EFFECT OF INSULATION FILM THICKNESS ON DURABILITY AGAINST SUSTAINED ARC

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ABSTRACT

The simplest mitigation method for permanent sustained arc on spacecraft solar array is increasing the thickness of the insulation film between the solar cell and the aluminum substrate. The results of the test, the discharge mitigation effect is increasing with a thickness. However, the tolerance decreased when insulating film is too thick. Therefore, the simple model that is close to actual results has been created to clarify the relationship between the thickness of polyimide film and the sustained arc tolerance. In this paper, energy input from sustained arc to the polyimide film has been considered. However, it was difficult to determine how to transmit energy from the sustained arc. Therefore, the transmission method of the energy from sustained arc to the insulating film was supposed.

1. INTRODUCTION

Recently, spacecraft is shifting to bigger and multiple functions. The high voltage power generation is needed for satellites to reduce the transmission loss. However, high voltage generation induces discharges on solar arrays and power cables in space. And discharge may lead to failure of the satellite.

Especially, Permanent Sustained Arc (PSA) directly leads to outage of satellite. Therefore it is necessary to mitigate PSA on the satellite. The effect of the insulation film thickness on PSA inception was investigated [1]. Figure 1 shows the results of the PSA tolerance in different thickness polyimide film [1].

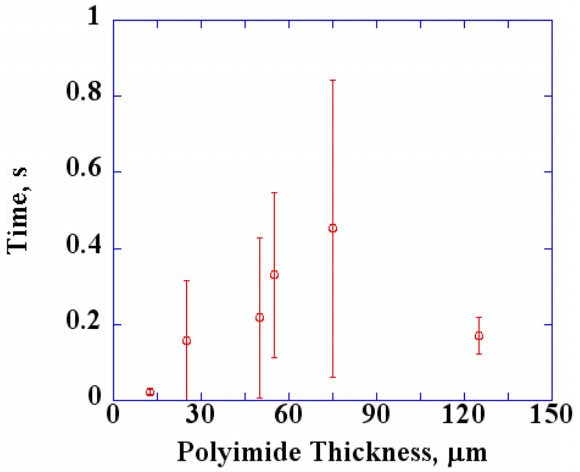


Fig. 1. Relations of time until current flows to structure and thickness of polyimide.

Figure 1 indicates the relationship between the time until polyimide film gets breaking and polyimide thickness. It shows the thicker film could withstands against sustained arc for longer duration. However, the mitigation effect decreased when the film is too thick.

The purpose of this research is to clarify relationship the polyimide thickness and mitigation effect to sustained arc. In this paper, it was discussed about energy input from the sustained arc to the insulating film, and performed thermal analysis in consideration of the transmittance of polyimide.

2. FAILURE OF SOLAR ARRAY BY SUSTAINED ARC

Figure 2 indicates the gap of solar array that happened PSA. If sustained discharge occurs between solar array gaps, solar cell and insulation film are changed to black (carbonization) and lost partially. It can be assumed that insulation film was received energy from the sustained discharge, and degraded. Therefore, it is necessary to know how to transmit the energy from sustained arc in order to clarify the relationship between the thickness and inhibitory effect of the insulation film.

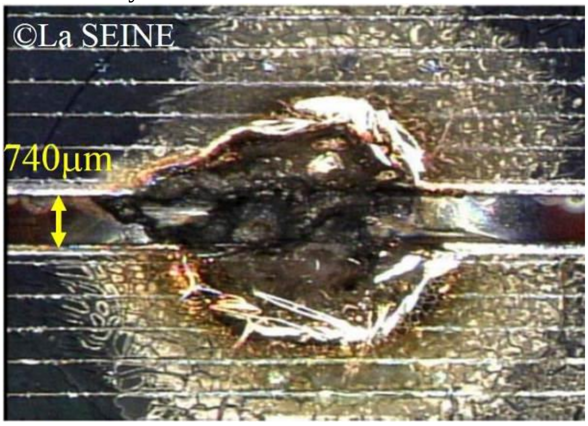


Fig.2. Permanent Sustained Arc Crater

3. EXPERIMENTAL APPROACH

Sustained discharge is occurred on the sample coupon which simulated real solar array by using sustained discharge simulated circuit. And the sustained arc was observed from the cross section side of the sample by long-distance microscope to examine the insulating film receives what kind of energy from the sustained arc.

3.1. Sample coupon

Figure 3 and 4 shows cross section of real solar array and sample coupon. The sample coupon is fixed copper electrodes (thickness: 0.3mm, width: 10mm) on substrate which covered by polyimide films (Kapton®) (25µm and 125µm) with polyimide tapes. Here, there are no air between aluminum substrate (thickness: 1mm) and the polyimide films. And the gap length is about 1mm. Polyimide tapes are put without covering gaps. Figure 5 is the picture of sample coupon. In this study all polyimide was used Kapton® H type of DuPont. Co.

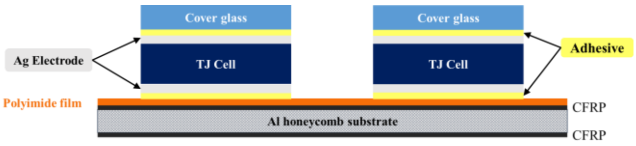


Fig.3. Cross section of solar array

Fig.4. Cross section of sample coupon

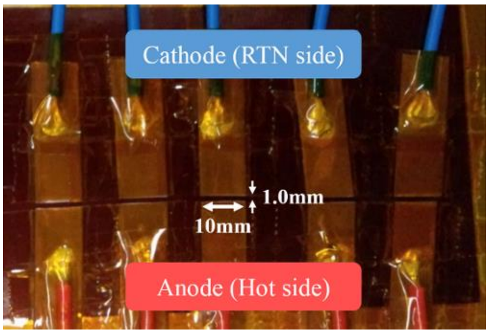


Fig.5. Picture of sample coupon

3.2. Sustained arc test

Figure 6 shows all system of sustained arc test. And Table 1 indicates some parameters of the test circuit.
In this test, the long-distance microscope was placed to observe the gaps from outside of the chamber.

Tab.1. Circuit parameter

Parameter	Value
V_{bias}	5kV
R	10MΩ
C_{ext}	1nF
C_{BC}	10mF

V_1 (constant voltage source) and CRD (current regulative diode) make constant current simulated generation current (string current I_{ST}) of the solar array paddle. In this time, I_{ST} is 3A. R_L is simulating satellite load. And I_{ST} and R_L decide V_{gap} (Voltage between gaps) (150V). V_2 (constant voltage source) is simulating the satellite bus voltage and buttery. V_2 can supply the current to R_L when secondary arc occurs on gaps. Two diodes limit the direction of current flows. C_{ext} is simulating all capacitance of coverglasses on solar arrays. V_{bias} simulate the potential difference of neighboring plasma and the satellite.
Currents always flow through Cp1 and usually flow through Cp2. But currents follow through Cp3 and Cp4 when secondary arc occurred. When secondary arc becames PSA, currents flow through Cp5. Therefore Cp3, Cp4 and Cp5 show duration of the sustained arc, arc current. Cp6 measures the blow-off current.

3.3. Thermal analysis model [2]

In thermal analysis, it was thought about internal temperature change of the insulation film when PSA occurred. The analysis model is assumed dividing polyimide film into the layers every 1µm, constant heat flux bunch incidence, and backside is constant

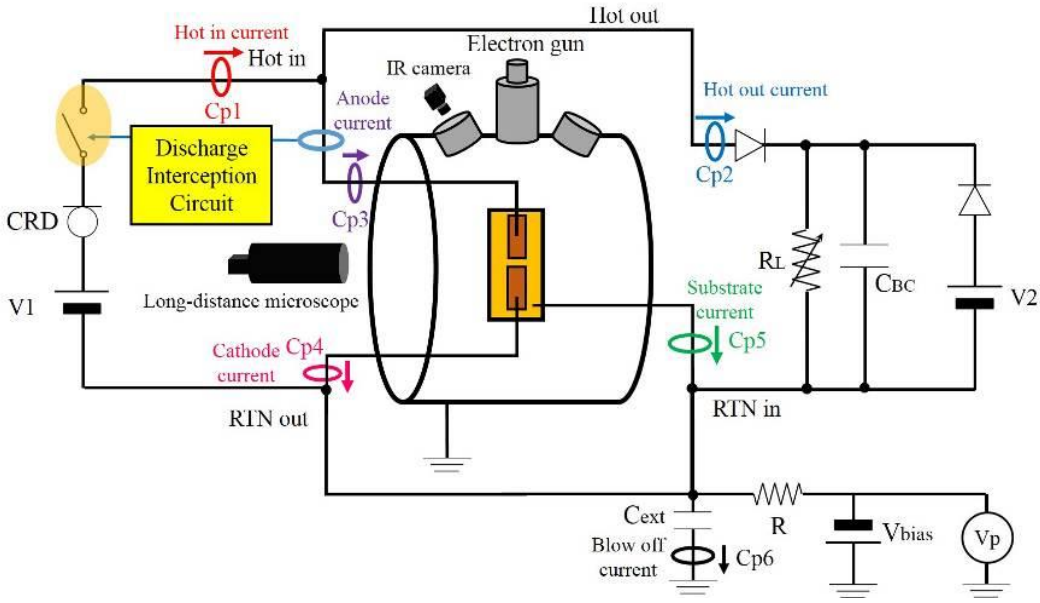


Fig.5. Sustained arc test circuit

temperature (20°C). The method of thermal analysis shown below. Here, thinking about the board which mass density is ρ, thermal conductivity is λ, specific heat at constant pressure is Cp, The board has enough wide area. The thickness from the surface is x, and the elapsed time is t. Then, if the layer temperature is θ, (1) is valid.

$$\frac{\partial\theta}{\partial t} = a\frac{\partial^2\theta}{\partial x^2},\quad a = \frac{\lambda}{\rho Cp} \tag{1}$$

Using differential approximation method,

$$\frac{\theta_{x,t+\Delta t} - \theta_{x,t}}{\Delta t} = \frac{\theta_{x+\Delta x,t} - 2\theta_{x,t} + \theta_{x-\Delta x,t}}{(\Delta x)^2} \tag{2}$$

Transform (2),

$$\theta_{x,t+\Delta t} = \frac{a\Delta t}{(\Delta x)^2}\left\{\theta_{x-\Delta x,t} - 2\theta_{x,t} + \theta_{x+\Delta x,t}\right\} + \theta_{x,t} \tag{3}$$

Temperature field in the x direction is divided into every dx. Similarly, divide time into every dt. The division of position and time is assumed computational grid. Here, i represents the number of these coordinates, and j expresses the number of these coordinates.

$$\theta_{i,j+\Delta j} = \frac{a\Delta t}{(\Delta x)^2}\left\{\theta_{i-\Delta i,j} - 2\theta_{i,j} + \theta_{i+\Delta i,j}\right\} + \theta_{i,j} \tag{4}$$

Convergence condition,

$$\frac{a\Delta t}{(\Delta x)^2} \leq \frac{1}{2} \tag{5}$$

Next, think about the boundary condition of surface. If increments of time is sufficiently small, it can be assumed that the quasi-stationary state. And thermal equilibrium between the heat flux at the surface and internal heat conduction is established. Therefore,

$$q = -\frac{\lambda}{\Delta x}\left(\theta_{1,j+1} - \theta_{0,j+1}\right) \tag{6}$$

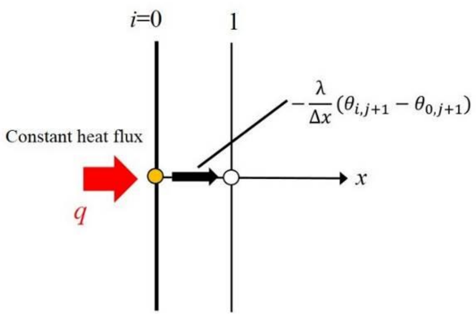


Fig. 6. Boundary condition of surface.

Transform (6),

$$\theta_{0,j+1} = \theta_{i,j+1} + q_1\frac{\Delta x}{\lambda} \tag{7}$$

Our thermal analysis is used (4), (5), (7) and C language. (4) indicates temperature change internal the board. (7) indicates temperature change of board surface.

4. TEST RESULTS

4.1. Discharge currents

Figure7 shows discharge current when PSA happened (polyimide thickness: 25μm). Then, all the waveform could not be gotten because discharge time was longer than the expected time. And this discharge was very unstable.

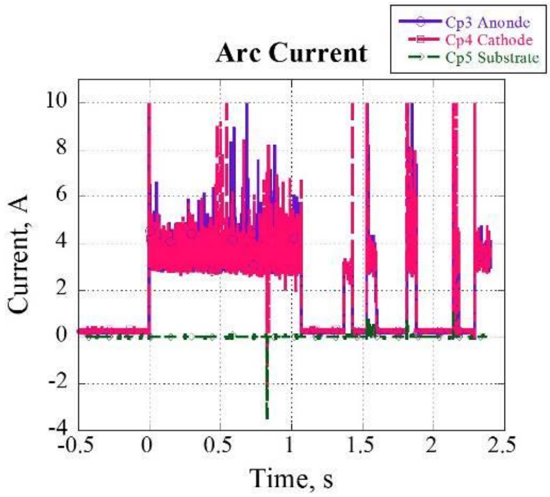
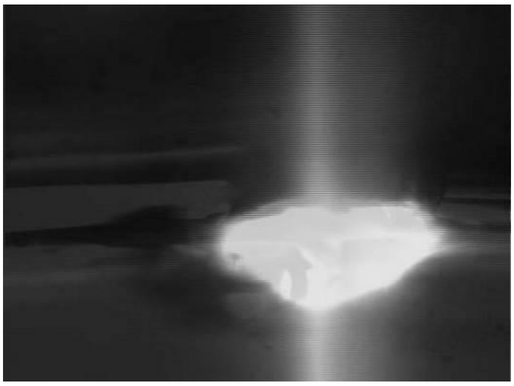


Fig.7. Arc current

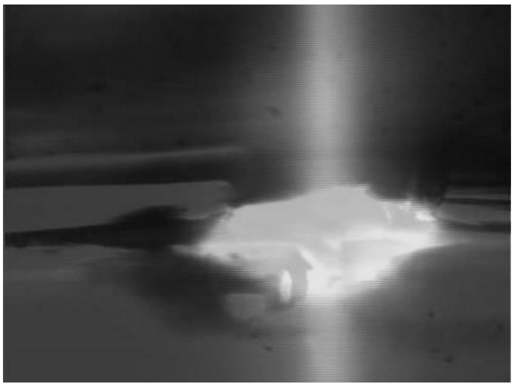
4.2. Image of long distance microscope

The states of the gap at the time of sustained arc are shown in Figure 8. (a) - (d) is gap state every 30msec (frame rate: 30fps) from the discharge time. They are the initial portion of the sustained arc. The arc images have not been able to capture throughout discharge. Here, the thickness of polyimide film was on 25μm.

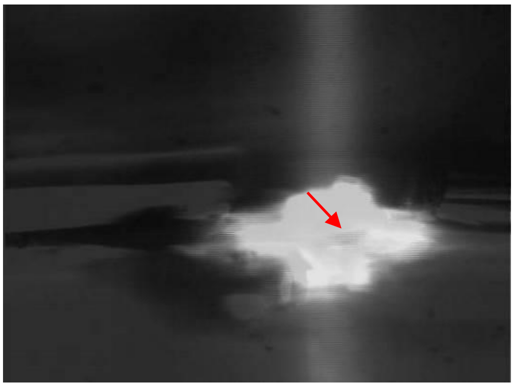
(a) Discharge occurred



(b) After 30msec



(c) After 60msec



(d) After 90msec

Fig.8. Image of discharge

4.3. Thermal analysis

The thermal analysis has been performed on assumption that evaporation at 500 °C. Here, not considering reaction speed and heat.

In this paper, the thermal analysis was considered the transmittance of polyimide. The transmittance of each layer was calculated from (10), and heat flux which each layer received was calculated. Here, (10) is calculated from Lambert-Beer law.

$$T = e^{-\alpha x} \qquad (10)$$

Here, when wavelength is 500nm, the transmittance is about 20% [3]. Absorption coefficient α is,

$$\alpha = 6.438 \times 10^3$$

Figure 9 shows the relationship which obtained from the analysis between substrate arrival time and thickness. Here, substrate arrival time is the time of reach the layer that reaches thermal equilibrium.

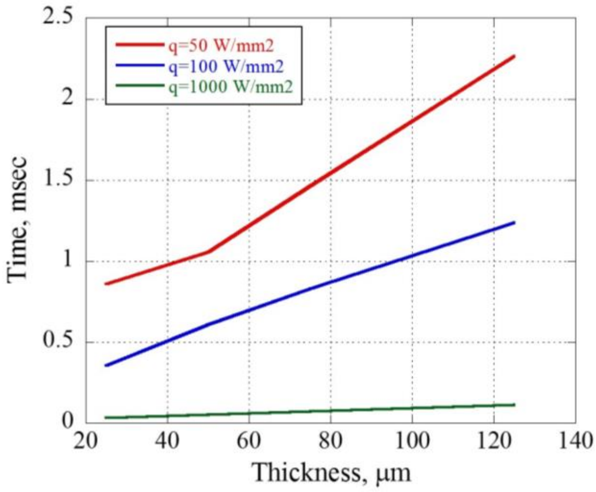


Fig.9. Board arrival time @ thermal analysis

5. CONSIDERATION

In Figure 8, (b) and (c) cannot be determined the arc shape because they are too bright. However, (d) has a portion that is dark in the middle of the picture. Then, sustained arc connected above the polyimide of the gap, it is presumed that not contact with the polyimide film (Figure 10 indicate arc shape of (d)). Here, light of the lower side is a reflection by the polyimide film. However, it is difficult to determine how the energy input from the arc, because all the images could not be taken throughout discharge. The following section shows the predictions about the energy input.

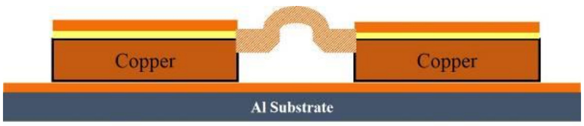


Fig.10. Arc shape

Thermal analysis that takes into account the transmittance of polyimide was different from actual results as shown in Figure 9. As the reason, it is considered that (10) does not match the transmittance of polyimide. Then, transmittance of inside polyimide film each thickness (25μm, 50μm, 75μm and 125μm.) was measured. The results is indicated in figure 11. Because the actual transmittance is dependent on the wavelength and polyimide thickness, it cannot be reproduced in this calculation. And it is necessary to consider also the reflection at the surface. The reflection of polyimide is shows in figure 12.

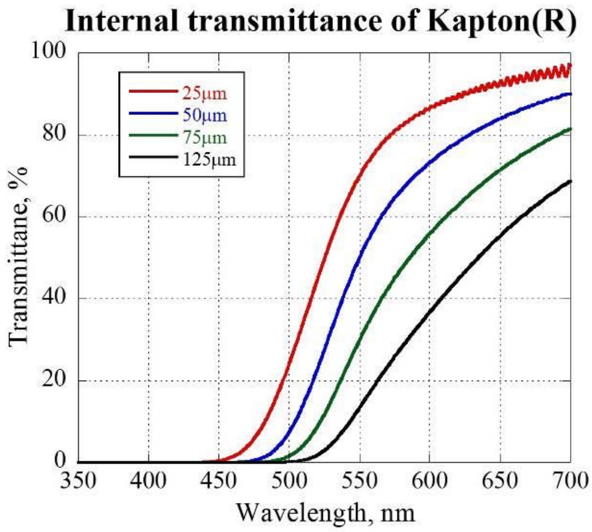


Fig.11. Internal transmittance of Kapton®

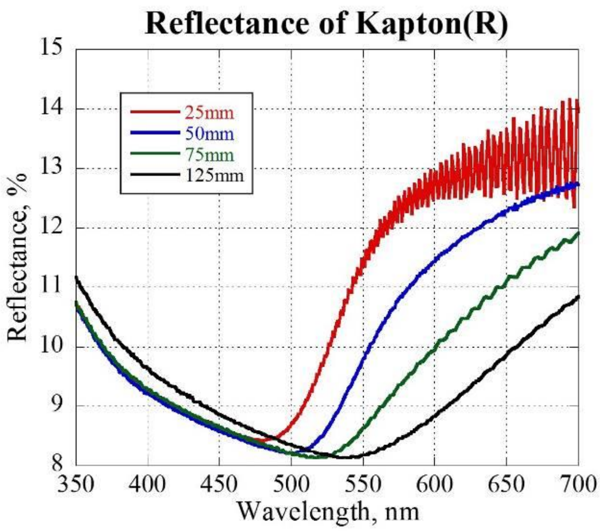


Fig.12. Reflectance of Kapton®

5.1. Prediction of energy input

There is a possibility as the energy input from the sustained arc that the due to both convection and radiation.

In the case of energy input due to radiation, the absorptance of the polyimide film affect the energy input.

Figure 13 shows absorption in each thickness. There is a difference between 25μm and 125μm polyimide film in the wavelength range of bigger than 450nm.

And if no difference of intensity of light between each thickness of polyimide film, the absorptivity difference is likely to be a major factor of the relationship between the thickness and the sustained arc tolerance of the polyimide film.

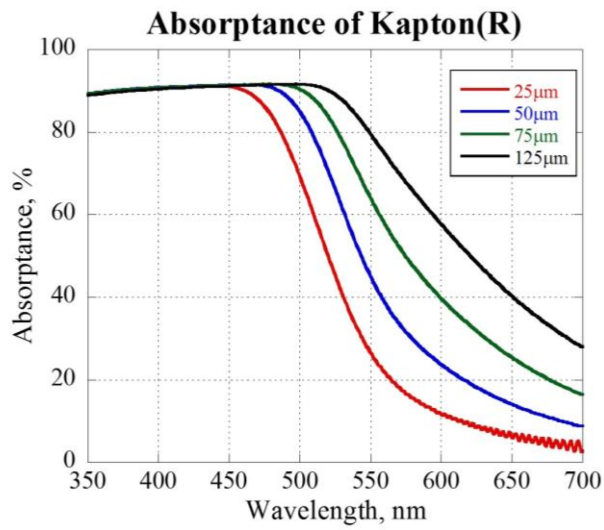


Fig.13. Absoptance of Kapton®

In the case of energy input due to convection, the energy input is caused by the forced convection. Then, the polyimide film may have received more energy input when the polyimide film is too thick since the gas is increased.

Here, the plasma resistance of sustained arc calculated from the experiment shows in Table2 [1]. Table 2 indicate that the plasma resistance of 125μm polyimide film is smaller than that of 25-75μm polyimide film. From table 2, 125μm polyimide film is expected to generate more gases than other thicknesses when PSA is occurred.

Table 2. Plasma resistance of sustained arc

Thickness	Arc resistance
25μm	3.25 Ω
50μm	3.30 Ω
75μm	3.39 Ω
125μm	2.64 Ω

The energy input method of discharge on 125μm polyimide film can be different from that on 25-75μm polyimide film. In particular, the energy is transmitted by radiation when thickness is 25-75μm film. And the energy is transmitted by convection when thickness is 125μm film.

6. CONCLUSION

It was successfully in imaging of sustained arc with the long-distance microscope. However, it was difficult to determine whether the energy is how to transfer, because the arc images could not be taken throughout discharge.

The thermal analysis considering the transmittance of the polyimide was subjected. But the results were not match the actual results. It is necessary to improve the analysis model.

7. FUTURE WORK

Continue to take the picture of the arc image, to investigate how the energy is transmitted from the sustained arc into insulating film, and improve thermal analysis.

8. REFERENCES

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