OPTICAL MEASUREMENT OF CHARGING AND DISCHARGING PROCESSES ON INSULATOR SURFACE IN SIMULATED LOW EARTH ORBIT PLASMA ENVIRONMENT

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Abstract

In order to predict arcing occurrence on a high voltage solar array in Low Earth Orbit (LEO), it is important to know the correlation among successive arcings on multiple points over a two-dimensional plane. We have developed an experimental system which can identify arc points over solar array surface placed in a plasma environment by detecting the light emission from the arc point. By preliminary experiment, the systems operation has been confirmed.

1. Introduction

In near future, a large space platform which requires high power (> $100kW$), such as International Space Station or Solar Power Satellite (SPS) will be constructed in Low Earth Orbit. These space platforms must be operated at a high voltage, typically higher than $100V$ in order to minimize the loss and save the cable mass. When a solar array has a high voltage in LEO, most of the high voltage becomes negative, due to interaction with the space plasma. Therefore, ions from the surrounding ionospheric plasma are attracted to the insulator surface of solar array, such as coverglass. The surface of coverglass is charged by the positive ions, and the electric field of the triple junction (the position where vacuum, interconnector, and insulator meet as shown in Fig.1) is intensified and lead to arcing. When the arc occurs, it leads to degradation of the solar cell performance and electromagnetic interference (EMI) with on-board instruments.

The final goal of our research is to make a prediction model of arcing occurrence for a given array and to make an effective tool for spacecraft design by estimating the degradation of solar array and the effects of EMI. Arcing frequency of the solar array depends on the charging time for the electric field to reach a sufficient strength at the triple junction. The charging time and the arcing frequency of a single triple junction can be calculated. Ref.1. But for the case of a solar array which has many interconnectors and the corresponding triple junctions, an arc at one point might affect the charging condition at the other points on the array and the problem becomes very complicated.

Once an arc occurs a high density plasma is generated. Also the influx of the arc current changes the solar array potential and charges stored on the other points on the insulator are exposed to the surrounding plasma. Therefore, the effect of one arc on the charging condition on the other points must be clarified to estimate arcing frequency for solar array with a large area.

An image processing system which can specify the arcing point on two-dimensional surface has been developed in order to examine what kind of correlation exists among the multiple arc points. The system can give spatial and temporal distribution of arc points and the correlation among the arc points can be identified through statistical treatment of the results. In the present paper, we have confirmed that the system operates properly through a preliminary experiment and report its results.

2. Experimental method

The experiment circuit diagram is shown in Fig. 2. The plasma chamber used for this experiment has a diameter of $1m$, and a length of $1.2m$. A diffusive plasma source is installed in the chamber, which produces Argon plasma whose density is $3\times10^{12}m^{-3}$ and temperature is $5eV$. We placed

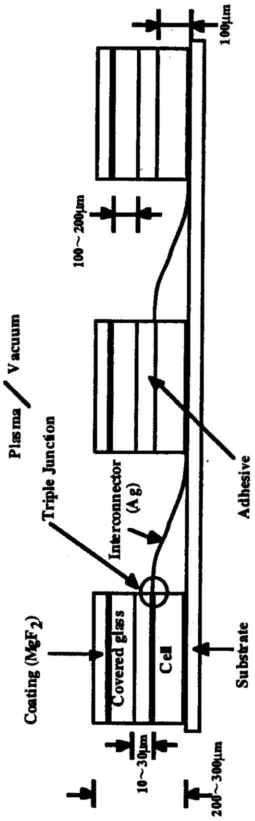

Figure 1: Typical structure of solar array.

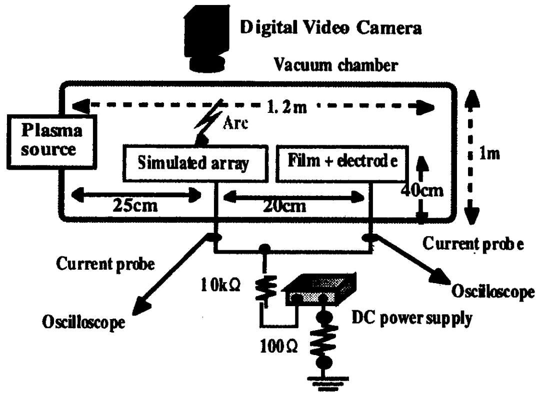

Figure 2: Experimental setup.

a stainless steel electrode of $4cm$ radius which is covered with Polyimide film ($7.5\mu m$ thickness, dielectric constants 3.5) with 5 square holes. We call this electrode as "simulated array" and show its picture in Fig. 3.

The holes of the simulated array simulate the interconnectors of solar array, and the film simulates the covered glass. The reason of using the simulated array, instead of real solar array is because there are too many triple junctions for the real solar array and the analysis becomes complicated. We intentionally reduce the number of the triple junctions by using the simulated array. We also place a stainless steel electrode whose surface is covered with Polyimide film in the plasma chamber. We call this as "film electrode". This plays a role of capacitor connected in parallel with the simulated array, and increases the discharge current so that the light emission due to arcing is easy to detect. This film electrode simulates the electrical capacitance of solar array surface connected to the arc point.

The simulated array and the film electrode are biased to $-800V$ by the DC power supply for nearly one hour. The arc current is measured by a current probe. The waveforms of the arc current

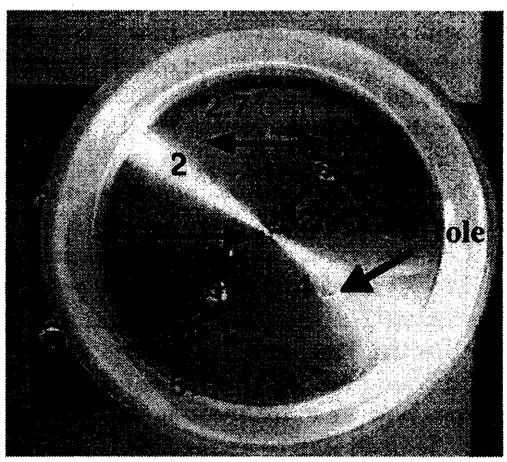

Figure 3: Photograph of simulated array.

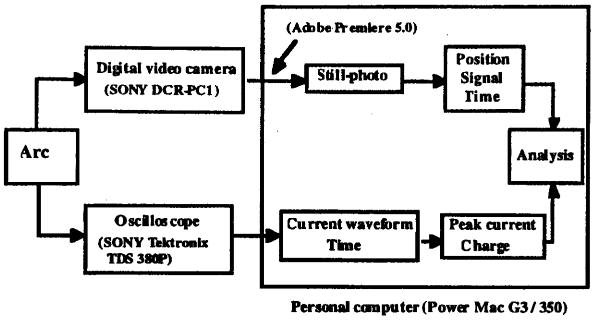

Figure 4: Flow-chart of image processing.

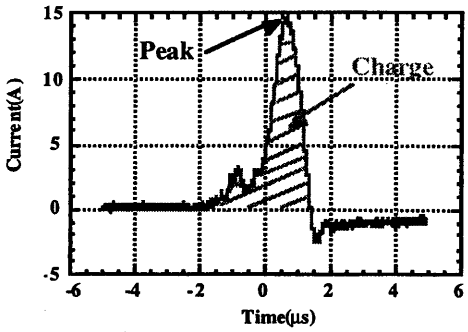

Figure 5: Typical arc current.

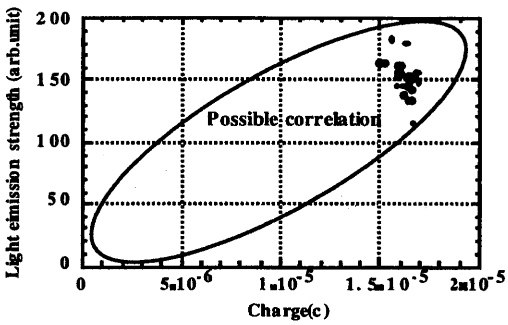

Figure 6: Charge vs light emission strength.

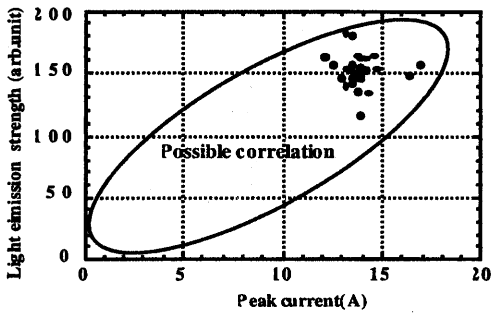

Figure 7: Peak current vs light emission strength.

are stored in a computer along with its occurrence time. The light emission associated with arcing is recorded by a digital video (DV) camera. The gas flow rate during the experiment is $5sccm$, and the back pressure is $6.8 \times 10^{-4} Torr$. The flowchart of the image processing is shown in Fig. 4.

The image taken by the DV camera is transfered to a computer in the digital style, and converted into still-photos for 30frames per second. The still-photos are converted into a gray scale of 256tones. We takes difference of each image pixel by pixel, and when the difference exceeds a certain threshold, the x-y coordinate, the frame number, the light emission strength are given as output. Taking the peak current and the total charge given as the integral of the current from the oscilloscope data, we can take correlation among, arc time, arc position, light emission strength, peak current and charge.

In the present paper, each image consists of 240×180pixels. The threshold to determine the arc occurrence is set to 70. The lower the threshold is, the smaller arc we can detect, but it also increases the false detection. The image processing is carried out on Power Mac G3/350. And it takes nearly 1 hour to process the image of 3 minutes, however it is still possible to reduce this number drastically if the frames of Digital Video are directly handled, which will be done in near future.

3. Experimental Results and Discussion

Fig. 5 shows a typical arc current waveform in the simulated array. The total charge is obtained by taking the time integral of the current waveforms similar to this. The relationship between the total charge and the light emission strength is shown in Fig. 6. The relationship between the peak value of arc current and the light emission strength is shown in Fig. 7. If the scale of the arc current is big, the light emission should be big too, and if we plot like Fig. 6 and Fig. 7, we should see positive correlation. However the number of the data is small to draw any conclusion and we need wider variation on the current.

In the video image, we identified 204arcs during the first three minutes of the experiment. The time and distribution of the arcs is shown in Fig. 8, whose one pixel corresponding to $0.7mm$. As shown in Fig. 8, initially arc occurs frequently but later it occurs less frequently. Also the arc points move among the five holes. The distribu-

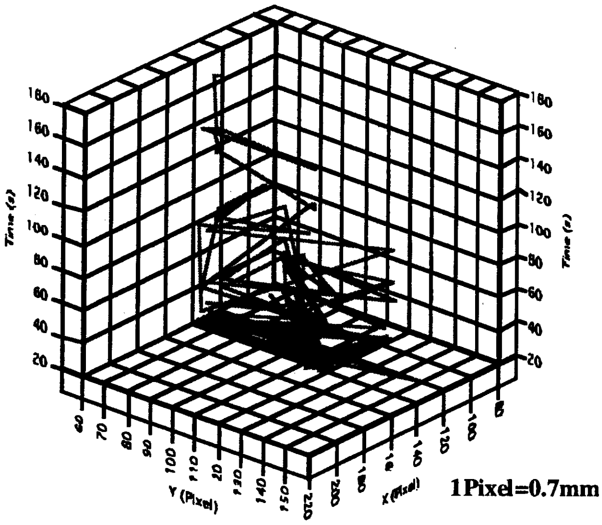

Figure 8: Temporal profile of arc point.

tion of the arc points is shown in Fig. 9, along with the corresponding image of the simulated array. We can see that the arc points concentrate at the edges of the square holes where the triple junction is formed.

Once an arc occurs, the positive charge near the arc spot is neutralized and the charging must restart to have the next arc. If a point is separated far enough from the arc spot, the charging condition is not affected by the arc, and the next arc can occur regardless when the previous arc occurred. For the points near the previous arc spot, because the charging must be restarted, the most probable point for the next arc is the same point as the previous arc because that point should have some reason to arc more easily than the neighbor. Therefore, if an arc occurs, it is likely that the next arc occurs very far from the arc spot or at the same arc point.

In Fig. 10 we plot the distance between the two adjacent arcs against the time interval of the two arcs. If the hypothesis is correct, the plot like Fig. 10, should show that arc interval is randomly scattered for a larger distance. Also, if the next arc occurs near the previous arc spot, but different point, the closer the point the more time for the charging condition to reach the arc condition. Therefore, we should see a negative correlation between the arc interval and the distance for smaller distance.

In Fig. 11 we plot the distance to the next arc point against the light emission strength. If the hypothesis is correct, the plot like Fig. 11 should show that the positive correlation between the distance and the light emission signal and concentra-

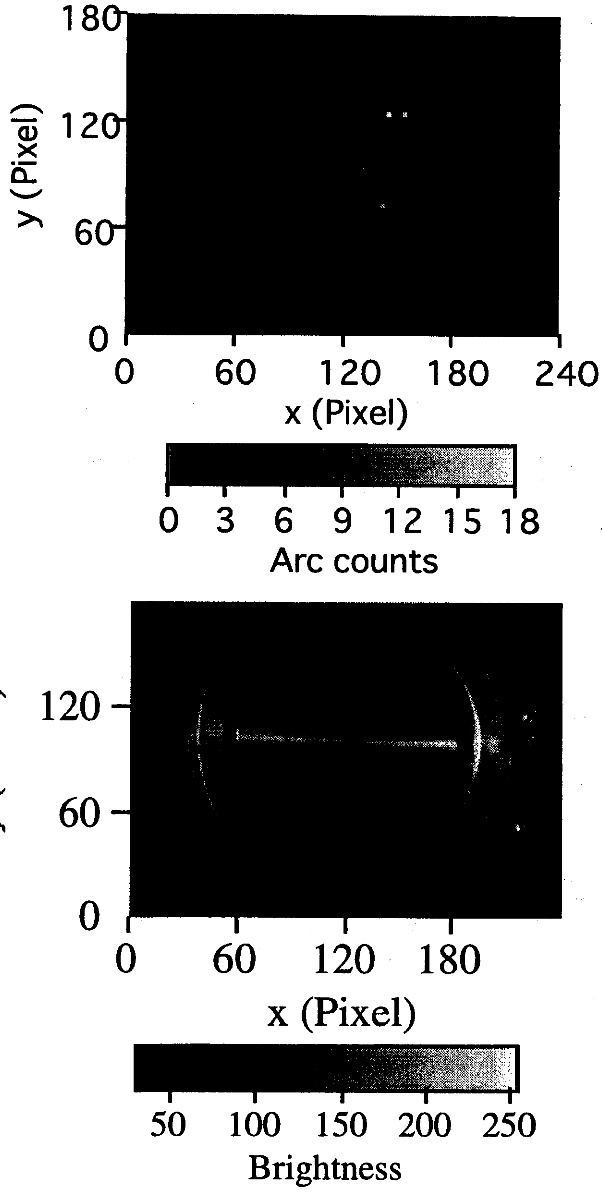

Figure 9: Distribution of the arc points.

tion of points at the zero distance. Because the larger the arc is, longer distance its effect reaches. By looking at Figs 10 and 11, however, it is difficult to draw any conclusion regarding the hypothesis because the number of data is too small.

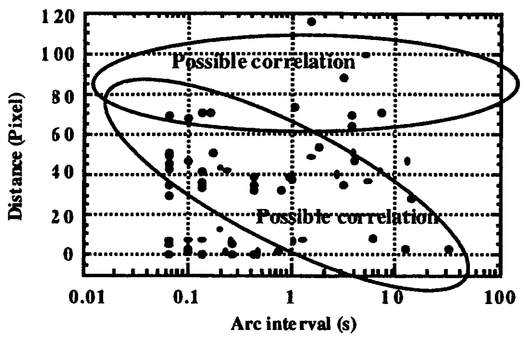

Figure 10: Distance between to two adjacent arcs against the time interval of the arc occurrence.

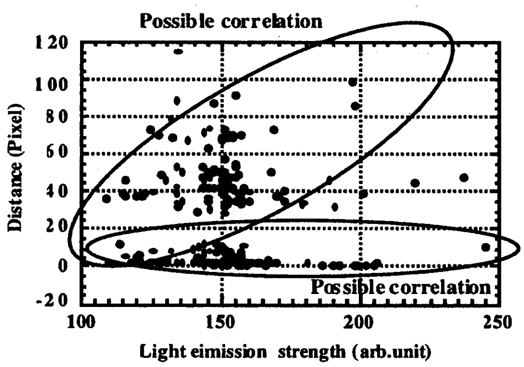

Figure 11: Distance to the next arc point against the light emission strength.

Conclusion

In order to predict arcing occurrence on a high voltage solar array, it is important to know the correlation among successive arcings on multiple points over a two-dimensional plane. We have developed an experimental system which can identify arc points over solar array surface placed in a plasma environment by detecting the light emission from the arc point. By a preliminary experiment, the systems operation has been confirmed. From the present preliminary experiment, however, the statistical conclusion with any meaning cannot be obtained, because the amount of data is still small. In near future, more data will be collected and statistical analysis of the experimental system will be made.

Acknowledgment

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References

[1] M.Cho, D.E. Hastings, "Dielectric Charging Processes And Arcing Rates of High Voltage Solar Array," Journal of Spacecraft and Rockets , Vol.28, No.6, p698-706, 1991.