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Laser plasma in a magnetic field

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DISCLAIMER

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Laser Ion Source (LIS) is a candidate among various heavy ion sources. A high density plasma produced by Nd:YAG laser with drift velocity realizes high current and high charge state ion beams. In order to obtain higher charged particle ions, we had test experiments of LIS with a magnetic field by which a connement effect can make higher charged beams. We measured total current by Faraday Cup (FC) and analyzed charge distribution by Electrostatic Ion Analyzer (EIA). It is shown that the ion beam charge state is higher by a permanent magnet.

PACS numbers:

I. INTRODUCTION

In the Laser Ion Source (LIS), a high current and high charge state ion beam can be provided from a solid target on, which is irradiated by a focused Laser[3, 4]. LIS enables control of the beam pulse length by changing the plasma drift length between a target and an extraction. LIS also controls the charge state by laser power density on the target. However, the laser intensity limits the maximum charge state of the beam. To produce a higher charge state ion beam, we have a test LIS experiment with a permanent magnet. A magnetic field is expected to extend the confinement time of a laser ablation plasma, which is related to the charge state distribution. The experimental results of a charge state distribution by EIA, as well as total current by FC, are presented.

II. EXPERIMENTAL SETUP

A sketch of the experimental setup using a Nd:YAG laser (900 mJ / 7 ns) with a permanent magnet is shown in Figure 1. The wavelength of the laser with the spot size of 17 mm was 1064 nm. During operation, the laser went into the vacuum target chamber through a BK7 window, using flat mirrors in the air. In the target chamber, the laser with the incident angle of 30 degrees to the target, focused on a solid target by a convex lens ($\phi = 25$ mm, $f = 100$ mm). Silver, which was selected as the target material for a typical heavy atom, was perpendicularly-placed to the beam line in the chamber[5]. The vacuum in the beam line was controlled by turbopumps connected with scrollpumps and its residual gas pressure was an order of 10^{-4} Pa for minimizing recombination processes of the ablation plasma.

The permanent magnet that was used in the experiment has a surface magnetic field of 4200 Gauss. To investigate the dependence of a magnetic field on charge state distribution, experiments were conducted with and without the magnet. For the experiments without the magnet, there are two locations of the magnet; 0.5 mm and 2.5 mm from the irradiation surface.

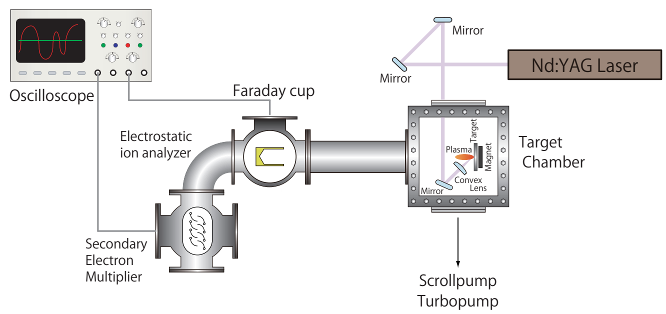

FIG. 1: (Color online). LIS experimental setup with a permanent magnet.

The total plasma current was measured by the Faraday Cup (FC) at 2.38 m from the solid target. The aperture size and suppressor voltage of the FC were 10 mm and - 2 kV, respectively. The ions, which had the proper charge to energy ratio corresponding to the Electrostatic Ion Analyzer (EIA) applied voltage, could go through the EIA. The Secondary Electron Multiplier (SEM) at 3.46 m from the target, detected ions after the EIA. To obtain the signals, FC and SEM were connected with an oscilloscope. The trigger in this experiment was set by a photo diode signal detecting the laser shot.

III. RESULTS AND DISCUSSION

We had three experimental conditions: First, the magnetic field of the irradiation surface was about 4000 Gauss with the magnet at 0.5 mm from it, secondly, the B field strength is about 2600 Gauss at 2.5 mm from it, and then the last is without the magnet. Each experimental condition, total current was measured by the FC and each charge state was analyzed by EIA. By comparing the sum of each charge state signal multiplied by its charge state with total current signal, we obtained the charge distribution and average charge states of the plasma.

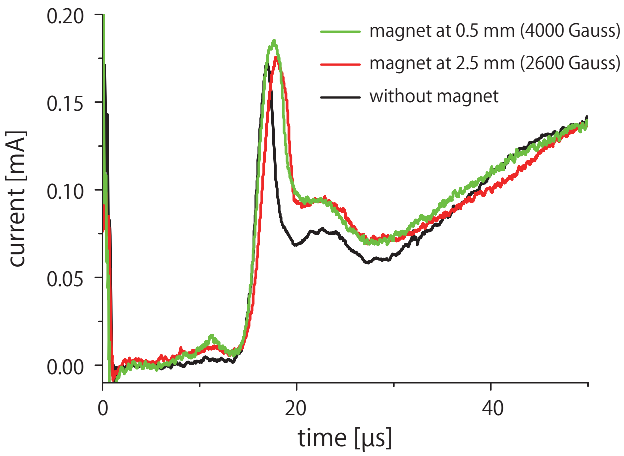

FIG. 2: (Color online). Total current profiles by FC with and without the magnet

A. Total current measurement

The FC at 2.38 m from the solid target with the suppressor voltage of -2 kV, detected total plasma current for the three conditions: 4000, 2600 and 0 Gauss as shown in Figure 2. The trigger signal by the photo diode detecting the laser shot controlled the measurements. In all conditions, there is a sharp peak in less than 20 μs, which is mainly contributed by high charge state ions with fast drift velocity. The contribution of the lower charge states in the current profile becomes larger with time. As seen Figure 2, there is a difference between the experiments with and without the magnet around the sharp peak, this shows that the magnetic field enhances the yield of higher charged ions. Moreover, the pulse length is longer by the magnet.

B. Analysis of charge state separated by EIA

We show three velocity distributions of typical charge states separated by the EIA, in Figure 3, with the magnetic field of 4000 and 2600 Gauss, and without the magnetic field. Figure 3 (a) shows the existence of low charge state Ag^{1+} in a wide time region. Both of the signals with the magnetic fields are slightly larger than that without the magnet.

In Figure 3 (b), which is a distribution of Ag^{4+}, the enhancement of the two signals with the magnet are remarkable. The distribution of high charge state Ag^{7+} also demonstrates the significant difference between with and without the magnetic field in Figure 3 (c). These results show that the magnetic field increases the yield of the ions having higher charge states.

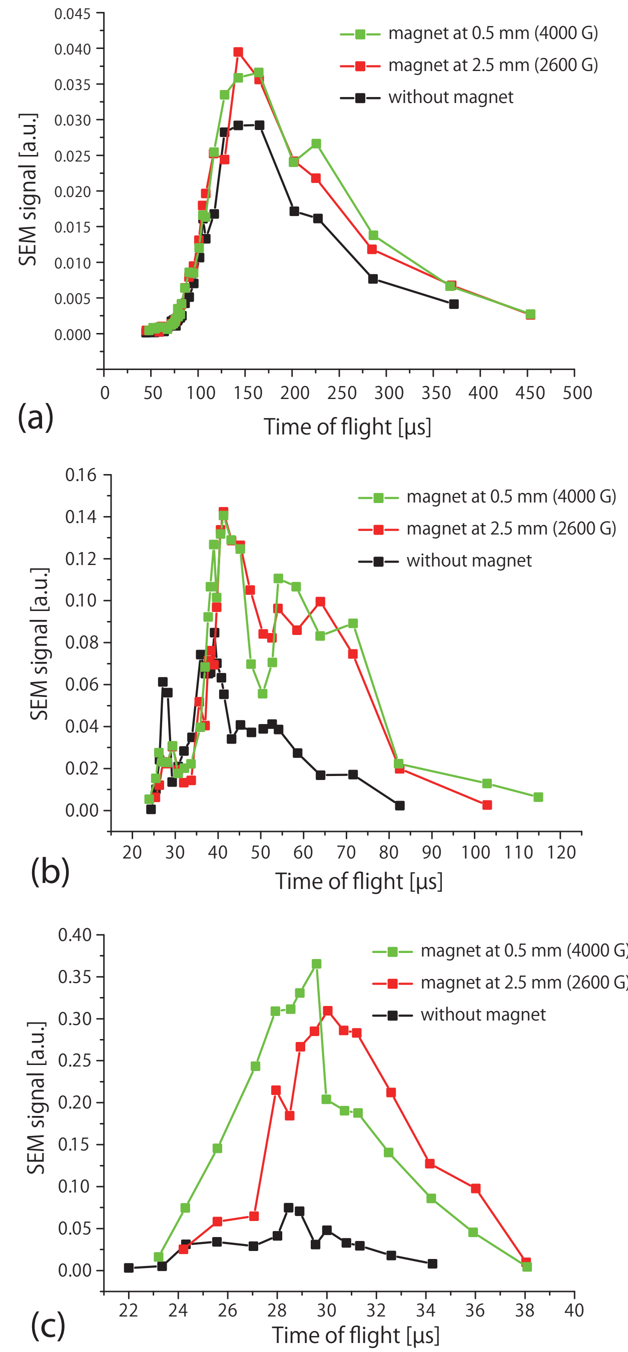

FIG. 3: (Color online). Typical velocity distributions of (a) Ag^{1+}, (b) Ag^{4+}, (c) Ag^{7+} by SEM signals

C. Charge state distribution

The charge state distributions were obtained by comparing the sum of each charge state signal multiplied by its charge state to the FC total current as shown in Figure 4. From the results, average charges of the ablation plasmas also were obtained in Table I. In this experiment, ions did not include the higher charge state ions

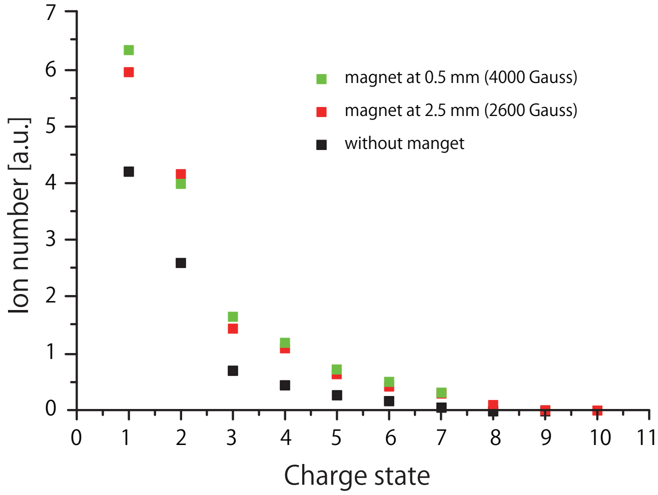

FIG. 4: (Color online). Charge state distribution with and without magnetic field

such as Ag^{15+} and Ag^{16+}, which were observable in the last experiment[5], because the laser rod was damaged.

Figure 4 shows that the magnet increases the yield of ions each charge state. Also, average charge of the plasma is enhanced by the magnetic field shown in Table I. However, we observed unremarkable enhancement of the yield of ions with magnetic field, because the enhancement can be contributed not only by plasma behavior in the magnetic field but also by the magnetic configuration.

TABLE I: Average charge to magnetic strength

Magnetic field [Gauss]	4000	2600	0
Average charge	2.3	2.2	1.9

IV. CONCLUSION

We have conducted an LIS experiments with the inclusion of a permanent magnet behind the irradiated target. The results showed an increase in total beam current and plasma pulse length. An inclusion of a magnetic field has shown to produce higher ion beam charge states.

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