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Interaction of Laser Ablation Plasma with Axial Magnetic Field
レーザーアブレーションプラズマと縦磁場との相互作用実験

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We investigated interaction of a laser ablation plasma with an axial magnetic field. The laser was operated continuously for cleaning of the target surface which greatly improved reproducibility of the ablation plasma. A pulsed magnetic coil made a converging-diverging field geometry in front of the ablation plasma. We measured the plasma ion flux through the magnetic field by a Faraday cup as a function of field intensity and the position of the coil. Results of the interaction experiments were shown and the potentiality of the guiding method was discussed based on the experimental results.

1. Introduction

Plasmas made by laser ablation have a lot of advantages; they (1) are reproducible, (2) can make high flux of ions, (3) can be highly ionized, (4) have directivity of motion, namely can be low emittance ion sources, (5) can make a wide variety of ions, and (6) can be made with simple experimental system [1]. Then the laser ablation plasma has a variety of applications. For example, high ion-flux plasma made by laser ablation is one of the candidates for the beam source of Heavy Ion Fusion.

In order to be compatible to high flux and low emittance ion source, an axial magnetic field was applied and a guiding effect was shown [2]. However physics of the ablation plasma interaction with magnetic field is not clarified yet. The drifting plasma expands into a vacuum with a wide range of parameter changes during the expansion. The timescale of interaction and magnetic field strength are also considered to be the effective parameter for interaction. It is considered that there are two different modes for the plasma guiding with magnetic field. One is guiding of plasma by a diamagnetic effect, that is, the magnetic pressure suppresses the expansion and guides the plasma hydrodynamically. The other is collective guiding in which magnetized plasma drifts along the magnetic field line by virtue of the magnetized electrons [3]. Laser-ablation plasma passes through these boundary conditions drastically as it expands and drifts in vacuum. So, appropriate model which uniformly describes the interaction of plasma with magnetic field has not established. We measured the plasma ion flux with parameters changing magnetic field strength, the coil-target distance, and laser-power intensity. The subject of this study is to discuss the physics of interaction between the laser-ablation plasma and a magnetic field using a coil which has a convergent and divergent configuration.

2. Experimental Set up

2.1 *Experimental arrangement*

As explained in introduction, plasma density can be a parameter for the interaction with magnetic field. At the initial phase of laser ablation, the plasma density is almost that of target material. However it decreases rapidly during the expansion in vacuum. So the distance of plasma drift to the coil position can be an important parameter for the interaction. We made an experimental device composed of a guiding tube, so as to continuously change the distance between the target and the coil. This means when magnetic strength is fixed, the coil-target distance is an indicator of the plasma density interacting the magnetic field.

Figure 1 shows a schematic of the experimental arrangement. A frequency doubled Nd:YAG Laser (wave length: 533nm, pulse width :8-10nsec), irradiated the surface of copper cylinder with 130mJ output energy through a lens with focal distance of 3000mm.

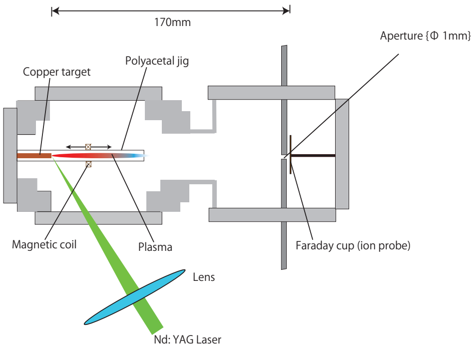

Fig.1. Experimental setup.

The laser was operated continuously with normal mode and 10Hz for cleaning of the target surface. For the flux measurements, a trigger pulse for Q-switching was sent with optimal timing to make the ablation plasma on the target surface.
At the same time, another trigger pulse was sent to the LRC discharge circuit for the formation of pulsed magnetic field. The coil was fixed around the guiding tube, and magnetic field is applied by LRC discharge. Magnetic current decays milli-second order like Fig.2. below. Then, we can regard the magnetic field to be static to the plasma. We measured the ion flux of laser ablation plasma with a Faraday cup placed at 170mm from the target surface.

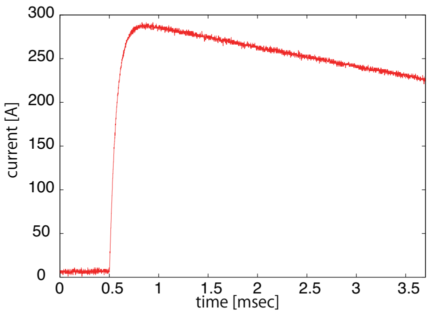

Fig.2. Magnetic current.

2.2 *Reproducibility of ablation plasma*

To discuss the interaction between laser plasma and magnetic field, the plasma flux should be reproducible. As shown in the previous section, we continuously operated the laser for cleaning the target surface. That greatly improved shot-to-shot reproducibility of the ion-flux waveforms. Figure 2 shows waveforms of flux signals overlapped for three shots. As shown in the figure, the waveforms were reproducible within 3% error.

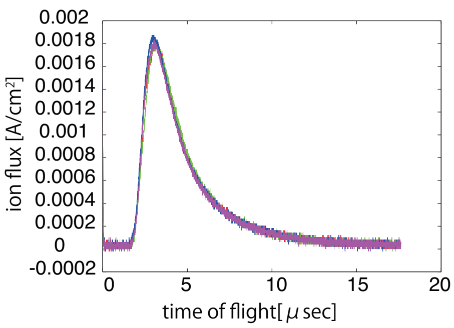

Fig.3. Ion flux waveforms (3 shots overlayed).

2.3 *Magnetic coil for formation of converging-diverging pulsed field*

We used a pulsed coil with 5mm in length for the axial field with converging-diverging configuration. The magnetic field was driven by a current with hundred micro-second rise-time and milli-second decay-time. The reason of pulsed magnet drive is to apply strong magnetic field, and make extremely convergent magnetic field around the surface of copper target by diamagnetic effect.

3. Result

The ion flux was measured as a function of the field strength. Waveforms of the ion flux are shown in Fig.3. As shown in the figure, the waveforms clearly depended on the magnetic field and the flux peak value increased almost proportionally to the magnetic field. However, as shown in the figure, the peak value saturated against the field strength.

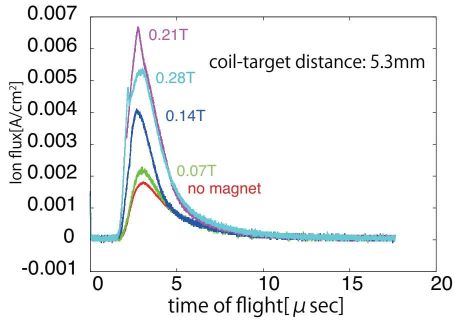

Fig.4. Plasma ion flux with changing field strength (measured at 170mm from the target).

4. Summary

We made interaction experiments between laser ablation plasma and a pulsed magnetic field. The ion flux measured at 170mm from the target clearly depended on the magnetic field. By the field application, the peak of ion-flux increased almost linearly to more than three times. However, the enhancement saturated at a certain value of field strength. Also, the waveform was modified after the saturation. This may-be due to the change of the guiding mode. In order to make clear the guiding mechanism, we are planning to make detailed measurements.

References

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