Optimization of SEE yield physical model

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Abstract—We studied the method to measure the secondary electron emission of metal and insulating materials used for spacecraft thermal insulation or similar purposes. SEE yield measurement is crucial for analyzing charge accumulation on the spacecraft surfaces due to space environment, because electron emission caused by irradiated electrons = SEE influences the amount of surface charge. Therefore, we developed a new measurement system to obtain characteristics of the SEE yield from metal and insulation materials irradiated by electron beam with energy of 200 eV to 10 keV. Furthermore, we tried optimization of SEE yield physical model. From the research results, we have succeeded optimization in the most of the tested materials.

Keywords—component; secondary electron emission (SEE) yield; spacecraft charging; spacecraft materials

I. INTRODUCTION

Recently, electrostatic discharge (ESD) phenomenon has been reported as the cause in a number of spacecraft accidents. Electrons, protons and plasma on spacecraft orbit are the main cause of the discharging phenomenon and sometimes this phenomenon leads to fatal operation error.

Koons et al. researched the cause of spacecraft losses due to the space environment from 1973 to 1997 [1]. Figure 1 shows the causes and their ratio of spacecraft accidents. ESD accounted for more than 50 % of all spacecraft accidents.

To prevent such accident at the designing stage of spacecraft, “Multi-Utility Spacecraft Charging Analysis Tool (MUSCAT)” has been developed as a simulation tool to provide the surface electric potential distribution of spacecraft during the operation on its orbit. Electric material properties, for example, secondary electron emission (SEE), photoelectron emission, permittivity and conductivity, are required for analysis by the MUSCAT. However, these parameters are yet to be prepared by the Japanese space development community. Therefore, we aimed to provide the SEE yield measurement, one of the most important parameters for surface charging indispensable for surface potential calculation by MUSCAT.

We focused on numerical analysis of SEE yield using semi-empirical model which studies the maximum energy $E_m$ [eV] and maximum value of SEE yield $\delta_m$. In the past researches, only a few semi-empirical models have been proposed, and predictions of these models does not agree much with the experimental results, especially when the irradiation energy is equal to or higher than 2 keV. The numerical model on the Japanese spacecraft design standard is also in the same situation. In this report, we focused on a SEE physical model proposed by A. J. Dekker et al. and investigated whether the experimental results on metal and polymer samples match the theoretical values within a wide irradiation energy range from 200 eV to 10 keV.

II. MEASUREMENT PROCEDURE

A. Experimental Setup

In this section we will describe the experimental setup of our secondary electron emission current measurement system, which applies pulsed electron beam and the faraday cup (FCi) as its key components. The schematic diagram of the measurement system is shown in Figure 2. The electron gun (EGG-3101, Kimball Physics Inc.) is attached to the vacuum chamber to generate pulsed primary electron beam. This electron gun can irradiate electron beam of 0.5 ms pulse width with energy ranging from 200 eV to 10 keV. The faraday cup is set in front of the sample stage inside the vacuum chamber. Detailed description of the faraday cup is in the next section. Primary electron beam is irradiated through the hole on the faraday cup. Secondary electrons generated by this irradiation are captured by the faraday cup, and their data is obtained as a voltage signal on a digital oscilloscope (DSO, 104MXs by LeCroy Corp.) through a current amplifier (428 Current Amplifier by Kethley). At the same time, the absorption current on the sample stage is also observed by the same DSO after it is amplified through another current amplifier.

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Definition of symbols in this formula are shown in table II [2]. The material constants $B$ and $\lambda_d$ are fitting parameters used for fitting of the formula and SEE yield experimental values. The symbol $\zeta$ stands for either plasmon energy (metal samples) or for band gap energy (polymer samples) according to the sample type [3]. Band gap energy is measured by material absorbance. Maximum electron range $R$ was calculated by Casino software [4]. Figure 4 shows a simulation result of electron range distribution and trajectories in polyimide-2 when irradiated with 1 keV electron beam. In polyimide-2, $R$ is the position shown in figure.

\[
\delta = \frac{BE_p \lambda_d}{R \zeta R} \left( 1 - e^{-\frac{R}{\lambda_d}} \right)
\]  

(3)

**C. Dekker’s SEE Physical Model**

Dekker’s SEE physical model is shown in equation 3.

\[
\delta = \frac{I_s}{I_p}
\]

(1)

where $I_p$ is incident primary electron beam current and $I_s$ is secondary electron emission current from the sample.

As $I_p$ is obtained by integral value of absorption current and SEE current, equation 1 is represented by the equation as follows;

\[
\delta = \frac{I_s}{I_s + I_{ab}}
\]

(2)

where $I_{ab}$ is absorption current on the sample.

Measurement samples are shown in table I. Au is used as reference sample. FEP, polyimide-1 and polyimide-2 are widely used materials for spacecraft surface. Samples were prepared with ultrasonic cleaning using ethyl alcohol and acetone before setting in the vacuum chamber.
III. MEASUREMENT RESULTS OF SEE YIELD

A. Metal Samples

Figure 5 presents the measurement results of SEE yield by metal samples (Au, Ag, Cu and Ti). In this figure, plots show the experimental values, and solid lines show the fitting results using Dekker's formula. From the results, we found that the maximum value of SEE yield $\delta_m$ was 2.0 at 700 eV for Au. This is consistent with the value measured by other researchers, and therefore the accuracy of data obtained by our system has been confirmed [6].

Experimental values of Ag matched the fitting values by the formula throughout the measured range, while those of Au, Cu and Ti did not. We assumed that the errors may be due to calculation method of $R$, and we are aiming to establish a more adequate physical model of SEE by focusing on $R$.

B. Polymer Samples

Figure 6 presents the measurement results of SEE yield by polymer samples (FEP, polyimide-1 and polyimide-2). From the results, experimental values of polyimide-1 and polyimide-2 matched the fitting values by the formula throughout the measured range, while those of FEP did not.

C. Sample Density and 2 Fitting Parameters

Figure 7 presents the relationship between sample density $\rho$ and escape probability $B$, and figure 8 presents the relationship between $\rho$ and MEED $\lambda_d$. From these figures, we found that there is correlation neither between $\rho$ and $B$ nor between $\rho$ and $\lambda_d$. However, only metal or polymer samples, we consider that there is linearity. Therefore, it is necessary to consider separately metal and polymer samples.

IV. CONCLUSION

In this study, application of our system allowed us to obtain the SEE yield measurement results of metal and polymer samples. From these measurements, we discussed the optimization results using Dekker's formula, and the relationship between sample density and escape probability or sample density and mean electron escape depth. From the results, experimental results of Ag, polyimide-1 and polyimide-2 fit the fitting results with in the measurement range. However, the fitting results did not fully account for Au, Cu, Ti and FEP. Furthermore, we could not find correlations between sample density and escape probability or sample density and mean electron escape depth. Therefore, we should be considered separately metal and polymer samples.

Our future perspective is to measure SEE on other conductive and insulating materials for spacecraft by using this system, in addition to optimization of SEE physical model. We have already started to obtain data of SEE on the other spacecraft materials.

Fig. 5. The measurement results and the fitting results using Dekker’s formula on metal samples.
Fig. 6. The measurement results and the fitting results using Dekker’s formula on polymer samples.

Fig. 7. Relationship between sample density $\rho$ and escape probability $B$.

Fig. 8. Relationship between sample density $\rho$ and mean electron escape depth (MEED) $\lambda_e$.

REFERENCES


