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Proton beam production by a laser ion source with Hydride target

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Proton Beam Production by a Laser Ion Source with Hydride Target[a)]

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We studied proton beam production from a laser ion source using hydrogen rich target materials. In general, gas based species are not suitable for laser ion sources since formation of a dense laser target is difficult. In order to achieve reliable operation, we tested hydride targets using a sub nanosecond Q-switched Nd-YAG laser, which may help suppress target material consumption. We detected enough yields of protons from a titanium hydride target without degradation of beam current during the experiment. The combination of a sub nanosecond laser and compressed hydride target may provide stable proton beam.

I. INTRODUCTION

Proton beam production from hydride targets using a laser ion source (LIS) has been tried [1, 2, 3]. In the previous studies, we tested MgH_2 and ZrH_2 as targets using a 6 ns 1064 nm Nd-YAG laser. We obtained hydrogen ions in the ablation plasmas. However, we found that the hydride targets were easily fractured. Although we have tried to form a plate shape hydride target using a piece of titanium, we could not fabricate a good quality laser target having enough irradiation area with a reasonable surface flatness. In this work, we used compressed titanium hydride powder as a laser target with a short pulse (170 ps FWHM) laser. The short pulse laser irradiation may reduce the target consumption and multiple laser irradiations at the same spot enables long time operation without changing the target.

II. EXPERIMENTAL SETUP

A. Hydride target

An aluminum shell was used to hold the titanium hydride powder with the dimensions shown in Fig. 1. The usable area was large enough to scan the laser spot position. The photo of the shell is shown in Fig. 2. The powder was pressed for 30 minutes with 10,000 lbs. of pressure.

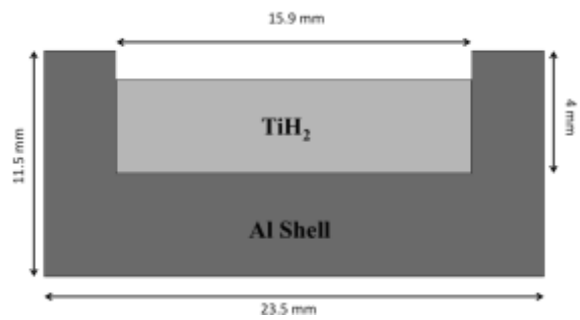

FIG. 1. Cross-sectional view of the titanium hydride target.

FIG. 2. Compressed titanium hydride powder in shell. The laser spots are seen on the surface.

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After 30 minutes, the pressure was increased back to 10,000 lbs. and pressed for an additional 15 minutes. The titanium hydride powder used was 99% pure.

B. Short pulse Laser

We used Ekspla SL334 [4] with a sub-nanosecond laser pulse length to confirm the plasma properties. Although a commercially available Q-switched Nd-YAG laser typically has a 5 to 7 ns pulse length, Ekspla SL334 can provide shorter pulse width using a stimulated Brillouin scattering (SBS) cell [5]. The supplied laser energy on the target surface was 295 mJ and the pulse width was adjusted to 170 ps. The wavelength was 1064 nm.

C. Beam line

Figure 3 shows the experimental setup. The titanium hydride target in the vacuum chamber was irradiated with a Nd: YAG laser of wavelength 1064 nm with a pulse length of 170 ps. The incident angle between the laser path and beam line was 20 degrees. The vacuum pressure in the chamber was below 2.5×10^{-4} Pa. A Faraday cup (FC) with a 10 mm aperture located 2.4 m away from the target was used to measure the ion current in the plasma. The suppressor voltage applied to the mesh in the FC was set to -3.5 kV. We analyzed the plasma with an electrostatic ion analyzer (EIA) with selected ions detected using a secondary electron multiplier (SEM). The total distance between the detector and the target was 3.7 m. The ion species and charge state were determined from the SEM time of flight information and the voltage applied to the EIA.

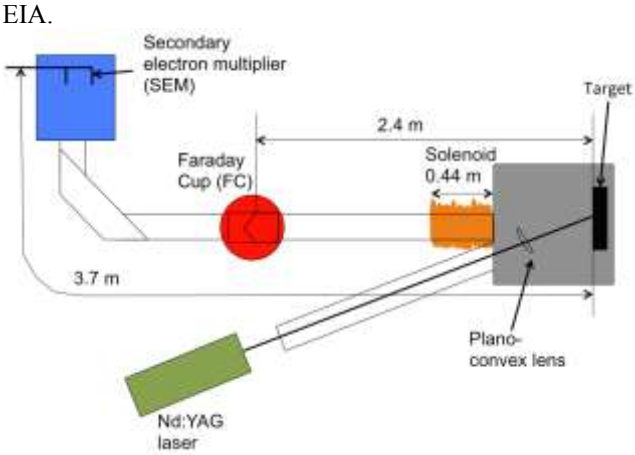

FIG. 3. Beam line for plasma analysis.

III. CONTENTS OF PLASMA

We tested two laser spot sizes by changing the laser focusing condition. The spot sizes were 8.7 mm and 2.9 mm in diameters and the corresponding laser power densities were 2.9×10^{9} W/cm^2 and 2.6×10^{10} W/cm^2 respectively. The analysis assumes the SEM sensitivity is proportional to charge state. All currents are normalized to a distance of 1 m from the target and a sensing cross sectional area of 1 cm^2 according to the scaling laws of expanding plasma, $t \quad L$ and $I \quad L^{-3} * S$, where t, L, I, and S are time, length, current, and cross sectional area respectively. Since there was not much overlap between the proton and the titanium peaks, the sum of the SEM data was scaled to the hydrogen peak in the FC signal.

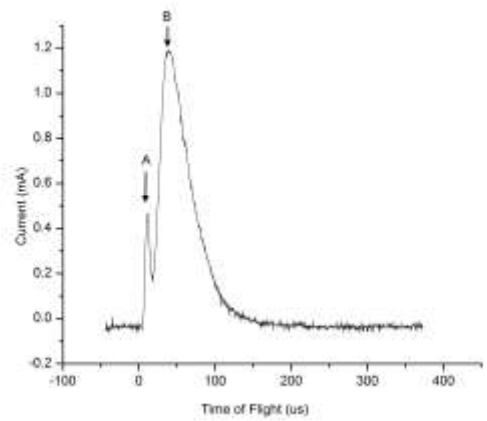

FIG. 4. Ion current measured by the F.C.
Peak A was formed by hydrogens ion and peak B mainly contains titanium ions.

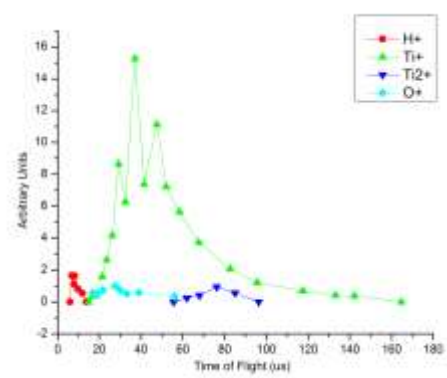

FIG. 5. Analyzed species and charge state.

A. Low laser power density result

Fig. 4 shows the total ion current from the TiH_2 target measured by the FC. Fig.5 shows the charge state distribution of the analyzed plasma based on the EIA and SEM data. Based on this data, the faster peak in Figure 4 can be identified as hydrogen.

B. High laser power density result

To increase the hydrogen signal, we changed the focusing lens and the laser power density was increased to 2.6×10^{10} W/cm^2. Fig. 6 shows the total ion current from the TiH_2 target at the higher power density measured by the FC. Fig. 7 shows the charge state distribution of the analyzed plasma based on the EIA and SEM data. The hydrogen peak current was increased as expected. However, the charge state distribution of titanium and impurities from the oxidized surface increased as well. These higher charge states had faster expanding velocities and overlapped to a greater extent with the hydrogen peak.

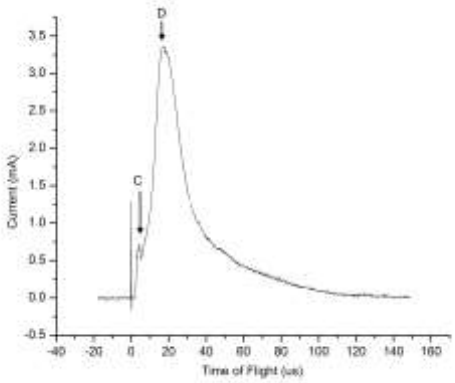

FIG. 6. Ion current measured by the F.C.
Peak C : hydrogen ion, peak D : titanium ion and impurities.

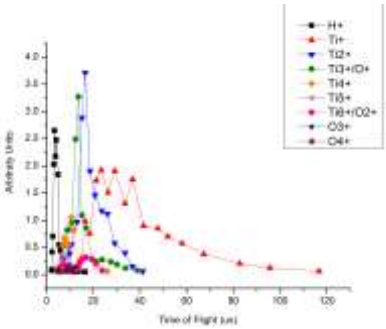

FIG. 7. Analyzed species and charge state.

C. Current enhancement by solenoid

We used a solenoid to further increase the peak current of the protons. To see the effect of the solenoid, we chose to only look at the FC signal because the SEM data reveal that there is minimal overlap between hydrogen ions and other species. The maximum amplification of the hydrogen peak occurred when a field of 6 Gauss was applied in the solenoid. The solenoid has a length of 500 mm, an I.D. of 75 mm and was positioned 350 mm from the target. The peak proton current increased by 50%. The enhancement was not as large as expected since the optimized field strength was too low to be controlled precisely in the current experimental setup. We may need to eliminate the Earth's field and slight residual field caused by the magnetization of the stainless steel beam pipes. We also observed that a higher magnetic field enhanced the titanium peak more efficiently as predicted.

IV. DISCUSSION

While taking data, we were not required to move the position of the target since obvious degradation of the ion current was not observed. Each spot was exposed to a few hundred laser shots. If we scanned the target very slowly, for instance, a few mm per hour, the compressed powder target may last for a reasonable number of hours of operation. This slow target scanning scheme is being used in the LION source at Brookhaven National Laboratory (BNL)[6]. The long time operation capability of a proton beam may be useful for some industrial applications. For example, we have proposed to use a laser ion source with direct plasma injection scheme (DPIS) for a cancer therapy accelerator [7] and now by only changing a graphite target to the compressed titanium hydride target, we can supply both fully stripped carbon beams [8] and proton beams from an identical radio frequency quadrupole (RFQ) linear accelerator. Also, an RFQ can effectively filter lower charge/mass particles like Ti^{1+} and O^{1+}.

V. CONCLUSION

A hydrogen peak was observed by irradiating the sub-nanosecond Nd-YAG laser onto the compressed TiH_2 powder target. The lower laser power density has an advantage to distinguish a hydrogen peak from the substrate originated plasma current. The slow scanning technique may help to extend the operational hours and will be useful for some industrial applications.

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