PROPOSAL OF A CURRENT REGULATIVE DIODE FOR POWER SUPPLY IN SUSTAINED ARC TEST

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Abstract

We proposed a power supply for electro static discharge (ESD) test on solar arrays. The Current Regulative Diode (CRD) was adopted in this power supply. The CRD can flow a constant current in spite of the applied voltage. The CRD can also reduce the surge current due to a large internal capacitance in the power supply. We measured the performance of the CRD power supply on short-circuit condition. We also tested this circuit for ESD tests. The CRD circuit showed good performance and could cause the sustained arc as well as the secondary arc. We confirmed that the CRD power supply was useful for ESD ground test.

1 Introduction

Many spacecrafts suffered from serious troubles on orbit as their bus voltages became higher. The most dangerous trouble is sustained arc [1]. The sustained arc means that the short-circuit between adjacent strings of solar arrays is formed and the current flows continuously by photovoltaic power of itself. To prevent the destructive troubles in advance, the ground tests are needed to justify whether the sustained arc occurs or not.

In the ground tests, the voltage and current are set for test samples. The value of voltage is the potential difference between adjacent cells, and the current is the value supplied by solar array strings. These values are different in satellites. When an electro static discharge (ESD) occurs between strings with potential difference, the ESD produces plasma between strings and causes a secondary arc. The secondary arc means the arc continuing due to photovoltaic power with some duration. When the voltage and current condition is enough large to keep the arc continuing, the secondary arc can grow into a sustained arc. The voltage and current are important for the ground tests, because these values can affect whether the secondary arc occurs or not. If the value of voltage and current is larger, the probability of secondary arc becomes higher.

The ground test methods have been developed so far [2–4]. We had used the general power supplies for ESD tests at first stage [5, 6]. These power supplies have large capacitance inside their own and can supply a large amount of charge to the secondary arcs, when the strings are short-circuited due to ESD's plasma. As a result, these power supplies flow larger current than the limited value in themselves and can offer the overestimated condition. Nowadays, we use the power supply with small internal capacitance. This power supply is called as the solar array simulator (SAS) and is manufactured to output the electric characteristics of solar cells. The SAS has rapid response in its performance and small internal capacitance. However, the SAS has the weakness in voltage fluctuation from the outside and is also expensive.

In this paper, we proposed the power supply with current regulative diode (CRD) for ESD ground tests. We realized the constant current power supply without active control.

2 CRD power supply

We used CRD's for sustained arc test. The CRD power supply consists of many CRD's and DC power supply. The CRD is semiconductor and keeps the current constant. They are usually used for current regulation of LED, and those constant currents are generally small. In our study, we used the CRD which can flow the current of 5.6 mA with adequate applied voltage. The threshold voltage is 100V. We connected about 180 pieces of CRD in parallel to produce 1A (Fig. 1 and Fig. 2). When we want to test another current, we change the number of CRD in parallel. In the case of testing over 100V applied voltage on the CRD, we connect the CRD in series. The CRD has some temperature dependences. The current becomes a little less than 1A because the CRD's temperature becomes high due to its Joule heating. When the

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applied voltage becomes high, the temperature of CRD increases because the power is dissipated in the CRD in order to keep the current constant. In these experiments, the current was about 0.8 A after the CRD's temperature became constant. If we want to use the CRD at the maximum constant current, we set the applied voltage to around 10V.

We can use any power supply for DC power supply driving the CRD in Fig. 1. If we use the voltage adjustable power supply for the DC power supply, it is easy to set the constant current to the maximum constant current (about 5.6 mA per a CRD) by means of setting the applied voltage to 10V. In our experiments, we used not only the voltage adjustable power supply but also the cheaper switching DC power supply (SWPS). In this type of power supply, the output voltage is constant.

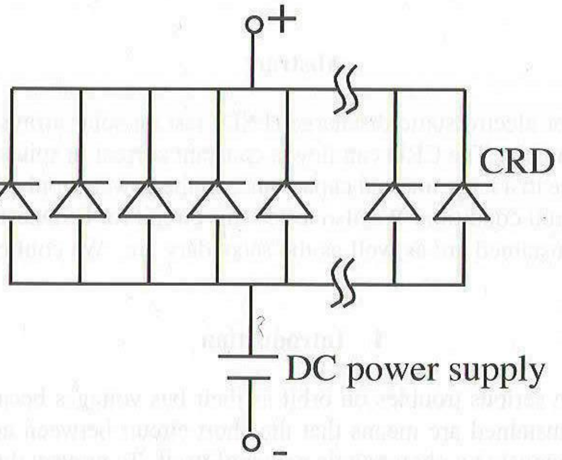

Fig. 1: Schematic picture of CRD power supply.

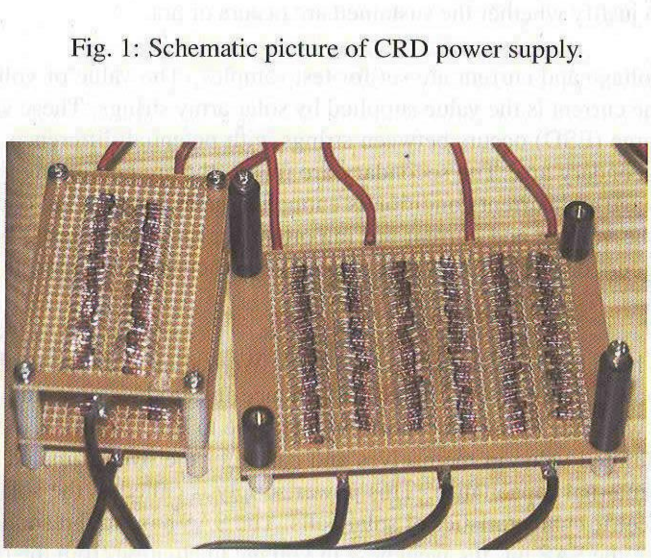

Fig. 2: Photograph of CRD circuit. The CRD's were connected in parallel.

3 Characteristics of power supplies

The short-circuit characteristics of four power supplies were measured. The power supplies used for short-circuit tests are listed in Table 1. The SAS and TM070 are constant current and voltage power supplies. In this test, these power supplies were used as constant current power supply. The SWPS is constant voltage power supply. Three SWPS's were connected in series to produce over 50V (test condition). The 180 CRD's connected in parallel were used for the CRD circuits and connected to TM070 and SWPS, respectively.

Figure 3 shows a schematic picture of test circuit for measuring short-circuit characteristics of power supplies. This

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Table 1: Power supplies for test.

Name of CC power supply	Abbreviation
Solar array simulator (Agilent)	SAS
TM070-1 (Takasago)	TM070
CRD (180 pcs) with TM070-1	CRD+TM070
CRD (180 pcs) with Switching power supply (24V-2.5A $\times$ 3)	CRD+SWPS

circuit consists of two power supplies, three diodes, a variable resistance, and a short-circuit switch. We used a MOSFET instead of a mechanical switch to short-circuit the test circuit so that the mechanical switch causes an unstable short-circuit. At first for the measurements, we set the current limitation of power supply to the suitable value. Next, we changed the variable resistance Rb in order to make the suitable potential difference in the Rb. The CV power supply is set to smaller value than the voltage biased by the CC power supply. When the switch is closed, the CC power supply feeds the current to the resistance Ra only so that the higher voltage is applied in Rb by the CV power supply. For short-circuit tests, we set the potential difference in Rb to 50V, the current to 1A. The CRD circuits, however, supplied the current of 0.85A due to heating of the CRD's.

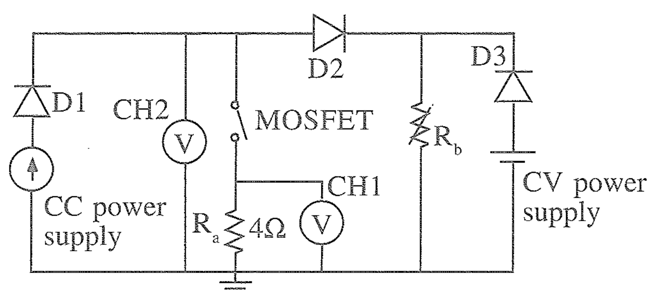

Fig. 3: Schematic picture of test circuit for characteristics measurement of power supplies.

Figures 4, 5, 6, and 7 show the waveforms of short-circuit current and voltage with each power supply.

In the case of SAS, the peak current was about 4.5 A in Fig. 4 (a). This peak current is within 5 times of limited current. It took about 2μs that the current became constant. The SAS supplied larger amount of charge than the limited current by about 3 μC. The current of SAS was constant in long time scale as shown in Fig. 4.

In the case of using the TM070 (Fig. 5), the peak current were about 8 A. It took over 2 ms to become limited current. This power supply fed much larger amount of charge than limit current by 3 mC. This kind of power supply was naturally not suitable for the sustained arc tests. However many DC power supplies have such a large internal capacitance.

On the other hand, the CRD+TM070 showed good performance of short-circuit current. As shown in Fig. 6, the peak current was 2.5 A. This current was only 3 times as the limit value. The duration for constant current was within 1 μ s despite the fructuation of current. In long time scale, the current was constant for the order of ms. The current decreases due to heat of CRD after the voltage applied in CRD increases. However, it takes a few seconds to become constant current. So the current is kept constant for the order of ms. From these results, we confirmed that the conventional power supplies, which had a large internal capacitance, were available for sustained arc test by means of additional CRD circuit.

Furthermore, we used the cheaper power supply for driving the CRD's. The CRD+SWPS also showed good performance. As shown in Fig. 7, the peak current was about 2.4 A, the duration for constant current was within 1 μs. This power supply fed larger amount of charge than limit current by only 0.4 μC. In long time scale, this also supplied constant current for the order of ms. The SWPS's are generally sold as power supply adoptors. This kind of power supply is generally cheap and strong.

Figure 8 shows the comparison of current waveform between CRD+SWPS and SAS. The SAS fed larger amount of charge, 2.6 μC, than the CRD+SWPS. The duration of CRD+SWPS for limited current was much shorter than that of the

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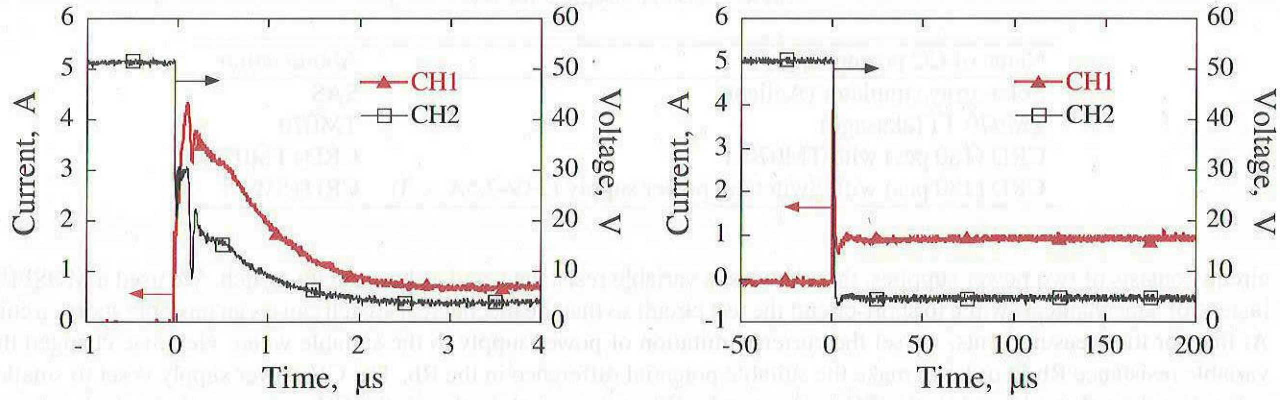


(a) Short time scale.
(b) Long time scale.

Fig. 4: Waveforms of SAS.

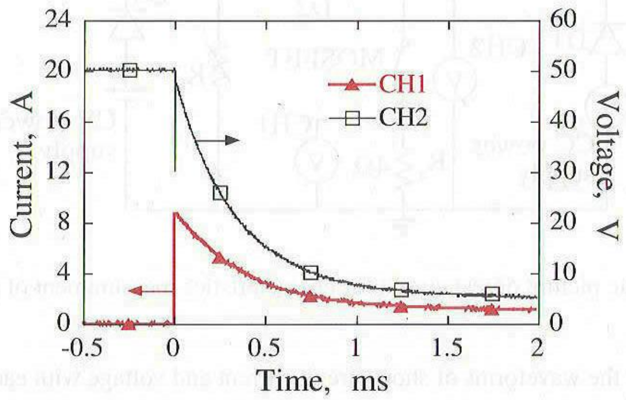
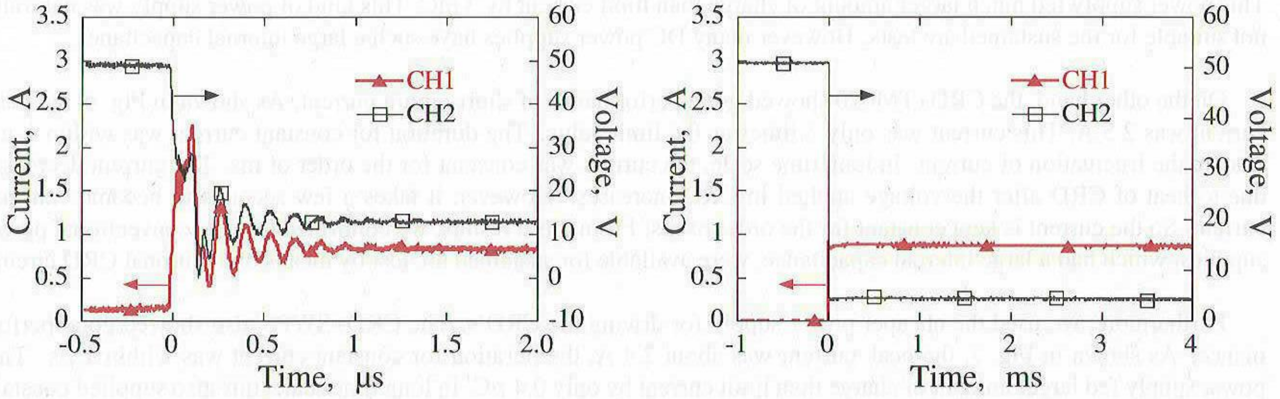


Fig. 5: Waveforms of TM070-1.



(a) Short time scale.
(b) Long time scale.

Fig. 6: Waveforms of CRD+TM070.

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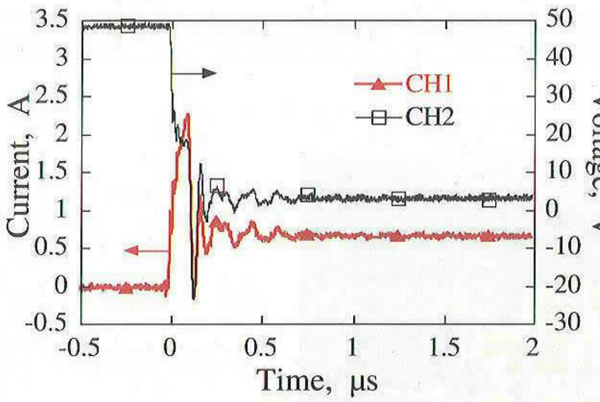
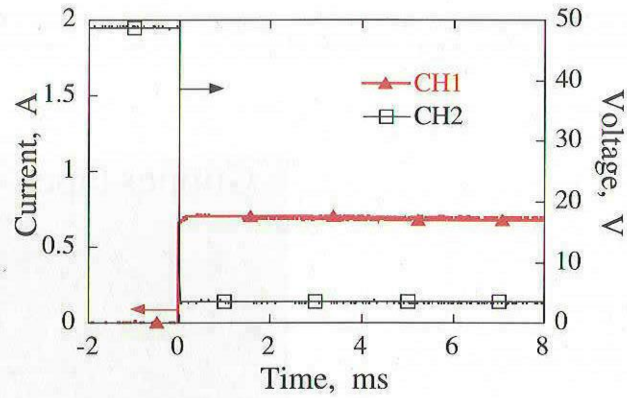


(a) Short time scale.



(b) Long time scale.

Fig. 7: Waveforms of CRD+SWPS.

SAS. The SAS has enough performance for ESD test. However, the SAS is weak against external noise and expensive. The CRD power supply is useful for ESD test with more rigorous condition in external capacitance.

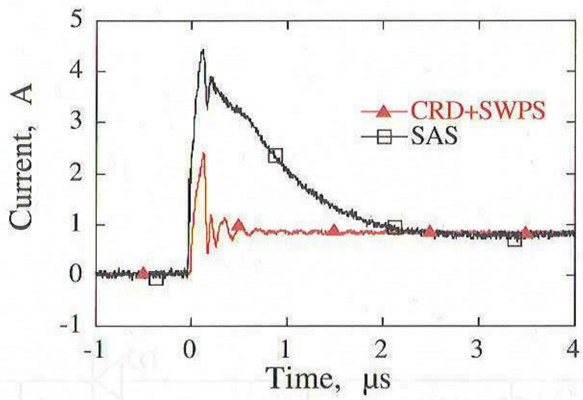


Fig. 8: Current waveforms of CRD+SWPS and SAS.

4 ESD test using CRD power supply

We performed the ESD tests using the CRD+SWPS and the SAS. Figure 9 shows the test sample used in this experiment. This sample simulates the solar array. Two cupper tapes are put on the Kapton tape. This Kapton tape and cupper tapes simulate the substrate and cell of solar array, respectively. These cupper tapes are covered with the Kapton tapes. These Kapton tapes simulate the coverglass of solar cells. The length of the gap between adjacent cupper tapes was measured by a microscope after the sample was assembled. The length of gap was 0.17mm. This length is much shorter than that of the real sample (0.5mm in general), because we wanted to cause the secondary arc on the active gap.

The tests were performed in a vacuum chamber. The chamber was filled with xenon plasma by an electron cyclotron resonance (ECR) plasma source [7]. The electron density was about 5×10^{11} m^{-3} on the sample. Figure 10 shows the circuit used for ESD test. This circuit has been developed for sustained arc test [2]. This circuit was basically the same as the circuit in Fig 3, except to be biased at negative voltage. The circuit was biased at -450V by a power supply. An external capacitance C_{ext} was connected in parallel to this power supply, and fed the amount of charge in onset of trigger arc. We used 40nF capacitance as C_{ext}. The CRD+SWPS and the SAS were used for CC power supply, respectively. The number of CRD's was 225. The CRD+SWPS supplied 0.9A at the potential difference of 50V in VR. We set the limited current of the SAS to 0.9A.

The potential difference in active gap was measured by a differential voltage probe (DVP). Two DC current probes

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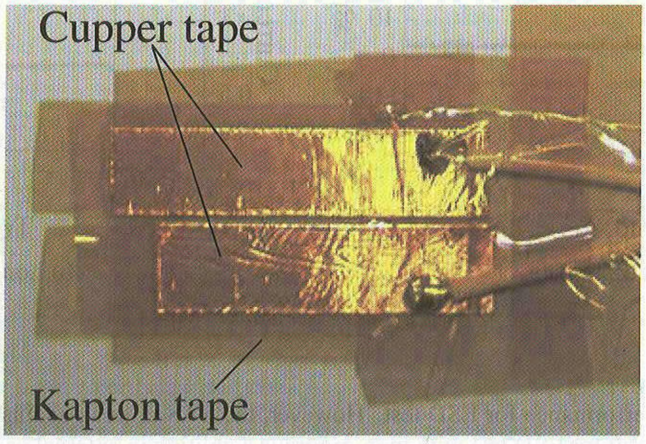

Fig. 9: Photograph of test sample.

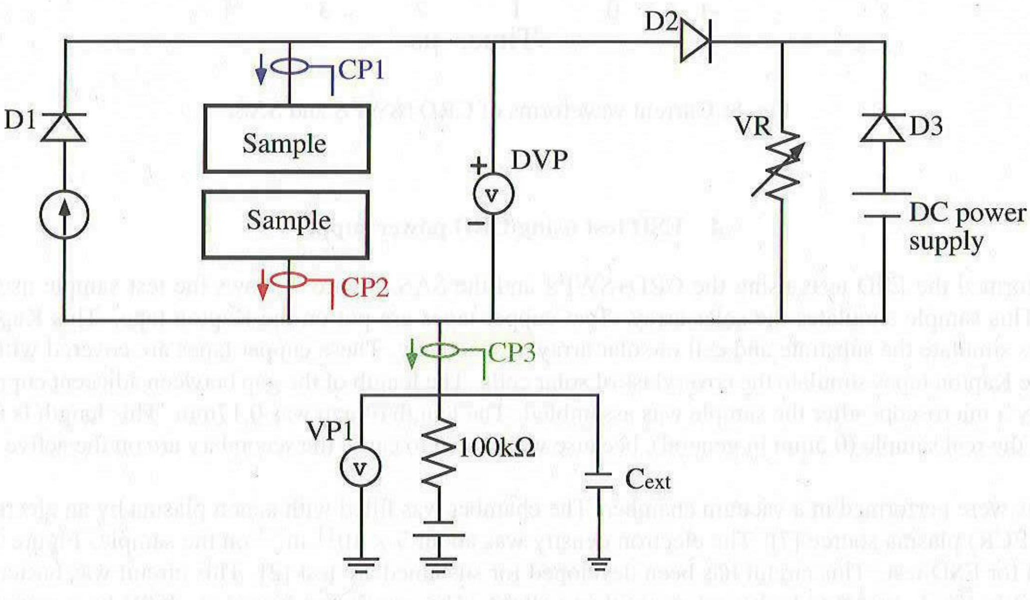

Fig. 10: Circuit for sustained arc test.

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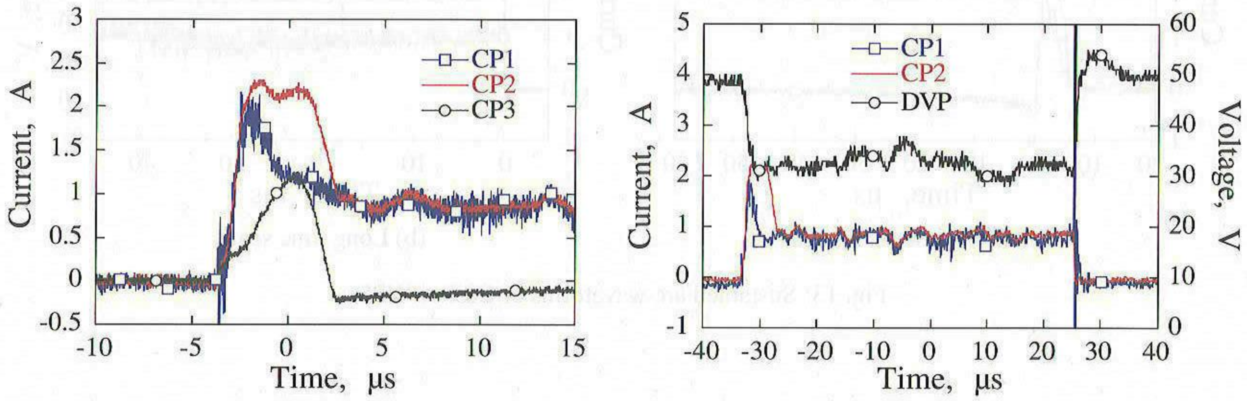
were used for CP1 and CP2, and a AC current probes for CP3. The CP1 and CP2 can detect the secondary arc current. The CP3 can detect the trigger arc current. These waveforms were recorded by two digital oscilloscopes with different time scales.

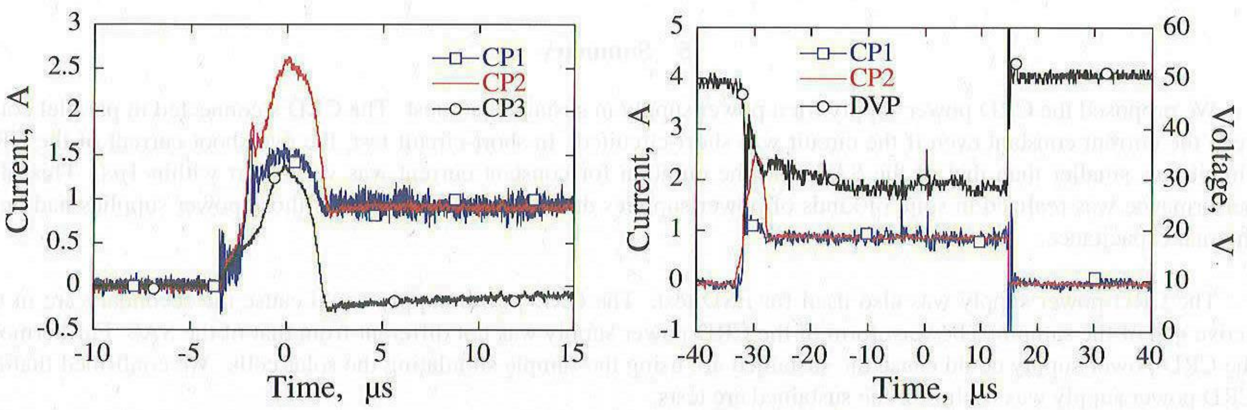
Figure 11 shows waveforms of secondary arc using the SAS as the CC power supply. In this case, the peak current of trigger arc was 1.2 A. We found from waveforms of CP1 and CP2 that the secondary arc started just after the trigger arc starting. The CP2 included trigger arc current with secondary arc current. The beginning of waveform of CP1 and CP2 correspond to the overshooting current due to internal capacitance of SAS, because the trigger arc current is much smaller than CP1 and CP2 in this time. After the trigger arc, the CP1 and CP2 showed constant current. However this current showed some unstableness. As shown in long time scale, the secondary arc had continued for about 60 μs. This current was almost constant. The differential voltage was about 30V in the secondary arc.



(a) Short time scale. (b) Long time scale.

Fig. 11: Secondary arc waveforms of SAS.

The secondary arc waveform of the CRD+SWPS is shown in Fig. 12. The peak current of trigger arc was about 1.4 A, and the pulse width was about 4.5 μs. After the trigger arc, the current was kept at 0.9A. The current waveform was very stable. The secondary arc lasted for about 50 μs. The differential voltage was around 30V. The waveform of the CRD+SWPS was not different from that of the SAS. The SAS is widely used for ESD test. From these results, we confirmed that the CRD circuit could be used for secondary arc tests.



(a) Short time scale. (b) Long time scale.

Fig. 12: Secondary arc waveforms of CRD+SWPS.

We caused the sustained arc using the CRD+SWPS. The gap distance of the sample was 0.31 mm. The differential voltage ind gaps was 64 V. The limited current was 1.9 A. The 360 CRD's were connected in series. The bias voltage was -650V. Figure 13 shows the waveform of sustained arc. The secondary arc current was 1.9 A just after the trigger arc.

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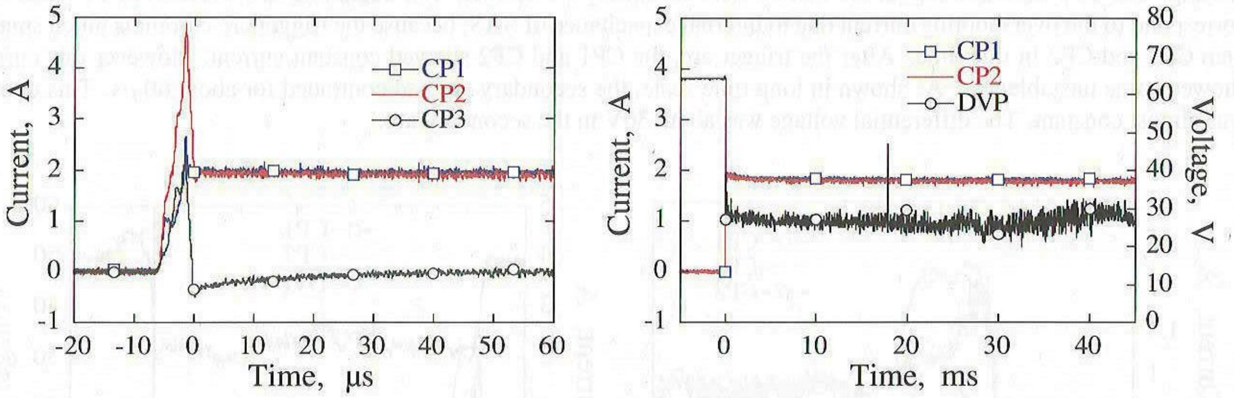
The secondary arc lasted over 45ms. We could not measure the duration of sustained arc. However, we can guess that the sustained arc lasted over 5 seconds from the video image.

Figure 14 shows the photograph after the sustained arc. After the sustained arc, the sample was destroyed from the gap in where the arc occurred. We confirmed that the CRD circuit could cause the sustained arc, and also confirmed that the sustained arc could occur on this type of sample simulating the real solar cells.



(a) Short time scale. (b) Long time scale.

Fig. 13: Sustained arc waveforms of CRD+SWPS.

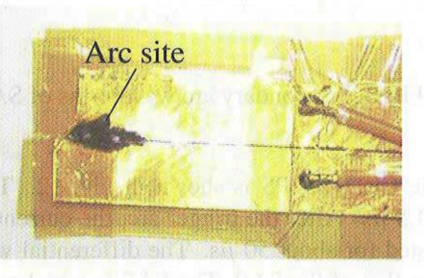


Fig. 14: Photograph of the sample after the sustained arc.

5 Summary

We proposed the CRD power supply for a power supply in sustained arc test. The CRD's connected in parallel could keep the current constant even if the circuit was short-circuited. In short-circuit test, the overshoot current of the CRD circuit was smaller than that of the SAS, and the duration for constant current was very short within $1\mu s$. This high performance was realized in spite of kinds of power supplies driving the CRD's, even if those power supplies had large internal capacitance.

The CRD power supply was also used for ESD test. The CRD power supply could cause the secondary arc in the active gap of the sample. The waveform of the CRD power supply was not different from that of the SAS. Furthermore, the CRD power supply could cause the sustained arc using the sample simulating the solar cells. We confirmed that the CRD power supply was useful for the sustained arc tests.

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