ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPML070

LASER ABLATION PLASMA WITH SOLENOID FIELD CONFINEMENT*

G.C. Wang[1], H.Y. Zhao†, Q.Y. Jin, J.J. Zhang, X.Zh. Zhang, L.T. Sun, H.W. Zhao,
Institute of Modern Physics, 509 Nanchang Road, Lanzhou 730000, China
[1]also at University of Chinese Academy of Sciences, Beijing 100049, China

Abstract

A Laser Ion Source (LIS) can produce high charge state and high intensity ion beams (~emA), especially refractory metallic ion beams, which makes it a promising candidate as an ion source for heavy ion cancer therapy facilities and future accelerator complexes, where pulsed high intensity and high charged heavy ion beams are required. However, it is difficult for LIS to obtain a long pulse width while ensuring high current intensity, thus limiting the application of LIS. To solve the conflict, magnetic fields are proposed to confine the expansion of the laser produced plasma. With a solenoid along the normal direction to the target surface, the lateral adiabatic expansion of the laser ablation plasma is suppressed which extends the pulse width of the ion beam effectively.

INTRODUCTION

Since the idea to use laser produced plasma as a source of ions for particle accelerators was first proposed by Peacock and Pease1 in 1969[1], the research activities on laser ion sources had been carried out in many laboratories around the world. The capability of laser ion sources (LIS) to produce high charge state and high intensity ion beams (several ~emA), especially the refractory metallic ion beams, make them promising candidates as the ion sources for heavy ion cancer therapy facilities and future accelerator complexes. For example, in the High Intensity heavy-ion Accelerator Facility (HIAF) project, tens of emA highly charged heavy ion beams with about 10 µs pulse duration are required[2]. However, the beam transportation, stability and short beam pulse problems limit the application of LIS. In 2000s, direct plasma injection scheme (DPIS) was proposed by Okamura[3], which improves the transmission efficiency of LIS to the largest extent. With the precise control of the target and the use of solid-state lasers, the stability of LIS is no longer an issue. Then, it is a key development for the LIS to extend its pulse width.

As the plasma expands, ion current density j decreases proportionally to L^{-3}, and the pulse width increases proportionally to L, where L means the drift distance from the target.[4]

So it is impossible to obtain both long pulse width and high current density at the same time without introducing external constraints. For this reason, the solenoid magnetic field is applied.

With a longitudinal solenoid magnetic field to the drifting part of LIS, the lateral adiabatic expansion of laser ablation plasma is suppressed. So we can extend the pulse width while maintain a high current.

* Work supported by NSFC
† email address: zhaohy@impcas.ac.cn

EXPERIMENTAL APPRATUS

The layout of the experimental setup is shown in Fig. 1. The LIS system is mainly composed of four parts: a laser system (including laser transport line), target chamber, plasma drifting tube, and ion beam diagnostic devices (a Faraday cup (FC) and Time-of-Flight (TOF) spectrometer). The TOF spectrometer consists of a 90°cylindrical electrostatic ion analyser (EIA) and an electron multiplier tube (EMT).

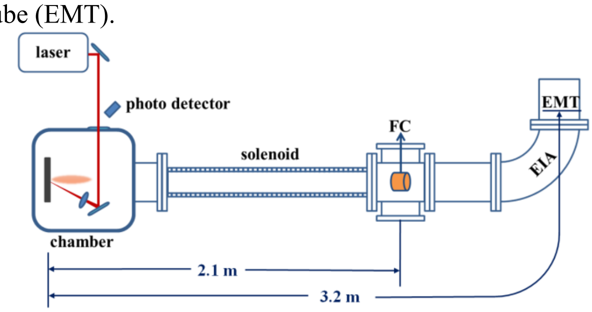


Figure 1: Layout of LIS.

The main parameters of the laser system are listed in Table 1. The laser beam is transmitted for several meters in air by several high reflection flat mirrors and finally focused at 20°incidence angle by a convex lens with a focal length of 100 mm onto the target. With the setup, the laser power density at the focal spot is estimated at around 10^{13} Wcm^{-2}. After each laser shot, a fresh target surface will be supplied by a three-dimensional target manipulation system.

Table 1: The Main Parameters of Laser System

Laser type	Q-switched Nd: YAG
Wavelength	1064nm
Energy	8J
Pulse duration	8-18ns
Divergence	<1m rad
Energy stability	<1%

The target chamber and the diagnostic equipment were evacuated to about 10^{-4} Pa and 10^{-5} Pa.

In order to measure the total current intensity and time structure of the laser produced ion pulses, a movable Faraday cup (FC) with an entrance aperture of 3 mm was located normally to the target surface at a distance of 2.1 m from the target. A meshed suppressor with a transmission of about 70% was installed in front of the Faraday cup. The all current measurements presented here were carried out with a suppressor potential of −2.5 kV, and the

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPML070

current intensities have been calibrated by the mesh transmission of 70%.

The EIA was installed for measuring the charge state and energy distribution. More detailed description of the EIA is presented in Ref[5]. The widths of the input and output slits of the EIA were set as 0.1 and 0.2 mm, respectively. The EMT was used for getting detectable signals. During the evaluations of the charge state distribution presented in this paper, we assume that the Secondary Electron Emission (SEE) coefficient is proportional to the charge state Z, while ignoring the dependence on the ion energy, in which way the yields of the highly charged ions might be underestimated.

The solenoid with inner diameter of 76mm and a length of 1377mm has 5256 turns with 8 layers of copper wire of 2.1 mm diameter. It can give a magnetic field of 47gauss/ampere at the centre of the solenoid.

EXPERIMENT RESULTS

Ion Pulses Measured with FC

The carbon ion pulses measured by the FC with different solenoid magnetic field are shown in Figure 2. It's obvious that the pulse duration is extended and the current intensity is enhanced with magnetic field.

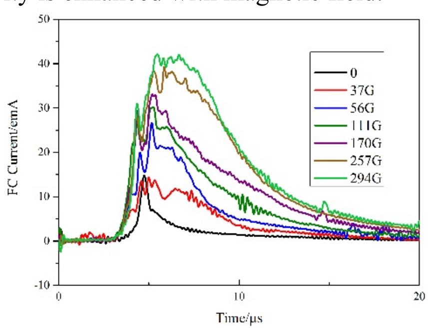
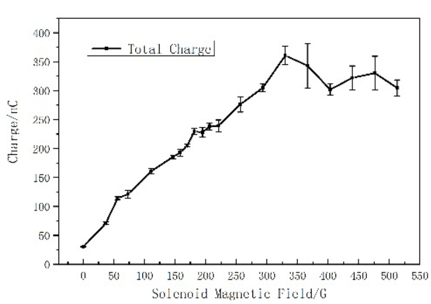
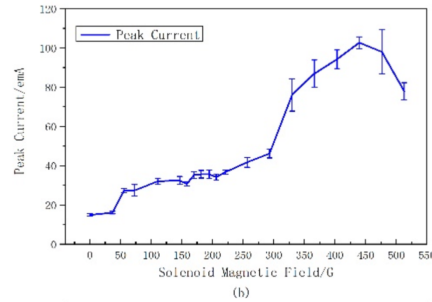


Figure 2: Waveform of carbon ion pulses with different B-fields.

The total charge quantity, peak current and full width of half maximum (FWHM) of the ion pulse are shown in Fig. 3. Each plot presented here is the averaged result of five laser shots with the exactly same experimental conditions.





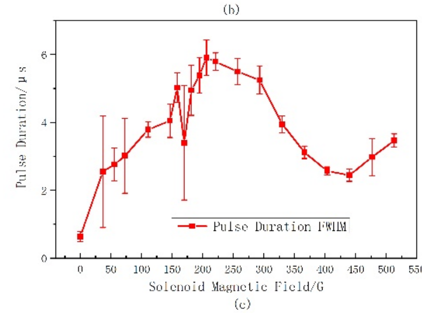


Figure 3: Evolution of total charge(a), peak current(b) and FWHM(c) of ion pulse with B-field.

The results showed that the total charge and peak current increase with the magnetic field and then becomes saturated. The FWHM of carbon ion pulse was maximized at 221G, which is about 9 times longer than the result without magnetic field.

Charge State Distribution

The charge states distribution of the carbon beam was measured by the TOF spectrometer. Compared with Fig. 4 and Fig. 5, we know the waveform of C ion pulses with different charge state is influenced by the magnetic field.

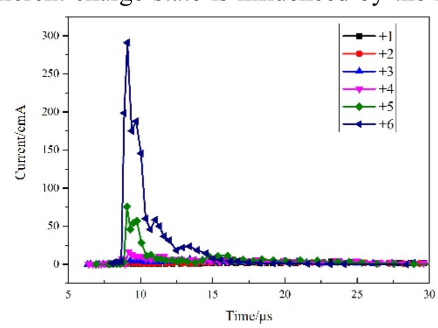


Figure 4: Waveform of C ion pulses with different Z and without solenoid.

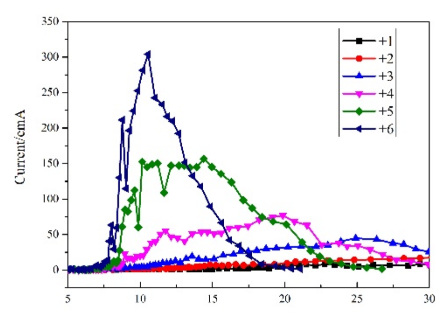


Figure 5: Waveform of C ion pulses with different Z and with 147G magnetic field.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPML070

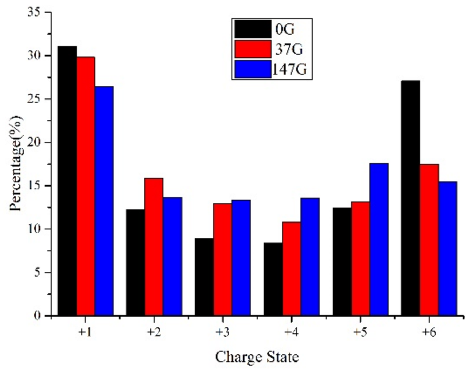


Figure 6: Charge state distribution of C ions with and without solenoid magnetic field.

Compared with the result of without magnetic field, the introduction of solenoid magnetic field increases the yield of each charge state. However, the percentage of C^{6+} is decreased with the increasing of B-field (see Fig.6). According to the experimental results, the magnetic field can be optimized for a specific charge state.

Repeatability Test for Carbon Ion Current

In order to investigate the reliability of the laser ion source with the solenoid magnetic field, we measured the carbon ion pulses with the FC for 1000 laser shots with 170G magnetic field. The test results are presented in Figure 7.

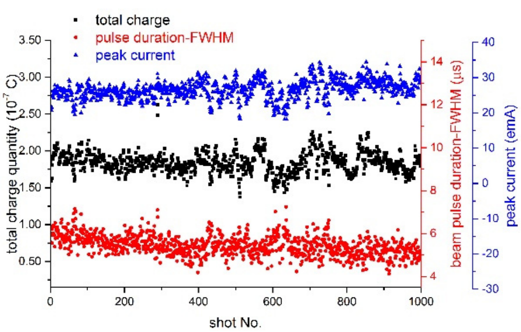


Figure 7: Shot-to-shot reproducibility of C ion pulses for 1000 laser shots with 170G magnetic field.

The standard deviation of each parameter is less than 11.9% without the magnetic field.[6] When the B-field is added, the result is 10%. So, the reproducibility of LIS is not affected by solenoid magnetic field.

The transverse distribution of the C ion beam

The transverse distribution of the ion beam was observed by moving the Faraday cup. The FC was moved from the central positon to the outer edge with the step of 3mm.

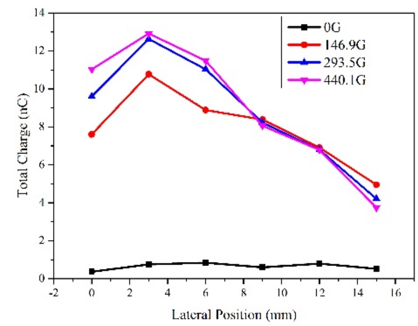


Figure 8: Total charge quantities at different radial position for different B-field.

The Fig. 8 shows that the total charge quantity of the ion beam at different radial position is almost constant without B-field. However, the magnetic field of solenoid changed the transverse distribution of the carbon ion beam. It seems like the plasma density is converged to the middle of the radius under the influence of B-field.

DISCUSSION AND CONCLUSIONS

With the influence of solenoid magnetic field, the pulse width of the C-beam increases by about 9 times. The total charge and peak current increase with the magnetic field and then becomes saturated. The magnetic field of the solenoid changes the lateral distribution of the laser ablation plasma. And it is possible to optimize the yield of a specific charge state by controlling the magnetic field. In addition, the introduction of a medium magnetic confinement seems to have no effect on the stability of LIS.

ACKNOWLEDGEMENT

This work is supported by National Natural Science Foundation of China (Grant Nos. 11722547, 11605263 and 11505257) and West Light Foundation of The Chinese Academy of Sciences (Grant Nos. 29Y637020).

REFERENCES

[1] Peacock, N. J.*et al*,. "Sources of Highly Stripped Ions", *Journal of Physics D-Applied Physics*, 2, 1969
[2] Zhao, H. Y. *et al*,. "New development of laser ion source for highly charged ion beam production at Institute of Modern Physics", *Review of Scientific Instruments*,87,Feb 2016.
[3] Okamura, M. *et al.,* "Direct plasma injection scheme in accelerators (invited)", *Review of Scientific Instruments*, 79, Feb 2008.
[4] Kondo, K. *et al.* "Laser ion source with solenoid for Brookhaven National Laboratory-electron beam ion source",*Review of Scientific Instruments*,83,Feb 2012.
[5] Jin, Q. Y. *et al.* "Study on space charge effect in an electrostatic ion analyzer applied to measure laser produced ions", *Review of Scientific Instruments*,Vol. 85, Mar 2014.
[6] Zhao, H. Y. *et al.* "The study towards high intensity high charge state laser ion sources", *Review of Scientific Instruments*, Vol. 85, 2014.