Transient Charge Flows Induced by the Evolution of Laser Ablation Plasma

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Charge flows were induced from a laser ablation plasma to a grounded target. The current signals, which were directly measured using a current monitor, developed from negative to positive depending on the dynamically evolving plasma. The results showed that, initially the current was induced by an electron flow from the plasma plume to the surrounding wall and, after a transient phase, the current was replaced by an ion flow to the wall. The results suggest that there was a breaking of the quasi-neutral state of the ablation plasma and that an ambipolar electric field (double layer; DL) was generated during the ablation process.

Keywords: laser ablation, double layer, sheath, two-electron temperature, ion acceleration

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Laser ablation plasmas are widely used in a variety of scientific and industrial fields. Although the velocity distribution of ions in the plasma plays an important role for high flux beam sources of charged particles [1, 2] and, plasma applications such as the deposition of thin films and surface treatments, their transient behaviors have not yet been clarified. One of the issues that is yet to be addressed for ablation plasmas is the extraordinary fast drift speed of ions in a vacuum [2, 3].

Along with the acceleration mechanism of these plasmas, the transient process induced by the evolution of ablation plasmas in vacuums is of primary importance. The purpose of this communication, therefore, is to exhibit evidence of the charge flows induced by dynamically evolving plasma. The charge flows to a grounded target were directly measured using a current monitor and a charge collector probe.

A schematic of the experimental set-up is depicted in Fig. 1. A frequency-doubled YAG laser irradiated a solid titanium (Ti) plate with a pulse energy of 115 mJ, a pulse width of 15 nsec, and an irradiation power density of $I_L = 1.3 - 3.0 \times 10^8$ W/cm^2. To measure the charge flow, the Ti target was electrically isolated from the vacuum chamber except for a connection made to the ground by a cable, around which a Rogowskii-type current monitor (R.G.) was placed. Moreover, to change the boundary condition for the plasma plume, a charge collector probe composed of a brass disk with diameter of 10 mm was placed at L = 10 - 200 mm from the Ti plate. The background pressure of the chamber which was made of stainless steel was maintained less than 10^{-3} Pa throughout the experiments.

The typical waveforms of the ion flux of the plasma are shown in Fig. 2. As we can see, they were shifted-Maxwellian, i.e., the ions are composed of fast (drift) and thermal (random) components.

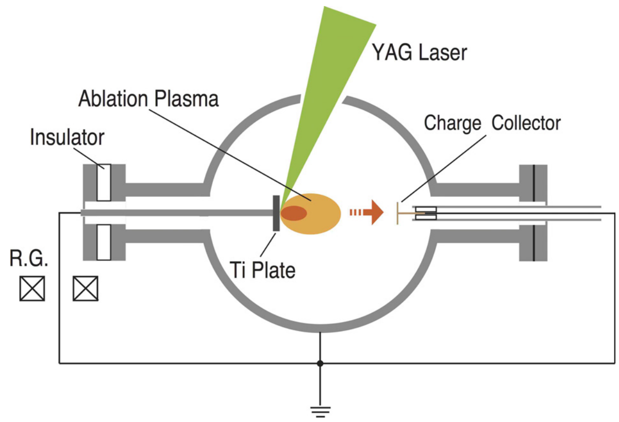

Fig. 1 Schematic of experimental set-up for charge flow experiments.

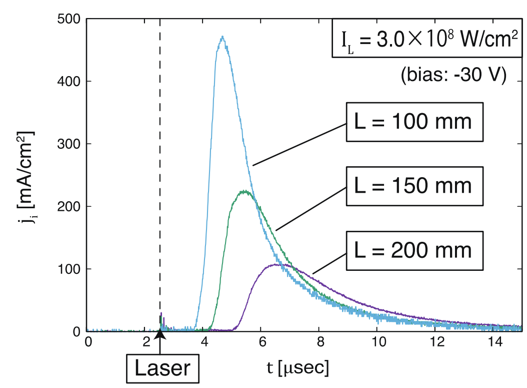

Fig. 2 Typical waveforms of plasma flux made using laser ablation (with a charge collector that was biased to −30 V).

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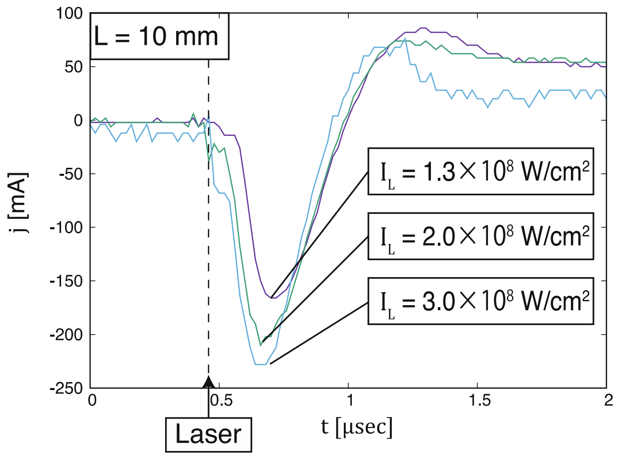

Fig. 3 Current through ablation target to the ground potential.

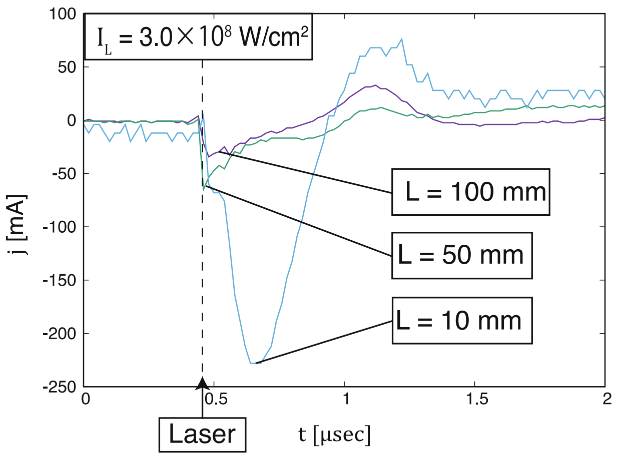

Fig. 4 Dependence of the target-to-ground current on distance L.

According to fluid dynamical theory, the ions can be accelerated up-to the thermal speed at the stagnation state [4]. However, as depicted in Fig. 2, the flux peak was obtained by the collector at L = 150 mm with time-of-flight of 3.3 μsec. Then the ion energy: $(1/2)m_i v_i^2$ corresponding to the flux peak is estimated to be ~520 eV, which was an order of magnitude larger than that predicted by the hydrodynamical acceleration mechanism for this laser irradiation level.

Figure 3 shows the signals obtained from the current monitor. As can be seen, the currents were negative (electron flow from the target) at the initial phase, but after that they were replaced with positive signals (ion flow to the boundary wall). The negative peak increased as the laser intensity increased, whereas the positive current only depended slightly on the laser intensity. The results clearly show that the ablation plume broke quasi-neutrality and the plasma potential fluctuated depending on the evolution of the plume.

To characterize the spatial distribution of the charge flows, we investigated the effects of the conductive boundary on the current signals. We changed the position of the charge collector probe, and measured the dependence of the current waveforms on L. As depicted in Fig. 1, in these measurements, the collector probe was also directly grounded without a connection to the vacuum chamber and the collected charge flux within a narrow solid angle to the target normal. The waveforms are shown in Fig. 4. As shown in the figure, when we decreased L, the current peak increased. These results indicate that the charge flow was induced by the dynamic behavior of the plasma plume. The sharp increase of the first peak was due to the increase in the solid angle of the charge collector. The dependence of the charge flow waveforms on L reflected the dynamically evolving un-isotropic current distribution.

The negative signals were likely due to energetic electrons escaping the plume boundary and the positive signals were probably due to ion flows from the plasma that were induced by the potential hump of the plume [5]. Although a hot electron population is considered to be critical for producing a double layer structure [6], the electrostatic probe measurements indicated that a hot electron component existed in the laser ablation plasma in a manner similar to that found in experiments that had previously been conducted [2]. The absorption of the laser radiation and the rapid expansion in the vacuum right after the absorption, are probably essential to form the energetic electrons and two-electron temperature components in laser ablation plasma.

In the present work, charge flows to the ground potential from the ablation plasma were directly measured using a current monitor. The results reflect the transient structure of the ablation plume, and may corroborate a breaking in the quasi-neutrality of the ablation plume and the effect of energetic electrons on the plasma potential. The results also indicated that not only did the hydro-dynamical mechanism contribute to the acceleration of the fast ions in the plasma but the ambipolar electric field induced in the rapidly expanding ablation plasma did so as well. The goals of this study are to clarify the acceleration mechanism and control the fast ions in the ablation plasma under moderate irradiation levels (10^8 - 10^9 W/cm^2). Those results are useful for high-flux ablation type ion sources, well-controlled thin film deposition processes and the reliable laser triggering of pulsed discharges.

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