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Energy Distribution of Current Density in Spontaneously Focused Low-energy High-current-density Ion Beam
自発的集束状態にある低エネルギー・高電流密度イオンビームにおける電流密度のエネルギー分布

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In the former JSPF meeting held in 2013, we presented the result that the spontaneous focusing was observed in the low energy (~150eV) and high current (~100mA) hydrogen ion beam extracted through the electrodes with concave shape. As the ion beam energy was being increased, the abrupt transition to the highly focused state took place at around ~150eV. Simultaneously it was also observed in the electrostatic double probe measurement that the low temperature (<~10eV) and dense (more than ten times larger than the beam density) plasma appeared in the almost same region of the ion beam propagation. Since the beam current measurement also measured this low energy component, it was not clear whether the focusing of the ion beam truly took place. To make it clear we added the mesh grid in front of the simple Faraday cup to distinguish the beam component from the low energy part. We will present the result obtained by using this modified Faraday cup and will show what happens in the transition to the highly focused state.

1. Back Ground for the Experiments

In the experiments of low energy ion beam being conducted at AIST, the focusing of the beam was observed by several methods.

In the high current case, as high as 100mA, the focusing was triggered by the electron beam injection to the grounded electrode.[1] This focusing was observed for the ion beam energy, E_{ib} slightly less than 100eV. Probably the secondary electrons emitted from that electrode by the electron beam injection may play an important role to produce electrons necessary for compensating the positive electrostatic potential produced by space charges of beam ions.

In the region of ion beam energy higher than 150eV, spontaneous focusing of the beam was observed.[2] In Fig. 1, the current densities, J_{cup} at the beam center (z=0), at z=50mm and 100mm, are shown as functions of E_{ib}. Those are measured by the simple Faraday cups.[1] Beam current reaching to the target plate, I_{plate}, and current flowing into the grounded electrode, I_{ground}, are also shown. The J_{cup} at z=0 jumps up at E_{ib} = 150eV, which indicates the strong transition to the focusing state takes place at E_{ib} =150eV.

Figure 2 shows the ion beam radial profiles in non-focused and focused states for E_{ib} =40eV and E_{ib} =160eV with the same I_{plate} values. This figure clearly shows the transition to a highly focused state.

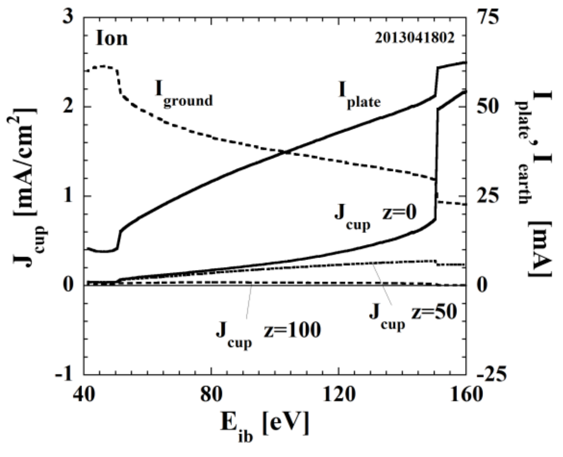

Fig.1 Variations of current densities, J_{cup} at the beam center (z=0), at z=50mm and 100 mm, and, I_{plate} and I_{ground} as functions of ion beam energy, E_{ib}.

Independent to these measurements, the electron density was measured by the electrostatic double probe[3,4], which indicated that the dense plasma, more than ten times larger than the ion beam density, with low temperature

(~1 eV) does exist in the almost same region with the ion beam propagation region. These low temperature plasma compensated the beam ion space charge.

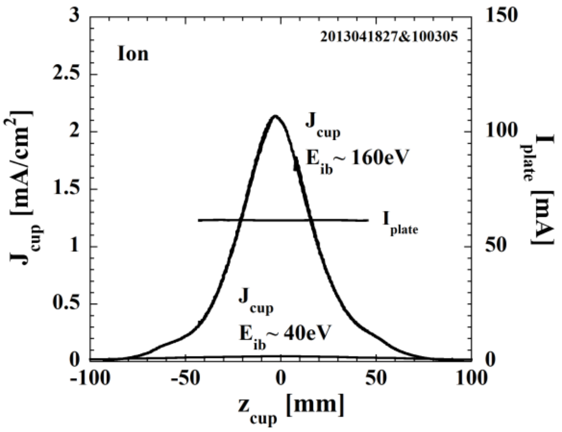

Fig.2 Profiles of ion beams with different Eib, 40 and 160 eV.

In the measurements described above, however, the energy distribution of the measured current density was not measured. Therefore, not only the beam ion component but also the low energy component may be included in the measured values and the possibility cannot be excluded that the low energy component may contribute to almost all measured values.

2. Experimental Apparatus

Details of the experimental apparatus are given in references [1-4]. Here we describe characteristics of it briefly. The apparatus consists of a plasma source chamber, beam propagation chamber and measurement system. The plasma source is an ordinary bucket type chamber with cusped magnetic field of neodymium magnets and has 160 mm width and height, and 190 mm depth. Plasma is produced by an arc discharge between the chamber wall and four tungsten filaments.

Ion beam is extracted by three molybdenum electrodes (acceleration, deceleration and grounded) having concave shapes with the same active 80mm diameter, 350mm focal length and 50% transparency. The beam propagation chamber is a stainless steel cylinder with a diameter of 300mmϕ and has several ports with a diameter of 150mmϕ.

The measurement system consists of a set of two double probes [3,4], a wide (140 mm) and long (460 mm) beam target copper plate (2 mm thickness) covered with a thin molybdenum plate (0.2 mm thickness), and three Faraday cups. The Faraday cups are installed closely behind three holes in the target plate along a vertical line with a 50mm distance. The cups are shielded with a copper channel in the back region of the plate. The open areas are only at the top and bottom of channel. They are in the side port and far from the beam propagation region. The cups can be scanned vertically with the plate and channel as a whole.

Three types of Faraday cups are installed and tested. The bottom one is the simple cup, without any electrode in front of it, which was used in the former experiment and is installed for comparison. The middle one has a tungsten mesh electrode in front of it. An independent voltage can be applied to it and electrons or ions can be rejected from flowing into the cup. The top one has a copper disc electrode with a hole (5.5 mmϕ) instead of the mesh to estimate damping effect of the mesh.

3. Test of Faraday Cups

The cup with the mesh electrode has been mainly examined. It is confirmed that the ion beam component can be separated from the low energy component and electrons. Therefore, it is possible to observe whether the transition to the highly focused state truly happens in the ion beam. However, some difficulties have been found. When a certain value of positive voltage is applied to the mesh, the rapid transition to the focusing state does not take place, which makes it difficult to observe the electron behavior in the transition event. Another is the poor sensitivity to the low energy ion, which is considerably smaller than that measured by the double probe.

Details of these results and comparison with other type cups will be presented at the conference.

Acknowledgments

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