

MEASUREMENT OF ION BEAM FROM LASER ION SOURCE FOR RHIC EBIS

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Abstract

Laser ion source (LIS) is a candidate of the primary ion source for the RHIC EBIS. LIS will provide intense charge state 1+ ions to the EBIS for further ionization. We measured plasma properties of a variety of atomic species from C to Au using the second harmonics of Nd:YAG laser (532 nm wave length, up to 0.5 J / 6 ns). Since properties of laser produced plasma is different from different species, laser power density for singly charged ion production should be verified experimentally for each atomic species. After plasma analysis experiments, Au ions was extracted from plasma and emittance of the ion beam was measured using pepper pot type emittance monitor.

INTRODUCTION

The RHIC-EBIS is the future heavy ion injector for Relativistic Heavy Ion Collider and NASA Space Radiation Laboratory [1]. The low charge state, low emittance and high ion yield laser ion source (LIS) using a high power Nd:YAG laser with a defocused laser beam is being studied as the primary ion source for the RHIC-EBIS [2]. Charge state 1+ ions of various species are required to control charge state well. LIS produces ions by pulsed high power laser irradiation onto a solid state target. Target is rapidly heated, vaporized and becomes plasma which is called laser ablation plasma then plasma expand adiabatically perpendicular to the target surface. Properties of Laser ablation plasma such as charge state distribution, current and ion energy mainly depends on laser power density. By decreasing laser power density, LIS can be optimized for singly charged, low energy ion production which is suitable to provide seed ions for charge bleeding system such as EBIS. We determined the laser power density to produce singly charged ions, and emittance of Au ions extracted from laser ablation plasma was measured.

SINGLY CHARGED ION PRODUCTION

We investigated the laser power density to produce charge state 1+ ion dominant plasma by changing the laser power density on the target. Target species of C, Al, Si, Fe, Fe, Ta and Au were used for this experiment.

Experimental Setup

Figure 1 shows a schematic view of our experimental setup to measure the plasma total current and charge state distribution. We used a second harmonics of Nd:YAG laser (0.5 J / 6 ns). A laser light was transported by three flat mirrors to a convex lens. We used three lenses which

had focal length of 800 mm, 1000 mm and 1500 mm, respectively to change a laser spot size on the target. The lens was placed on an optical rail fixed parallel to the laser path to control a spot size too. These lenses and optical rail allowed us to control laser power density ranging from 10^8 W / cm² to over 10^{10} W / cm² during experiment. Laser light was focused onto the target with an incident angle of about 6 degrees. The target plate was attached to a 3D manipulator to provide fresh surface when it was damaged. The target surface was aligned perpendicular to measurement line. Laser ablation plasma generated by laser shot was expanded adiabatically normal to the surface. A Faraday cup (FC) was placed at 1.74 m far from target to measure plasma total current which had an aperture of 10 mm diameter and a mesh of which transmission was 85 % with a suppressor voltage of -2.5 kV to suppress secondary electron and extract ions from plasma. The charge state distribution was measured using a cylindrical 90 degrees electrostatic ion analyzer (EIA) and a secondary electron multiplier (SEM) located downstream of the FC. SEM was biased -3.5 kV. Ion signal from each charge state was obtained by scanning EIA applied voltage until ion signal disappeared. The signal was enhanced and detected by SEM of which multiplicity was different from ion energy, charge state and ion species. We calibrated ion signal by comparing the sum of each charge state signal multiplied by its charge state to FC total current.

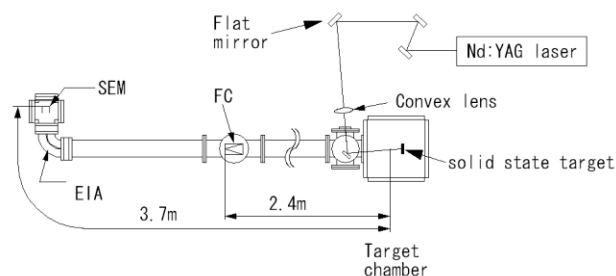


Figure 1: schematic view of experimental setup

Results

The relationship between power density and plasma total current was measured using FC. Laser power density was controlled by changing laser spot size on the target. Laser was irradiated from high power density to low power density until plasma signal vanished. As decreasing laser power density, total yield increased and there was a peak yield then it started to decrease and plasma was vanished finally. This was because that increasing area irradiated

by laser at the first increasing stage and the area above plasma generation threshold was decreasing during the ion yield decreasing phase although laser irradiated area was large.

These results obtained using FC could contain multiple charge state, so we analyzed charge state distribution inside plasma. Figure 2 shows the ratio of charge state 1+ ions as a function of a laser power density. In this laser power density range, only charge state 1+ and 2+ ions were detected. We defined that laser power density where 95 % of particles were singly charged ions was threshold for charge state 1+ ion production. Below this limit, plasma properties such as the number of particles, peak current and pulse duration were obtained based on FC signal. Figure 3 shows the plasma parameters as a function of laser power density scaled at 1 m with 1 cm² extraction area using the relationship:

$$I \propto L^{-3}$$

$$\tau \propto L,$$

where I , τ and L represent a current density, pulse duration and plasma drift length, respectively. LIS performance can be controlled by laser power density, drift distance and extraction aperture using these relationship. Based on the obtained data, the example of LIS design for a primary ion source for the RHIC-EBIS was designed from the point of the requirement for number of particles. Table 1 shows the requirement, example of LIS design and plasma properties for C, Si, Fe and Au. Extraction aperture of 30 mm diameter was considered for this design. The detail of particle requirement is shown in [2]. LIS was successfully optimized for singly charged ion production and it was confirmed that LIS can use as an external ion source for the RHIC EBIS.

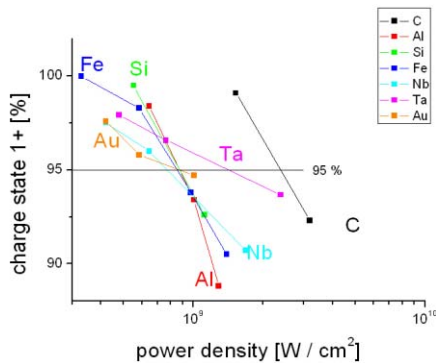
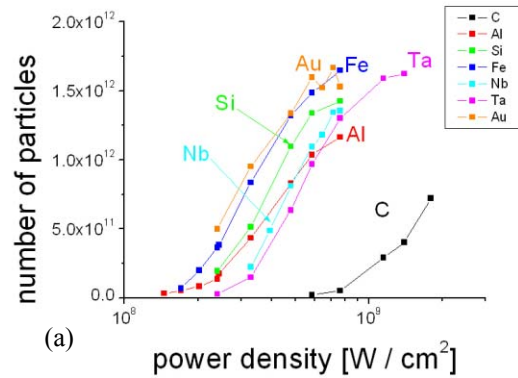


Figure 2: Percentage of singly charged ions inside

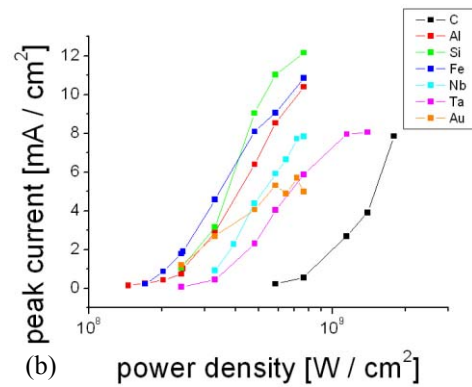
Table 1: LIS design to satisfy the requirements for primary ion source for the RHIC-EBIS in case of 30 mm extraction aperture.

	Required particle for LIS	Power density[W / cm2]	Drift distance [m]	Peak current[mA]
C	1.15E+12	3.2E+9	2.5	4700
Si	4.26E+11	4.0E+8	2.65	920
Fe	2.40E+11	2.6E+8	3.6	325
Au	1.72E+11	2.0E+8	3.6	116

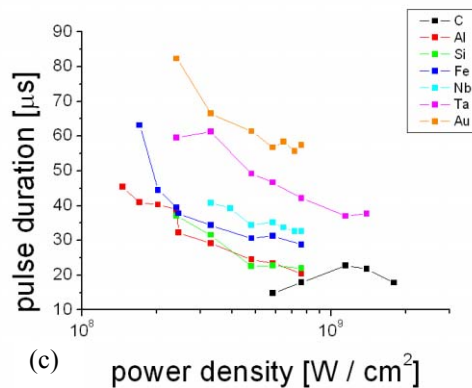
plasma.



(a)



(b)



(c)

Figure 3: Number of particles (a), peak current (b) and pulse duration (c) of the plasma scaled at 1 m with 1cm² aperture below threshold for charge state 1+ ion production.

EMITTANCE MEASUREMENT

Emittance of Au ion beam was measured using pepper pot emittance monitor [3]. For this experiment, ion source test bench was modified to extract ions from plasma and to transport them to pepper pot. Laser power density and extraction condition was chosen to achieve sufficient particles as a primary ion source although condition was not the same written in Table 1 due to the setup limitation.

Experimental Setup

Laser power density of $1.7 \times 10^8 \text{ W / cm}^2$ was used for this experiment. Faraday cup and EIA were removed and an ion extraction column, a gridded lens to focus ion beam and pepper pot emittance monitor was installed. The extraction column which consisted of a 25.4 cm long insulator, extraction electrode with 18 mm aperture at the entrance of the insulator, grounded electrode with 70 mm aperture at the other side and intermediate electrode which has 36 mm aperture was placed 1.6 m far from the target. The intermediate electrode was movable along the beam axis. At the downstream of the insulator, there was a gridded lens which had a mesh and ring electrodes on both sides of the mesh. Beam aberration can be minimized by applying independent voltage to mesh and ring. A pepper pot was located at a distance of 2.4 m far from the target. Ion beam current was monitored using a pepper pot mask which is a metal screen with small holes attached in front of emittance monitor system. The mask was biased to 150 V to suppress secondary electrons. Target, Target chamber and plasma drift chamber was biased to 16 kV to extract ions from plasma.

Result

Plasma drifting length and extraction aperture was 1.6 m and 18 mm as mentioned above. The number of particles, peak current and pulse duration of the extracted beam were calculated to 1.9×10^{11} , 0.28mA and 110 μ s in this condition. The position and applied voltage of intermediate electrode and gridded lens applied voltage was determined to transport ions which have peak current and half of the current in a pulse without losses to the pepper pot using Kobra 3 code[4]. The optimized position and applied voltage was 17 cm upstream from entrance of insulator and 0 kV. Emittance of Au beam was tested with these conditions.

At first, gridded lens voltage was optimized to extract all plasma and to minimize emittance by monitoring an ion signal and emittance value. Since the difference between ion signal of mask and plasma pulse shape scaled at the optimized extraction condition was small and the pulse shape was almost same, most of ions was considered to be extracted and transported to the pepper pot. Peak current of extracted ion signal was 0.30mA which is in good

agreement with the peak current expected from plasma peak current.

Figure 4 shows a measured horizontal phase space processed by pepper pot. Normalized RMS emittance was $0.025 \pi \text{ mm mrad}$. This value is comparable to the Hollow cathode ion source (HCIS) used as the primary ion source for the RHIC-EBIS test stand although the current from the HSIS was typically several tens of micro amperes which is about a order of magnitude lower than that of LIS.

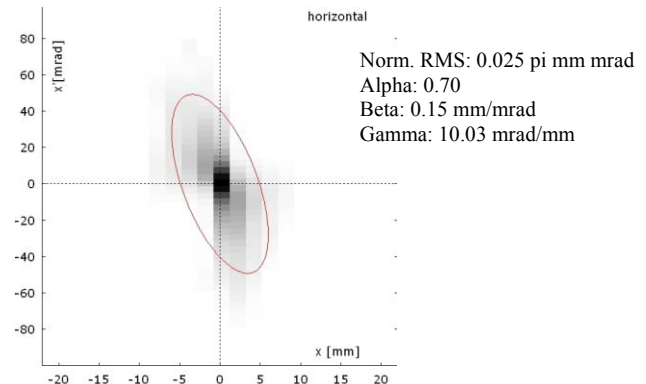


Figure 4: Measured horizontal phase space using Au target with 16 kV extraction.

CONCLUSION

Emittance of Au ion beam was measured using pepper pot Charge state distribution of C, Al, Si, Fe, Nb, Ta and Au was optimized for a singly charged ion production by adjusting laser power density on the target. The obtained LIS performance can satisfy the requirements for use of a primary ion source for the RHIC-EBIS from the view point of the number of the particles. Emittance of the Au beam was measured with a 16 kV extraction voltage. The measured normalized RMS emittance was $0.025 \pi \text{ mm mrad}$ which is comparable to a hollow cathode ion source which is used as a primary ion source for the RHIC-EBIS test stand..

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