

## ESD TEST FOR TRIPLE-JUNCTION SOLAR CELLS WITH MONOLITHIC DIODE

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### ABSTRACT

Recently many spacecraft use triple-junction (TJ) solar cells as their primary electrical power source because of their excellent efficiency. However it is also known that triple-junction solar cells are easy to be broken by a low reverse bias voltage. Therefore a discrete by-pass diode should be connected to every solar cell in parallel for the shadow protection. Under these circumstances, TJ solar cells with integrate monolithic diode (MD) have been introduced to market recently.

In the CICing of TJ solar cell with MD, cell-to-cell interconnector is connected on MD pad. The interconnector region forms triple-junction in orbit, making primary arc inception easy. Therefore, it is necessary to study the behavior of arcs on MD solar cell array.

The result of the ESD test for MD solar array revealed that the degradation of MD solar cell is caused by not only large current but also total energy of the discharge. The waveform seems to be affected by the impedance of the solar array circuit.

This paper presents the recent results of ESD test for MD solar array and proposes further investigation based on the test results.

### 1. Triple Junction Solar Cell with Monolithic Diode

Recently highly efficient triple junction solar cells are mostly used as the primary power source of spacecraft. The power density of the cell is almost double in comparison with crystal Silicon solar cell, a big benefit in the light of the weight and area of the solar array. However, triple junction solar cell is weaker than Silicon solar cell under the reverse bias condition. Therefore by-pass diode connected to each solar cell is required as its shadow protection.

To add the by-pass diode to the TJ solar cell, a discrete Silicon diode is connected by the in-plane inter-connector. But recently TJ solar cell with integrated by-pass function has become available for space solar array. One monolithic diode is grown around the edge of the solar cell in this design and the solar array manufactures can reduce the welding of the inter-connector between by-pass diode and solar cell. Figure-1 shows the typical example of MD solar cell.

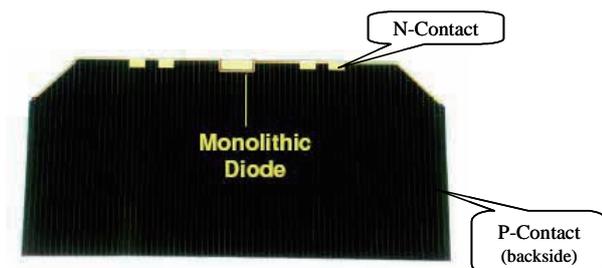


Figure-1 Typical MD solar cell configuration

### 2. ESD test for MD solar cell array

As shown in Figure-2, the discharges around the interconnector could be observed so often. But cell-to-cell interconnector is usually connected on the MD pad for MD cell as shown in Figure-3. Therefore there is possibility that discharge may occur near or on MD. This is the reason why the ESD test for MD solar cell array was planned.



Figure-2 Image of the typical discharge on solar array

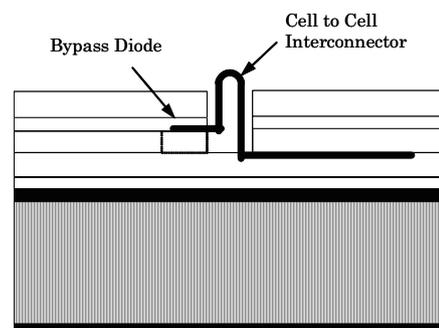


Figure-3 Cross-section of solar array panel

### 3. MD design for ESD Test and test coupon panel

Two types of MD solar cell were available for our ESD test. Figure-4 shows their schematics.

MD in Design-A is categorized as a Schottky diode. By-pass function is applied between the Top-junction and Middle junction solar cells only.

On the other hand, three junctions are protected by P/N junction diode in Design-B. The MD is grown on the triple junctions shunted by metal layer. The forward voltage drop of this function is slightly higher than the  $V_f$  of MD in Design-A.

Same silver interconnector and same cover-glass (CMG-100 with AR coating) are assembled on both types of MD cells. The sizes of both cells are the same. To see the difference between them, they are bonded on the same coupon substrate. The coupon panel for ESD test is shown in Figure-5. The right module is Design-A CICs and the left CICs are Design-B.



Figure-5 Coupon panel for ESD Test

### 4. ESD Test for MD cell coupon

Test coupon was set in a space chamber as shown in the Figure-6. The length and diameter of the test are 1.2m and 1.0m. An electron gun, mounted on top of the chamber, irradiate the test coupon with the electron beam. An infrared camera is set in front of the upper window to monitor discharges on the coupon.

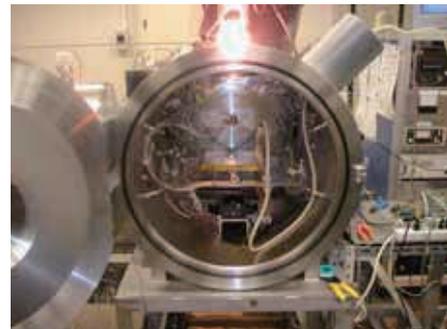


Figure-6 MD cell array coupon in the test chamber

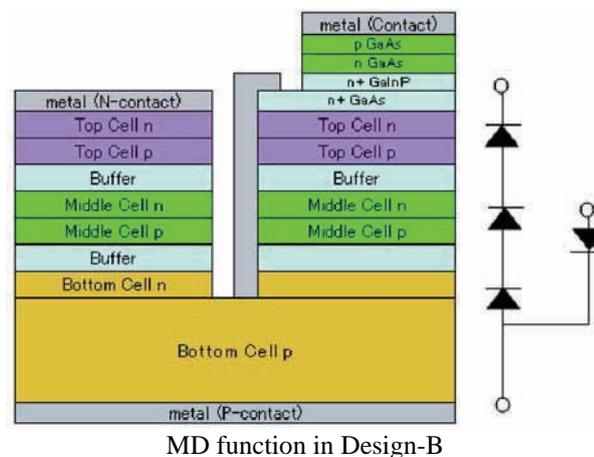
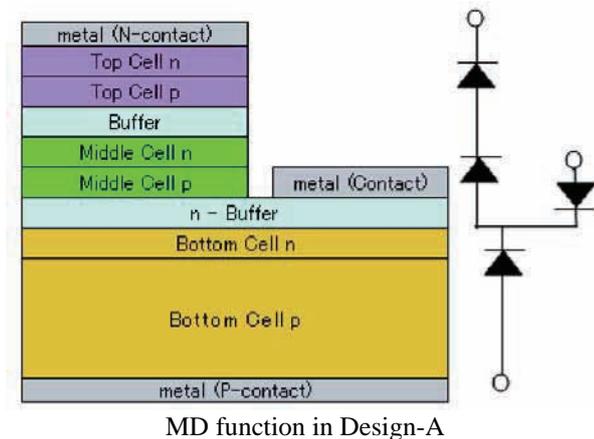


Figure-4 Two types of design of MD for ESD Test

Figure-7 shows the electrical connection in the ESD test. Two solar arrays were connected together and were negatively biased at  $-4.7\text{kV}$  by DC power supply during the test to simulate the inverted potential gradient conditions. Coupon substrate was insulated from the chamber and was also negatively biased along with the solar cells. This is a typical ESD test configuration of solar array coupon for GEO environment. [1]

$C_{\text{ext}}$  in Figure-6 can control the level of the discharge energy. At first,  $2\ \mu\text{F}$  with resistor and inductance was connected, but it became difficult to record the waveform of discharge because of its complex waveform. So  $C_{\text{ext}}$  was changed from  $2\ \mu\text{F}$  to  $160\text{nF}$  without resistor and inductance.

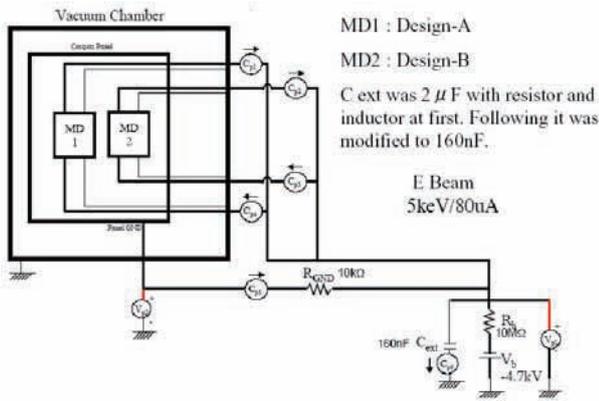


Figure-7 ESD Test Configurations

5. The first ESD test result

The electron beam had been applied on both MD1 and MD2 solar arrays on the coupon panel under the inverted potential gradient condition for 20 hours. V-I curves of each solar array were measured by solar simulator using Xenon lamp before and after ESD test to estimate the degradation of electrical performance of the MD solar arrays precisely.

During the test, 74 discharges were observed. 31 discharges occurred on MD1 solar array and 43 discharges occurred on MD2. Typical discharge images are shown in Figure-8.

The V-I curve of MD2 measured by solar simulator estimation after ESD test was degraded so much. The maximum discharge current was more than 60 Ampere. Both by-pass function and solar array junctions were damaged.

On the other hand, the electrical performance of MD1 array didn't change. The maximum discharge current was less than 30 Ampere. The discharge current of MD1 was smaller probably because of the higher impedance of series connected Ge. Therefore, the degradation of electrical performance was prevented.

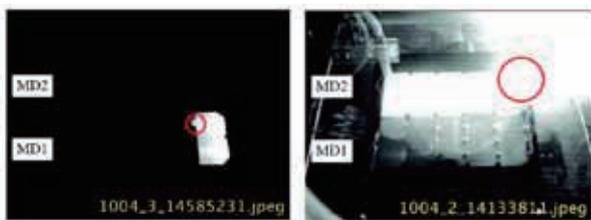


Figure-8 Typical discharge of MD1

6. The second ESD test and the result

To identify the threshold discharge energy to affect the by-pass function, one more coupon panel was prepared. Because MD2 solar cells degraded

during the first test, MD1 solar array was covered with Mylar sheet, exposing only MD2 to the electron beam. To control the direction of the discharge current, two diodes were added on array harness as shown in Figure-9.

Electron beam (4keV / 40~100 μA) was applied on the surface of the coverglass of MD2 solar array. Coupon panel was kept at -4kV to generate inverted potential gradient condition on the solar array. C\_ext was increased from 10nF till when the cell dark V-I curve was changed.

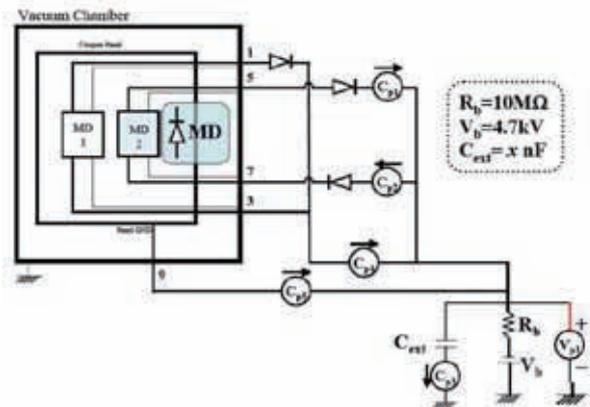
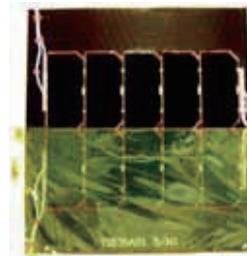


Figure-9 2<sup>nd</sup> ESD test configuration

Figure-10 shows an image of typical discharge of MD2 observed during the second ESD test. Due to the extra diodes at the positive and negative lines of the solar array, discharge current flow through by-pass function only.

Up to C\_ext of 60.3nF, dark V-I curve measured after every discharge of the array circuit had not been changed. Five discharges were generated in the case of C\_ext=60.3nF and the maximum discharge current was 50.3A. There is no change in dark V-I curves. However, when C\_ext was raised to 73.7nF, the dark V-I curve was changed by the third discharge. The primary arc at the third cell from positive end of the string was observed as shown in Figure-10.

The peak discharge current was 37.5A as shown in Figure-11. The duration was for 30 μ sec and discharge energy was 0.8J (350 μ C).

Dark I-V curve measured before and the discharge changed as shown in Figure-12. It was clear that the solar array was damaged by the discharge whose waveform is shown in Figure-11.

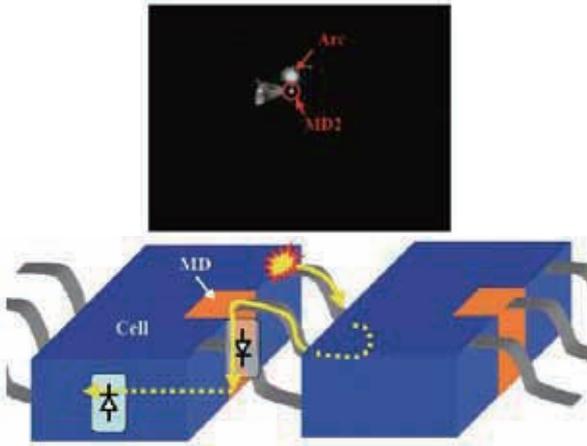


Figure-10 Typical discharge on MD2 solar array

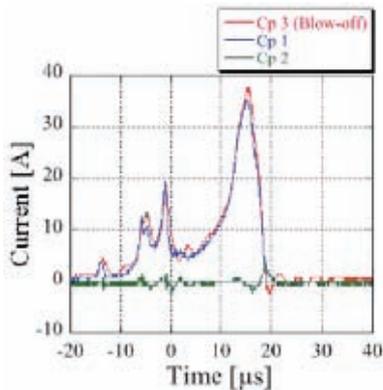


Figure-11 Waveform of the third discharge  
Cext = 73.7nF

The coupon panel was removed from the test chamber. The V-I curves of solar array and MD function measured separately indicate that MD function was damaged. Therefore, 0.8J could be considered as the threshold of discharge energy for the by-pass function of MD2 solar cell.

It is interesting that MD2 solar array didn't degrade by 50.3Ampere discharge but 37.5Ampere discharge could affect the performance. This means the energy of the discharge is important when we consider the damage caused by ESD on solar array

#### 7. Discussion and further investigation

Following two things could be pointed out from the above tests.

- (1) Discharge current of MD1 was lower than MD2 solar array.
- (2) MD2 was healthy to 50A surge current but it was damaged by 38A discharge current (for about 30 μ sec).

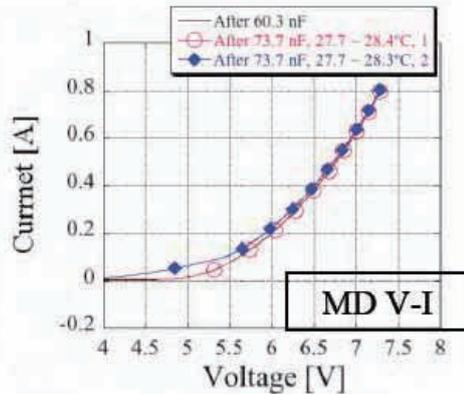
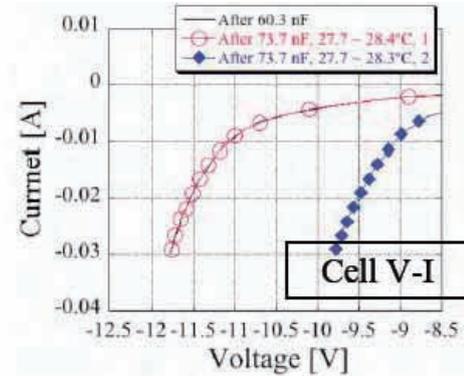


Figure-12 Cell V-I and MD V-I before and after the discharge shown in Figure-11

Related to (1), the discharge current (and/or wave form) might be affected by the circuit impedance. Therefore we should investigate the relationship between the circuit impedance and the discharge current (or waveform).

Based on (2), not only discharge current but also total energy of discharge should be considered in the light of the degradation of by-pass function. This might be the same for MD1, so we would like to do ESD test for MD1 to identify the threshold energy for degradation of MD of Type-A.

#### 8. REFERENCE

1. Toyoda K, et al. Power reduction of solar arrays by arcing under simulate GEO environment, Journal of Spacecraft and Rockets, Vol. 41, No. 5, September-October 2004.