Directional Control of Ablation Plasma in a Laser Ion Source Using a Permanent Magnet

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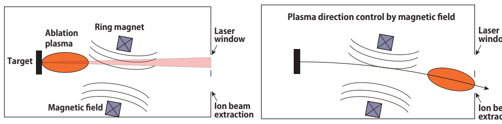
Background and Motivation

In laser ion sources, it has been shown that the maximum ion charge state increases as the laser irradiation angle relative to the target surface approaches normal incidence. However, in practical systems, a plasma transport line for extracting ion beams is typically aligned along the vertical axis of the target, making it difficult to irradiate the target at normal incidence. To solve this issue, we propose a method that controls the directionality of the ablation plasma using a magnetic field, enabling the vertical laser irradiation of the target. Since plasma density decreases with distance from the laser target, we installed a ring-shaped permanent magnet close to the target, slightly offset from the vertical axis, to deflect the plasma while maintaining high density.

Purpose of this research:
Control of ablation plasma using magnetic field

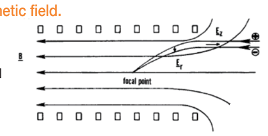


Concept of Ablation Plasma Control by Magnetic Field

- Robertson proposed "collective focusing model" to describe the behavior of neutralized high-intensity ion beams in a solenoidal magnetic field [1].
- The model assumes that the neutralized beam always propagates while maintaining quasi-neutrality.
- Accordingly, the beam particles are regarded as having the effective (center-of-mass) mass of electrons and ions.

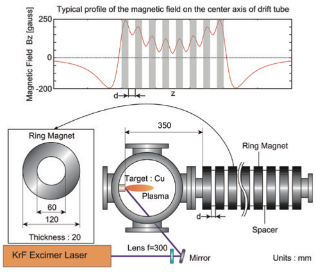
→ This concept is applied to laser ablation plasmas injected into an axisymmetric magnetic field.

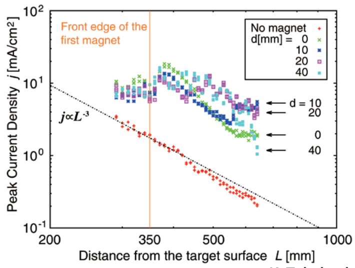
Image of collective focusing [2]



[1] S. Robertson, Phys. Rev. Lett. 48, 149 (1982).
[2] R. Kraft, et al., Phys. Fluids, 30, 245 (1987).

Demonstration of plasma transport using permanent magnets



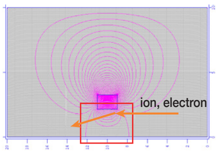


- Plasma transport was attempted with four different magnetic field configurations by varying the spacing between the ring magnets.
- In all configurations, a tendency for the plasma to focus at the entrance of the magnetic field was observed.
- This indicates that plasma focusing can be achieved with ring magnets as well, due to the presence of the radial magnetic field component Br.

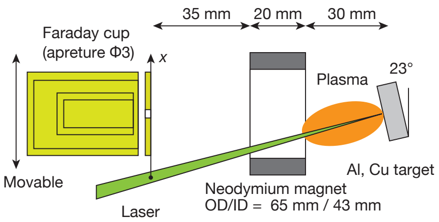
K. Takahashi et al, Plasma Fusion Res., 8, 1206005 (2013)

Experimental Setup

Concept of plasma focusing using a permanent ring magnet



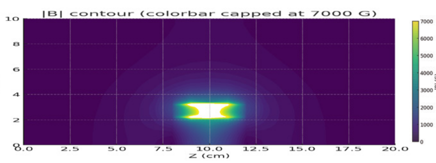
The Br field induced inside the permanenet ring magnet focus the drifting plasma generated by laser ablation.

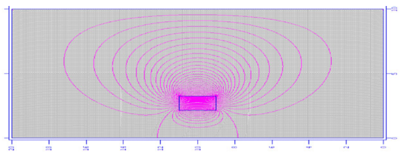


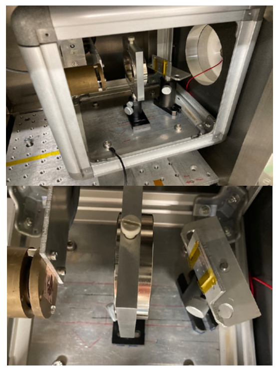
Wavelength: 532 nm
Pulse duration: 17 ns

Energy: 50 mJ
Laser spot: 1 mmΦ

Magnetic field generated by ring magnet

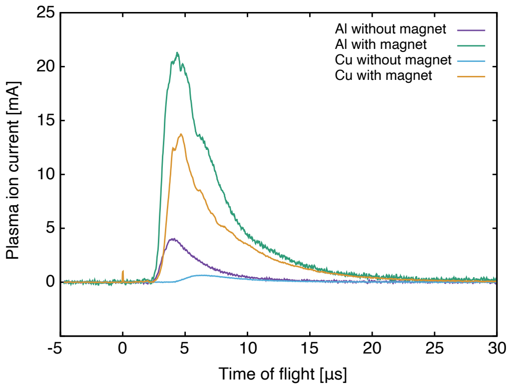




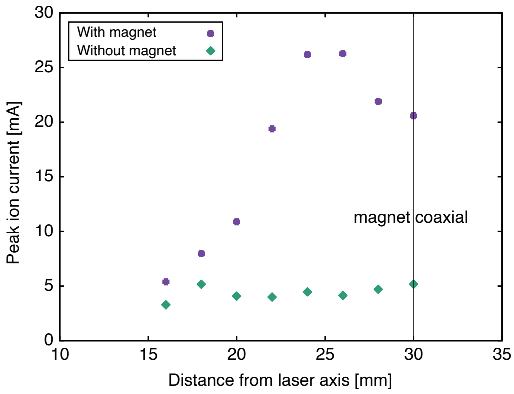


Experimental Results

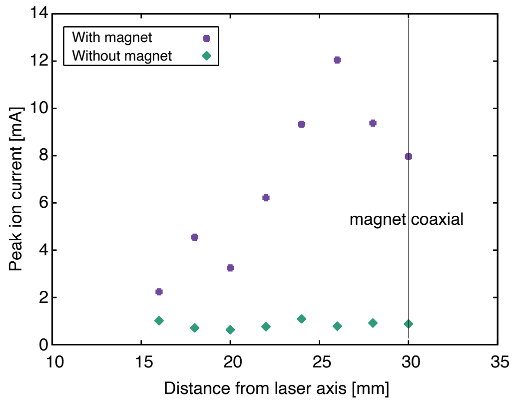
Typical ion current waveforms @ 26 mm from laser axis



Transeverse ion current distribution for Al



Transeverse ion current distribution for Cu



- Current increased with applying magnetic field for both targets.
- Not only bending, but also focusing effect for plasma was shown by magnetic field.

- Without magnets, the ion current distribution showed almost flat profile for both targets.
- By applying magnetic field, the peak in the transverse current distribution appeared near the magnet coaxial line for both targets.

→ Ring magnets guided the plasma to the direction of magnet coaxial line.

Summary

In this study, we propose a method to control the directionality of ablation plasma in laser ion sources using an external magnetic field, aiming to overcome the difficulty of achieving normal laser incidence on the target, which is favorable for producing higher charge states. A ring-shaped permanent magnet was installed near the target, slightly offset from the vertical axis, to guide the plasma toward the magnet's coaxial line while maintaining high density. The results showed that without the magnetic field, the ion current distribution exhibited a nearly flat profile, whereas with the magnetic field, a clear peak appeared near the magnet's coaxial line, indicating effective plasma guidance. Furthermore, the ion current increased for both targets when the magnetic field was applied. These findings demonstrate that ring magnets can serve as an effective approach to control ablation plasma in desired directions.