, R1: the satellite structure resistance;
P1: provide a stringed voltage of solar array;
P2: provide bias voltage of solar array.

3. RESULTS AND DISCUSSIONS

In order to study high voltage solar array discharge characteristics depended on bias voltage, the DC power supply P2 is set up bias voltage from 0V to -100V at every 10V for 120 min, and the P1 is set up stringed voltage from 50V to 160V (every 10min increase of 10V) when the bias voltage is fixed.

The plasma source produces energy as 1 eV, with a density of 2.7 x $10^{12}m^{-3}$ plasma. Experimental results show that high-voltage solar array has been discharged when the bias voltage is set up to -70V. Figure 3 show the discharged numbers of high-voltage solar array depended on string voltage when bias voltage is -70V, -80V, -90V and -100V relatively.



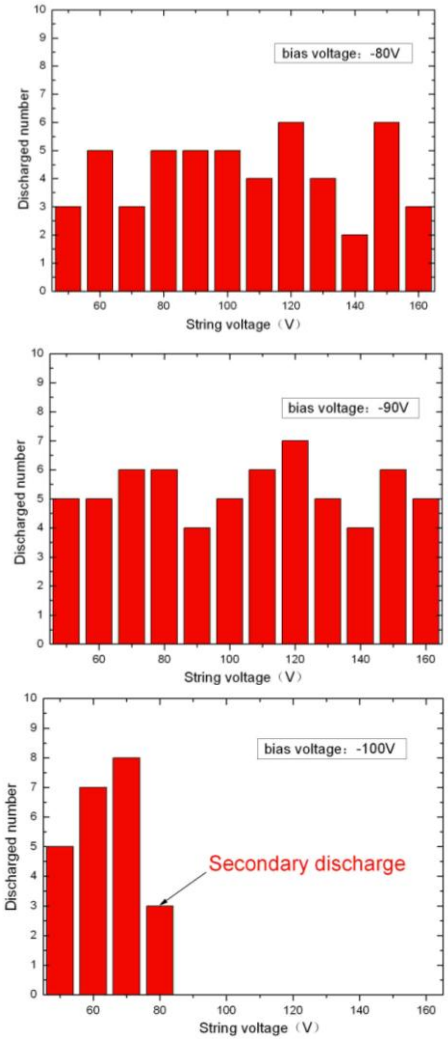


Figure 3. Discharged numbers of high-voltage solar array depended on string voltage when bias voltage is -70V, - 80V, -90V and -100V relatively

Fig. 3 tells us that although discharge numbers of high voltage solar array are different depended on string voltage at the same bias voltage because of the randomness of the discharge, but overall discharge numbers are increased when the bias voltage decreases.

In previous investigation [6,7], the arc discharge occurs at the triple junction formed by the plasma, cover glass and conductive solar cell interconnect. When high voltage solar bias potential is negative, insulator surface is positively charged and forms electric field from cover glass to interconnect, and the electric field is intensified as the insulator surface accumulates more positive charges. As the electric field is further intensified, electrons are emitted from the conductor surface due to field emission. The potential structure around the triple junction forms the electric field where field-emitted electrons are attracted to the insulator surface. The electron incident on the insulator surface emits secondary electrons that leave positive charges near the triple junction and enhance the electric field further.

This process is thought to be particularly important to the initiation of arcing on high-voltage solar arrays.

With bias voltage becomes lower, insulator surfaces will be charged more positive, and electric field at the triple junction will be intensified, resulting in electrostatic discharge is more likely to occur. At the same time, experiment is observed the occurrence of high-voltage solar secondary discharge when the bias voltage is -100V and the string voltage is 80V, as shown in Figure 4.

Figure 4. Video image of the secondary discharge

For study the arc discharge characteristics of high voltage solar depend on energy of plasma, the plasma energy is chosen as 1.0eV and 8.0eV when density is 2.7 x $10^{12}m^{-3}$. Figure 5 shows arc discharge numbers of high-voltage solar array in different energy plasma when the bias voltage is -70V.

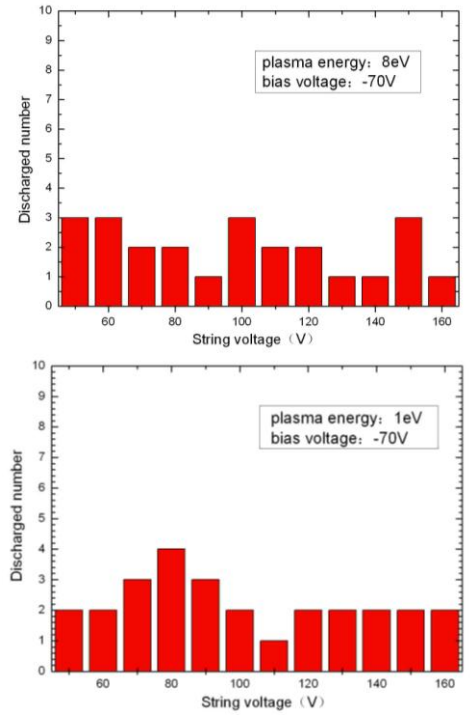


Figure 5. Arc discharge numbers of high-voltage solar array in different energy plasma

As can be seen from Figure 5, when the plasma energy is 1.0eV and 8.0eV, the total arc discharge numbers of the high voltage solar cells are equal approximately. This is mainly due to the bias voltage is -70V and plasma energy is only several electron volts. The ion in plasma will be accelerated by the bias voltage and the energy will reach tens of electron volts after the acceleration. The original energy of the plasma will not have influence over the charge process. Therefore the energy of plasma has little impact on the arc discharge numbers of high voltage solar array.

The density of plasma is chosen as $1.2x10^{12}m^{-3}$ and $2.7x10^{12}m^{-3}$ to investigate the influence of plasma density on arc discharge characteristics when the energy of plasma is 1 eV. Figure 6 shows arc discharge numbers of high-voltage solar array in different density plasma when the bias voltage is -70V.

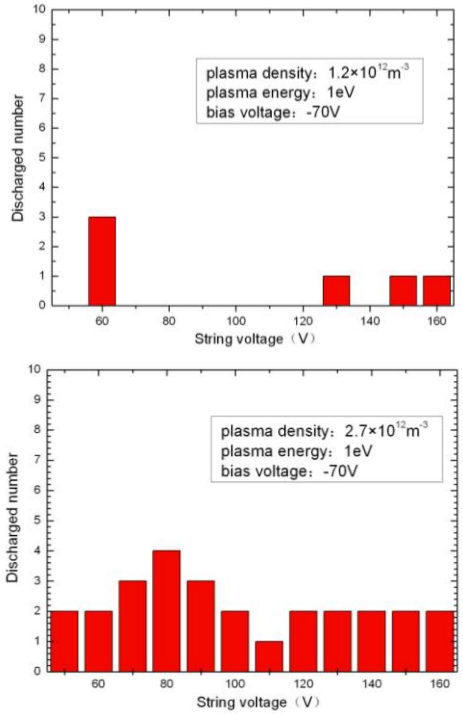


Figure 6. Arc discharge numbers of high-voltage solar array in different density plasma

It is found that the number of arc discharge of high voltage solar array is more in the denser plasma. This is due to that more ions in the denser plasma are attracted to interconnect and cover glass, resulting in more secondary electrons. In this condition, the arc discharge of high voltage solar array occurs easier.

4. CONCLUSIONS

Arc discharge and secondary discharge of GaAs high voltage solar array have been measured in LEO plasma environment simulated by the plasma source. Research results show that high voltage solar array begin to occur arc discharge when the bias voltage is -70V and arc discharge number increase with decreasing the bias voltage. Secondary discharge of high voltage solar array is observed at the bias voltage of 100V and voltage is 80V. Additional, results show that the energy of plasma has little impact on the arc discharge number of the

high-voltage solar array, and the arcing discharge number is observed to be more when the plasma density increases.

5. REFERENCES

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