

SLANTED BEAM EXTRACTION ON LASER ION SOURCE*

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Abstract

We experimentally verify how performance is achieved when the direction of the extraction field is at an angle to the direction of motion of the plasma in a laser ion source. If the extraction field can be slanted without degradation of the ion source performance, it is considered to be able to shield neutral vapours and debris generated simultaneously with the plasma, which will be advantageous for the long-term operation of the laser ion source. Also, the layout of the laser ion source can be more flexible, since the long plasma drift section occupies a space at the very highly populated equipment area. The effect of the angle of the extraction surface on the beam current is greater than a simple angular reduction in the extraction area. However, an angle of up to about 25 degrees is acceptable in practical use.

INTRODUCTION

The laser ion source is a pulsed ion source capable of delivering a high current beam with low emittance. The laser beam is irradiated onto the surface of a solid target to generate an ablation plasma. This plasma is directed perpendicular to the target surface. At the same time, it diverges isotropically. The pulse length of the ion beam is determined by the time it takes for this expanded plasma to pass through the beam extraction electrodes of the ion source. Therefore, to obtain a long pulse, the plasma must be flown over a long distance. Also, flying over a longer distance means that the plasma has a longer time to expand isotropically, and thus the density of the plasma reaching the extraction zone becomes thinner. To mitigate this degradation of the plasma density, modern laser-ion sources use a long solenoid with a weak magnetic field[1]. Therefore, the solenoid occupies a large space of the laser-ion source.

Since 2014, at Brookhaven National Laboratory, we have been using a laser-ion source to generate ions at the beginning of the Hadron Accelerator Facility. This device is called LION. The solenoid of the LION that generates a few tens of gauss magnetic fields is 3 meters long. The distance used for this long expansion results in a pulse width of several hundred microseconds for the beam delivered to the EBIS charge breeder in the succeeding stage[2]. The solenoid magnetic field suppresses the isotropic expansion and can deliver beams in the submilliampere class.

Modern laser-ion sources require a large straight space at the front end of the real accelerator chain because the long solenoid limits the layout. Therefore, in this study, the

solenoids were placed at an angle from the beam direction and experimentally verified that the performance of the source is not compromised. Normally, the plasma moves with constant velocity from the laser target to the extraction section at a velocity of several to several hundred electron volts, and the extraction voltage is applied without changing the direction of travel. However, when an angled extraction field is applied to the plasma velocity, the effect on emittance is expected to be limited if the extraction voltage is clearly greater than the plasma's flight velocity. A further complication is the solenoid magnetic field. It is usually weak, a few hundred gauss at most, so its contribution to emittance increase is almost negligible, but if it is angled, experimental verification is required.

EXPERIMENTAL SETUP

The laser was a Thales SAGA 230 and was set to produce mainly single charge state. The targets used were aluminium and tantalum. The laser power densities were estimated as 4.2E8 W/cm² and 5.0E8 W/cm² respectively and incident angle of the laser path was 30 degree. The laser parameters are summarized in Table 1. To obtain table beam, three hundred laser shots were applied before taking the data and possible impurities were minimized. Geometric information for the solenoid is listed in Table 2. The beam current measurement was done by a Faraday cup with a -3.5 kV bias mesh that represents an ion extraction electric field. Figure 1 shows how the Faraday cup was mounted. The cup was supported by a rotatable rod and can be swung without changing the aperture position. The cup was placed 103 mm downstream of the solenoid edge. The entire setup photo is shown in Fig. 2.

Table 1: Laser Parameters

Wavelength	1064 nm
Pulse width	6 ns
Energy for aluminium	550 mJ
Energy for tantalum	760 mJ

Table 2: Solenoid Geometries

Vacuum pipe ID	102 mm
Solenoid ID	114 mm
Number of layers	9
Length	1980 mm
Wire diameter	2 mm
From Target to entrance	312 mm
To FC from exit	103 mm

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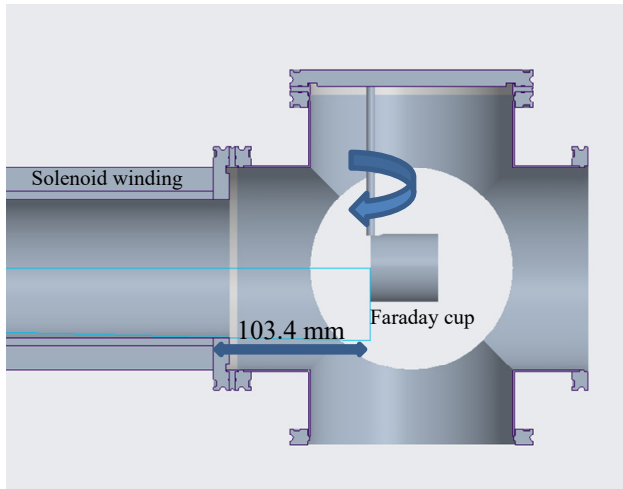


Figure 1: Faraday cup position.

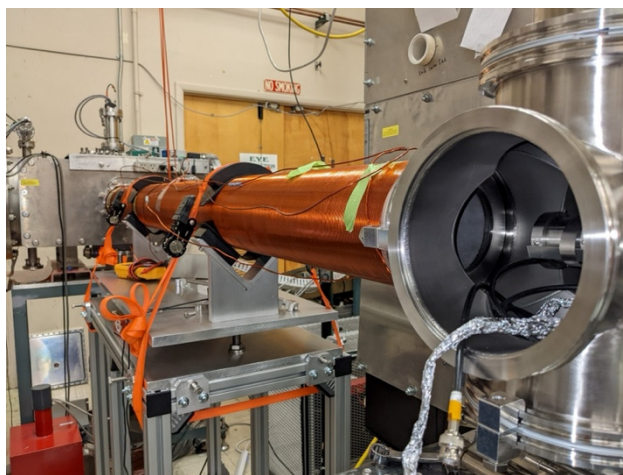


Figure 2: Solenoid and FC chamber.

Effect of the Thickness of the Extraction Hole

Due to the thickness of the aperture that restricts the incoming plasma to the Faraday cup, the projected area to the plasma flow is slightly deformed. If the thickness is zero, the projected area can be simply expressed as a cosine function. The area is expressed as follows. The thickness and radius of the aperture hole are t and r , respectively.

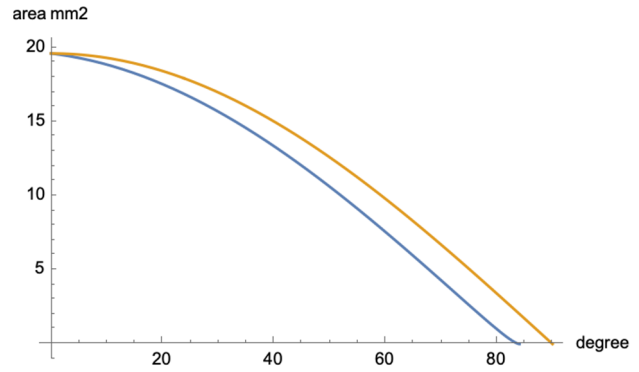


Figure 3: Projected area of the slanted extraction hole.

$$\frac{1}{2} r \left(4 r \text{ArcSec} \left[\frac{2 r \text{Cot}[\theta]}{t} \right] \text{Cos}[\theta] - t \text{Sin}[\theta] \sqrt{4 - \frac{t^2 \text{Tan}[\theta]^2}{r^2}} \right) \quad (1)$$

The comparison of the formula and cosine function is shown at Fig. 3 as the blue curve and orange cosine curve. The thickness and radius are 0.52 mm and 2.5 mm, respectively. As a result of the thin extraction aperture, the effect of the thickness is almost negligible.

RESULTS

From the expansion velocities we estimate that the ions have energies of 12 eV/u for aluminum and 3 eV/u for tantalum at the peak positions. The charge composition for both species is assumed as mainly single with a small amount of double charge ions. First, we show the observed beam performance at the zero angle beam extraction condition. The observed beam current waveforms are shown in Fig. 4. The vertical scale is in voltage with a 1 kΩ terminator. The zero in the horizontal axis corresponds to the laser irradiation timing. Each graph contains five laser shots, and the reproducibility can be seen. For aluminum case, 12 Gauss and 20 Gauss solenoid fields indicated instability of the beam. The tantalum data show the instability at from 20 to 60 Gauss [3]. The current enhancement by the solenoid field was saturated above 30 Gauss for the aluminum plasma.

Then, the extraction angle dependences are shown in Figs. 5 and 6.

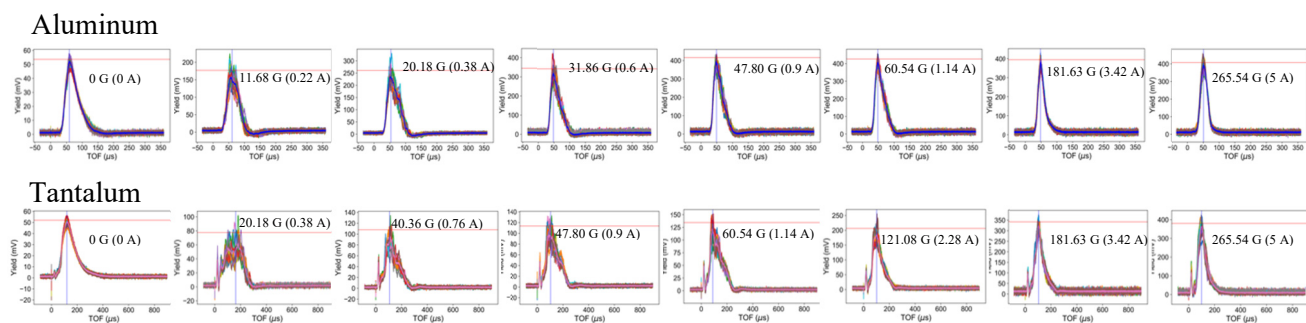


Figure 4: Observed beam current waveforms.

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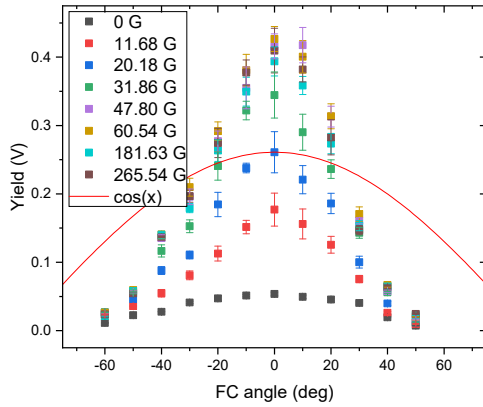


Figure 5: Aluminum beam current vs. extraction angle.

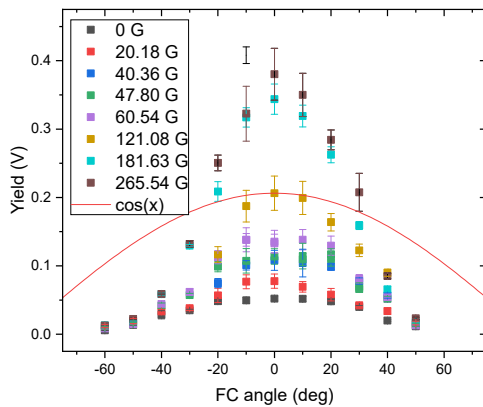


Figure 6: Tantalum beam current vs. extraction angle.

Each point in the graphs shows peak beam current with standard deviation. As you can see, by applying solenoid field stronger, degradation of the currents are more obvious. Therefore, one should avoid using this method at an angle that is too extreme. However, if the angle is within 25 degrees or so, the effect is not so severe and a compromise is acceptable. Furthermore, the advantage of an angled extraction is that it prevents the inflow of unwanted particles, such as neutrals and clusters emitted after the laser ablation plasma, which would interfere with the operation of a high vacuum, high electric field linear accelerators.

CONCLUSION

The effect of the angle of the extraction surface on the beam current is greater than a simple angular reduction in the extraction area. However, an angle of up to about 25 degrees is acceptable in practical use.