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Research on Sheath Formation and Process of Applying Potential to Laser-Ablation Plasma
レーザーアブレーション・プラズマにおけるシース形成と ポテンシャル付与過程の研究

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The potential of laser ablation-plasma can be applied up to 2kV by keeping distance between electrodes and the plasma boundary. The plasma potential is determined by the configurations of an electron current and an ion current flowing from the plasma toward the electrodes. In the experiment, an electron sheath was formed in front of electrodes, and an ion sheath was formed in front of a grounded grid at downstream. The electron sheath contributed to raise and keep the plasma potential near the applied voltage. We investigated the formation processes of the sheath and the potential of drifting plasma.

1. Introduction

Sheath region at surface of plasma is widely recognized, but it holds a mysterious and complicated structure that has not be solved. Since sheaths play an important role to know the interaction between plasma and walls, or for the diagnostic of plasma using probes, it has been studied with simulations and experiments mainly in condition with static plasma [1][2]. On the other hand, a sheath structure of plasma under transient dynamics has been studied little due to its complicated conditions. Also, electron rich sheaths are hardly seen owing to electrons' small mass compared to that of ions.

We have demonstrated a formation of an electron sheath when laser-ablation plasma drifts along with a distant wall. What makes this configuration distinctive is, first the distance between the plasma and the wall which is determined to be much longer than the Debye length, second the separated flow of ions and electrons which are supported by the potential configuration of the device, and third the anisotropic velocity distribution of ablation plasma in which the drifting velocity is much larger than the Bohm velocity.

In this study, relations among the bulk potential of the plasma, the current flow, and the geometrical condition of the device were studied.

2. Sheaths and Current

When plasma is bounded by two walls, ion sheaths are usually formed in front of the walls because electrons are easy to escape and positive charge is left at plasma. However, when the potential of two walls is different and the loss area of electrons is limited, ions can flow toward a wall easier and an electron sheath is created [2]. The potential of plasma here is determined by the balance of an ion current and an electron current flowing between plasma and walls.

Assuming that an ion current and an electron current flow to a different wall that has area A_i and A_e, following equation holds [1].

$$J_\mathrm{i}A_\mathrm{i} \approx J_\mathrm{e}A_\mathrm{e} \tag{1}$$

For static plasma, an ion current and an electron current in the sheath region drift with thermal velocity, which is proportional to $1/\sqrt{m_\mathrm{i}}$ and $1/\sqrt{m_\mathrm{e}}$ using mass $m_\mathrm{i,e}$, assuming that charge density of the two currents is same. Thus A_e should be much smaller than A_i to satisfy Eq.(1). For the drifting plasma, on the other hand, the currents are occasionally dominated by the drift velocity rather than the thermal velocity.

The current flowing toward an electrode with initial velocity can be derived from Poisson's equation [3]. When a current that has an initial velocity v_0 and the kinetic energy $E_0 = m{v_0}^2/2$ flows from one plane with potetntial V_0 at $x = 0$ to the other plane with potential V placed at $x = x$, the current becomes ;

$$J = \frac{4}{9}\varepsilon_0\left(\frac{2q}{m}\right)^{1/2}\frac{1}{x^2}\left(\sqrt{V_0 - V + E_0/q} - \sqrt{E_0/q}\right)\left(\sqrt{V_0 - V + E_0/q} + 2\sqrt{E_0/q}\right)^2. \tag{2}$$

Here, q is a charge in absolute value, and ε_0 is a permittivity in vacuum.

Thus the plasma potential is retained by forming an electron sheath at one wall and an ion sheath at other wall if the electron current is limited to meet Eq.(1), which is determined by the drift velocity toward the electrode, distance from plasma to the electrodes, plasma potential, area of electrodes and mass of the two species.

3. Setup

A frequency doubled Nd:YAG laser (532nm) or a KrF Excimer laser (248nm) was used to produce laser-ablation plasma. The power density was around $10^8 \sim 10^9$ W/cm^2. Under the pressure of ~10^{-4} Pa, laser-ablation plasma was produced from a grounded copper target and drifts through the aligned ring electrodes where voltage up to 2kV is applied. An aperture with radius of 1.0mm or 2.0mm was placed in front of the target to limit the angle of plasma expansion and to change the distance between the plasma boundary and the electrodes. A detailed diagram of electrodes is shown in Fig.1. The ablation plasma drifts toward the grounded grid after it passes through the electrodes. An ion sheath is expected to form around the grid. A Z_0 probe was used to measure the plasma potential [4], and a Rogowski type current probe was used to measure an electron current flowing toward the electrodes.

4. Results and Discussion

Figure 2 shows the difference between the plasma potential and the voltage applied to electrodes (100~2000V). The plasma potential was derived by averaging the value while it showed constant, which was measured with the Z_0 probe. Excimer laser was used, and the radius of the aperture was 2.0mm at this time. As shown, the measured value was 15~35V lower than the applied voltage. Also, we confirmed by the current probe that an electron current was still flowing from the plasma to the electrodes after plasma potential was successfully raised. From these facts, we think that there was a voltage difference between the measured potential and the applied potential due to the formation of electron sheath around the electrodes.

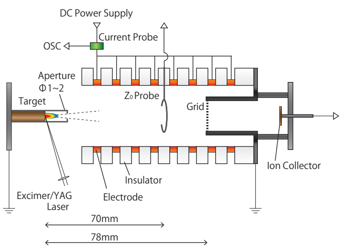

Fig.1. experimental setup

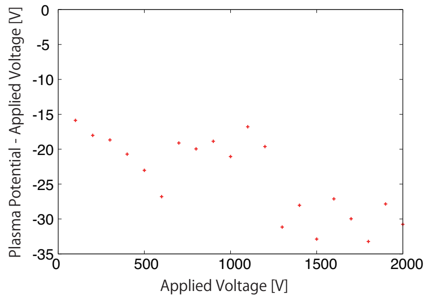

Fig.2. Plot of difference between plasma potential and voltage applied to electrodes.

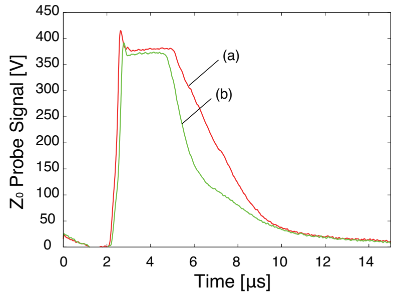

Fig.3. Time evolution of plasma potential when 400V is applied to (a) eight electrodes and (b) four electrodes.

Figure 3 shows the time evolution of plasma potential when 400V was applied to all electrodes, and to four electrodes close to the target. As shown, the potential when applying the bias to four electrodes is lower than when applying it to all electrodes. The result suggests that the plasma potential is correlated to the surface area of electrodes.

Similarly, the distance between the plasma and the electrodes is expected to affect the potential configuration as expected from Eq.(2). In order to investigate this effect, we are planning to measure the potential using 1.0mm aperture.

As discussed above, the potential of laser-ablation plasma is determined by currents flowing from the plasma toward electrodes. An advantage of this device is that it can control the plasma potential easily because of the steady formation of an electron sheath. We think that this method of raising the potential of laser-ablation is not only useful for the study of sheath dynamics but also for the study of ion extraction with grounded extraction grid, without the biased extraction gap.

References

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