Experiment on Low-Energy and High-Current-Density Ion Beam produced by Concave Electrodes
凹型電極を用いた低エネルギー高電流密度イオンビームの実験


1. Introduction
It is well known that the charged particle beam with low-energy less than 100 eV has divergence problem by its own space charge of charged particles itself. Suppression of this divergence is essential for practical use of the low energy ion beam. For the ion beam, it is necessary to neutralize the ion charge with electrons by some means. The commonly used method is to use thermal electrons produced by heated filaments inserted and/or surrounding the beam [1], although this method has the problem of contamination by filament material.

In this manuscript we will present the newly developed method; neutralization of ion charges by secondary electrons which are emitted from the grounded electrode of the ion source by the independently produced electron beam injection.

The secondary electrons are produced at the position very close to apertures in the grounded electrode, through which the ions are extracted. The majority of the secondary electron is emitted with very low energy, whose velocity is not so much different from the ion beam velocity, hence, it is expected that these electrons can be captured by the beam ions with high efficiency.

2. Experiment Setup
The experimental apparatus is composed by an ion beam source, electron gun and target plate with Faraday cup. The ion beam source is made of a bucket type plasma confinement chamber, four tungsten filaments, extracting electrodes and gas supplying system. The three concave molybdenum electrodes of 80 mm effective diameter with multiple apertures are used. The diameter of each aperture on the acceleration electrode is 1.5 mm on the ion-source side. The transparency of each electrode is ~50%. The distance between the acceleration and deceleration electrodes, and that between the deceleration and grounded electrodes are both 1.5 mm. The thickness of all electrodes is 1.0 mm. The power supply system has capability to extract the DC beam. In this beam source, the ion beam current, I_{ion}, up to 200 mA with the energy up to 1.5 keV is possible. The total of the ion source is presented in [2].

The electron beam gun is a standard type, which has a LaB6 cathode heated by a tungsten ribbon, tungsten mesh grid, accelerating and focusing electrodes and electrostatic shielding cylinder. It is found that the shielding of the electric field is very important to obtain reliable ion beam current and its profile measurements. In the typical operation, the electron beam current, I_{e}, up to 50 mA is used.

To measure the extracted ion beam profile, a biased conical cup (20 mm diameter at the beam entrance) is used to correct the ion beam, which is installed 214 mm from the grounded electrode. At a distance of 71 mm behind the cup, a biased disk plate with 130 mm diameter is installed to correct the ion beam that passes through the cup region. Both the cup and plate are biased to -20 V.

3. Experimental Results
Helium gas is used for the ion beam source and He\(^+\) ions are extracted. Filling Helium gas pressure is usually set at around 1 mTorr in the source chamber. Following sections, data taken with 50 V acceleration voltages will be presented. The bias voltages of the detecting cup and plate are -20 V, thus the ion beam energy at the detecting target is 70 eV.
Figure 1 shows the dependence of the summation of detected plate and Faraday cup currents, \( I_{\text{pc}} = I_{\text{plate}} + I_{\text{cup}} \) on the electron beam current, \( I_{\text{eb}} \) for three different acceleration electrode currents, \( I_{\text{acc}} \), which is almost proportional to the ion beam current, \( I_{\text{ib}} \). The \( I_{\text{acc}} \) is varied by changing the filament current of ion beam source. The electron beam energy is 1 keV and its current is varied also by changing the filament current of electron gun. Therefore, the change of electrostatic condition is expected to be very small during the variations of them.

In Fig.1 the effect of the electron beam is clearly shown. As the \( I_{\text{eb}} \) increases from zero, the \( I_{\text{pc}} \) increases from 1.7 mA to 3.9 mA at \( I_{\text{eb}} = 22 \) mA (2.3 times increase) for \( I_{\text{acc}} = 10 \) mA, 3.5 mA to 7.5 mA at \( I_{\text{eb}} = 19 \) mA (2.1 times) for \( I_{\text{acc}} = 20 \) mA and 8.3 mA to 13 mA at \( I_{\text{eb}} = 13.5 \) mA (1.5 times) for \( I_{\text{acc}} = 40 \) mA. The \( I_{\text{pc}} \) increases as the \( I_{\text{acc}} \) increases. However, the ratio of \( I_{\text{pc}} \) values with and without \( I_{\text{eb}} \) decreases as the \( I_{\text{acc}} \) increases. Moreover, the \( I_{\text{eb}} \) value which gives the maximum of \( I_{\text{pc}} \) also decreases. Reasons why these decreases observed are now being surveyed.

Figure 2 shows the ion beam profiles measured by the Faraday cup which is scanned vertically from \( Z = 80 \) mm to 270 mm. \( R_{\text{cup}} \) is given by \( R_{\text{cup}} = Z - 190 \).

\[ Z = 190 \text{ mm is approximately the center of the beam, hence the negative } R_{\text{cup}} \text{ corresponds to upper half. The ion beam profiles are shown for three cases of } I_{\text{acc}} = 10 \text{ mA, } 20 \text{ mA and } 40 \text{ mA, and cases with and without the electron beam are compared. Asymmetries of profiles with respect to the peak position are mainly caused by the supporting rod of the cup, which is deeply inserted for positive } R_{\text{cup}}. \text{ In all cases, } I_{\text{eb}} \text{ is kept almost constant at about } 22 \text{ mA.}

For all \( I_{\text{acc}} \) cases, more peaked ion beam profiles are observed with the electron beam, especially in the cases with \( I_{\text{acc}} = 10 \) mA and 20 mA. However, the effect becomes less clear for the \( I_{\text{acc}} = 40 \) mA case, probably because the \( I_{\text{eb}} \) is not sufficient for efficient charge cancelation.

Surprisingly, the concentration on the beam in the \( I_{\text{acc}} = 40 \) mA case is not bad even without the electron beam, where the central current density reaches to ~0.3 mA/cm², which possibly is the effect of the concave electrodes.

4. Discussion and Summary

Suppression of the beam divergence by the electron beam injection (1 keV, 20-50 mA) to the grounded electrode of ion source is demonstrated for the low energy (70 eV) ion beam with high current (up to 40 mA). The ion current reaching to the target plate (biased -20 V) increases as the electron beam current increases from zero. The well peaked current density profiles are obtained with the electron beam injection.

In the present stage of the experiment, it is difficult to distinguish whether the observed increase of ion beam current in the target plate is caused by the secondary electrons or some other direct interaction with the injected beam electrons, although it is confirmed that the more than 70% of the electron beam reaches the grounded electrode. It will be answered by the change of secondary electron emission efficiency with different electron beam energies and/or with different electrode materials.

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References
