Comparative Measurements of Ion and Electron Beams from Laser Ablation Plasma

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A laser ablation plasma was characterized as a source for high-flux particle beams. The ablation plasma was biased systematically from positive to negative high voltages and the fluxes of charged particles through a pair of extraction electrodes were measured. The ratio of available flux of electrons to that of ions was around 10. The result means the ion extraction is basically provided by the flux of supersonically drifting plasma and the electron extraction is determined by the flux of co-moving electrons exceeding a reduced sheath potential at the extraction electrode.

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Laser ablation plasma has been attracting as a high flux particle beam source for a variety of scientific and industrial applications. So called laser ion source has been widely studied and its controllability is becoming well established [1, 2]. In a similar way, the plasma source can also be applicable for a high-flux electron source.

Maximum available fluxes of charged particles from stationary plasma sources were well investigated. For example, the ratio of available fluxes of electrons and ions can be basically $(J_e/J_i) \sim (J^e_{th}/J^i_{th}) \sim (m_i/m_e)^{1/2}$ based on the thermal fluxes of charged particles. However, in case of charged particle extraction through an extraction grid, the ratio reduces to $(J_e/J_i) \sim 1$ due to the formation of ion sheath at the extraction grid [3].

Laser-ablated plasma moves in vacuum to the extraction gap faster than the thermal speed of ions [1, 4]. The beam extraction processes from the supersonically drifting plasma source are not established yet. In this paper, we show results of a comparative study on the available fluxes of ions and electrons from the supersonically drifting ablation plasma. The results are briefly evaluated based on the drift and the thermal fluxes of plasma.

Figure 1 shows a schematic diagram of the experimental setup for the flux measurements. The device consists of a Ti-plate as the plasma source, a Q-switched Nd:YAG laser, a plasma drift tube made of stainless steel, an extraction gap, and a Faraday cup made of a brass plate that is usually biased −100 V or +100 V to the ground potential for ion and electron flux measurements. The Faraday cup is connected to a digital oscilloscope through a coupling capacitor.

In the experiment, the laser was focused on the Ti plate with 20 ns, 150 mJ and the spot size of 2.5 mm^2. Then the laser beam intensity was estimated to be 3.0×10^8 W/cm^2 which is enough to make the target ablation. The ablated plasma expands through the drift tube to a pair of mesh electrodes which were attached with 5 mm space, at the end of the drift tube for beam extraction. Ions or electrons were extracted through the gap depending on the polarity of plasma potential. The extraction electrodes are composed of fine tungsten meshes with 80 mesh/inch. Then the half spacing ($\delta/2 = 0.16$ mm) is smaller than the Debye length ($\lambda_D = 0.2$ - 0.6 mm) at the extraction grid when the plasma has a density of $n_e = 10^{10}$ cm^{-3} and an electron temperature of $T_e = 10$ - 100 eV. An external voltage V_{ex} was applied to the plasma positively for ion extraction or negatively for electron extraction through the target and the drift tube. The Faraday cup was located 5 mm downstream from the extraction electrode. The background pressure was kept less than 4×10^{-5} Pa throughout the experiments.

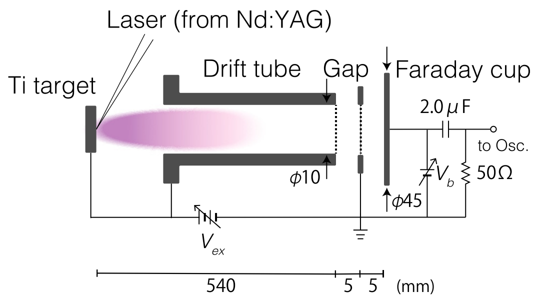

Fig. 1 Schematic of experimental apparatus.

Figure 2 shows ion flux waveforms measured with $V_{ex} = 0$. They are overlaid three shots to show the repro-

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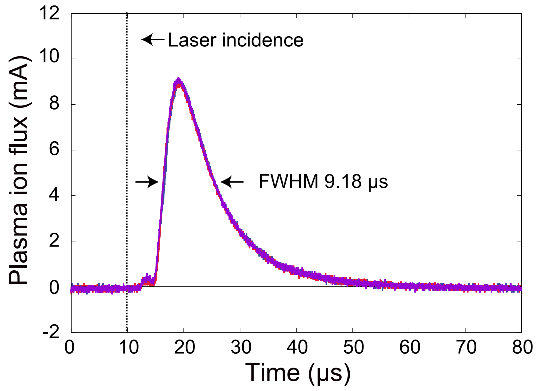

Fig. 2 Typical waveforms of plasma flux. Overlaid for 3shots.

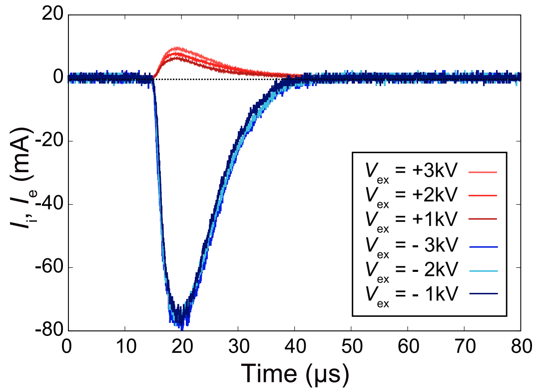

Fig. 3 Typical waveforms of ion and electron beams.

ducibility of plasma source. From the flux waveforms, we can estimate the average plasma (and co-moving ion and electron) drift velocity $v_d = v_d^i = v_d^e$ = (drift length)/(peak arrival time) = 6.1×10^4 m/s, and supposing the plasma ions are singly charged, ion density n_i was estimated to be (ion flux density)/$ev_d = 7.8 \times 10^9$ cm^{-3}.

Figure 3 shows waveforms of the beam flux where the plasma potential was biased sequentially from +3 kV to −3 kV with 1 kV step. Note that, the Child-Langmuir currents for the extraction gap were always larger than the current levels. Thus we could evaluate available fluxes from the plasma source. As shown in Fig. 3, the ion fluxes were the same level with the plasma flux. The results also show that the flux is almost the same level regardless of the biased potential changes. This justifies the extraction mesh is enough fine to shield the plasma from the extraction electric field.

As shown in Fig. 3, in contrast to the ion flux, the electron fluxes were more than 10 times of the plasma flux. This asymmetrical property basically comes from the discrepancy of available charge flux through the plasma sheath. In case of stationary plasma sources, available ion flux can be characterized as the Bohm current $J_B \sim 0.4en_i(2kT_e/M_i)^{1/2}$ considering the ion sheath potential; $\Delta\phi$ at the extraction electrode, in which ions are assumed to be thermal speed at the sheath edge [3]. In plasma cathode, electrons should overcome the plasma potential barrier to escape from the ion sheath to the acceleration region. That is, the electrons must be extracted through the potential barrier [5]. Then the sheath potential also regulates the electron flux so as to be $J_e \sim J_{th}^e \times \exp(-e\Delta\phi/kT_e) \sim J_i$. However, charge extractions from the ablation plasma source are not the cases. The ion thermal velocity is estimated to be, v_{th}^i = (drift length)/(FWHM of the plasma flux) = 3.0×10^4 m/s which is clearly smaller than the drift velocity v_d^i. This means, in the condition of supersonically drifting plasma ($v_d/v_{th}^i > 1$), the flux by the ion drift $J_D \sim en_iv_d^i$ dominates the Bohm current $J_D > J_B$. Beside, the enhanced ion flux is known to decrease the sheath (barrier) potential to $\Delta\phi$'. Then, the electron flux is expected also to increase with $J_e \sim J_{th}^e{}' \times \exp(-e\Delta\phi'/kT_e)$ where $J_{th}^e{}'$ shows the flux of co-moving electrons; thermal flux modified by the drift motion.

From the beam extraction study, available charge fluxes of laser ablation plasma were characterized. Results showed that the ratio of available electron and ion fluxes is around 10, which is neither $(J_e/J_i) \sim (m_i/m_e)^{1/2}$ nor $(J_e/J_i) \sim 1$. This result indicates that, in case of the ablation plasma source, the electron flux is enhanced by the reduction of the potential barrier at the extraction grid due to the enhanced ion flux. The result also means that control of the ablation plasma is important for a high flux beam extraction not only for ions but electrons also.

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