# BASIC EXPERIMENTS FOR VACUUM ARC DISCHARGES TRIGGRERED BY ESD

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**Abstract**

The anomaly of Japanese satellite ADEOS-II (Advanced Earth Observing Satellite II) appeared in 2003 is supposed to be caused by arcing discharge initiated due to ESD (Electrostatic Discharge) in the bundled wire-harnesses of the solar paddle. In order to make the conditions of the occurrence of the discharges clear, it is necessary to evaluate the discharge characteristics in vacuum quantitatively. Therefore we tried to investigate the characteristics of arcing discharge between two electrodes consisting of a pair of thin copper plates. The discharges were triggered by ESD released from a capacitor. These characteristics were obtained as parameters of the amplitude of the ESD, the pressure in the chamber and so on. We preliminarily obtained the result that the arcing discharge time increased with the amplitude of the ESD.

## 1. Introduction

Recently the larger electric power capability and the longer mission life of the satellite are progressed. The high power requires the electric power generation with high voltage to the satellite in order to reduce the heat loss and the weight of the wire cables. So the satellites generating the electric power with the voltage of more than 100V have started to be operated from the latter half of 1990's. On the other hand, it is thought to be a threat that space plasma around the satellite causes electrostatic charging and discharges on the satellite [1]. In reality, Japanese polar-orbiting satellite ADEOS-II unfortunately fell into malfunction in 2003. The cause is thought to be the occurrence of arcing discharge triggered by ESD between wire's conductors in the bundled wire-harnesses. The ESD occurred due to charge-up of non-grounded conductive layer of MLI (multi-layer insulation) in polar plasma. In order to make the discharge mechanism clear, it is necessary to evaluate the arcing discharge characteristics quantitatively.

From the viewpoint, we are trying to investigate the arcing discharge characteristics triggered by ESD in vacuum. We have carried out the experiments for arcing discharges between two conductors triggered by ESD released from a capacitor charged up by DC power supply. We will present the preliminary experimental results in this paper.

## 2. Experimental Procedure

We used the model sample shown in Fig.1. A pair of 0.15mm-thick copper plates of the size of 20x50mm$^2$ was used as conductors. The long sides of the plates were opposed to each other with the gap distance d. We also used a needle electrode of the diameter of 1mm which was set closely to the edge of 0.15mm-thick borosilicate glass to initiate discharges along the side wall. This sample was set in the vacuum chamber.

The experimental setup shown in Fig.2 was constructed for the sample. The resistor of the resistance R was inserted between both conductors. And the other terminals of the conductors were connected to the DC current source (Takasago KX-100H). The needle electrode was connected to one terminal of a three-terminal switch. The switch was also connected to the capacitor of the capacitance C and the DC voltage power supply (Kikusui Electronics Corp. PAD1K-0.2L) through the resister of the resistance of 5MΩ. By turning the switch on to the power supply, the capacitor was charged and then by turning it on to the needle electrode the charge stored in the capacitor was released to one conductor accompanying with ESD along the side wall of the glass.

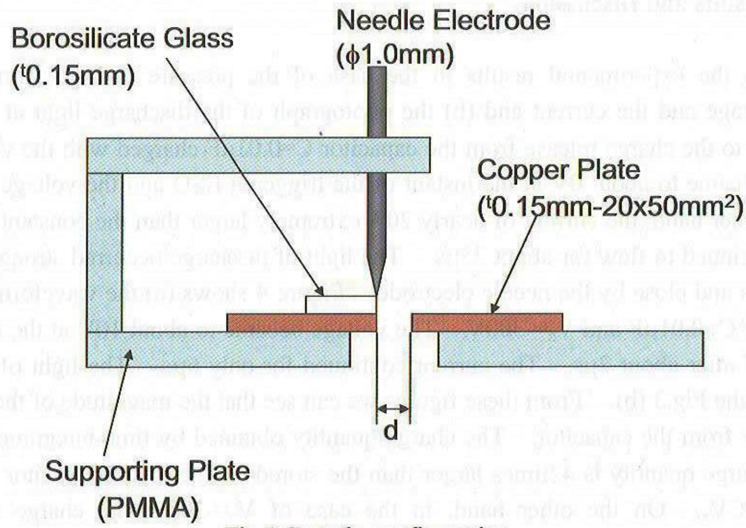



Fig.1 Sample configuration.

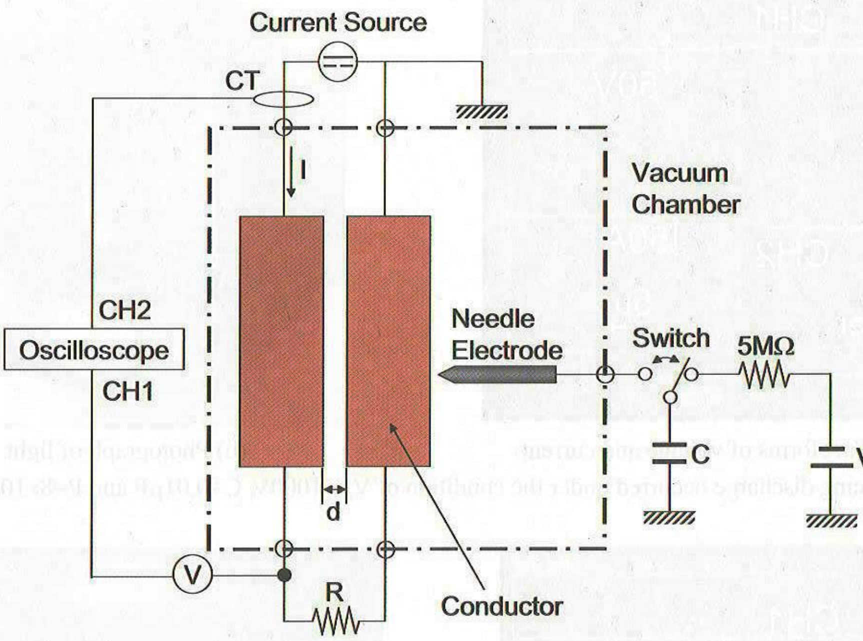


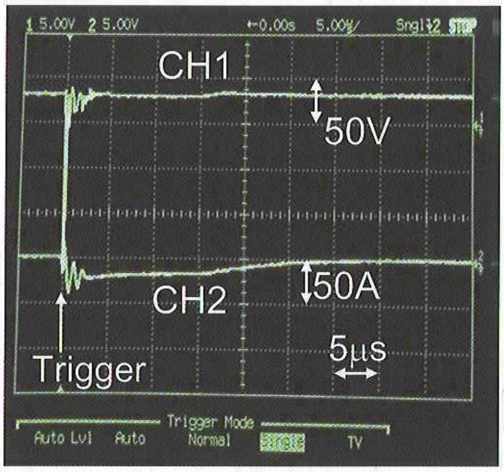

Fig.2 Experimental setup.

Next we explain the experimental procedure. The chamber shown in Fig.2 was evacuated by a rotary pump and a turbo-molecular pump. The current I was supplied from the current source to the conductors and the resistor R. Then the potential difference RI was generated between the conductors. At the same time, the capacitor C was charged by applying the voltage $V_c$ with the DC power supply. After that, the switch was turned on to the needle electrode and the charge stored in the capacitor was released as ESD. In such a circumstance, the voltage induced in the resistor R was measured by a voltage probe and the current I was measured by a current transformer CT (Pearson 411). These signals of the voltage and the current were displayed on the oscilloscope (Kikusui Electronics Corp. COR5521).

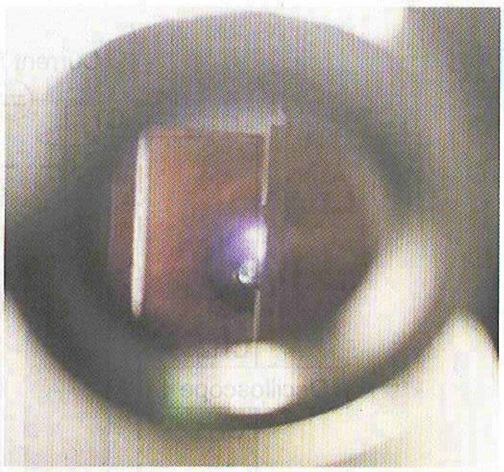
As I=0.5A and R=66Ω were used in this experiment, the voltage appeared in the resistor R was 33V under regular condition. The pressure P in the vacuum chamber, the charging voltage $V_c$ were changed. And the gap distance d was always 0.4mm. All the experiments were carried out in room temperature.

## 3. Experimental Results and Discussions

Firstly we describe the experimental results in the case of the pressure $P=8x10^{-3}$Torr. Figure 3 shows (a) the waveforms of the voltage and the current and (b) the photograph of the discharge light at the instant of the discharge triggered by ESD due to the charge release from the capacitor C=0.01μF charged with the voltage $V_a$=-1000V. We can see that the voltage became to about 0V at the instant of the triggered ESD and the voltage returned to about 33V after about 3μs. On the other hand, the current of nearly 20A extremely larger than the constant current of 0.5A supplied by the current source continued to flow for about 25μs. The light of discharge occurred strongly near the center of the gap between the electrodes and close by the needle electrode. Figure 4 shows (a) the waveforms and (b) the photograph of the light in the case of C=0.01μF and $V_a$=-300V. The voltage became to about 10V at the instant of triggered ESD and returned to about 33V after about 2μs. The current continued for only 6μs. The light of discharge was considerably weak comparing with the Fig.3 (b). From these figures we can see that the magnitude of the arcing discharge is affected by the released energy from the capacitor. The charge quantity obtained by time-integration of the current in Fig.3 (a) was 420μC. This charge quantity is 42times larger than the stored charge in the capacitor C because the quantity Q is 10μC calculating $Q=CV_a$. On the other hand, in the case of $V_a$=-300V, the charge quantity obtained from the time-integration of the current in Fig.4 (a) is about 27μC. This value is 9times larger than the stored charge Q of 3μC.

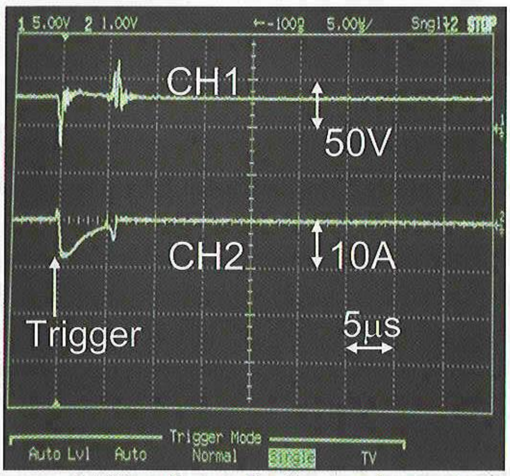



(a) Waveforms of voltage and current



(b) Photograph of light

Fig.3 Arcing discharge occurred under the condition of $V_a$=-1000V, C=0.01μF and $P=8x10^{-3}$Torr.




(a) Waveforms of voltage and current

(b) Photograph of light

Fig.4 Arcing discharge occurred under the condition of $V_a$=-300V, C=0.01μF and $P=8x10^{-3}$Torr.

Figure 5 shows the dependence of the discharge time on the stored charge in the capacitor. This figure indicates that the discharge time almost linearly increases with the stored charge and negative charge injection makes the arcing discharge continue for longer time.

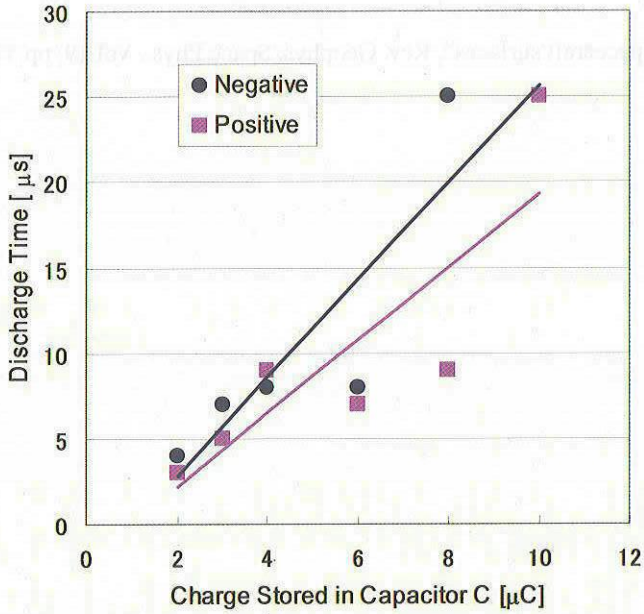
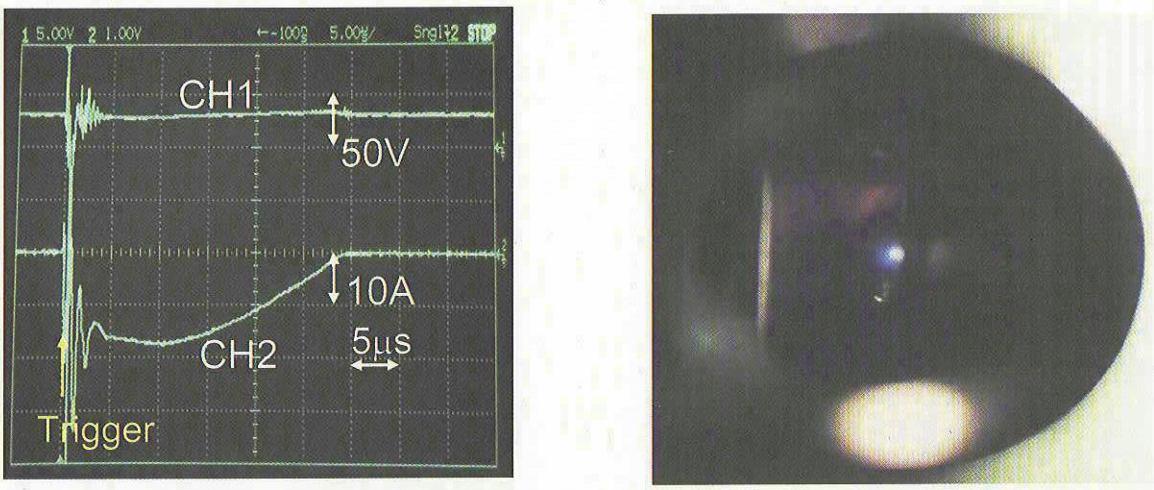



Fig.5 Dependence of discharge time on the charge quantity stored in capacitor.
C=0.01μF and P=8x10$^{-3}$Torr

Next we describe the results under the condition of P=1x10$^{-4}$Torr. Figure 6 shows (a) the waveforms of the voltage and the current and (b) the photograph of the discharge light at the instant of triggered ESD due to the charge release from the capacitor C=0.01μF charged by $V_a$=-1000V. Comparing Fig.6 (a) with Fig.3 (a), both the waveforms are almost similar in the discharge time and the amplitude of the current in spite of the pressure in the chamber. Therefore the discharge characteristics are seemed to be determined by the injected stored charge.




(a) Waveforms of voltage and current (b) Photograph of light

Fig.6 Arcing discharge occurred under the condition of $V_a$=-1000V, C=0.01μF and P=1x10$^{-4}$Torr.

## 4. Conclusion

The experiments of arcing discharge between the current-flowing conductors were carried out by injecting ESD due to the charge stored in the capacitor. The preliminary results are as follows.

(1) The discharge time of arcing increased with injected charge quantity.

(2) The discharge time and the amplitude of discharge current is seemed not to be changed by the surrounding pressure.

We will continue further experiments and detailed analysis in order to make the discharge characteristics clear.

**Reference**

1. H. B. Garrett, "The charging of spacecraft surfaces", Rev. Geophys. Space Phys., Vol.19, pp.577-616 (1981)