GENERATION OF HIGHLY-CHARGED CARBON IONS FROM THIN FOIL TARGET

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Abstract

Generation of highly-charged heavy ions such as fully stripped C^{6+} of more than hundreds mA of beam current can be possible only with a laser ablation ion source (LIS). Heavy ions are produced from a solid target irradiated by a pulsed high power laser. Recent study showed that only sub-micron range of surface layer contributes for the generation of highly-charged heavy ions. In this paper, we experimentally investigated the difference of the performance of highly-charged carbon ion production from graphite targets of different thickness (25, 70, 254, and 3000 μm) to seek the possibility of a rolled target to overcome the limitation of a target lifetime.

INTRODUCTION

A laser ablation ion source (LIS) is a pulsed high current heavy ion source of more than hundreds mA of beam current. Heavy ions are produced from a solid target irradiated by a pulsed high power laser. The charge state distribution of a laser ablation plasma depends mainly on the laser power density on a target. Typically more than 1E11 W/cm^2 is required to generate highly-charged ions, and higher laser power density generates higher charge state of ions. By decreasing the laser power density to the range of 1E8 W/cm^2, which is just slightly higher than that of the threshold of plasma generation, the charge state distribution becomes 1+ dominant. Laser produced plasma has an initial expansion velocity toward the normal direction of a target surface. As the plasma expands, ion peak current decreases proportional to L^{-3}, and the pulse width increases proportional to L, where L is the distance from a target [1]. Ions are extracted after the plasma is expanded to have a required pulse width. A solenoid magnetic field is applied on a plasma drifting region to transversely confine the expanding plasma. Because the ion current at ion extraction point is too high such as more than hundreds mA in case of high current beam operation, it is impossible to transport and focus the extracted beam in a low energy transport line before a Radio Frequency Quadrupole accelerator (RFQ). A so-called direct plasma injection scheme (DPIS) is a scheme to capture and accelerate such ion beam by a RFQ, where laser produced plasma is extracted between RFQ electrodes and a plasma transport pipe [2, 3, 4]. Because a crater is made after each laser shot for highly-charged ion production, the positon of target or laser spot must be moved at least by the size of a crater to provide a fresh surface of a target to generate stable plasma. A thick bulk target typically more than 1 mm has been used as a laser irradiation target. The target life time is limited to the area of a target, which could be a problem for a thick target for high-repetition-rate operation though low-repetition-rate operation can be managed by optimizing a target scanning scheme. However, previous studies showed that only the target depth between 500 nm to 1000 nm contributes the generation of highly-charged ions [5, 6]. If we can reduce the target thickness, the use of a rolled target could be possible and the problem on the life time will be solved. We experimentally measured the charge state distribution of carbon ions generated from different thickness of graphite targets (25 μm, 70 μm, and 254 μm) and the result was compared with that with a bulky 3-mm-thick target.

Table 1: Laser Parameters

Model	Quantel laser Brilliant B (Nd:YAG laser)
Wave length	1064 nm
Maximum energy	850 mJ
Energy on target	230 mJ
Pulse width	6 ns
Power density on target	~1E12 W/cm^2

EXPERIMENTAL SETUP

We used a Nd:YAG laser (Quantel laser Brilliant B, max. 850 mJ / 6 ns). Table 1 summarizes the laser properties. Laser light is focused by a f = 100 mm plano-convex lens in vacuum on a graphite target. The lens is mounted on a holder connected to a linear feedthrough to change the focal distance without breaking vacuum. Aluminium shielding with a hole for the laser to path through is placed between a final mirror and the lens to protect the mirror in vacuum from debris produced by a laser ablation. The incident angle of the laser is 20 degrees. The laser energy on the target was 230 mJ, and the estimated laser power density was 1.2E12 W/cm^2. The graphite target is mounted on a 2D linear stage to provide a fresh surface at each laser shot. The graphite target was aligned not to change the longitudinal position more than 0.2 mm within the area used in each experiment measured

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by a laser displacement sensor. Typical pressure in the target chamber was 1E-4 Pa. A faraday cup (FC) which has a mesh biased at -5kV is located at 2.4 m from the target and is used to measure total current of ions. An electrostatic ion analyser (EIA) separates ions according to the charge-to-mass ratio, and ions are detected by a secondary electron multiplier (SEM, HAMAMATSU R2362) biased at -3.5 kV. Time structure of each charge state of ions is obtained by scanning deflector voltages of the EIA. We assumed that the SEM gain is constant for all charge states for data analysis. We used the same method described in [1] to analyse the data. Figure 1 shows the experimental set up.

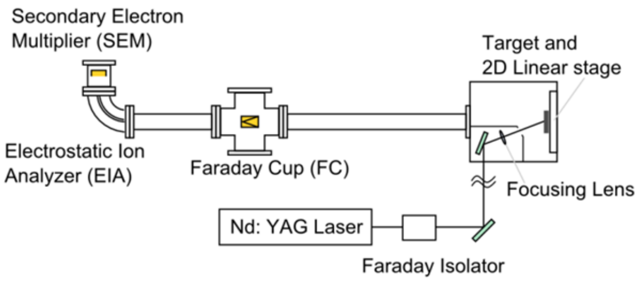

Figure 1: Experimental setup.

RESULTS AND DISCUSSION

Figure 2 shows FC signals of different thickness of graphite target. This is an averaged signal over 20 shots. Time structure of the signals is almost same for all thicknesses. The difference of peak current could be caused by the difference of the condition of the set up because the signal of a 3000-mm-thick target and that of a 25-µm-thick target were very close. The position of the lens was searched for every thickness to obtain the fastest FC signal, which is an indication of the highest plasma temperature. Note that FC signals were stable for each thickness as similar to that shown in Fig. 3.

Figure 4 shows the charge state distribution of C^{6+} and C^{4+} scaled to 1 m far from the target and 1 cm^2 of aperture using the relationship between a distance from a target and ion current and pulse width described before. There was no major difference of charge state distributions of highly-charged ions. This indicates that the laser produced plasma from different thickness of targets has the same plasma temperature. There is no degradation of the performance for highly-charged ion production between the target thicknesses from 25 to 3000 µm. It is feasible to use a rolled target of this thickness range. The use of thinner thickness could be possible. A rolled target system which is durable as an operational target and a mechanism to keep the variation of the distance between a focusing lens and a target surface less than 0.2 mm needs to be developed.

Figure 5 shows the charge state distribution of all charge states from the 25-µm-thick graphite target scaled at 1 m and 1 cm^2 aperture. The ratio of number of ions of C^{6+} ions was estimated as 46 %. This plot is a basis to design a LIS. Ion beam properties of each charge state of

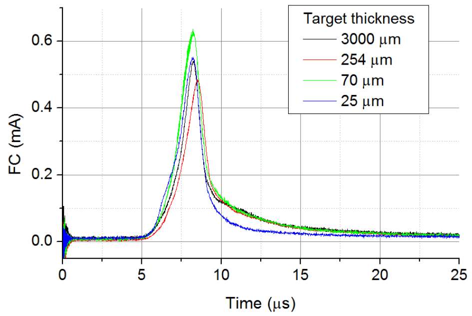

Figure 2: FC signals of different thickness of graphite target. This is an averaged signal over 20 shots.

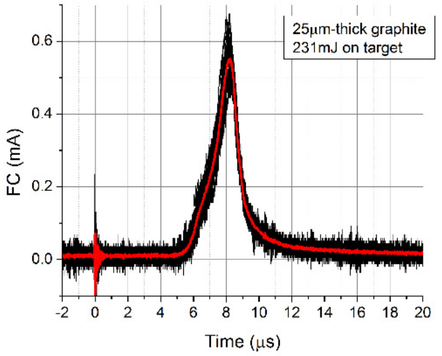

Figure 3: 20 shots of FC signals plotted together (black), and an averaged wave form of those (red).

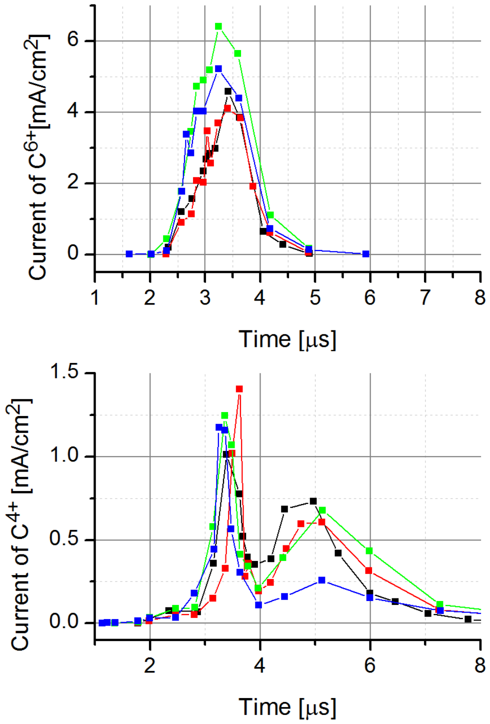

Figure 4: Charge state distribution of C^{6+} and C^{4+} scaled to 1 m far from the target and 1 cm^2 of aperture.

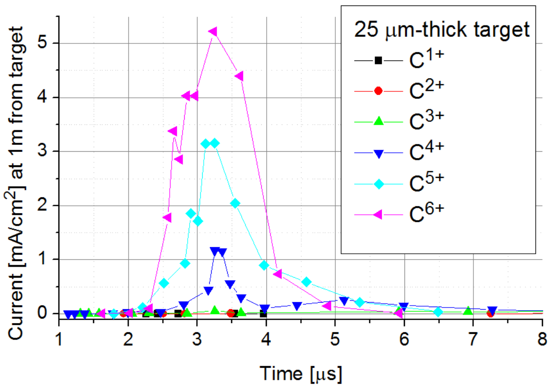

Figure 5: Charge state distribution of carbon ions scaled to 1 m far from the target and 1 cm^2 of aperture generated from a 25-μm-thick graphite.

ions at a given extraction condition can be derived using the scaling mentioned above.

Figure 6 shows craters on the targets after the experiment. Each crater is made by one laser shot. The laser spots are separated by 1 mm except for the 3000-µm-thick target, where the spots are separated by 0.5 mm. The 70-µm-thick and 25-µm-thick targets were fully penetrated. The main crater size was almost same for all thicknesses, but the damage on the surrounding area was small for the 25-µm-thick target. The size of the main crater was about 1.8 mm in diameter based on the 25-µm-thick target.

CONCLUSION

We experimentally investigated the difference of the performance of highly-charged carbon ion production from graphite targets of different thickness (25, 70, 254 µm, and 3000 µm). No degradation was observed for highly-charged ion production within the tested range of thicknesses. We found that there is no problem to use a rolled thin sheet target, which can solve the limitation of the target life.

ACKNOWLEDGMENT

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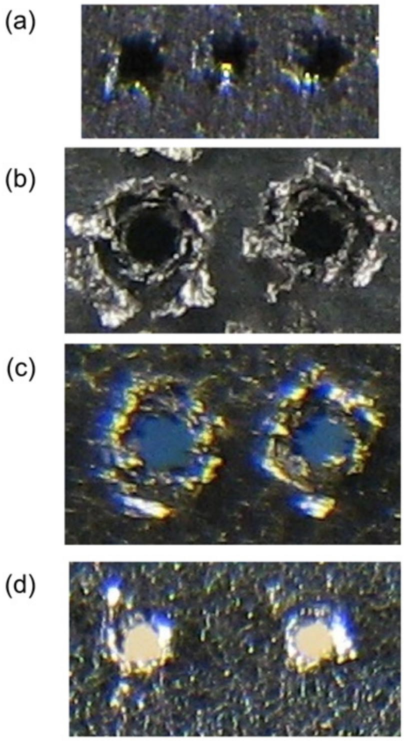

Figure 6: Craters on the targets after laser irradiation. The thicknesses of the target are (a) 3000µm, (b) 254µm, (c) 70µm, and (d) 25µm. The crater is made by one laser shot.

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