

# Measurement of Secondary Electron Yield by Charge Amplification Method

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## 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. 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  $\sim 1$  pC.

## Charge Amplification Method

Figure 1 shows the schematic of the measurement of  $\delta(E_p)$  of insulators by the charge amplification 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 is designed to be close to  $2\pi$  as much as possible. The pulsed primary electron beam is used to reduce the amount of the irradiated primary electrons for the measurement of SEY, and 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  $\delta$ , the backscattering electron yield  $\eta$ , and the total secondary electron yield  $\sigma$  are obtained by

$$\delta = \left| \frac{Q_{SE}}{Q_p} \right|, \quad \eta = \left| \frac{Q_{BE}}{Q_p} \right|, \quad \sigma = \left| \frac{Q_C}{Q_p} \right|$$

$$Q_p = Q_s + Q_c, \quad Q_{BE} = Q_C^{-54V}, \quad Q_{SE} = Q_C - Q_{BE}$$

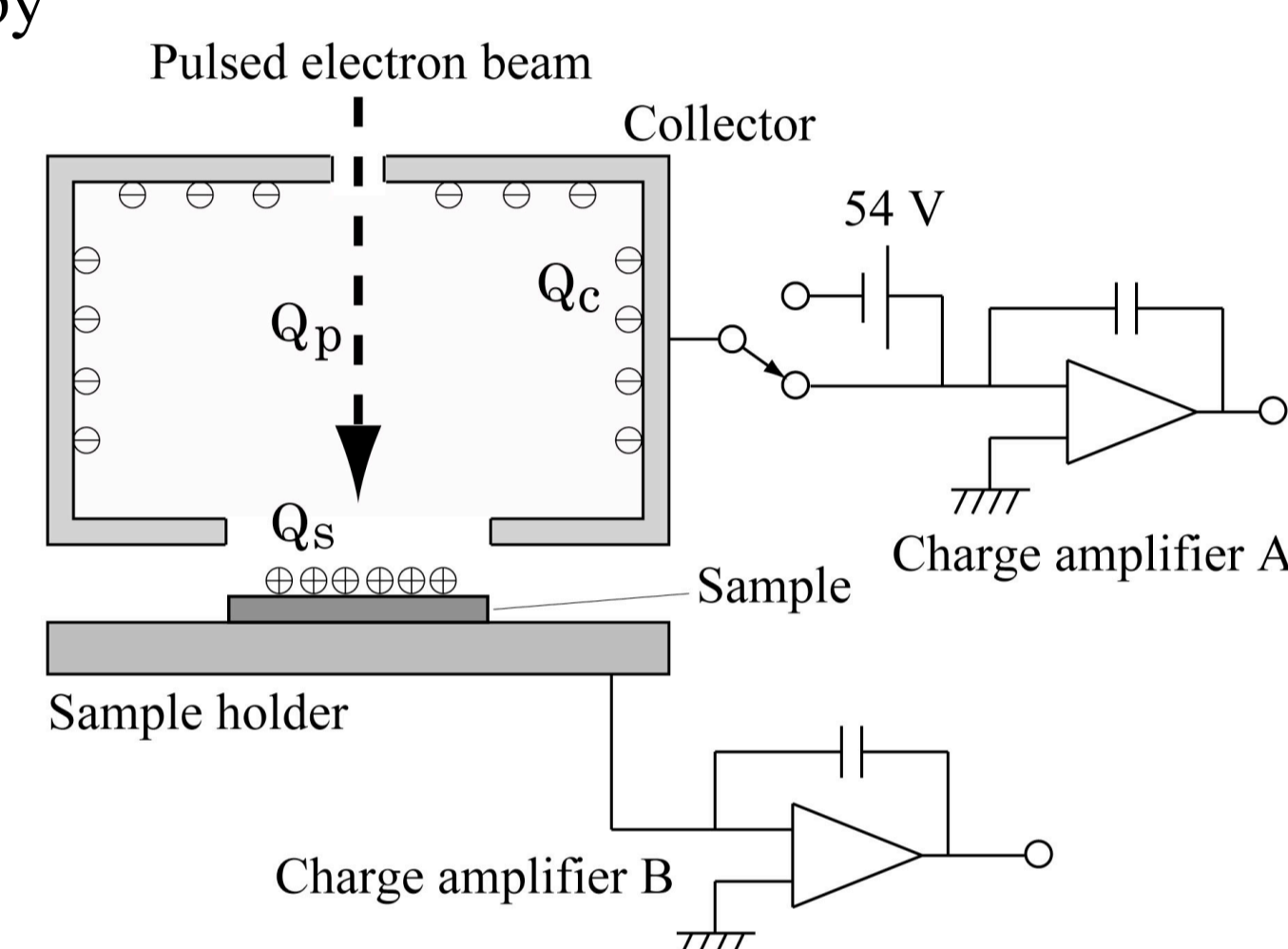


Fig.1. Schematic of the measurement of SEY by the charge amplification method.

## 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  $\sim 3 \times 10^{-6}$  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 are controlled by the handmade pulse generator.

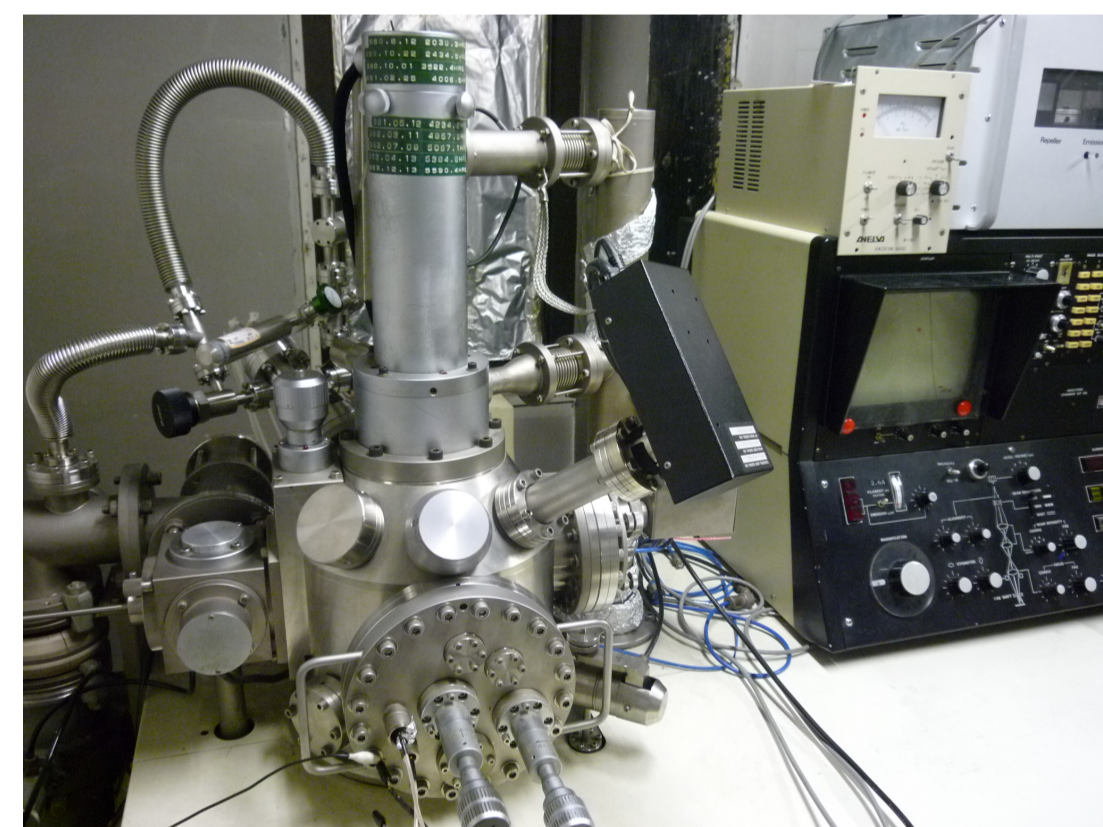


Fig.2. Outer view of Scanning Auger Electron Microprobe, JAMP-10 (JEOL).

Figure 3 shows the photograph of the retractable secondary electron collector (a) and its schematic drawing (b). The sample holder and the collector box 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.

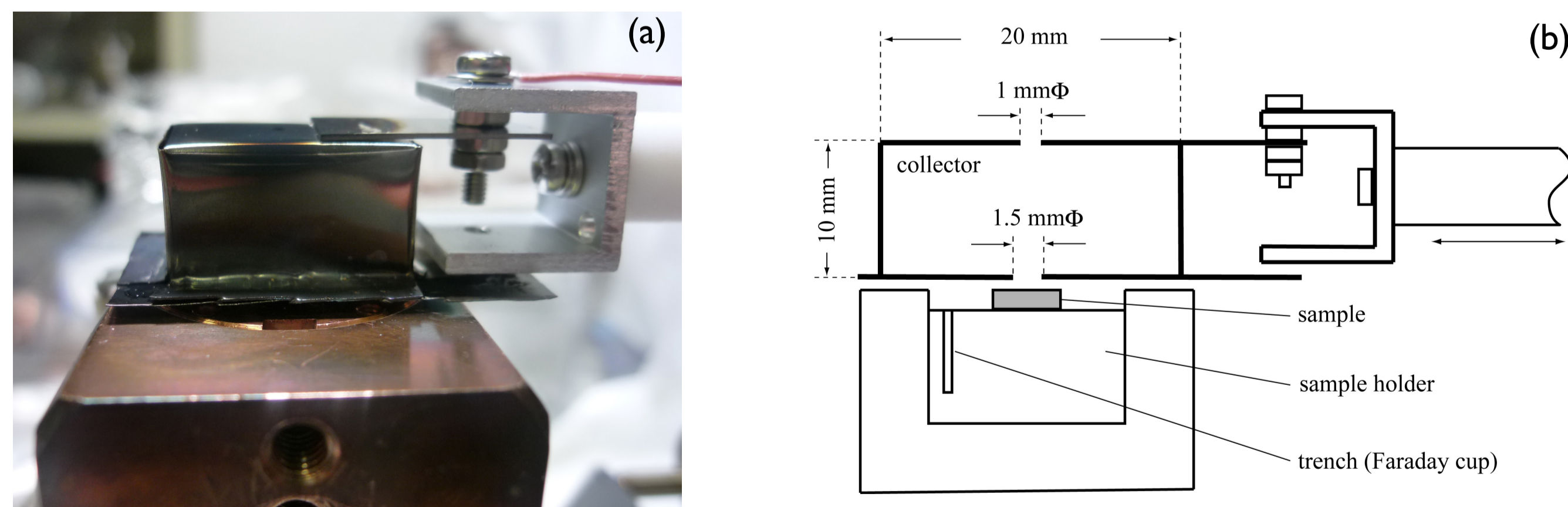


Fig.3. Outer view of the secondary electron collector located on the sample holder (a), and its schematic drawing (b).

## Charge Amplifiers

Figure 4 shows the electric circuit diagram of the charge amplifier we made.

The feedback condenser  $C_F = 2.2 \pm 0.5$  pF, and the feedback resistor  $R_F = 10$  G $\Omega$ . ( $\tau \sim 22$  ms)

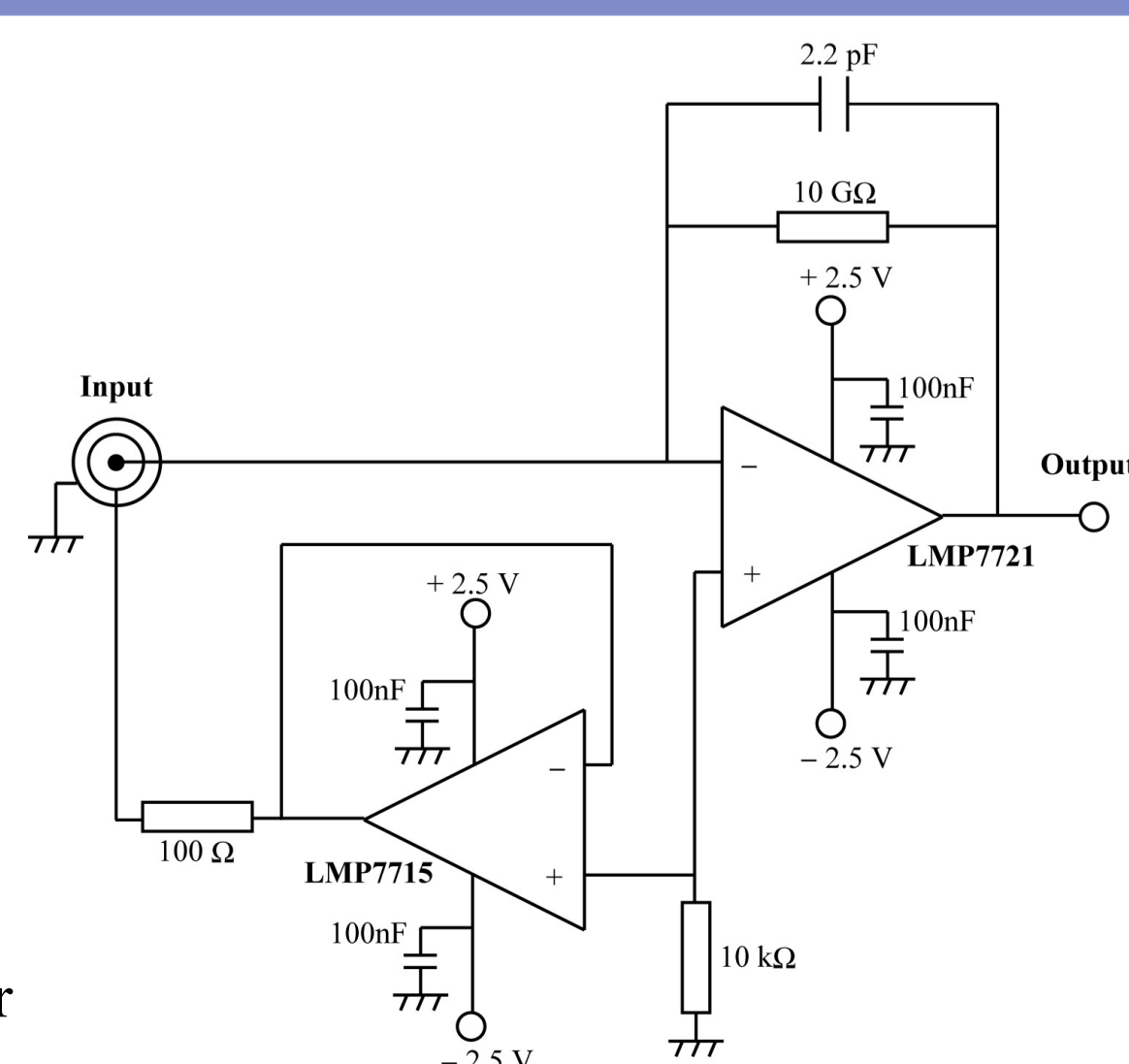


Fig.4. The circuit diagram of the charge amplifier

The peak to peak height of the output wave form is proportional to the input charge, that is,  $Q_{input} = CV_{output}$ . The proportional constants for amplifiers A and B were determined to be  $C_A = 2.27 \times 10^{-12}$  [C/V] and  $C_B = 2.31 \times 10^{-12}$  [C/V] from the input/output characteristics of these amplifiers as shown in Fig.6 by the least mean square fitting. These values are consistent with the capacitance of the feedback condenser of  $2.2 \pm 0.5$  pF.

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.

From Fig.6, it can be confirmed that both of charge amplifiers A and B shows linear input/output characteristics within the range of the input charge of  $\sim 0.1$  to  $\sim 6$  pC.

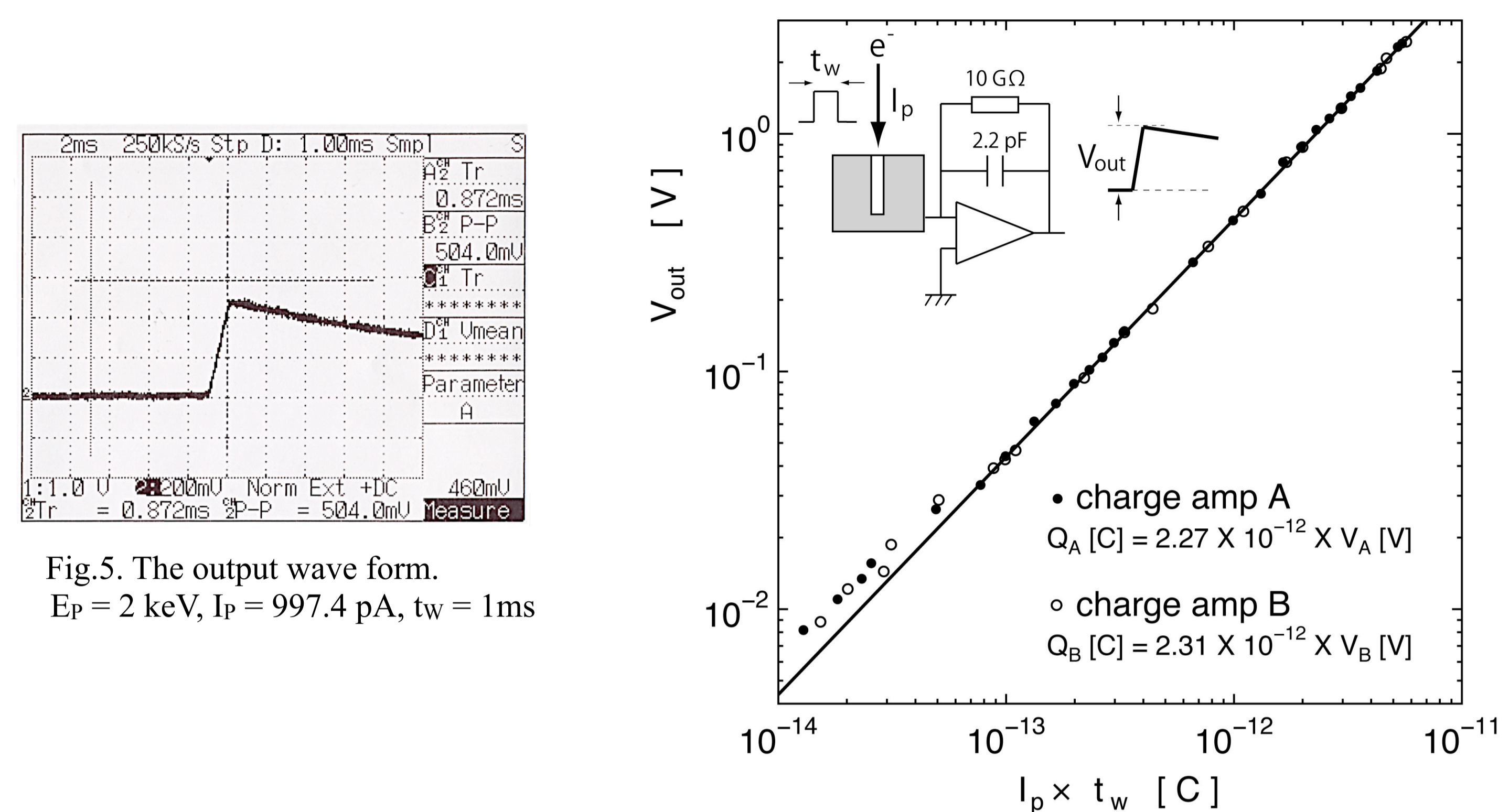


Fig.5. The output wave form.  $E_p = 2$  keV,  $I_p = 997.4$  pA,  $t_w = 1$  ms

Fig.6. The input/output characteristics of charge amplifiers A and B. The primary electron energy was  $E_p = 2$  keV, and the pulse width was  $t_w = 1$  ms. 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.

## Secondary Electron Yield of soot

In order to check the reliability of the present measurement system, the secondary electron yield of soot was measured. Results were shown in Fig. 7. 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  $I_p = 1$  nA and the width is  $t_w = 1$  ms, that is,  $Q_p = \sim 1$  pC. A dashed 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 especially 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  $\sim 1$  pC.

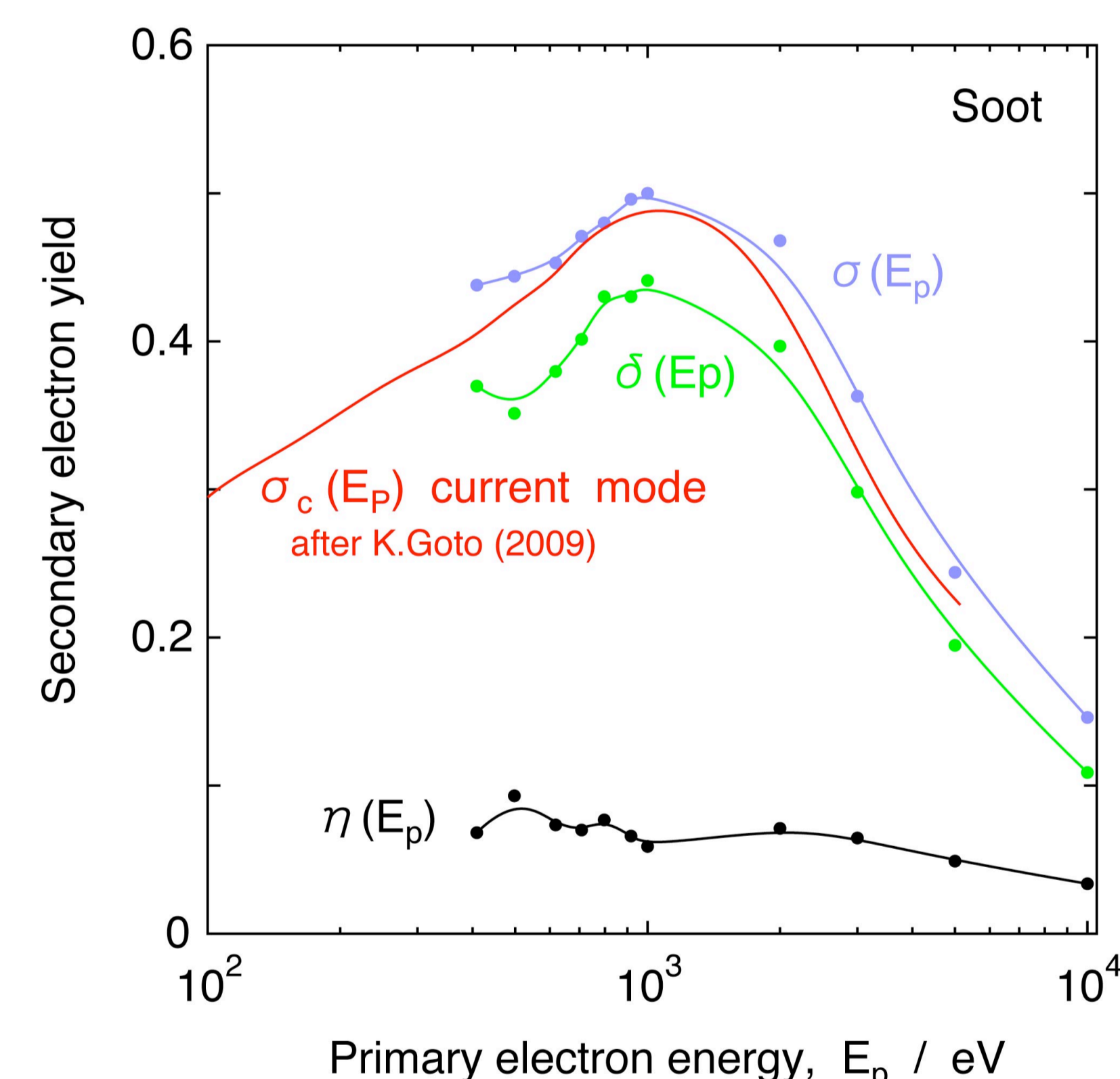


Fig.7. The secondary electron yields of soot measured by the charge amplification method as a function of the primary electron energy in comparison with that measured by the conventional current-mode method indicated by dashed line.  $\sigma(E_p)$  denotes the total secondary electron yield,  $\delta(E_p)$  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  $\sim 1$  pC.

## 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  $\sim 1$  pC have been developed. These amplifiers showed linear input/output characteristics within the range of the input charge of  $\sim 0.1$  to  $\sim 6$  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  $\sim 1$  pC.

## References

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