CONFINEMENT OF LASER PLASMA BY SOLENOIDAL FIELD FOR LASER ION SOURCE*

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Abstract

A laser ion source can provide high current, highly charged ions with a simple structure. However, it was not easy to control the ion pulse width. To provide a longer ion beam pulse, the plasma drift length, which is the distance between laser target and extraction point, has to be extended and as a result the plasma is diluted severely. Previously, we applied a solenoid field to prevent reduction of ion density at the extraction point. Although a current enhancement by a solenoid field was observed, plasma behavior after a solenoid magnet was unclear because plasma behavior can be different from usual ion beam dynamics. We measured a transverse ion distribution along the beam axis to understand plasma motion in the presence of a solenoid field.

INTRODUCTION

A laser ion source is an ion source which produces intense plasma by a pulsed high power laser focused onto a solid-state target. Laser-produced plasma adiabatically expands in the direction perpendicular to a target surface. This expansion makes the plasma pulse width longer and the current density lower. The plasma pulse width becomes proportional to a plasma drift distance L and a plasma current density becomes proportional to L^{-3} because the plasma expands three dimensionally. So the pulse width becomes too short when a high peak current is required and a satisfactory amount of ions cannot be produced when a long pulse is required.

A much longer pulse width can be achieved by increasing the plasma drift distance if the expansion in the transverse direction is suppressed. In this case, both ions and electrons should be confined simultaneously so that ions can be transported without space charge effects. This is a distinct advantage of the LIS. Plasma confinement by a solenoid field was tested before and we obtained an enhanced ion current by a factor of forty when a 209 gauss field was applied using singly charged Carbon plasma [1]. Although strong current enhancement was verified at the exit of the solenoid, plasma behavior after the solenoid magnet and effect of fringe field is still unknown because this motion can

Table 2: Transverse position of probe detection point. Probe is aligned vertically along the normal to the beam axis.

Detection points	No.1	No.2	No.3	No.4
Radius [mm]	-29.2	-20.9	-13.2	-5.6
No.5	**No.6**	**No.7**	**No.8**	**No.9**
-0.9	3.0	11.2	18.9	27.0

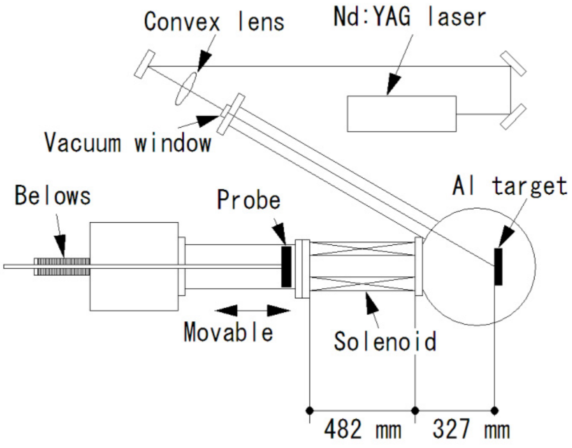

Fig. 1. Schematic view of experimental setup

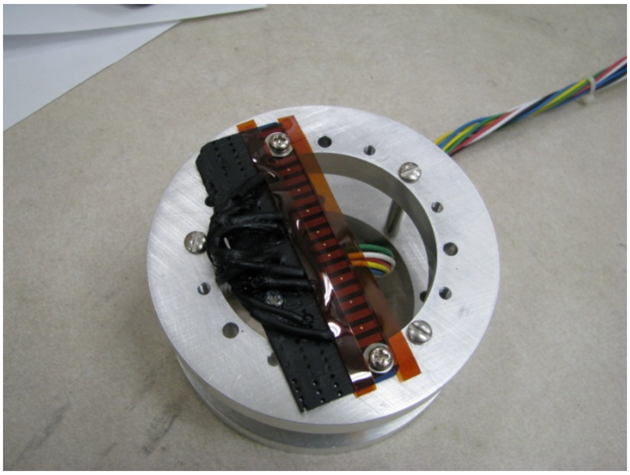

Fig. 2. Probe to be used in the transverse distribution measurement

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be different from usual beam optics. So, we measured a transverse ion distribution along the beam axis after the plasma passed through the solenoid magnet.

EXPERIMENT

Figure 1 shows the schematic of the experimental setup. In this experiment, an Aluminum target and a second harmonics of Nd: YAG laser (wave length of 532 nm) was used. The laser energy and the pulse width were 0.56 J and 6 ns, respectively. A laser light was partially focused by a convex mirror (f = 2500 mm) and the laser spot size was 6.0 mm. The estimated laser power density was 3.5×10^{8} W / cm^{2}, where more than 95 % of ions are singly charged ions based on the previous experiment [2]. We used singly charged ions to understand ion distribution easily. A solenoid magnet which had a length of 482 mm and an inner diameter of 76 mm was placed at a distance of 326.5 mm from the target. We made a special probe shown in Fig. 2 to measure a transverse distribution of ions. This detector had nine detection points of small metal plates along the perpendicular to the beam line. These detection points were masked by an insulation sheet which had nine aperture of 0.75 mm in diameter corresponding to the position of the detection points. Since this probe was several millimeters smaller than the beam line, center of the probe was not the same as the center of the beam pipe. Table 1 shows the measured distance between the detection points and the beam line. The detection plate was biased to -100 V to prevent electrons from hitting the plates during experiment. This probe was able to move 120 mm along the beam axis. The minimal distance between the end of the solenoid magnet and the probe was 22.5 mm.

RESULTS

As the solenoid field was increased from 0 to 154 gauss, the peak current measured at the center of the probe, at 22.5 mm downstream of the solenoid, increased almost linearly, until the current enhancement was saturated at a factor of eight when the solenoid field of more than 154 gauss was applied (Fig. 3). We studied an ion distribution in a transverse direction under the fixed solenoid field of 154 gauss. We used one of the detection points at a same transverse position during experiments because the transverse distribution using all of the detection points on the probe showed good axial symmetrical distribution.

Figure 4 shows the transverse distributions at 22.5 mm, 82.5mm and 142.5 mm from the solenoid magnet, respectively. The transverse distribution at 22.5 mm without the solenoid field is also plotted in this figure. At 22.5 mm from the solenoid, the detected current without the solenoid field was about 60 μA over the detection points. With the solenoid field of 154 gauss, the highest current was measured at the center of the probe and the current decreased at off-center points because of the confinement by the solenoid field. Full

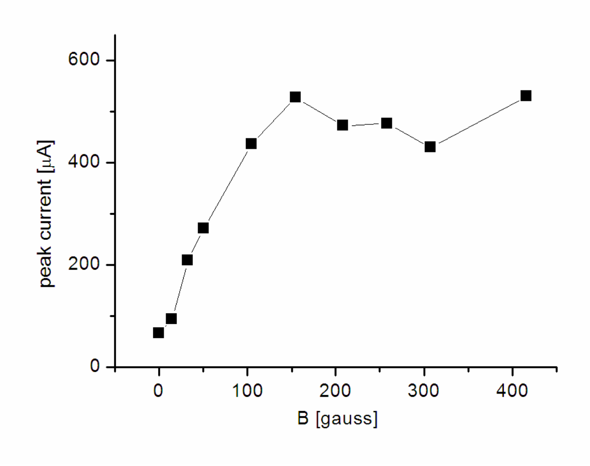

Fig. 3. Solenoid field and peak current at center of probe

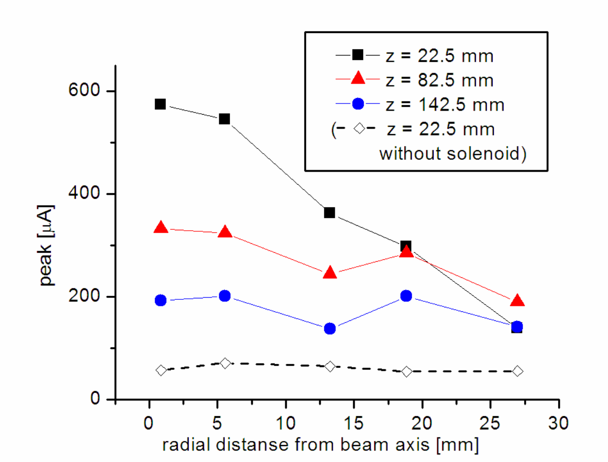

Fig. 4. Transverse ion distribution with solenoid field of 0 and 154 gauss

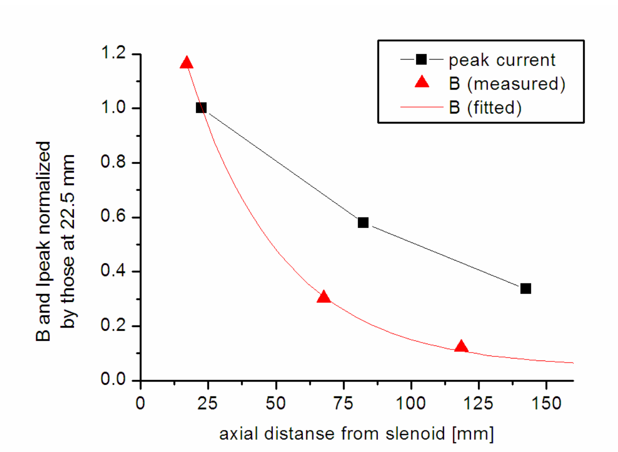

Fig. 5 Solenoid field and peak current at center of probe

width at half maximum of beam was 36 mm. At 82.5 mm and 142.5 mm far from the solenoid magnet, the measured distributions were similar and these were wide and flat transverse distributions. The effect of the solenoid field was clearly observed in all of the measured ranges.

Figure 5 shows the peak current at a radius of 0.9 mm from the beam axis and the measured magnetic field strength at 22.5 mm, 82.5 mm and 142.5 mm far from the solenoid. In this graph, both the peak current and the magnetic field strength are normalized by the value at 22.5 mm from the solenoid magnet, respectively. Although both the peak current and the magnetic field strength were decreased at increases distances from the solenoid, the reduction of the peak current was smaller than that of the magnetic field strength.

DISCUSSION AND CONCLUSION

The enhance factor of eight in this experiment was smaller than forty measured in the previous experiment. This can be explained by the fact that the distance between a target and a solenoid magnet in this experiment (326.5 mm) was longer than that in the previous experiment (295 mm). The increased distance of the solenoid allowed the plasma to expand longer and as a result, the amount of plasma that was captured by the solenoid field decreased. This result indicates that the effect of the solenoid field is strongly related to the position of the solenoid magnet to the target. The role of distance between the target and the solenoid magnet should be investigated to optimize performance of solenoid confinement.

Based on time of flight of ions, kinetic energy of electrons was estimated up to 0.03 eV. Even if electron motion is perpendicular to the magnetic field line, Larmor radius at 154 gauss is about 40 μm. So we can say electrons travel along the field line. Note that there is a possibility that electrons are influences by ion potential.

However, as mentioned above, it was found that the reduction of the peak current was smaller than that of the magnetic field strength. This indicates that ions are not travelling along the fringe field of the solenoid because ion current became proportional to the magnetic field strength in case ions travel along the fringe field. It can be said that ions are partially attracted to electron.

We confirmed that the strong effect of the solenoid field exists within 27 mm in the transverse direction and 142.5 mm in the longitudinal direction from the beam axis. We will continue to try to understand the behavior of laser-produced plasma confined by the solenoid in order to upgrade the performance of the laser ion source.

REFERENCES

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