Development of e-Induced Electron Emission Pulse Yield Measurement System

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Abstract: E-induced electron emission on the surface of space materials is a very important factor to understanding the spacecraft charging process. A single pulse yield measurement system for insulating material is developed. The electron yield results of Au specimen between DC yield test and pulse yield test are compared. Using the single pulse yield measurement system, the secondary electron emission yields of highly-insulating, 25 μm thin Kapton H film have been measured for the incident primary beam energies, 300 < E_p <3000 eV.

Key words: E-induced electron emission yield, single pulse yield measurement method, Kapton H film

1. Introduction

A spacecraft acts like an isolated electrical probe in the space plasma. Like any electrical probe in plasma, it will collect charge and adopt an electrostatic potential consistent with charge collection as required by Maxwell's equations. This collection of charge from the environment has been called "spacecraft charging". The differential surface charging due to surface secondary electron emission of space materials, results from potential differences on the surface of a spacecraft of a few volts to several thousands of volts. Although typical a lower potential difference, this type of charging is often more destructive because it leads to damaging surface discharge or arcing [1].

The electron emission yields of conductors are relatively easy to measure, however, the yields measurement of insulating materials are more difficult because of the inside charging phenomenon. The accumulated charge can affect the secondary electron yields by altering incident energies or by affecting the escape energies of secondary electrons and backscattered electrons, or by neutralizing the incident electrons [2,3]. In this condition, a single pulse yield measurement method for dielectrics is the best choice to reducing the influence of accumulated charge.

In this paper, a single pulse yield measurement system for space material is developed. Some electron yields of Au specimen and highly-insulating, thin Kapton H film have been measured for the incident primary beam energies, 300 < E_p <3000 eV. The experimental results are discussed, and some suggestions are proposed in order to fully avoiding the influence of accumulated charge.

2. Measurement principle

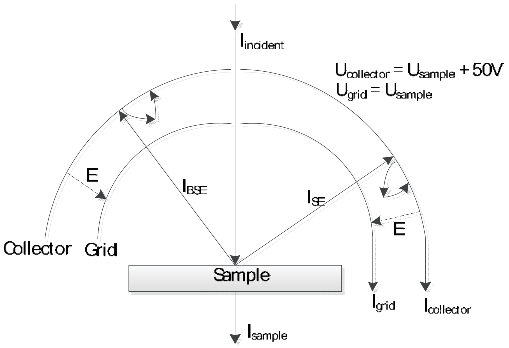
Reviewing the basic physics of electron emission, the total yield $\sigma(E_p)$ is the ratio of emitted current to incident current, and the SE yield $\delta(E_p)$ is the ratio of emitted electrons with energy E_{SE} < 50 eV, and the BSE yield $\eta(E_p)$ is the ratio of emitted electrons with energy E_{BSE} > 50 eV. The choice of the 50 eV value is purely arbitrary and historical, as higher than 50 eV secondary electrons, such as Auger electrons, are also produced as a result of electron beam solid interaction [4-9]. However, the number of these secondary electrons is rather small and in comparison to backscattered electrons can safely neglected. The electron yield curves show the yield as a function of incident electron energy. The basic schematic of electron yields measurement is illustrated in Fig. 1(a) and (b). For total electron yield (TEY) test, the sample stage and grid are set to the same potential, and the collector is 50 V higher than them. In this condition, real secondary electrons and backscattered electrons could pass through grid and reach to the inner side of collector. For backscattered electron yield （BEY）test, the sample stage and the collector are set to the same potential, and the grid is 50 V lower than them. In this condition, real secondary electrons return to the surface of sample, and just backscattered electrons are collected by collector electrode.

In this experimental test, U_{coll} = 50 V, U_{grid} = 0 V, U_{sample} = 0 V are set for total yield test, and U_{coll} = 0 V, U_{grid} = -50 V, U_{sample} = 0 V are set for BSE yield test. All the yield equations are given by Eq. (1) ~ (3).

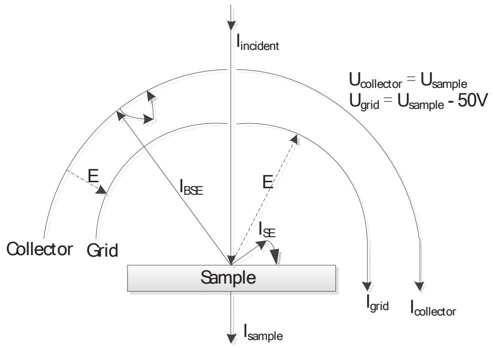
$$\sigma = \frac{I_{BSE} + I_{SE}}{I_{primary}} = \frac{I_{collector}}{I_{primary}} = \frac{I_{collector(50V)}}{I_{collector(50V)} + I_{grid(0V)} + I_{sample(0V)}} \quad (1)$$

$$\eta = \frac{I_{BSE}}{I_{primary}} = \frac{I_{collector}}{I_{primary}} = \frac{I_{collector(0V)}}{I_{collector(0V)} + I_{grid(-50V)} + I_{sample(0V)}} \quad (2)$$

$$\delta = \sigma - \eta \quad (3)$$



(a) Total electron yield test



(b) Backscattered electron yield test

Fig. 1: Basic schematic of electron yields measurement

3. Experimental system

The e-induced secondary electron emission pulse yield measurement system was developed based on the JAMP-10SX Auger test system by JEOL. After baking processing at 250 °C for 24 h, electrons emission measurements can be performed in a ultrahigh vacuum chamber with pressure < 5×10^{-5} Pa. Electron sources provide electron enegy ranges from 300 eV to 3 keV and incident electron currents with pulse emission mode and continuous DC emission mode.

A hemispherical detector has an Φ1.5 mm aperture for incident electrons. A cylidrical shape sample stage extends into the detector, and this ensures that all electrons that may backscatter from the collector are captured. The grid used in the detector is made out of stainless steel with 30 % transparency. The collector is made of copper, and its upper side is coated with MgF_2 film in order to locating the electron beam position and focusing the beam spot diameter. The inner surface of collector and all parts of grid are coated with sputtering carbon. The use of this material ensures that a minimum of electron emission occurs from the interaction of electrons emitted from the sample with grid and collector.

An Au sample with 1 mm thick and 5mm × 5 mm square shape and a 25 μm in thickness, 5 mm in diameter polyimide Kapton H film were used, and it was adhesive to the sample stage using conducting silver paste. All the samples were cleaned using alchol before intruduction into the vacuum chamber, but were not ion-cleaning.

In order to confirm the performance of single pulse yield test system, two methods with a continuous electron beam and a single pulse electron beam are used to measure the electron emission from Au sample. Charge injection or removal from a conductor via electron emission can be easily and rapidly replaced by connecting the sample to ground. For the insulator, charge deposition should be minimized by using a single short pulse (~ 100 μs) low current electron beam (~ 100 nA) focused on a spot area of ~ 1 mm^2.

A variable-Gain high speed current amplifier (AMP , DHPCA-100) made by FEMTO Inc. is used in this single pulse yield test system, and its response time is ~ 1.6 μs and low noise level is 60 fA at high gain 10^7 V/A. The single pulse generator is provieded by Tek. AFG 310 function signal generator. Alkaline Battery pack with 50 V was used for different test purpurse, as shown in Fig. 3.

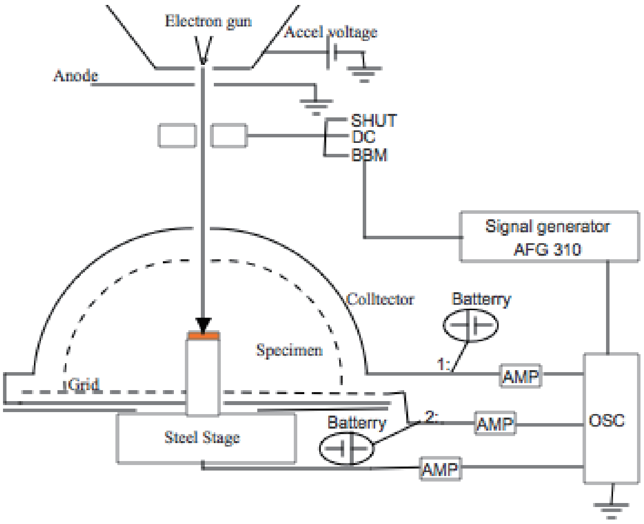


Fig. 2. Schematic of a single pulse yield measurement system.

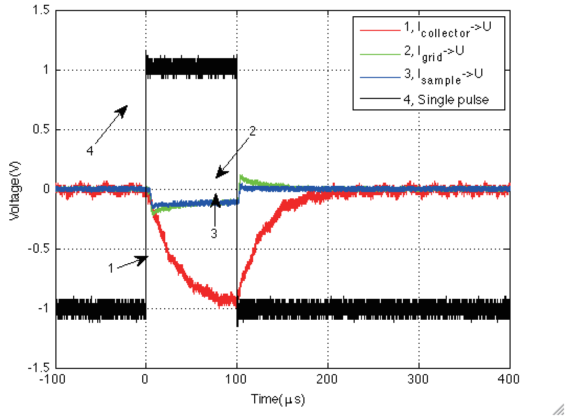
1: TEY, 50 V bias at collector, 2: BEY, -50 V bias at grid.

4. Experimental result

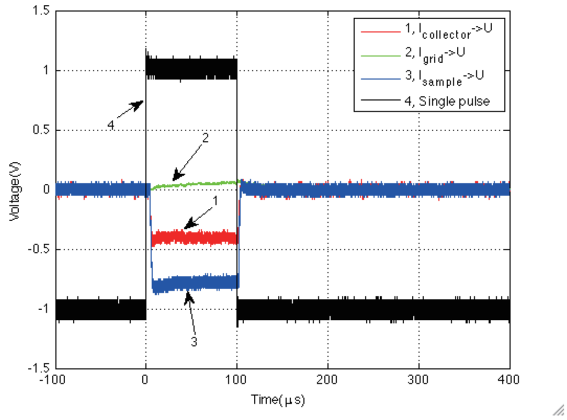
4.1 Electron yield test using Au sample

The induced current was converted to voltage signal by high-speed amplifier. Fox examples, the output signals at TEY test and BEY test injected by 500 eV beam are respectively shown in Fig.3 (a) and (b). In order to testify the performance of single pulse yield test system, the comparison test was carried out between DC emission and pulse emission using high purity Au sample. The experimental results are shown in Fig. 4.

The signal 1in Fig. 3(a) and the signal 2 in Fig. 3(b) have the special charging response times. Obviously, that should be contributed to the internal capacitance of Alkaline battery pack. In this experiment, as shown in Fig. 4, R, the opening reatio of grid is 30 %, so the obtained secondary yield data is lower. The recalculated sceondary electron yield was calculated by δ' = δ/R, and it is close with the as-inserted Au sample without ion-cleaning in Reference [9].



(a) Total electron yield test



(b) Backscattered electron yield test

Fig. 3: Voltage signal converted using induced current in detector under single pulse (100 μs) emission

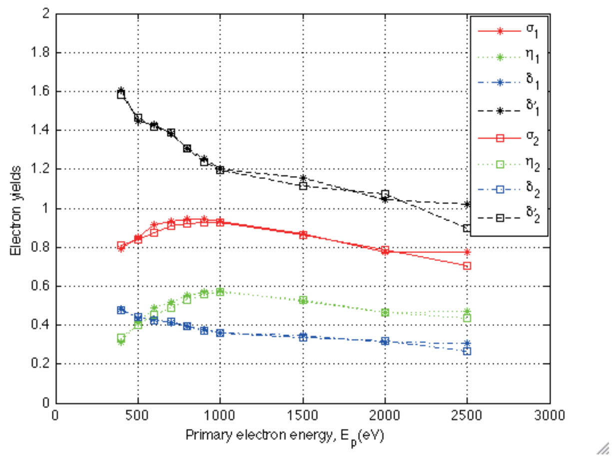


Fig. 4: Electron yields comparison of Au sample under two test methods. Symbol σ is total electron yield and drawn with "solid line"; Symbol η is backscatter electron yield and drawn with "dotted line"; Symbol δ is secondary electron yield and drawn with "dash-dot line"; Symbol δ' is recalculated secondary electron yield considering to opening ratio "R" and drawn with "dashed line";

Data marked by “star” is obtained using AMP and OSC under continuous electron emission; Data marked by “square” is obtained using AMP and OSC under 100μs single pulse electron emission.

4.2 Total electron yields test using Kapton H film

Based on this single pulse yield test system, the total electron yields of Kapton H film was measured, and the result is plotted in Fig. 5. In this test, from low beam energy to high beam energy, each yield point was only tested by once measurement using 100 μs pulse electron beam with 1 mm^2 spot diameter on the surface of sample. During the test, the injection position was not changed.

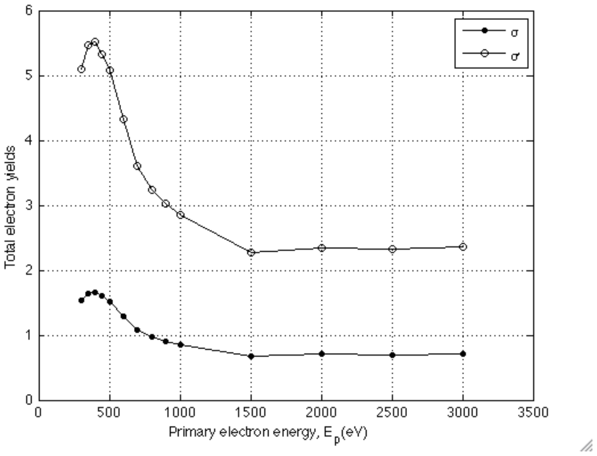


Fig. 5: Total electron yields of Kapton H film.

It can be found from Fig. 5, E_{max} is around 400 eV, and the recalculated SEY δ'_{max} is around 5.5 considering to the 30 % opening ratio. Comparing to Reference [2] and [10], this result was also influenced due to accumulated charge. More short pulse, and more lower beam current are needed.

5. Discussion

In order to avoid further space charge effects and possible polymer degradation at the surface of sample, in Reference [10], the electron beam current was limited to 1 pA for pulse duration of 1 μs over an area of 5 mm^2. Even very little charge deposition, the influence of accumulated charges is also present and cannot be neglected. In Reference [2], a combination of methods was used to control the deposition and neutralization of charge. The charge dissipation techniques include a low-energy electron flood gun for direct neutralization of positive charge and a UV light source for neutralization of negative charge. Even the charge neutralization method is used, but there will be a several tens of nm deep distribution along the electron beam injection direction. The low energy electrons just can store at the very shallow surface, and the internal charges are very difficult to neutralize. According to the following discussion, more short pulse, and more lower beam current are preferred, and it had better to change the injecting position for each yield measurement point. Based on these considerations, more research works are going on in our laboratory.

6. Conclusion

A basic single pulse yield measurement system for insulating material was developed. The electron yields of Au specimen between DC yield test and pulse yield test almost show the same result. Using the system, the total electron emission yields of Kapton H film have been measured with 100 μs pulse beam. The test position change method for each yield test is strongly suggested.

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