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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

Y. Hirano, S. Kiyama, H. Sakakita, H. Koguchi, T. Shimada, and Y. Sato
平野洋一，木山　學，榊田　創，小口治久，島田壽男，佐藤康宏

Innovative Plasma Technologies Group, Energy Technology Research Institute, National Institute of Advanced Industrial Science and Technology (AIST),　Tsukuba Central 2, Umezono 1-1-1, Tsukuba 305-8568, Japan
産業技術総合研究所エネルギー技術研究部門先進プラズマ技術グループ
〒305-8568　つくば市梅園1-1-1、つくば中央２

High-current-density ion beam in low-energy region (<100 eV) has been studied. The ion beam is produced by an ordinary bucket type ion source with three extracting concave electrodes. Divergence of the beam caused by its own space charge is suppressed by compensating ion charges with secondary electrons emitted from a grounded electrode produced by an electron beam (~500-1000 eV) injected to that electrode. The electron beam is independently produced by an electron gun. It is observed that the 22 mA and 1 keV electron beam can suppress the divergence of 70 eV and 10 - 40 mA ion beams. The ion beam reaching the target plate increases from 3.5 to 7.5 mA with peaked profile in 10 mA ion beam case.

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_{ib}, up to 200 mA with the energy up to 1.5 keV is possible. The detail 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_{eb} 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.

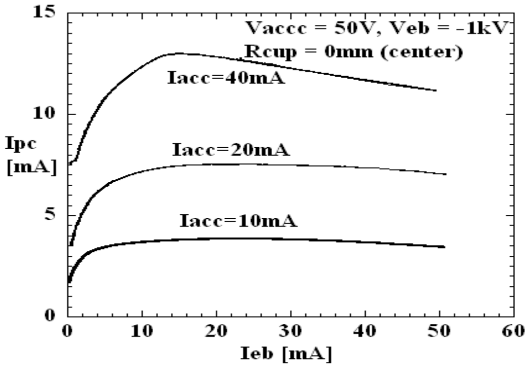

Fig.1 Variations of sum of target plate current and cup current as a function of electron beam current for different acceleration electrode currents.

Figure 1 shows the dependence of the summation of detected plate and Faraday cup currents, $I_{pc} = I_{plate} + I_{cup}$, on the electron beam current, I_{eb} for three different acceleration electrode currents, I_{acc}, which is almost proportional to the ion beam current, I_{ib}. The I_{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_{eb} increases from zero, the I_{pc} increases from 1.7 mA to 3.9 mA at I_{eb} = 22 mA (2.3 times increase) for I_{acc} = 10 mA, 3.5 mA to 7.5 mA at I_{eb} = 19 mA (2.1 times) for I_{acc} = 20 mA and 8.3 mA to 13 mA at I_{eb} = 13.5 mA (1.5 times) for I_{acc} = 40 mA. The I_{pc} increases as the I_{acc} increases. However, the ratio of I_{pc} values with and without I_{eb} decreases as the I_{acc} increases. Moreover, the I_{eb} value which gives the maximum of I_{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_{cup} is given by R_{cup} = Z -190.

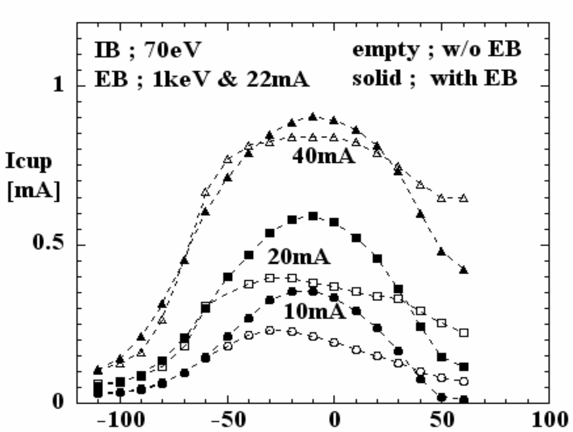

Fig.2 Ion beam current profiles with and without electron beam for different acceleration electrode currents.

Z =190 mm is approximately the center of the beam, hence the negative R_{cup} corresponds to upper half. The ion beam profiles are shown for three cases of I_{acc} = 10 mA, 20 mA and 40 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 Rcup. In all cases, I_{eb} is kept almost constant at about 22 mA.

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

Surprisingly, the concentration on the beam in the I_{acc} = 40 mA case is not bad even without the electron beam, where the central current density reaches to ~ 0.3 mA/cm^2, 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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