ION GENERATION VIA A LASER ION SOURCE WITH HOT TARGET

Robert Dabrowski*, City College of New York, NY 10031, USA
Takeshi Kanesue, Kyushu University, Fukuoka 819-0395, Japan; RIKEN, Saitama 351-0198, Japan
K. Kondo, BNL, Upton, NY 11973, USA; RIKEN, Saitama 351-0198, Japan
Masahiro Okamura, BNL, Upton, NY 11973, USA

Abstract

Using the Laser Ion Source (LIS), a heated Ta target was irradiated by a Nd:Yttrium Aluminum Garnet Laser. The produced plasma was experimentally studied at target temperatures of 22 C°, 200 C°, 400 C° and 600 C° with various irradiation repetition rates. Constant repetition rates were found to be critical in achieving consistent, reproducible plasma measurements despite the presence of target impurities. Target pre-heating demonstrated an increase in total beam current and the ability to produce high charge-states at each heating condition. A decrease in plasma beam impurities with increased temperature was observed with further decreases at higher repetition rates.

INTRODUCTION

The Laser Ion Source (LIS) is an efficient method of generating heavy ions for acceleration [1, 2, 3]. The method involves irradiating a solid-state target with a pulsed laser. The output produces high current and high charge-state beams from almost any type of elemental species [1, 4]. However, the method is limited by the intensity of the laser which limits the charge composition and overall current of the ablated plasma.

Using the LIS, we consider overcoming this limit by heating the target prior to laser irradiation. Prior deposition of thermal energy could yield beams of higher charge-state ions and/or increased net number of ions. We investigate this by using a retrofitted heater to heat the target to a variety of temperatures and subsequently analyze the produced beam.

EXPERIMENTAL SETUP

A standard LIS experimental setup was used [5]. The design included a target chamber and a solid-state target that was irradiated by a Nd:yttrium aluminum garnet laser operating at 1064 nm (1.09 J / 7 ns). The target chamber is shown in Fig. 1. During operation, the laser was directed to the target through a BK7 chamber window and focused from the exterior of the chamber by a lens (f = 800 mm). Inside the chamber, the laser had a 30° incident angle with respect to the target and a target spot size of 12 mm. Target thickness was 0.5 mm. A Tantalum target was selected because it is a typical heavy ion and possesses a high melting point. The focusing element, the spot size and the power of the laser were specifically chosen for the primary development of Ta^{1+} ions. The chamber and subsequent beam line elements were held at 10^{-4} Pa in order to minimize plasma recombination effects.

The heating apparatus was placed in thermal contact behind the target and served as a target mount throughout the experiment. The heating device utilized highly resistive material to heat the target and the heating was controlled by varying the DC supplied to the device. Uniform heating of the target was realized by retrofitting the heater with an iron mount used to secure the target and provide increased thermal contact. Tungsten-Rhenium thermocouples were employed to verify the target temperature. To reduce energy loss due to blackbody radiation, we erected heat shielding surrounding the length of the heater. The maximum temperature achieved with this arrangement was 600 C°. We tested 200 C°, 400 C° and 600 C° with a control (baseline) measurement at 22 C°.

Experimental results of the charge state distribution are provided by Electrostatic Ion Analyzer (EIA) separation and subsequent measurement by the Secondary Electron Multiplier (SEM), as well as total beam current by the Faraday Cup (FC) are presented. The FC and SEM were located 2.49 m and 3.57 m from the target, respectively. The EIA entrance slit width was 10 μm and the SEM applied voltage was -3.5 kV.

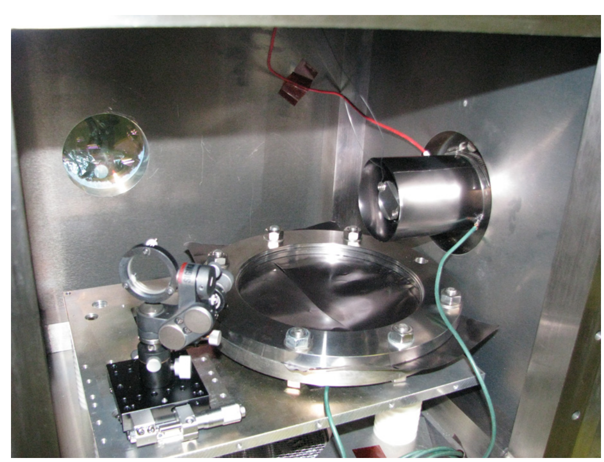

Figure 1: The target chamber with heating arrangement.

* Electronic-mail: robdabrowski@gmail.com

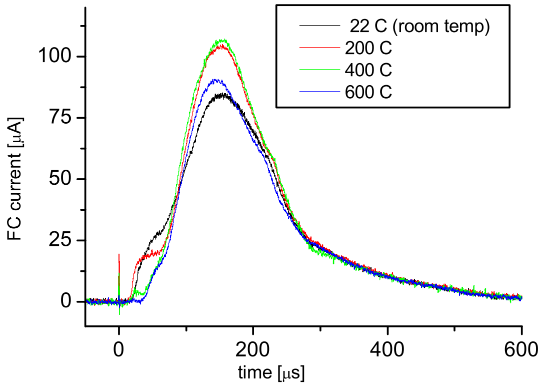

Figure 2: The averaged FC signal measured at temperature conditions of 22 C°, 200 C°, 400 C°, and 600 C°.

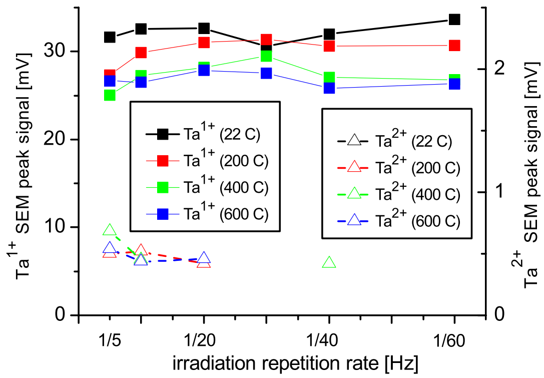

Figure 3: SEM peaks of Ta^{1+} and Ta^{2+} at specific temperatures and irradiation repetition rates.

RESULTS AND DISCUSSION

To determine whether pre-heating the target changes the charge-state composition of the ablated plasma, we test four temperature conditions: 200 C°, 400 C°, 600 C° and 22 C°. Laboratory room temperature was 22 C°. For each temperature condition, the FC was used to measure the total beam current, while the EIA was used to distinguish specific ion charge-states so they could be individually measured by the SEM. Specific ion charge states were measured by changing the EIA applied voltage until the ion signal vanished.

During experimentation, it was found that successive irradiation of the Tantalum target yielded improved results when compared to single shot measurements taken at a non-consistent repetition rate. This is attributed to the impurities found within and on the surface of the Tantalum target as well as the low irradiation intensity. It appears that the first shot removed natural impurities from the surface allowing future shots, immediately after the first, to show improved results. Shots not fired immediately afterwards showed results similar to the first. As a result, we adopted the procedure of successive shots, fired at a constant repetition rate to determine the charge-state composition and net current with minimum impurity impedance.

Measurement of the Net Current

At each temperature condition, several FC measurements were made using the irradiation procedure discussed above. The repetition rate between target irradiation was 1/60 Hz and this interval was maintained throughout the duration of the experiment. The measured signals were then averaged to form a composite signal that was compared to the 22 C° temperature condition. The results are illustrated in Fig. 2. For the 400 C° condition, the current increased by 22.1 μA. Each temperature condition above the control yielded higher peak values which suggests heating the target prior to laser irradiation increases the total beam current.

Ion Development

At each temperature conditions and at various repetition rates, the charge-state beam composition was analyzed to determine pre-heating effects. Ta^{2+} ions were observed at all measured heating conditions suggesting that pre-heating the target increases higher charge-state development, Fig. 3. Furthermore, it is suggested that increasing the irradiation repetition rate serves to increase the production of Ta^{2+}. A steady increase in the number of Ta^{2+} ions is observed, especially at the highest recorded repetition rate of 1/5 Hz. No noteworthy changes were observed in the SEM signal for Ta^{1+} at any measurement condition except for a slight decrease with higher temperature. The presence of Ta^{2+} demonstrates the potential for increased higher charge-state development.

A specific EIA voltage of ± 6.5 V was used to observe the signal peak of Ta^{1+}. The use of this specific EIA voltage limits the peak measurements of other ions like Ta^{1+}.

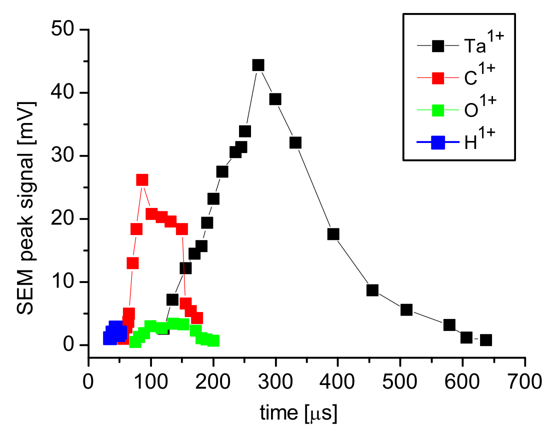

Figure 4: SEM signal of the elemental beam composition at 22 C° with a 1/60 Hz irradiation repetition rate. Ta^{1+} and the impurities O^{1+}, C^{1+}, H^{1+} were measured.

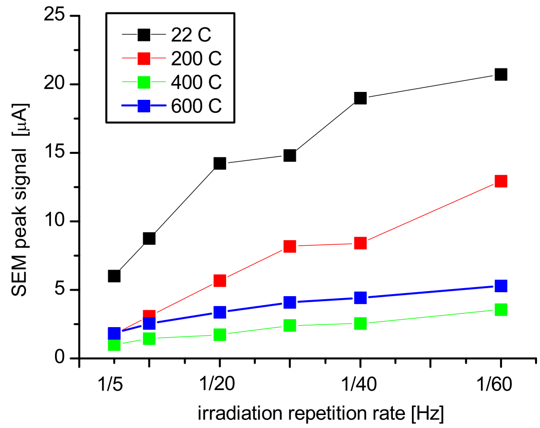

Figure 5: SEM peak signals of C^{1+} ions at a specific temperature condition and irradiation repetition rate.

As a result, the Ta^{2+} measurement in Fig. 3 does not include the peak value and only represents a partial signal. For this reason, no inconsistency exists between the FC signal of the total beam current (Fig. 1) and the apparently low development of Ta^{2+} ions (Fig. 3) at any given temperature.

Repetition Rate and Impurities

A consistent repetition rate was found to be critical in generating improved measurements. In the LIS, the presence of impurities in the target will manifest a plasma plume containing those impurities. Figure 4 illustrates the impurities found in the plasma plume at 22 C° with a repetition rate of 1/60 Hz, which mostly consisted of O, C, H, etc. We analyzed the C^{1+} impurity present in the plasma plume by changing the repetition rate and temperature condition. The amount of C^{1+} ions found with the plasma plume decreased as the temperature increased, Fig. 5. Also, as the repetition rate increased at a given temperature condition, C^{1+} ions that were found in the beam decreased demonstrating a potential method for removing unwanted elemental ions from the produced plasma.

CONCLUSION

Experiments in pre-heating the target in an LIS system have yielded results demonstrating the ability of this method to produce higher charge-states and an increased total beam current. These results were demonstrated at several temperature conditions and at a variety of laser irradiation repetition rates. Furthermore, experimentation revealed the importance of utilizing a constant irradiation repetition rate in order to achieve more consistent and reproducible plasma measurements. In addition, increasing the temperature of the target was found to decrease the presence of impurities in the subsequently produced plasma. The effect was increased by applying a higher repetition rate. In terms of composition, this demonstrates a potential method for generating highly homogeneous beams with diminished impurity levels, especially at low irradiation intensities. Pre-heating the target prior to laser irradiation may be used to increase average charge-state, increase total beam current and/or remove unwanted impurities from produced beams.

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