Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 204 (2017) 323–328

Procedia Engineering

www.elsevier.com/locate/procedia

14th Hypervelocity Impact Symposium 2017, HVIS2017, 24-28 April 2017, Canterbury, Kent, UK

Discharge On Solar Array Coupon By Debris Impact

Shogo TAGAMI*, Mariela Rojas Quesada , Takao KOURA, Yasuhiro AKAHOSHI

Department of Mechanical and Control Engineering, Kyushu Institute of Technology
1-1 Sensui, Tobata, Kitakyushu, Fukuoka 804-8550, Japan

Abstract

Recently, a risk of impact between spacecraft and debris is increasing. An impact on solar arrays can cause electrical damage such as sustained arc as well as mechanical damage. If sustained arc occurs, electricity does not flow to the payload and the power generation capacity is reduced. In this study, discharge due to debris impact is reproduced by hypervelocity impact test, and plasma and discharge currents are measured. As a result, high density plasma and discharge due to impact were confirmed. Moreover, it became clear that some difference appears in the discharge current waveform depending on the impact point.

Peer-review under responsibility of the scientific committee of the 14th Hypervelocity Impact Symposium 2017.

Keywords: Hypervelocity impact, Space Debris, Plasma, Sustained Arc,

Nomenclature

T_e	electron temperature
n_e	electron density
e	elementary electric charge
k	Boltzmann constant
A_p	surface area of the probe
m_i	ion mass

* Shogo Tagami. Tel.: +81-93-884-3151; fax: +81-93-884-3151.;
E-mail address: n104086s@gmail.com

1877-7058 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the scientific committee of the 14th Hypervelocity Impact Symposium 2017.
10.1016/j.proeng.2017.09.753

1. Introduction

The number of debris has been increasing since the beginning of the space development, and the number of spacecrafts orbiting the Earth has become larger. This means that the risk of impact between spacecraft and debris is also growing. Recently, voltage requirement on spacecraft has become higher and solar cell paddles have gotten larger [1]. Additionally, because its mission life is longer now, it can contribute to the increasing risk of debris impact. Actually, on 23rd August 2016, ESA detected that small debris impacted the solar cell paddle of Sentinel-1[2]. Firstly, the impact on solar arrays can cause electrical damage and then high density plasma is generated by the energy transfer at the time of the collision [3] [4] [5]. Secondary, electrostatic discharges, besides, the insulating layer of the solar cell is carbonized by Joule heat effect generated due to the current flowing through the discharge. Moreover, a permanent short circuit is considered to form, and it is called sustained arc [6].

Consequently, electricity does not flow to the payload and the power generation capacity is reduced when sustained arc occurs. Thus, this problem makes the spacecraft operation difficult from the ground because of the lack of the electric source. At present, the occurrence of discharge by debris impact cannot be confirmed. However, there is a high possibility that discharge occurs because of debris impact. And discharge by hypervelocity impact test has been confirmed in previous studies [7] [8] [9]. Therefore, consideration on discharge by impact is required in the spacecraft design.

The purpose of this study is to analyze and characterize the occurrence of the discharge due to hypervelocity impact on spacecraft solar arrays. In this study, discharge by debris impact is reproduced by hypervelocity impact test.

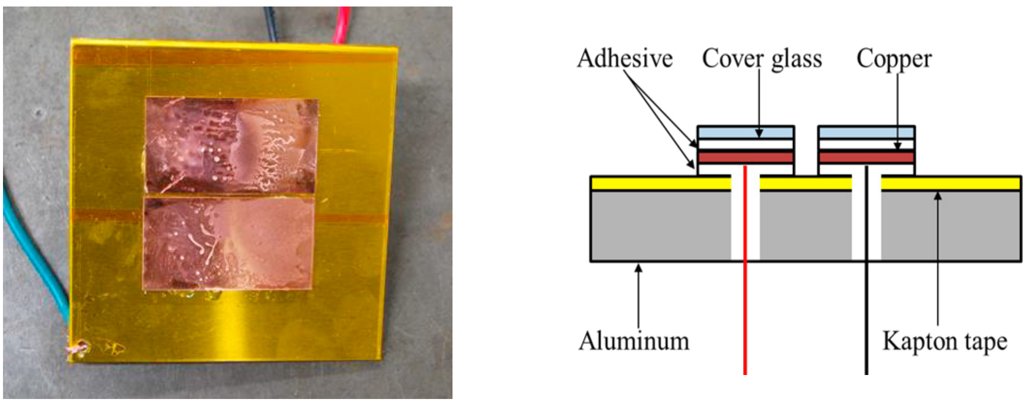
2. Methodology

2.1. Two stage light gas gun

Authors conducted hypervelocity impact test on the solar array coupon using two-stage light gas gun located in Kyushu Institute of Technology. The projectile was 3 mm A2017 spherical aluminum alloy. The impact velocity was maintained around 5 km/s. In the test chamber, the pressure was set at 1 Pa which will simulate space environment, and the sabot separation section pressure was set to around 7 kPa allowing sabot and projectile separation due to air resistance.

2.2. Pseudo solar coupon

In this study, pseudo solar array coupon made of aluminum plate, Kapton tape, cooper plate and cover glass was used. Figure 1 shows pseudo solar coupon. The specification of this target is shown in Table 1. In our test, the aluminum and copper plates represented respectively the substrate and the solar cells. The gap between the cells is approximately 0.7 mm.



(a) Front view (b) Cross section

Fig. 1 Pseudo solar coupon

Table 1. Specification of the target.

Cell	Material	Copper
	Alloy and temper	JIS C 1020P-1/4H
	Width [mm]	40
	Height [mm]	22
	Thickness [mm]	0.1
Substrate	Material	Aluminum
	Width [mm]	75
	Height [mm]	75
	Thickness [mm]	2

2.3. External circuit

The pseudo solar array coupon was connected to an external circuit. Fig. 2 shows external circuit. The current and voltage were applied from the current regulative diode (CRD) power supply to simulate the actual conditions of a solar array generating electric power. The cooper plate connected to the positive terminal called Hot cell, the another one connected to the negative terminal called Cold cell. Before the test, we insulated the space between cells and substrate and also between the cells, which will make all the current from the CRD power supply flew to the variable resistor. During the test, just after the impact, a discharge occurred, which burned the insulation protection leading to a sustained arc formation. Three current probes are connected to an oscilloscope which measured the current change on pseudo solar array. Current Probe 1 (CP1) measures occurrence of discharge. Current Probe 2 (CP2) measures discharge between Hot cell and Cold cell. Current Probe 3 (CP3) measures discharge between Hot cell and substrate.

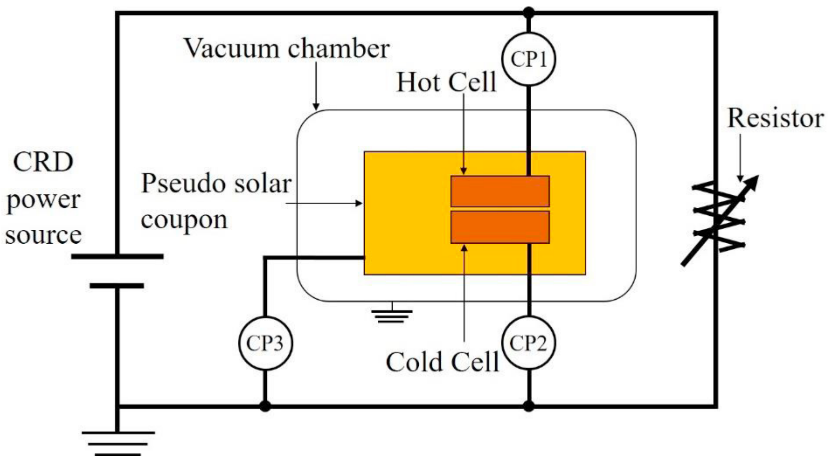


Fig. 2 External circuit

2.4. Triple probe

Triple probe was set at 50 mm above the front surface of the pseud solar coupon to measure electron temperature and density of plasma created by the hypervelocity impact. Figure 3 shows schema of the triple probe. The probe was made of copper wire. The diameter and the length of the triple probe were 10 mm. The electron temperature and density could be calculated by V12, V13, I13 and following equations. The electron temperature was calculated by equations (1) and (2). Also, the electron density was calculated by equation (3) [10].

$$I_1 = I_2, \quad I_3 = 0 \tag{1}$$

$$\frac{1}{2} = \frac{1 - exp(\frac{-eV_{13}}{kT_e})}{1 - exp(\frac{-eV_{12}}{kT_e})} \tag{2}$$

$$n_e = \frac{\frac{I_{13}}{A_p exp\left(-\frac{e(V_{12} - V_{13})}{kT_e}\right) - A_p}}{exp\left(-\frac{1}{2}\right) e\sqrt{\frac{kT_e}{m_i}}} \tag{3}$$

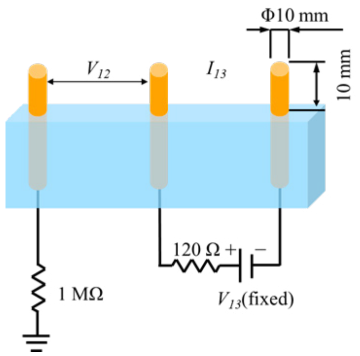


Fig. 3 Schema of triple probe

3. Experiment results

3.1. Plasma measurement

Table 2 shows the measurement results of electron density and electron temperature. On the other hand, in the plasma environment on the LEO, the electron temperature is 0.09 eV, and the electron density is 1 x 10^{11} m^{-3}. It was observed that high-density plasma is created by hypervelocity impact as compared with the plasma environment on the LEO.

Table 2. Result of plasma parameter.

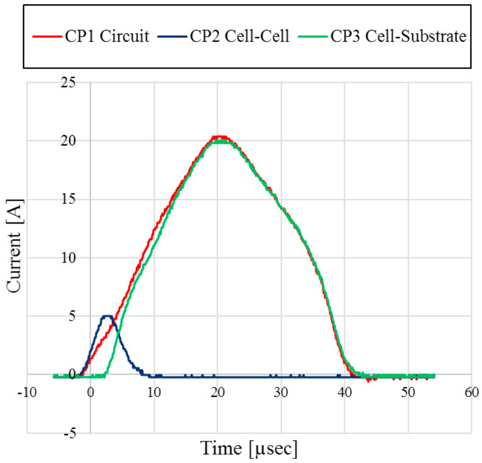
Test No.	Electron temperature [eV]	Electron density $\times 10^{15}$ [m^{-3}]	Impact velocity [km/s]
16-059	2.27	7.91	5.31
16-060	1.82	2.57	4.92
16-069	1.62	0.51	5.07
16-071	2.49	3.57	5.09

3.2. Discharge measurement

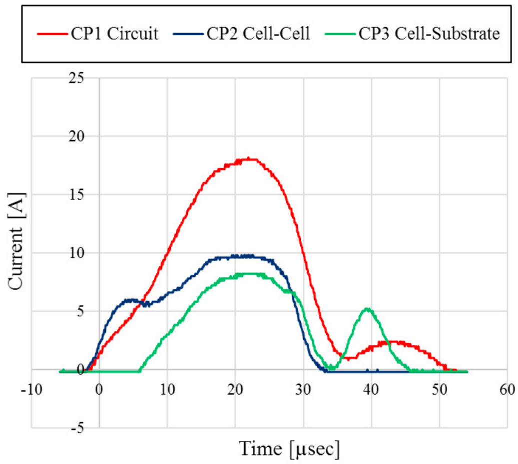
Table 3 shows the measurement results of discharge time. Fig. 4 shows discharge waveform. Fig. 4 (a) is impact at hot cell and (b) is impact between two cells. Fig. 5 and Fig. 6 show targets after impact test. Cold cell of Test No. 16-071 has impact mark, but it of Test No. 16-069 does not have. In this study, discharge phenomenon due to hypervelocity impact was confirmed, but permanent sustained arc could not be confirmed. In addition, waveforms are different due to impact point.

Table 3. Result of discharge measurement

Test No.	Discharge time [μsec]	Cell-Cell [μsec]	Cell-Substrate [μsec]	Impact point	Impact velocity [km/s]
16-068	35.3	3.0	29.3	Hot Cell	5.06
16-069	42.0	9.6	40.0	Hot Cell	5.07
16-071	52.4	34.6	39.3	Gap	5.09

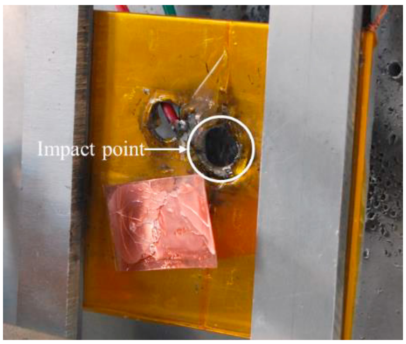


(a) 16-069 impact at hot cell

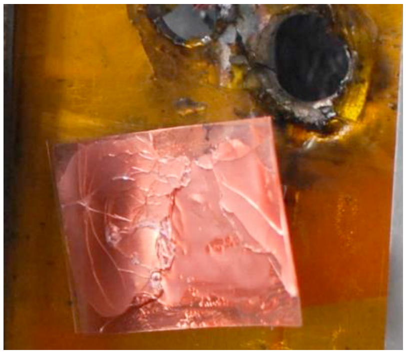


(b) 16-071 impact between two cells

Fig. 4 Waveform of discharge

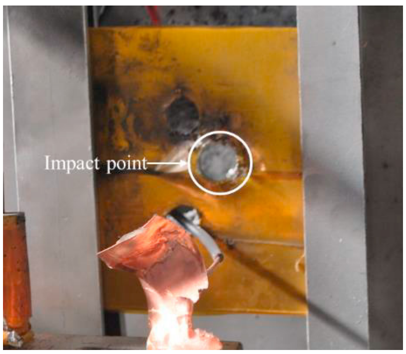


(a) Over all image

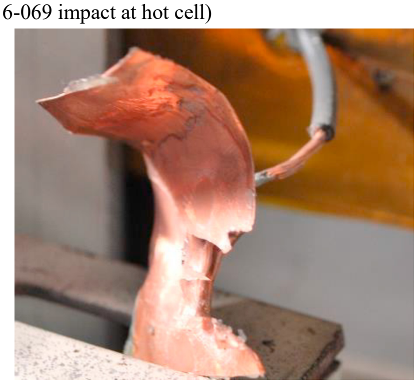


(b) Zoom of cold cell

Fig. 5 Target after impact test (Test No. 16-069 impact at hot cell)



(a) Over all image



(b) Zoom of cold cell

Fig. 6 Target after impact test (Test No. 16-071 impact between two cells)

In the case of impact between the cells compared to the case where it impacts at Hot cell, there was no large difference in the amount of current flowing in CP1, but amount of discharge current and the discharge time flowing in CP2 increased. In additional, Although the amount of discharge current flowing in CP3 decreased, the discharge time did not change significantly. As a cause of this, it is conceivable that discharge occurred through the projectile at the time of impact, since the projectile is aluminum having conductivity. Also, high density plasma is generated at the impact point and diffuses from there. When projectile impacts between two cells, it is assumed that the plasma density between two cells and between cell and substrate are equal. On the other hand, when projectile impact at hot cell, plasma density between cell and substrate is higher than between two cells. For the reason, such current waveform appeared.

4. Conclusion

In this study, we confirmed the discharge phenomenon due to debris impact on the pseud solar coupon. The plasma and the amount of discharge current were measured by hypervelocity impact test on the target connected to the external circuit in order to simulate the power generation state of the solar cell. The conclusions in this study are summarized as follows.

(1) The plasma created by hypervelocity impact had a higher temperature and higher density than that in plasma environment on the LEO.

(2) Discharge phenomenon was confirmed, but permanent sustained arc could not be confirmed. It was confirmed that waveforms are different due to impact point. One of the possibility in the future for this research would be to use real solar array and also change the projectile material for something less conductive.

Acknowledgements

The authors will appreciate suggestions and supports given by Prof.Cho and Prof.Toyoda, Kyushu Institute of Technology.

References

[1] Cho M, Haruhisa F. J. Jan. 2003.Soc. Aeronaut. Space. Sci., pp. 109-117.

[2] European Space Agency. “Coperinicus Sentinel-1A satellite hit by space particle”. European Space Agency. http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-1/Copernicus_Sentinel-1A_satellite_hit_by_space_particle, (accused 2016-11-17).

[3] D. Crawford, P. Schultz, 1999. “Electromagnetic properties of impact-generated plasma, vapor and debris”, International Journal of Impact Engineering, 23(1), pp. 169-180.

[4] Gerhard Drolshagen. 2001. Hypervelocity Impact Effects on Spacecraft. Proceedings of the Meteoroids 2001 Conference, ESA Publication Division, pp. 533-544.

[5] S. Close, P. Colestock, L. Cox, M. Kelly, N. Lee, 2010. “Electromagnetic pulses generated by meteoroid impacts on spacecraft”, Journal of Geophysical Research: Space Physics, Vol.115, A12328.

[6] I. Katz, 1998. “Mechanism for Spacecraft Charging Initiated Destruction of Solar Arrays in GEO”, 36th Aerospace Science Meeting, AIAA J., pp. 98-1002.

[7] Fukushige S, Akahoshi Y, Watanabe K, Harano T, Machida Y, Furusawa N, Koura T, Hosoda S, Cho M, Harada S, 2006. “Hypervelocity Impact Test to Solar Array for Evaluation of Possibility of Sustained Arc”, Proceedings of the 25th International Symposium on Space Technology and Science, pp. 1356-1361.

[8] Fukushige S, Akahoshi Y, Watanabe K, Nagasaki T, Sugawara K, Koura T, Cho M, 2008. “Plasma and solar array arcing caused by space debris impact”, Proceedings of the 4th Spacecraft Environment Symposium, pp. 113-116.

[9] Martin Schimmerohn, Martin Rott, Andreas Gerhard, Frank Schafer, Gianfelice D’Accolti. 2014. “Susceptibility of solar arrays to micrometeoroid and space debris impact”, Proceedings of 10th European Space Power Conference, pp. 619-625.

[10] M. Martinez-Fuentes, F. Castillo-Mejia, J.J.E. Herrera-Velazquez, M. Nieto-Perez, G. Ramos-Lopez. 2012. “Use of Langmuir probes in the study of expanding shocks from a dense plasma focus”, 39th EPS Conference & 16th Int. Congress on Plasma Physics,.