Trans. JSASS Space Tech. Japan
Vol. 7, No. ists26, pp. Tr_2_67-Tr_2_70, 2009

Investigation of Sustained Arc Under Solar Cell

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(Received May 7th, 2008)

We have so far studied the sustained arc between solar array strings using solar array coupons. The solar cells are connected electrically in series by interconnectors. The interconnector is conductor and is weld at both backside and top of cells. The solar array paddle undergoes the mechanical stress due to thermal cycles in orbit. This stress may cause the separation of interconnector welding backside of cells. If the interconnector is separated from the cell, the string circuit is opened. However solar cells can generate voltage. If the separated interconnector attached to the cell again, the current can flow. If the path between interconnector and cell is formed by insulated adhesive, sustained arc can occur between the separated interconnector and cell. In this paper, the sustained arc between interconnector and cells was investigated experimentally.

Key Words: Solar Array, Discharge, Sustained Arc

1. Introduction

As the power level of spacecraft increases, the failure of power system became a big problem. The failure occurred on the solar array due to sustained arc when the generation voltage of solar array exceeded 100V[1]. The high voltage can flow the short-circuit current between strings of solar cells with potential difference. The short-circuit current can carbonize an insulation film between cells and forms a conducting path. The current generated by the string continues flowing in itself through the conducting path and cannot be transmitted to the spacecraft power system. This failure is called "sustained arc". We have so far studied the sustained arc between solar array strings using solar array coupons.

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In this paper, this type of sustained arc was investigated experimentally. The experiment was performed in a vacuum chamber. A space-use solar cell was used. A side of cell was fixed by polyimide tape. The movable stage was attached at the opposite side of cell and could move the cell up and down. The interconnectors were mounted on the aluminum substrate covered with polyimide film under the cell at the movable part. The cell was moved up and down in order to attach and detach the interconnectors. In this experiment, the secondary arc was found between cell and interconnector. We concluded that this type of sustained arc could occur in orbit.

2. Experimental setup

A silicon solar cell coupon was used as a test sample. Figures 1, 2, and 3 show the solar cell. The cell was fixed on an aluminum substrate with a polyimide insulation film by room temperature vulcanization (RTV) adhesive. First the cell was removed from the substrate, and then the interconnector was removed from the cell. Next the removed interconnector was fixed on the substrate. An edge of the cell was fixed on the substrate by a polyimide tape so as to be movable for up and down.

A silver electrode was formed on the backside of the coupon. The RTV adhesive still remained on the backside of the cell, however the backside electrode can attach to the interconnector electrically when the cell is pushed to the substrate.

The interconnector, the cell, and the substrate were wired independently.

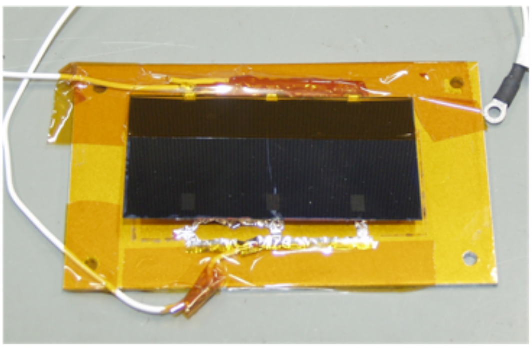

Fig. 1. Photograph of solar cell coupon.

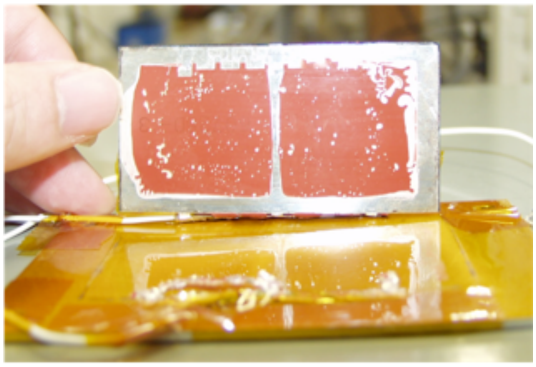

Fig. 2. Photograph of the backside of solar cell.

Fig. 3. Photograph of the interconnector.

Figures 4 and 5 show the experimental setup. The test sample was set in a vacuum chamber, which was evacuated by a diffusion pump and a rotary pomp. The pressure in the chamber was kept lower than 10^{-3} Pa during the experiments. In the chamber, the movable stage was installed. This stage can move vertically and can be controlled with 1μm step by a stepping motor.

The sample was fixed on an acrylic plate. The coverglass of the cell was connected to the movable stage by a rubber plate. The rubber plate was fixed to the cell with the polyimide tape.

Figure 6 shows the experimental circuit. This type of circuit has been used in the secondary arc experiments[2)]. In the circuit, two power supplies were used. Solar array simulators (Agilent Co.) were used as the power supplies. The V1 simulated the power generation of a solar array string. The V2 simulated the constant voltage in the satellite power line. The current was measured by two current probes at CP1 and CP2. The voltage was measured by two voltage probes at VP1 and VP2. The variable resistance R_L was used to adjust the voltage at VP2.

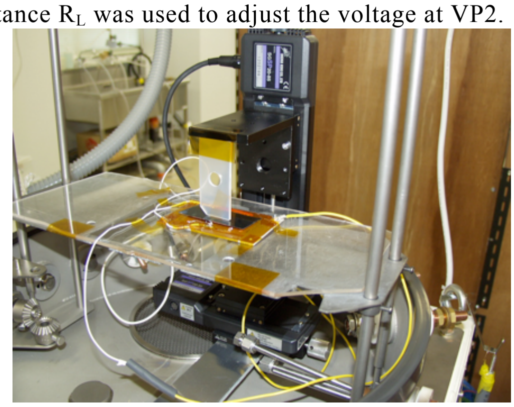

Fig. 4. Experimental setup.

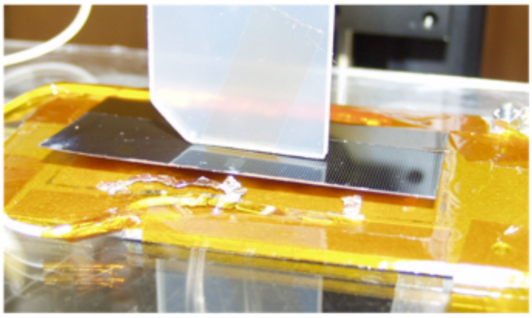

Fig. 5. Photograph of test sample controlled by the movable stage.

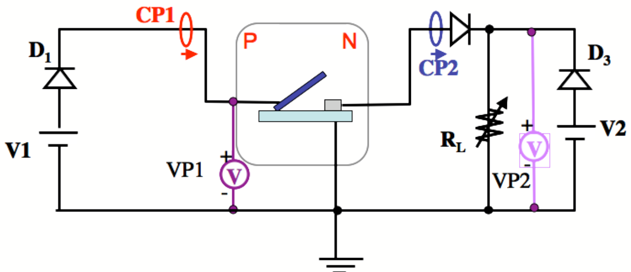

Fig. 6. Experimental circuit.

3. Results and discussions

It was verified whether the secondary arc occurred or not by means of attaching the cell to the interconnector or detaching the cell from the interconnector. The several strings are usually connected in parallel without blocking diodes isolating from the other parallel circuit. If a secondary arc occurs at a string, the other strings connected in parallel with the string can supply generated current to the secondary arc. Therefore the current was set to 0.5A, 1.3A, and 2.3A. The voltage of V1 was set to 120V in open-circuit between the cell and the interconnector, and was set to 90V in short-circuit by means of adjusting the value of R_L. The voltage of V2 was set to 80V in the constant voltage mode.

In open-circuit mode, the V1 applies 120V at VP1, and the V2 supplies the current to the R_L and keep 80V at VP2. In short-circuit mode, the V1 supplies the current to the R_L.

Figure 7 shows an image of flash of the discharge between the cell and the interconnector. This image was taken in detaching the cell from the interconnector at 2.3A. The flash of discharge was observed only in detaching the cell from the interconnecter in the case of both 1.3A and 2.3A without the case of 2.3A. This flash was not observed in 0.5A.

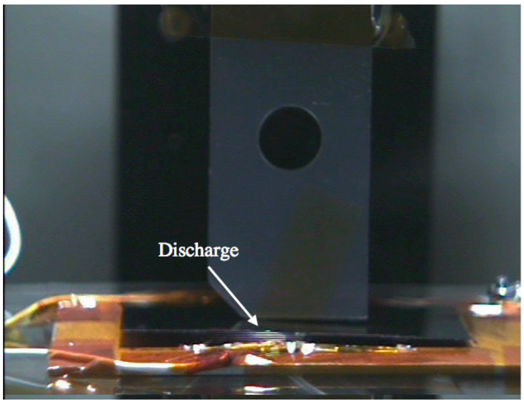

Fig. 7. Image of the discharge between the cell and the interconnector. This image was taken in detaching the cell from the interconnector at 2.3A.

Figures 8 to 13 show the voltage and current waveforms in attaching or detaching the cell. The sustained arc did not occur. The secondary arc occurred in detaching the cell from the interconnector in every testing current. In attaching the cell to the interconnector, the secondary arc occurred only in 2.3A.

For the measurement, the oscilloscope was triggered by the rising or falling edge of CP1. The time at zero second corresponds to the triggered time.

In Fig.8, the constant current of 0.5A was flowing in the R_L from the V1 at the beginning. The movable stage was moved upward with the step of 1μm until a secondary arc occurred. The secondary arc occurred at the time of about –160μs. Though the distance between the cell and the interconnector could not be measured when the discharge occurred, the distance was estimated as the order of μm. The voltage of VP1 was 90V during the constant current flowing, though the voltage rose suddenly up to 100V in spite of constant current. This shows that the secondary arc occurred between the cell and the interconnector. The duration of the secondary arc was 160μs. In the end, the current decreased to zero, and the voltage of VP1 rose more than the constant voltage of 120V and decreased to 120V after about 1ms. This response time was caused because this power supply needed the time in order to shift from the constant current mode to the constant voltage mode.

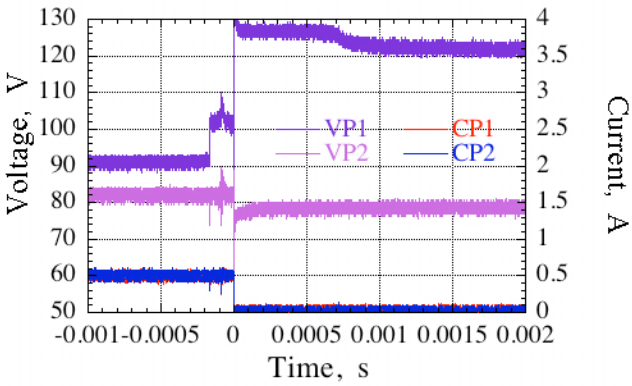

Fig. 8. Voltage and current waveforms with detaching the cell from the interconnector at 0.5A. The secondary arc duration was 160μs.

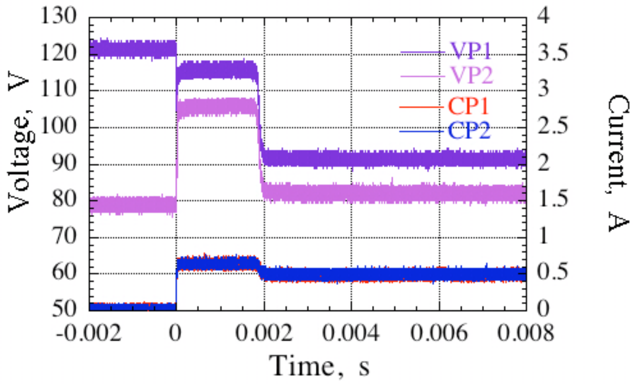

Fig. 9. Voltage and current waveforms with attaching the cell to the interconnector at 0.5A.

In Fig.9, the cell was approaching to the interconnector and attached to it. In this time, the current increased more than the value set to 0.5A and decreased to 0.5A after 2ms. This was caused by the response time of shifting from the CV mode to the CC mode. In the case of 0.5A, the secondary arc did not occur in attaching the cell to the interconnector.

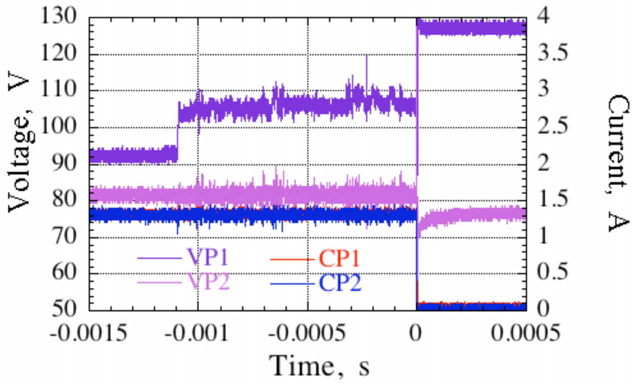

Fig. 10. Voltage and current waveforms with detaching the cell from the interconnector at 1.3A. The secondary arc duration was 1.1ms.

Figure 10 shows the secondary arc with the duration of 1.1ms in detaching the cell from the interconnector. The voltage of secondary arc was about 15V by considering from the difference in voltage between 92V and 107V. The power of the secondary arc was about 20W. The energy consumed in the secondary arc was about 21mJ in 1.1ms.

On the other hand, no secondary arc occurred in attaching with 1.3A as shown in Fig.11.

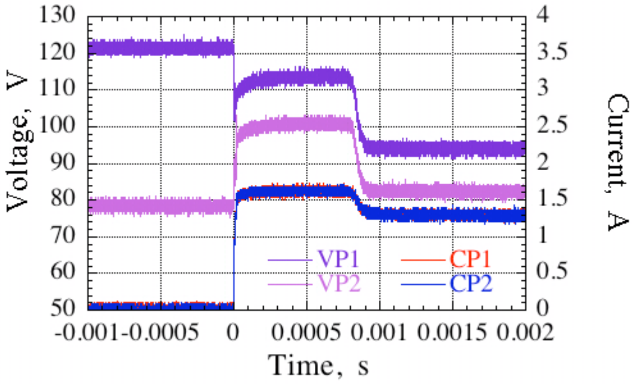

Fig. 11. Voltage and current waveforms with attaching the cell to the interconnector at 1.3A.

In the case of 2.3A, the secondary arc occurred in both detaching and attaching. In Fig.12, the duration of the secondary arc was 2.5ms. The average of the arc voltage was about 20V. Therefore the power of discharge was about 45W. The energy was about 113mJ in 2.5ms.

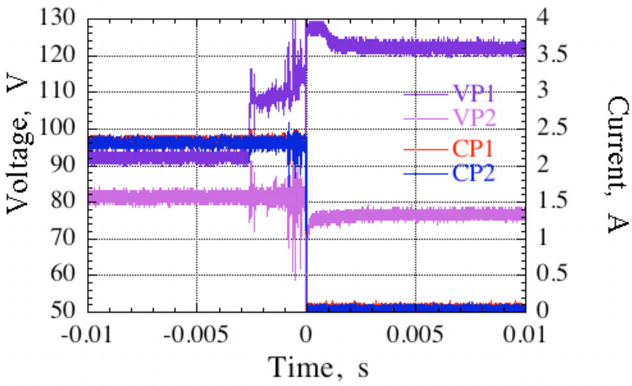

Fig. 12. Voltage and current waveforms with detaching the cell from the interconnector at 2.3A. The secondary arc duration was 2.5ms.

In the case of Fig.13, two secondary arcs were detected. The arc durations were 6.5ms and 5ms, respectively. The arc voltage was about 15V. So the power of the secondary arc was 35W. The total energy was 400mJ.

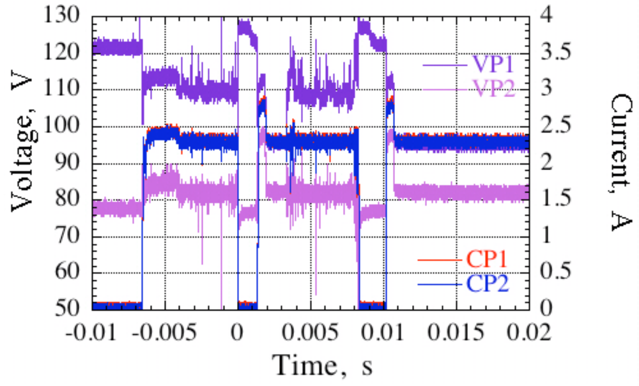

Fig. 13. Voltage and current waveforms with attaching the cell to the interconnector at 2.3A. Two secondary arcs had the durations of 6.5ms and 5ms, respectively.

4. Summary

The secondary arc between the cell electrode and the interconnector under the cell was examined.

The secondary arc occurred under the cell due to attaching and detaching of the cell backside electrode and the interconector, though the sustained arc did not occur. The duration of the secondary arc over 6ms was observed in the string current of 2.3A. From other results using solar array gap for secondary arc testing, the sustained arc was observed when the secondary arc duration was over 1ms. For the solar cell gap testing, the polyimide film between cells is carbonized resulting in short-circuit. In the experimental setup of this paper, however, there is no material carbonized between the interconnecter and the cell electrode. In the real solar array coupons, there is RTV adhesive between the interconnector and the electrode of the cell backside, when the interconnecter is detached from the cell. In this case, the sustained arc may occur due to detaching and attaching of interconnecter.

We will perform the experiment by simulating the condition under the cells precisely.

References

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