First Observation of Micro-Bunch Structure of the 100 MHz HIMAC-Injector Linac Beam by a Thin SEEM

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Abstract

The characteristics of a thin secondary-electron-emission type of beam monitor (SEEM) with three sheets of 1 μm-thick Al foils, an effective area of 40 x 40 mm^2 and gap distances of 2 mm are described. Our SEEM has been routinely used as a dose monitor with an accuracy of 1 % level. The total, forward and backward secondary electron emission yields, γ_t, γ_f and γ_b, from the Al foil were measured under bombardment with He^{2+} , C^{6+} , Si^{14+} ions at an energy of 6 MeV/amu, and their Z^2-dependence was studied. Experimental data showed that the Z^2 dependence is almost valid for the above bare projectiles, i.e., the emission yields are rather well proportional to the electronic energy loss. In addition we report on the first observation of a micro-bunch structure of 1 ns rise-time and 100 MHz repetition-frequency of linac beams with the SEEM. While we can utilize these fast-timing signals of SEEM only for the heavy-ion beam inducing a very high emission yield, it may be noted that a typical traveling time of the emitted electrons is of the order of 100 ps which is comparable with that of the Pestov chamber.

1 INTRODUCTION

The biological and medical applications of the heavy ion with energies of several MeV/amu create the need for accurate measurement of the number of ions incident on the samples located at an atmospheric circumstance. Since, in such a situation, the use of a Faraday cup (FC) arrangement is impractical for the small penetrating power of the heavy ions, we have developed a very thin SEEM and studied its characteristics.

Basic understanding of the phenomenon of secondary electron emission (SEE) from metal surfaces by the ion impact is very important not only for the research of atomic physics, but also for the application to accelerator science. However, studies of the SEE yields of thin foil and heavy ion with the energy of several MeV/amu are scarce, and experimental data with high accuracy are little [1]. We have used He^{2+}, C^{6+} and Si^{14+} beams at an energy of 6 MeV/amu from the HIMAC (Heavy Ion Medical Accelerator in Chiba) injector of NIRS, which consists of two types of linac (100 MHz RFQ and 100 MHz Alvarez linacs), and systematically investigated the SEE yields for the Al foil with ions having the same velocity.

On the other hand, a very fast timing signal from the SEEM can be expected if the γ_t is larger than 1. In this case the induced pulse height of the SEEM can far exceed that of the beam passage. In addition, the traveling time of electrons, in vacuum, between electrodes applied to several 10 V is very short, as can be estimated with a simple equation.

In the present work we report on the characteristics of emission yield and fast-timing of the SEEM for the bare ion beams, and describe the applications to the intensity monitor and to the tuning of linac.

2 EXPERIMENTAL SETUP

As seen in Fig.1, our SEEM is very thin. The active area is 40 x 40 mm^2. Each Al foil was put on a 1 mm-thick copper frame whose interior and exterior areas are 40 x 40 mm^2 and 60 x 60 mm^2, respectively. These electrodes were separated 2 mm apart from each other with teflon spacers, and the whole parts were set with lucite screws at the one of the lids of a copper vessel whose inner volume is 66 x 66 x 15 mm^3. After setting them the vessel was covered with another lid. Both the lids have a window of 30 mm dia. in the center so as to pass the ion beams. Since these are earthed, they also play a role

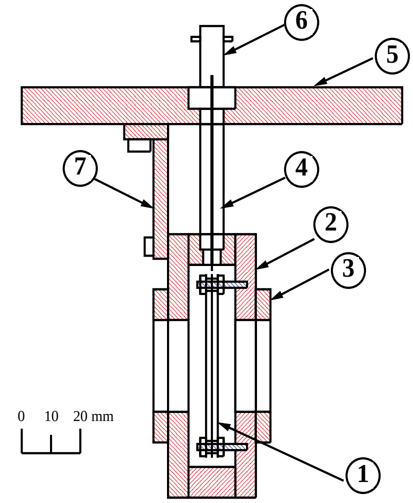

Fig. 1. A cross sectional view of the SEEM being used at the HIMAC injector(6 MeV/amu): 1 Three 1 μm-thick Al foils, 2 and 3 Field adjusting flange, 4 Cu pipes, 5 130 mmϕ vacuum flange, 6 SMA connectors, 7 Supporting plate.

to adjust the electric field of inlet and outlet surfaces. In order to pick-up the fast timing pulses from the SEEM, each signal line was stretched via a copper pipe of 8 mm ϕ, and connected with an airtight SMA connector being welded at the outside of a 130 mmϕ vacuum flange.

The SEEM was set in the vacuum chamber of the linac beam line, and operated under vacuum at 10^{-6} Torr. The inlet and outlet foils set on both sides were individually held at plus voltages through a Keithley and the middle foil was earthed to obtain both the yields of forward and backward SE from itself.

In this arrangement of voltage polarity, the forward and backward SE yields are collected into the outlet and inlet foils, respectively. The 60 mm ϕ x 600 mm long Faraday cup (FC), placed at about 50 cm downstream from the SEEM, collected the beam current via another Keithley electrometer. A permanent magnet with an area of 50 x 100 mm^2 and a magnetic field intensity of about 300 gauss was located near the entrance of the Faraday cup to make a closed loop for the measurement of the beam current.

Forward and backward emission currents from the middle foil were individually measured, by the inlet and outlet foils in a shape of charge, and compared with that of the FC. These ratios divided into the atomic number of projectile give the absolute emission yields, γ_f and γ_b, of the Al foil for a certain ion impact. Beam size was kept smaller than about 1 cmϕ in diameter and beam intensity was about 10 μA peak in a repetition rate of 1 Hz during the experiments. Each current-integration measurement was undertaken for 10 beam-pulses in order to improve the statistics of the data, and the experimental error was thus considered to be a few % for the beam intensity of about 10 μA.

Since the surfaces of Al foils are easily oxidized and covered by a thin layers of Al_2O_3 [2], our SEEM has been usually bombarded for about a half hour with the linac beams before the experiments. As described below, it was found that the reproducibility of measuring values of the yield is considerably improved, and found that it may depend on the beam intensity and/or the ionizing power of projectiles.

3 EXPERIMENTAL RESULTS

Fig. 2 shows plateau curves of the forward and backward SEE yields, γ_f and γ_b, obtained for the He^{2+} ion impact. As can be seen from the figure, γ_f is larger than γ_b. the kinetic energies of almost all secondary electrons are less than 20 eV, and half of them have energies less than 2 eV. Similar tendency also exists for the other projectiles. The yields and timing data were taken with the applied voltage of +30 V.

The values of various SEE yields for the Al foil under bombardment of He^{2+}, C^{6+} and Si^{14+} with an incident energy of 6 MeV/amu and 10 μA-peak are listed in Table 1. As shown from the table, the ratio of γ_f and γ_b becomes gradually large with the increase of projectile atomic number, i.e. 1.15, 1.43 and 1.58 for He^{2+}, C^{6+} and Si^{14+} ions, respectively. These yields and ratios are somewhat different from the reported values [2,3]. We believe this may be attributed to the differences of foil thickness and/or experimental setup.

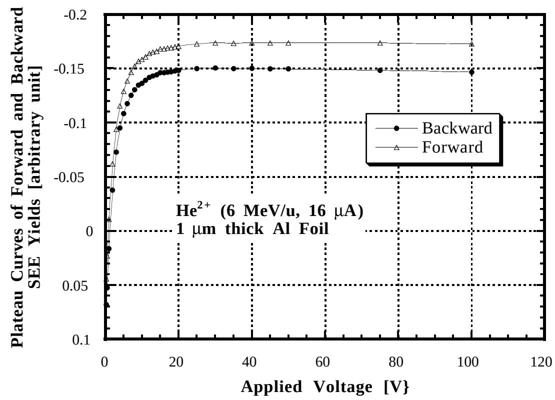

Fig. 2 : Plateau curves of forward and backward SEE yields for He^{2+} (6 MeV/amu).

Table 1: Secondary electron emission yields for the 1 mm-thick Al foil for various bare projectiles.

Projectile	γ_f	γ_b	γ_t
He^{2+}	3.21	2.79	6.00
C^{6+}	23.8	16.6	40.4
Si^{14+}	119.1	75.3	194.4

Fig. 3 presents the relation of γ_t, γ_f and γ_b versus Z^2. The increase in total emission yield γ_t for the squared atomic number of projectiles is slightly small, as seen in the figure.

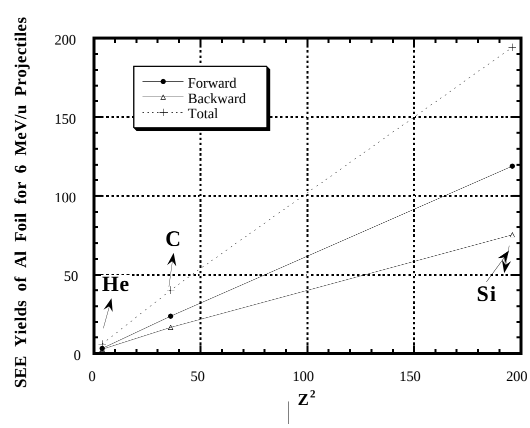

Fig. 3 : Linear plots of SEE yield for various ions with the same velocity..

The characteristics of the Z^2-dependence of SEE yields for projectiles with the same velocity is rather good, but the discrepancy becomes large with the increase of atomic numbers. As a mechanism for this, ion-induced effect, i.e., the change of surface-barrier-potential depth has been proposed [3].

This suggest us that the beam intensity may influence the escape of the adsorption compounds existing in deep layers. In fact, a large decrease of the yield has been observed for Si^{14+} beam with 200 μA-peak current. We show this in Fig. 4 and 5.

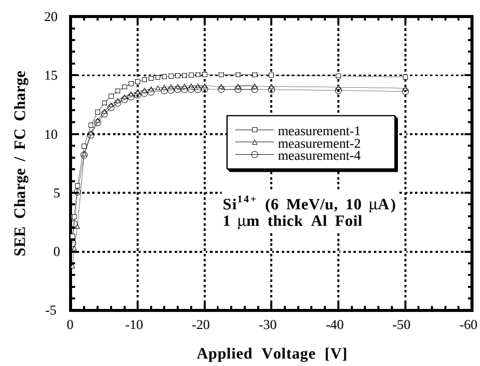

Fig. 4 : Time-varying Plateau curves for the 200 μA peak Si^{14+} beams.

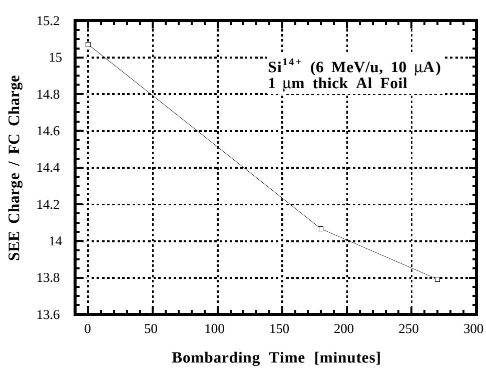

Fig. 5 : The change of the SEE yield for the Si^{14+} bombard time.

As shown from these figures, the SEEM yield for high intensity Si^{14+} beams decreases rapidly with the bombarding time, unlike the case of other lighter ions of a beam intensity of the order of 10 μA. While Al foils can be easily oxidized in air, the effect of adsorbed oxygen layers are considered to depend strongly on the electronic stopping power of projectiles.

The fast timing characteristics of the SEEM for 10 μA peak C^{6+} beams is given in Fig. 6. The micro-bunch structure of the linac is clearly observed for the first time. A SHF88 fast amplifier was used, and the ultimate timing properties of the amplifier were tested with a short-pulse electron accelerator at Nuclear Engineering Laboratory, University of Tokyo [4]. The rise time was 200 ps. On the other hand that of SEEM is faster than 100 ps, comparable with the Pestov chamber [5], which depends on the applied voltage. Such characteristics of the SEEM can be used to the linac tuning and the investigation of the space-charge effect of micro-bunched heavy ion beams.

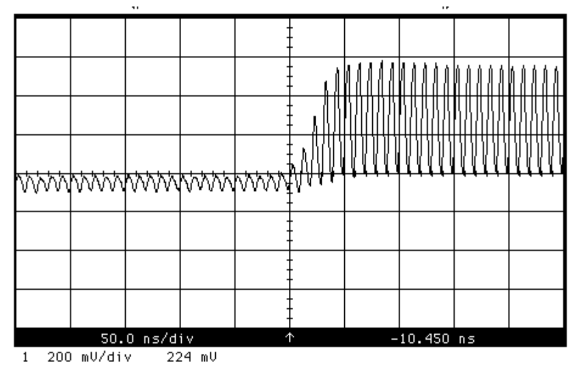

Fig. 6 : A fast timing signal observed from the SEEM for the 10 μA peak C^{6+} beams. Data is given by 200 mV/div and 50 ns/dive. The pulse height of the induction of the beam passage is about 130 mV.

While the signal height of the beam passage was about 130 mV, the SEEM signal was 4 to 5 times larger than that. It should be noted that if projectiles meeting both conditions of $\gamma_t > 1$ and atomic number Z are used, we can obtain Z times larger signals, from the SEEM, than the induction of beam itself.

SUMMARY

We have developed a thin SEEM with a high accuracy and used for biological and medical experiments at the HIMAC injector. Its basic characteristics such as SEE yields, Z^2-dependence and fast timing are described. However, the detailed investigations with respect to the emission yields for bare projectiles heavier than C^{6+} and high beam intensity are necessary. The fast timing signal obtained from the SEEM is considered to be useful for the study of some kind of heavy ion linac.

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