Simulation of small space debris impact inducing solar array discharge

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***Abstract*—When space debris impact with spacecraft high density and conductivity plasma will be induced. The plasma can constitute a discharge channel and triggering discharge. This was been regarded as the mechanism of space debris impact inducing discharge and regarded as a big threat to the safety to spacecraft. Solar cell is of vital importance to spacecraft and is regarded as sensible to space debris impact inducing discharge. Research of space debris larger than 1 mm impact solar cell discharge was carried out by Mengu Cho and other scientist. This paper gives the research of space debris smaller than 1mm impact inducing discharge.**

Based on the experiments of 200 micrometer particles impact inducing discharge carried on the small space debris accelerator the laser induce plasma simulation method for space debris impact inducing discharge was proven to be useful. Laser induced plasma facility was much more convenient in the experiment for position and energy control. Experiment were carried out and proved that the space debris smaller than 1mm can trigging solar cell discharge. If the voltage was high and the discharge current was large secondary discharge can be triggered too. The discharge can make serious damage on the solar cell during the discharge and secondary discharge.

Keywords—Small space debris; Discharge

I. INTRODUCTION

Space debris impact with spacecraft at an average velocity of 10km/s and the impact will induce high density plasma. The characteristic of high velocity impact inducing plasma has already been studied by Lee's experiment. And the plasma was very dense. So the plasma can constitute a temporary conducting channel which can trigger discharge on spacecraft easily if the voltage difference is big enough. This effect has been regarded as a big threat to the safety of spacecraft. This effect might be the serious disturbance that occurred on several spacecraft such as the Olympus, Jason-1 and Landsat 5 spacecraft. Based on ground space debris simulation facility a few study has carried out and confirmed this mechanism.

Solar cell is of vital importance for spacecraft as the main or even the only power resource for spacecraft. As the spacecraft become more complicated and has more functions the solar cells array has becoming larger and has higher voltages. Since the solar cell array becomes larger the impact frequency with space debris becomes higher especially the impact with small space debris. The high voltages of the solar array made it more likely to triggering discharge from space debris impact. Especially when the voltage is high even small space debris impact might trigger discharge. This trend has made the solar cells more sensible to space debris impact inducing discharge on solar cell. But research of space debris with diameters smaller than 1 millimeter impact inducing solar cell discharge was never carried out.

Mengu Cho's research have proven that impact of space debris with diameters larger than 1mm can inducing sustain arc and secondary discharge on high voltage solar cells. Scientist in Europe has although successfully carried out the experiment of 1mm larger space debris impact inducing discharge. But research about smaller space debris impact inducing discharge has not been reported. Since the space debris simulation facility is not able to accelerate only one particle smaller than 0.5mm and impact on a place settle before the experiment. And that is necessary for space debris impact inducing solar cells discharge. Since the main reason for space debris impact inducing discharge is actually the impact induced plasma that induced discharge. This kind of plasma is like the laser induced plasma. So if the laser induced plasma can be used to simulate the impact plasma that can be used to simulate space debris impact discharge. From this hypothesis the research of space debris smaller than 1mm induced discharge were carried out.

II. FACILITY

A. The Plasma Drag Particles Accelerator

The plasma drag particles accelerator which can accelerate particles with diameters between 10μm and 1mm. Since the diameter is so small the accelerator will accelerate many particles during one accelerating process. The particles can be accelerated to the velocity up to 15km/s. The main components of the accelerator were the coaxial gun, discharging chamber, Flying tube and the specimen chamber that was shown in Fig.1. During the accelerating process, the vacuum chamber which

include the discharge chamber, the flying tube and the specimen chamber were pumped to less than 5×10^{-3}pa. The particles were fixed onto a thin mylar film and placed at the end of the compression coil. The coaxial gun was used to produce high velocity plasma which then will accelerate the particles. When the plasma were flying to the mylar film the film would vaporizing and the particles would be accelerated to high velocity.

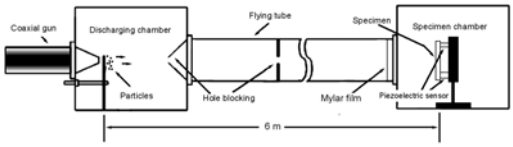

Fig. 1. Sketch map of plasma drag particles accelerator

The piezoelectric sensors were placed at the rear side of the specimen to detect the arriving time of the particles and then used to measure the velocity the velocity of the particles. The length from the discharging chamber where the particles place to the specimen in the accelerator is 6m. The flying time of the particles can get by the piezoelectric sensor. Based on the flying time and the length the average velocity of the particle can be measured. The Figure 2 gives the sketch map of the piezoelectric sensor and the experiments results of the discharging signal of the capacitor and the piezoelectric sensor signal when particles impacted on the specimen.

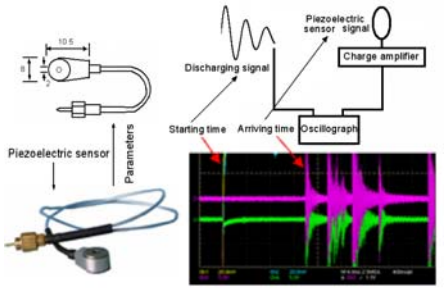

Fig.2. Particles velocity measured by piezoelectric sensor.

B. Laser induce plasma system

Space debris impact can produce high density plasma which is the main reason for space debris impact inducing discharge. And the laser induced plasma is similar to the impact inducing plasma. So the laser induce plasma system can be used to simulate space debris impact inducing discharge. Compared to the experiment carried on space debris impact facility the discharge position, time and other parameters can be easily controlled. That is very useful to the simulation experiment.

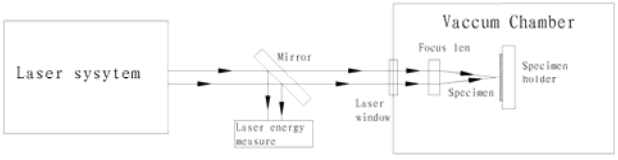

Fig.3.The composition of laser inducing plasma system

The composition of laser inducing plasma system is shown in fig.3. The wave length of the laser is 1064nm and the pulse width is about 10ns. The energy of the laser can be changed from 10mJ to 1000mJ. The original facula of the laser is about 9mm and can be focused to about 0.1mm. The specimen can move parallel and vertically to the laser line and makes the laser focused on the specimen and can change the position on the specimen.

III. EXPERIMENT

A. The comparation of focus laser on specimen and hypervelocity particles impact on specimen

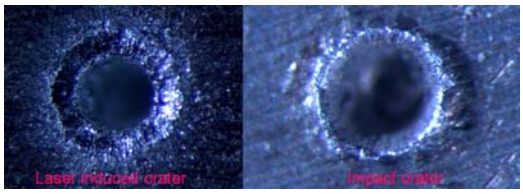

Fig.4. The craters on aluminum plate

The study between the character of laser induced crater and impact crater on aluminum plate and glass plate were carried out. And the typical results were shown in fig.4 and fig.5.During the experiment the energy of the laser was 50mJ.Based on the experiment result the character of the craters produced by laser and impact is similar.

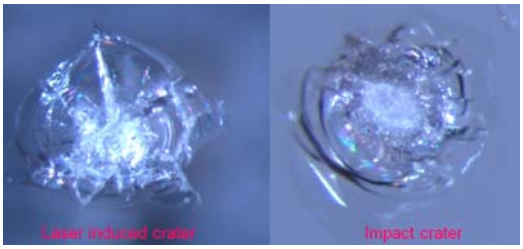

Fig.5. Craters on glass plate

The impact induced plasma and the laser induced plasma were similar. But the measurement of the plasma is difficult. So only the impact induced flash from the plasma were measured by the photoelectrical cell. And fig.6 is the typical light flash from laser induced plasma and impact induced plasma. It's clear the light flashes in two different processes are similar.

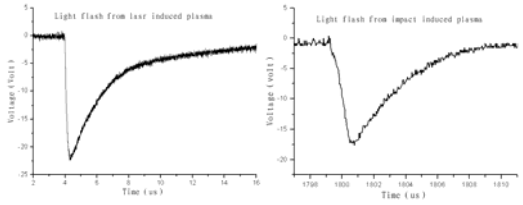

Fig.6.Light flash from plasma

B. Comparation of laser induced discharge and impact induced discharge

The experiment of focus laser produced plasma inducing discharge was carried out. The specimen and the circuit for the experiment is show in fig.7. Pulse laser has focused on the specimen to produce plasma which then inducing discharging

on biased electrodes. The discharge current was measured by the oscillograph. The energy of the laser is 50mJ.

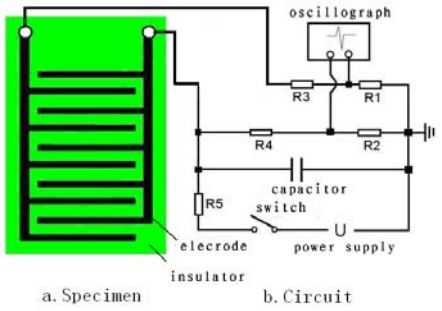

Fig7.The specimen and the circuit for the experiment

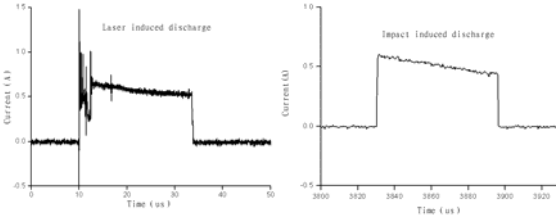

Fig8.Comparation of the discharge current

The typical result of the current was given out in fig. 8. And it is clear that the discharge begins when the laser focused on the specimen. The discharge current is about 0.5A and the current last about 33microseconds. And the discharge current is similar to the impact induced discharge current on the specimen. So it is reasonable to use the laser induced plasma to simulate the experiment for the small space debris impact induced discharge. And this would make the experiment more convenient especially the discharge position on the specimen can be accurately settled in the experiment.

C. Simulation experiment for small space debris impact dinducing solar cell dischage

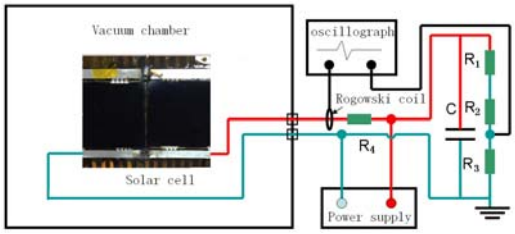

Fig.9.The setup for the experiment

Solar cell is of vital importance to spacecraft and will impact with small space debris. If the impact happened on the clearance of the cells that has relatively high voltage difference discharge might Solar cell that was similar to the ones used on spacecraft was used in the experiment. The setup of the experiment was shown in fig.9. The clearance between the solar cells is 0.9mm. The power supply is used to maintain the voltage difference between cells. The capacitor is used to provide the energy that for discharge. The rogowski coil is used to detect the discharge current. The voltage difference between the cells is also measured. The light flash is detected by the photoelectric cell. All the signals were recorded by the oscillograph. During the experiment the energy of the laser was 50mJ.The resistance of R1,R2,R3 and R4 were 2 megohm,5 megohm,20 kilohm and 10 ohm respectively. The value of the capacitor was 5.6 microfarad. The power supply has a maximum of current of 0.1 ampere.

IV. EXPERIMENT RESULTS

It was found out that when the voltage between the solar cells is high and the focused laser produced plasma near the area of the clearance of the solar cell discharge can be triggered. The typical result of the voltage change, discharge current and the light flash during the discharge were shown in fig.10, fig.11 and fig.12 respectively. From fig.10 the voltage decreased from -82.5 volt to -31.4 volt gradually and voltage shock appeared at the beginning and the end of the discharge. From fig.11 the discharge current increased from zero to 4.1 ampere rapidly at the beginning and then decreased to about 1 ampere gradually and turned out to zero rapidly. Compare to the voltage between the solar cells the discharge current has much less shock especially at the beginning and the end of discharge. The last time of the discharge was about 128 microseconds. The light flash detected by the photoelectric cell was shown in fig.12. The light flash last about 135 microseconds. The light flash last more time than the discharge current. That indicated the plasma was still existed after the discharge ended. From those results it also indicated that the discharge ended because the electric field is relatively low to maintain the discharge rather than the extinguish of the plasma. Compare the light flash in fig.12 to fig.6 it was clear the light flash last more time during the discharge. This indicated that the plasma produced from the focused laser might ionized during the discharge process or more plasma was produced during the discharge.

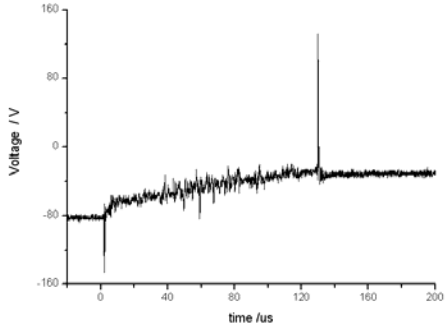

Fig.10.The voltage between the solar cell

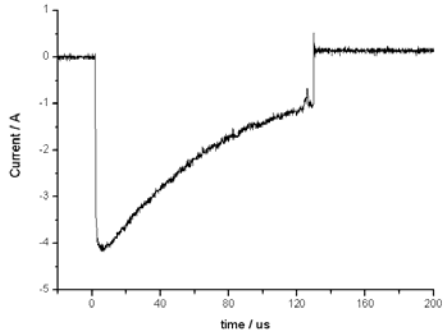

Fig.11.The discharge current

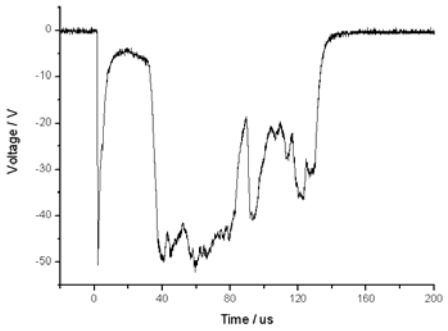

Fig.12.The light flash during the discharge

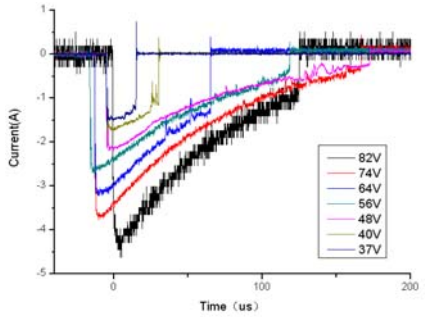

Fig.13.The discharge current change with voltage

A serial of experiment was carried out and the result was shown in fig.13 and table 1. During experiment it was found out that when the bias voltage was less than -36 volt discharge there was no discharge. From fig.13 the discharge current change with the bias voltage between the solar cells was given out. It was clear that the maximum current increase with the bias voltage. The last time of the discharge current was not increase with the bias voltage simply. It was found out when the bias voltage is -56 volt the last time of the discharge was 178 microseconds that is much longer than that when the bias voltage was 82 volt and 64 volt. The voltage between the solar cells before and after the discharge was also given out in table 1. From different experiment the bias voltage decrease during the discharge but in different range. And the bias voltages after different discharges were vary from -36.1 volt to -17.6 volt. This result agree with the experiment that when bias voltage less than -36 volt there was no discharge.

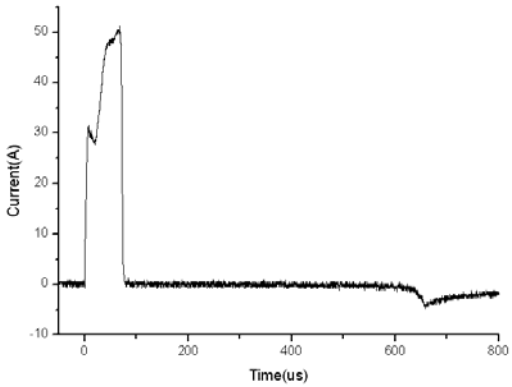

Fig.14.The discharge current

Table 1. The parameters of discharge

Number	Voltage before discharge	Voltage after discharge	Max. Current	Last time
1	-82.4V	-31.1V	4.7A	125us
2	-82.5V	-31.4V	4.1A	128us
3	-74.2V	-22.5V	3.7A	180us
4	-64.5V	-36.1V	3.2A	79us
5	-64.6V	-32.9V	3.1A	96us
6	-56.2V	-22.8V	2.7A	135us
7	-48V	-17.6V	2.1A	178us
9	-40.8V	-32.5V	1.7A	35us
11	-37.1V	-32.9V	1.4A	21us

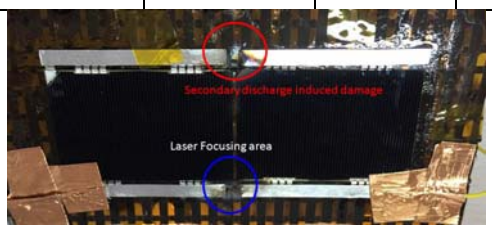

Fig.15.The soar array after experiment

When the resistance of R4 was changed to zero and the power supply was changed to the maximum of current of 3 ampere the discharge current was increased to about 50 ampere during the discharge. The typical result of the discharge current was shown in fig.14. And the current is different to the discharge current before. The current increased during the discharge process while the discharge current decreased in the experiment before. This was because during this discharge secondary discharge was triggered. The damage area of the solar cells was shown in fig.15. From fig.15 there were two damaged area one was the area that the focused laser and the primary discharge induced. The other damaged area was produced by secondary discharge.

V. SUMMARY

Laser induced plasma is similar to impact induced plasma and can be used to simulate small space debris impact inducing discharge. The experiment result prove that the character of laser induced discharge current was similar to the discharge current of small space debris impact induced discharge carried out on plasma drag small space debris accelerator. Based on laser induced plasma facility the simulation experiment of small space debris impact inducing discharge was carried out. From experiment it is clear that space debris with diameters smaller than 1mm can trigger solar array discharge when the voltage difference between the solar cells is bigger than 36 volt. The discharge current increased with the bias voltage between the solar cells. The last time of the discharge is not increase with bias voltage simply. When the resistance in the discharge circuit is low and the bias voltage is high the discharge current can increase to about 50 ampere. And in this condition secondary discharge can be triggered. During the discharge and secondary discharge the solar cell has been damaged.

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