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Study on Transport of Laser Ablation Plasma with Multicusp Magnetic Field
マルチカスプ磁場によるレーザーアブレーションプラズマ輸送の検討

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We investigated the possibility of the plasma guiding with multicusp magnetic field in order to increase the current and the pulse width of laser ion sources. The ablation plasma was generated by irradiation of a Nd:YAG laser to a copper target and transported in the multicusp field produced with eight neodymium magnets. The ion current density and the pulse width of the plasma were measured as a function of the expanding distance from the target surface w/wo the magnetic field and indicated approximately in inverse and direct proportion to the distance, respectively. The results imply that the ablation plasma is confined with the multicusp field in the transverse direction.

1. Introduction

A laser ion source has potential to provide high current ion beams compared to the other ion sources because laser ablated plasmas have high number density and initial velocity in direction perpendicular to the laser target surface. However, the laser ion source typically has short pulse width. Although we can control the pulse width by extending the drifting distance from the laser target surface, the ion current density decrease drastically due to free expansion when a long pulse beam is required.

To avoid decreasing the current density, guiding of the plasma by applying magnetic fields of 0.01 T produced with a solenoid coil has been examined [1,2]. The results indicated that the current is enhanced. However, plasma confinement in radial direction while the plasma is transported in the magnetic field has not been confirmed.

In this study, we propose to use multicusp magnetic field formed with permanent magnets for confining the plasma during transport. Permanent magnets allow us to produce larger magnetic flux density than 0.1 T easily. To investigate the effect of multicusp field on transporting plasma, we measured the ion current density and the pulse width of laser ablation plasmas as a function of the transport distance w/wo the magnetic field.

2. Experimental setup

Figure 1 shows the experimental setup. A Nd:YAG laser (532 nm wavelength) with 16-18 ns pulse width and 407 mJ pulse energy was irradiated to the copper plate target. The incident angle of the laser is 60 deg from the line perpendicular to the target surface. The laser was focused with a lens and the estimated intensity was order of 10^8 W/cm^2 on the target.

Plasma ion current densities were measured with a Faraday cup biased at -60 V with an aperture of 1 mm. To investigate the time of flight, starting time of plasma expansion was investigated by detecting a laser pulse with a photodiode.

To confine the plasma, magnetic pressure should exceed the plasma pressure. Previous results indicated the number density of the plasma is ~10^{18} m^{-3} after transporting for 300 mm from the target [2]. From this result, the plasma pressure is order of 0.1 Pa assuming temperature of 1 eV. To obtain comparable magnetic pressure with the plasma, the magnetic flux density of 10^{-3} T is required. To generate the larger magnetic field than that, eight neodymium magnets (L300 mm × W10 mm × H3 mm) whose magnetic flux density on the surface is about 0.2 T were located around a drift tube, which has inner diameter of 54 mm, with the diameter of 64 mm. The magnets were located at 250 mm from the target surface.

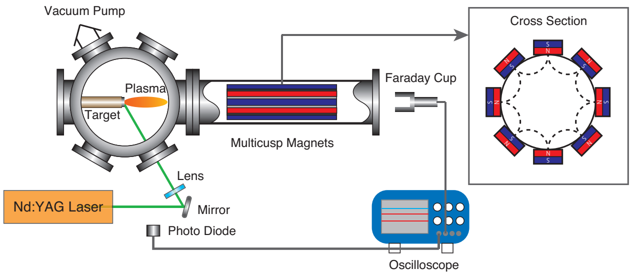

Fig. 1. Schematic of experimental setup using multicusp guiding for ablation plasma transport.

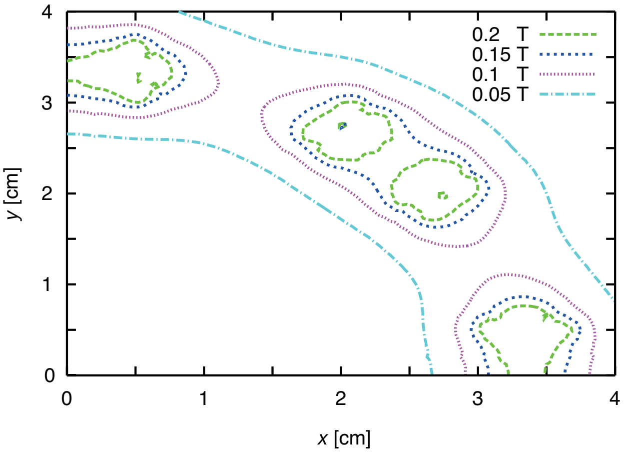

Fig. 2. Distribution of magnetic field shown by contour lines.

The distribution of the magnetic flux density was calculated by Poisson/Superfish, which is an electromagnetic simulation software developed at the Los Alamos National Laboratory, is shown in Fig. 2. This result shows that the magnetic flux in relatively weak region due to the gap of magnets is larger than 0.05 T.

3. Results and discussion

The ion current waveform of the laser ablation plasma indicates shifted-Maxwellian distributions [3]. We evaluated the peak value and the pulse width (FWHM) of the waveform as a function of the distance between the target surface and the Faraday cup.

Figure 3 shows the variation of plasma current density j w/wo the magnetic field. The current waveform measurements were performed in the range of 250 mm to 610 mm from the target with intervals of 20 mm. In the case of no magnet, the decay rate of the current density corresponds to the fitting curve as shown in $j \propto L^{-3}$. On the other hand, the decay rate in the magnetic field, which ranges in 250 mm to 550 mm, approaches the relation of $j \propto L^{-1}$ except for the fringe of the field.

The variation of the pulse width τ is shown in Fig. 4. The pulse width without magnetic field extended with proportional to the drifting distance L as shown by the fitting line $\tau \propto L$. The pulse width in longer distance than 500 mm with the magnetic field does not show extending. However, the tendency of the pulse width with magnetic field is approximately proportional to L. These results imply that the plasma is confined with the multicusp field in the transverse direction.

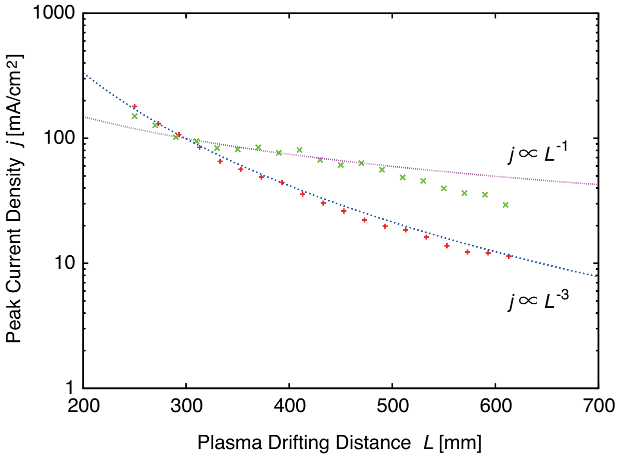

Fig. 3. Plasma ion current density as a function of distance from target surface with magnetic field (green dots) and without magnetic field (red dots).

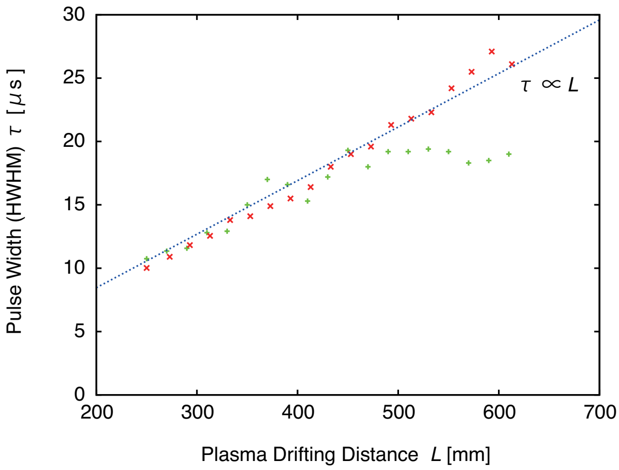

Fig. 4. Pulse width as a function of distance from target surface with magnetic field (green dots) and without magnetic field (red dots).

4. Summary

We investigated the plasma current density and the pulse width as a function of the distance from the target surface. They approach in inverse proportion and direct proportion to the distance, respectively. The results imply that the multicusp magnetic field can confine the ablation plasma in the transverse direction and has potential for developing the laser ion source with high current and a long pulse width.

References

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