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Paper

Measurement of Secondary Electron Yield by Charge Amplification Method

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As the initial step to realize a reliable measurement of the secondary electron yield of insulating materials using charge amplification method proposed by K. Goto, a pair of the charge amplifiers to measure a small amount of the electron charge of less than ~1 pC have been developed. These amplifiers showed linear input/output characteristics within the range of the input charge of ~0.1 to ~6 pC. The secondary electron yield $\delta(E_p)$ of soot was measured by employing these charge amplifiers, and compared with that measured by the conventional current-mode method. The result showed that the charge amplification method enables the secondary electron yield to be measured using the primary electron charge of only ~1 pC.

1. Introduction

The secondary electron (SE) emission has been attracting renewed attention because of rapid progress in the hardware of scanning electron microscope (SEM) and widening its application to various kinds of scientific fields. Although the measurement of the SE yield (SEY), $\delta(E_p)$, is one of the most basic issues to understand SE emission phenomena, it is very difficult to measure the SEY of insulators precisely due to the charging-up effect of samples. For this, the method to measure SEYs with a very small amount of the incident electron charge was proposed by K. Goto [1, 2].

In the present study, as the initial step to realize a reliable measurement of the SEY of insulators using Goto's method, a pair of the charge amplifiers has been developed. In this report we briefly describe the secondary electron yield $\delta(E_p)$ of soot measured by employing these charge amplifiers, as compared with that measured by the conventional current-mode method.

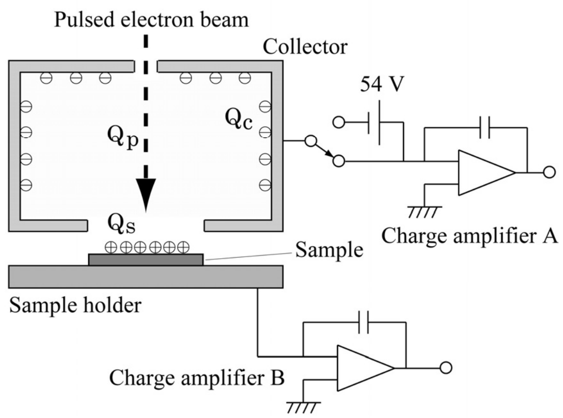

Fig. 1 Schematic of the measurement of SEY of insulators by the charge amplification method.

2. Charge amplification method

Figure 1 shows the schematic of the measurement of $\delta(E_p)$ of insulators by the charge amplification

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method, where the number of emitted SEs is directly measured by their charge. The measurement system consists of the collector electrode (Faraday cup) for the detection of SEs, the charge amplifiers connected to the sample holder and the collector electrode.

The solid angle of the collector was designed to be close to 2π as much as possible. The pulsed primary electron beam was used to reduce the amount of the irradiated primary electrons for the measurement of SEY. The basic concept is that the SEY is measured before significant charging is induced.

The total charge by irradiating a single pulse, Q_P, can be measured as a sum of the outputs of the charge amplifiers connected to the sample holder, Q_S, and the collector, Q_C, without applying voltage to the collector. Q_C corresponds to the sum of the charge due to true secondary electrons, Q_{SE}, and backscattered electrons, Q_{BE}. Then, Q_{SE} is measured from the output of the charge amplifier connected to the collector with applying the collector voltage of -54 V, Q_C^{-54V} (=Q_{BE}), i.e., $Q_{SE} = Q_C - Q_C^{-54V}$. Then, the secondary electron yield δ, the backscattering electron yield η, and the total secondary electron yield σ are obtained by

$$\delta = \left|\frac{Q_{SE}}{Q_P}\right|, \quad \eta = \left|\frac{Q_{BE}}{Q_P}\right|, \quad \sigma = \left|\frac{Q_C}{Q_P}\right|, \quad (1)$$

where $Q_P = Q_S + Q_C$, $Q_{BE} = Q_C^{-54V}$, and

$Q_{SE} = Q_C - Q_{BE}$.

3. Experimental

Experiments were carried out using a scanning Auger electron microprobe (JAMP-10, JEOL). The base pressure in the analysis chamber of the JAMP-10 was ~ 3×10^{-6} Pa (without baking). In order to generate the pulsed electron beam, we utilized the electrostatic beam chopper for the beam brightness modulation (BBM) of the JAMP-10. The number of pulse, the pulse width and the pulse frequency can be controlled by the handmade pulse generator.

3.1. Secondary electron collector

Figure 2 shows the photograph of the retractable secondary electron collector (a) and its schematic drawing (b). The sample holder and the collector box

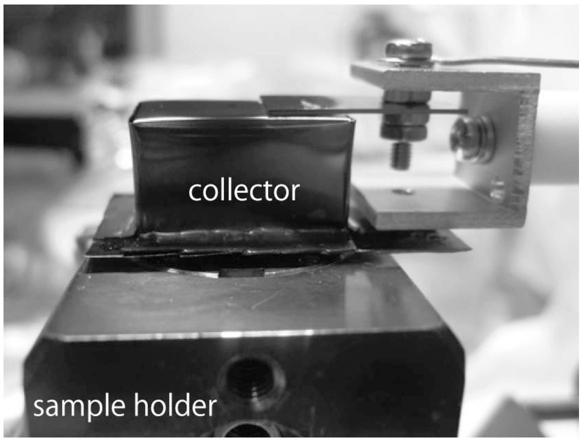

Fig. 2(a) The outer view of the secondary electron collector located on the sample holder.

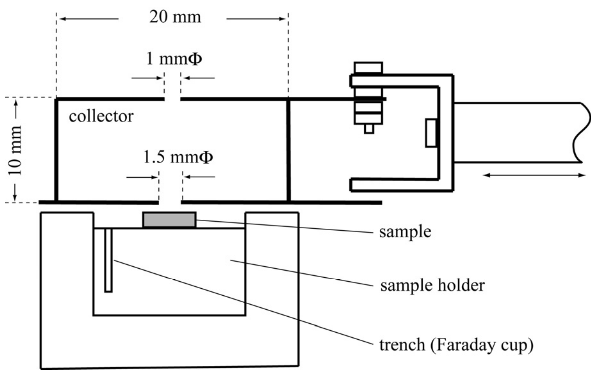

Fig. 2(b) The schematic drawing of the secondary electron collector.

are movable on a horizontal plane independently. The inside surface of the collector box is coated by soot. Alignment of the sample and two holes of collector could be carried out precisely by observing the SEM image.

3.2. Charge amplifiers

Figure 3 shows the electric circuit diagram of the charge amplifier we made.

The peak to peak height of the output voltage wave form V_{output} is proportional to the input charge, that is, $V_{output} = Q_{input} / C_A$ or $V_{output} = Q_{input} / C_B$, where C_A and C_B are the proportional constants for amplifiers A and B.

In order to determine C_A and C_B, the input/output characteristics of these amplifiers were measured. In this measurement, the primary electron energy E_P was 2 keV, and the pulse width t_W was 1 ms. The input charge was determined by $Q_P = I_P t_W$, where I_P is the primary electron beam current measured by the trench on the sample holder with the aspect ratio of more than 10. In this experiment, I_P was varied from 6 nA to 10 pA.

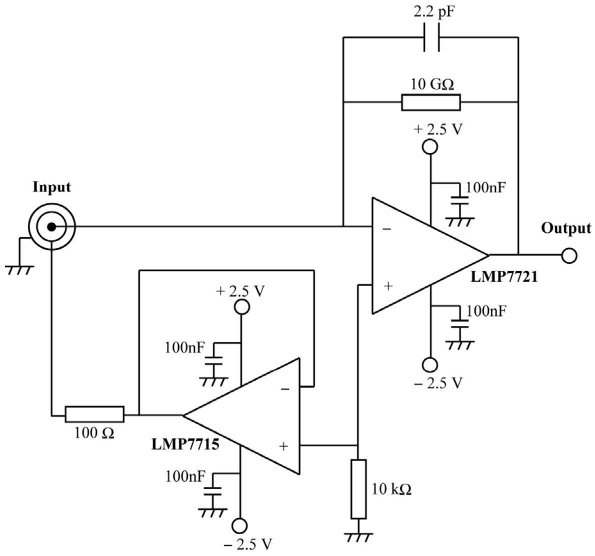

Fig. 3 The electric circuit diagram of the charge amplifier. The input bias current of the LMP7721 operational amplifier is 3 fA.

From Fig. 4, C_A and C_B were determined to be $C_A = 2.27 \times 10^{-12}$ [C/V] and $C_B = 2.31 \times 10^{-12}$ [C/V] by the least mean square fitting. These values are consistent with the capacitance of the feedback condenser C_f of 2.2 +/- 0.5 pF. It can be confirmed that both of charge amplifiers A and B show the linear input/output characteristics within the range of the input charge of ~0.1 to ~6 pC. Deviations of data from the straight-line under the input charge of ~10^{-13} C is mainly due to the background noise.

4. Results and Discussion

In order to check the reliability of the present measurement system, the secondary electron yield of soot was measured. Results were shown in Fig. 5. Here $\sigma(E_p)$ denotes the total secondary electron yield, $\delta(E_p)$ the true secondary electron yield, and $\eta(E_p)$ the backscattering electron yield, respectively. In this measurement, the primary beam current is I_P = 1nA and the width is t_W = 1ms, that is, Q_P = ~1 pC. A dashed

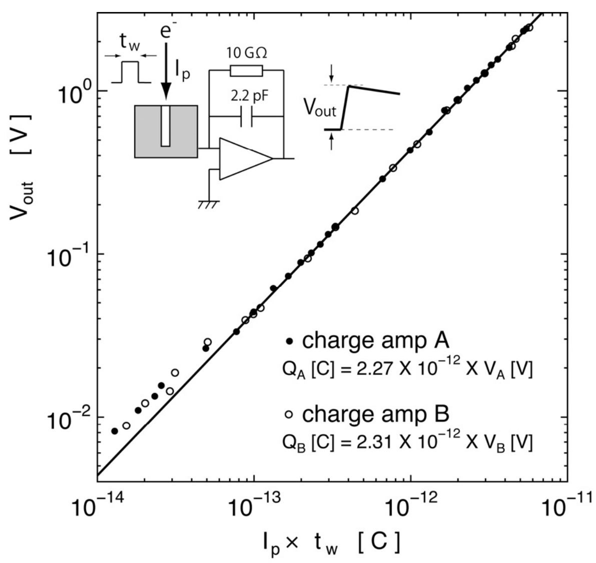

Fig. 4 The input/output characteristics of charge amplifiers A and B. The primary electron energy E_P was 2 keV, and the pulse width t_W was 1ms. The input charge was determined by $I_P t_W$, where I_P is the primary electron beam current measured by the trench on the sample holder.

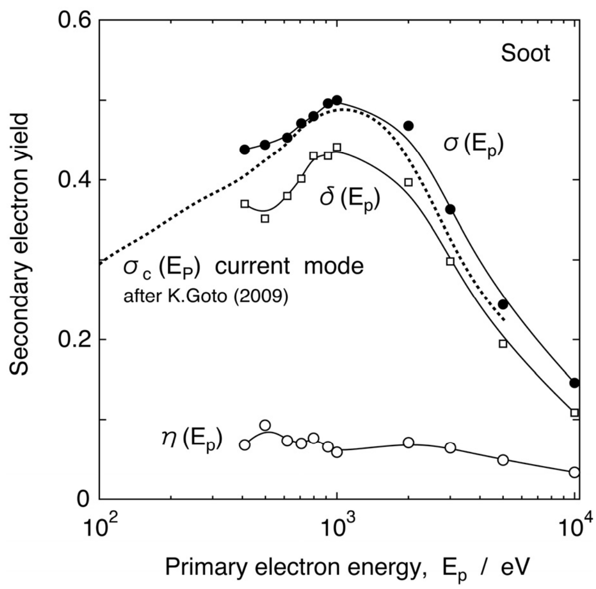

Fig. 5 The secondary electron yields of soot measured by the charge amplification method as a function of the primary electron energy in comparison with that measured by the conventional current-mode method indicated by dashed line. $\sigma(E_p)$ denotes the total secondary electron yield, $\delta(E_p)$ the true secondary electron yield, and $\eta(E_p)$ the backscattering electron yield, respectively. Each data point was measured with the primary electron charge of ~1 pC.

curve represents the total electron yield measured by the conventional current mode method, $\sigma_C(E_p)$ [2].

Curves of $\sigma(E_p)$ and $\sigma_C(E_p)$ are almost consistent with each other around their maxima. This shows that the charge amplification method enables the secondary electron yield to be measured using the primary electron charge of only ~1 pC.

5. Summary

As the initial step to realize a reliable measurement of the secondary electron yield of insulating materials using charge amplification method proposed by K. Goto, a pair of the charge amplifiers to measure a small amount of the electron charge of less than ~1 pC have been developed. These amplifiers showed linear input/output characteristics within the range of the input charge of ~0.1 to ~6 pC. The secondary electron yield $\delta(E_p)$ of soot was measured by employing these charge amplifiers, and compared with that measured by the conventional current-mode method. The result showed that the charge amplification method enables the secondary electron yield to be measured using the primary electron charge of only ~1 pC. The primary electron charge can be further reduced to at least ~0.1 pC by improving the charge amplifier. At the next step, we are planning to measure the secondary electron yield of glass, Al_2O_3 crystal, and etc.

6. References

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