PROPERTIES OF LASER-PRODUCED HIGHLY CHARGED HEAVY IONS FOR DIRECT INJECTION SCHEME

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Abstract

To accelerate highly charged intense ion beam, we have developed the Direct Plasma Injection Scheme (DPIS) with laser ion source. In this scheme an ion beam from a laser ion source is injected directly to a RFQ linac without a low energy beam transport (LEBT) line and the beam loss in the LEBT can be avoided. We achieved high current acceleration of carbon ions (60mA) by DPIS with the new RFQ optimized for the high current beam. As the next step we will accelerate heavier elements like Al as target in LIS (using Glass-laser: Max 4.39J/cm^2). To obtain very high current Al beam, we examined the properties of the laser-produced Al plasma. Also a comparison of the glass laser and small YAG laser for the DPIS was studied usin a carbon target.

INTRODUCTION

Since linac is used in various fields, for instance a synchrotron injector, implantation for semiconductor etc., it is important to improve that performance. However it is very difficult to handle high intensity beam especially in low velocity section like LEBT between the ion source and an accelerator, because in that region space charge effect is strong and a large fraction of the beam might be lost. On the other hand it is efficient to use high charge state ion in the linac, but it also causes stronger space charge effect and the acceleration of high intensity beam becomes more difficult.

Then a new acceleration scheme for high charge and high intensity heavy ion beam was invented in RIKEN and Tokyo Institute of Technology (TITech). This new technique is called “Direct Plasma Injection Scheme (DPIS).” An ion beam from a laser ion source is injected directly to an RFQ linac without serious beam loss in LEBT caused by space charge effect. It makes possible to accelerate high charge and high intensity heavy ion beam. In collaboration experiment RIKEN with TITech, we achieved to accelerate 60mA of carbon beam with CO_2-laser, and C^{6+} beam with YAG-laser.

As the next step we plan to accelerate heavier ions. We selected Al. To do this the laser induced plasma prooerties should be measured. We have started the investigation of the Al plasma with a Glass-laser, which is similar to YAG-laser on character but has higher power. Since we have some datas of the carbon plasma induced by a YAG laser, the carbon target was also used to compare the two laser systems.

EXPERIMENT SETUP

Figure 1 shows the experimental equipments for the Al plasma measurement. The glass-laser has a wave length of 1064 nm and its maximum energy is 4.39J/cm^2 per shot (measured by a thermal volume absorber). The spot size and pulse length are 1cm and 40nm respectively. It is needed about 45 second to cool down time every shots. The laser beam was reflected by two flat mirrors which are coated for high power laser and was injected to a target chamber through a BK7 window. In the target chamber, the laser was focused by convex lens (focus length 100 mm) and was emit to the target suspended by a supporting rod. Since the laser produced plasma has high density region on vertical direction against the target,the surface was aligned normal to the beam axis. We placed a faraday cup (aperture 10mm) on the axis (2.4m away from target) and measured the total current of the plasma. An electrostatic analyzer was used to obtain charge distribution and signals were detected by a secondary electron multiplier (SEM) located 3.7m away from target.

To get the best focusing spot on the surface, the target was scanned along the axial direction by a three dimensional manipulator which is driven by stepping motors. This manipulator also moved transverse direction to provide a new surface to every laser shots.

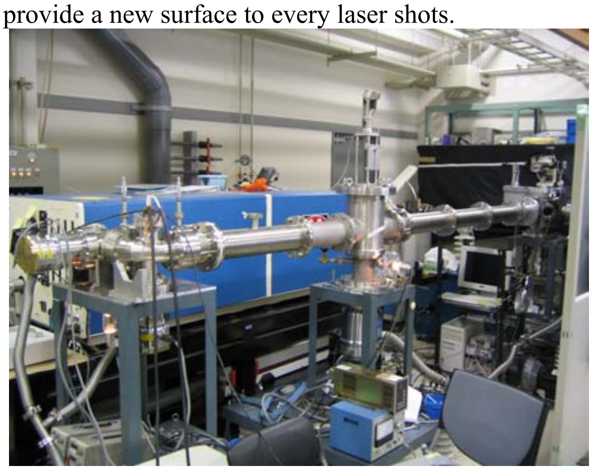

Figure1: Experiment equipments.

MEASUREMENT OF CHARGE DISTRIBUTION

Figures 2 and 3 show the charge states distribution of the Al plasma and the C plasma. The raw data were taken by the SEM and were calibrated by a Faraday cup at some reference points. In those figures, the Al plasma mainly contains Al^{7+} or Al^{8+} and C plasma mostly has C^{5+}. The C plasma has an advantage about charge to mass ratio, however the laser power was not identical in each experiment (Al: about 2.5 J/cm^2, C: about 3.8J/cm^2). The simple comparison cannot be applied.

Figures 4 and 5 show converted wave shapes of each element. These pulses are originally observed at the different distance and then the time and the currents were scaled as it appears at the point, 1 m from the target. The vertical axis is in mA/cm^2. Again the peaks of each charge states were measured by the SEM and were calibrated. According to the figures, Al^{10+} current reached about 1.7mA/cm^2 and C^{6+} current raised up to 7.58mA/cm^2. The peak taken by the Faraday cup should include all the charge states. In Fig.4, the analyzed wave shapes look to be shifted to the right side. The reason of this shift is not clear. However this tendency was commonly observed on experiments of other heavier elements in our experiences.

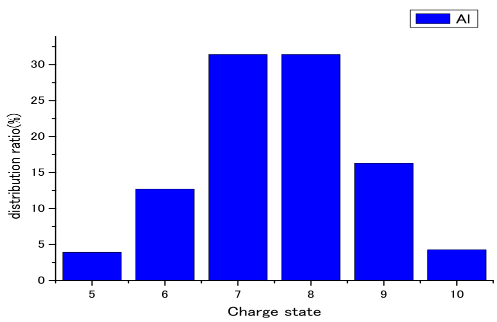

Figure 2: Charge state distribution (Al).

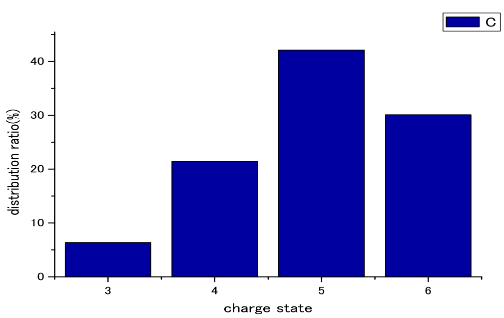

Figure 3: Charge state distribution (C).

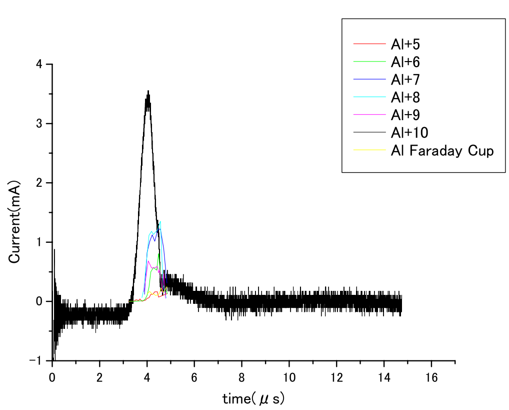

Figure 4: Pulse structure (Al).

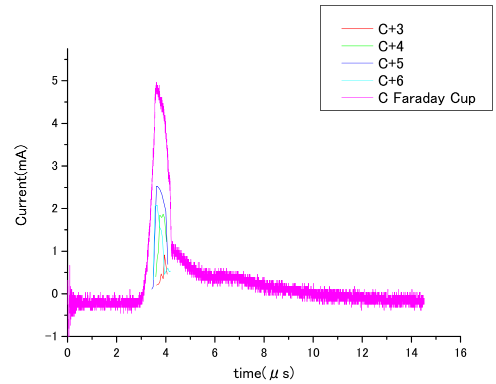

Figure 5: Pulse structure (C).

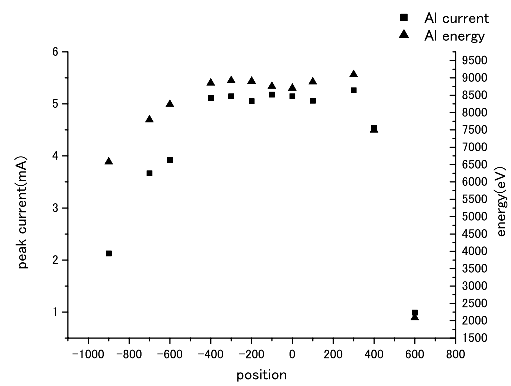

Figure 6: Current change by focus position (Al).

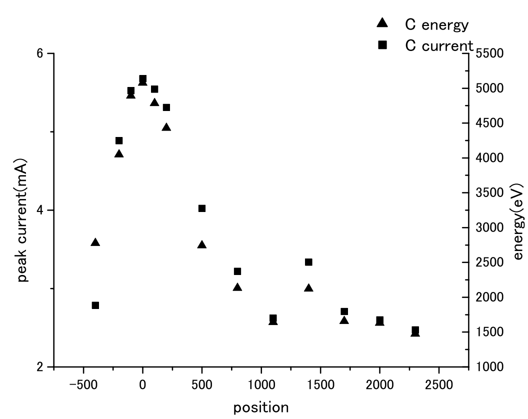

Figure 7: Current change by focus position (C).

Figures 6 and 7 show the target position dependences on the maximum currents. The position affects the size of the laser spot. As we mentioned above, the direct comparison cannot be applied because the laser powers are different. However, one can say that the Al target is more in-sensitive about its position to obtain the maximum current. The flat peak like in Fig.6 was observed in other heavier element experiments which were measured with the same laser power.

COMPARE GLASS-LASER AND YAG-LASER

The properties of the carbon plasma with the YAG laser had been tested[2]. The results are shown in Figs. 8 and 9. In this experiment, almost all instruments are same as the Glass-laser experiment except optical elements. For final focusing, concave mirror (focus length 125mm) was used. The wave length, maximum power, spot size and pulse length are 1064nm, 2.03J/cm^2 per shot, 0.5cm and 15ns. The induced carbon plasma by the Glass-laser has higher current than that by the YAG-laser(peak current of YAG: about 5.0mA at 420mm from target, Glass: about 4.8mA at 1000mm), but charge distribution shifts to lower side. The YAG laser experiment achieved higher charge states, but lower current. This discrepancies might be caused by the different focusing system or the different pulse widths of the lasers.

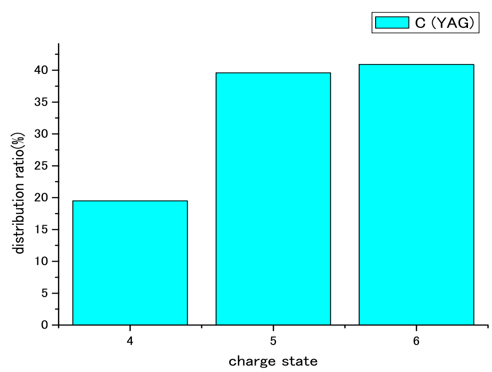

Figure 8: Charge state distribution with YAG-laser.

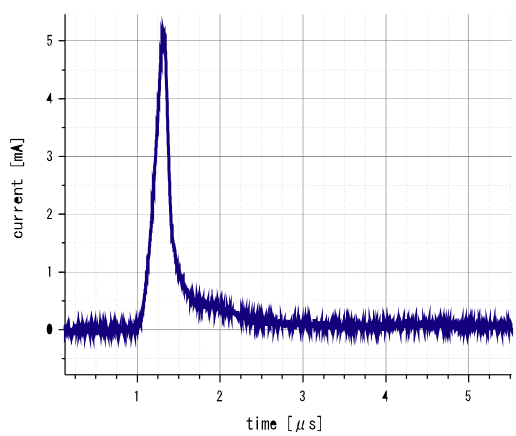

Figure 9: Pulse structure with YAG-laser (C).

SIMULATION OF ACCELERATION

A simulation study was done by using a multi species beam tracking cord, Pteq-HI, in the RFQ. Al^{9+} was selected as a next ion. The beam current including multiple charge states which will be injected to the RFQ can be estimated from the plasma property measurement. The acceleration performance of the Al^{9+} beam was investigated. In the simulation, we assumed only Al^{6+}~Al^{9+}. The total of the simulated currents corresponded to 83.4% of all the current of the measured plasma. The initial parameters are listed in Table.1. The operating frequency and the extraction energy are 100 MHz and 100keV/amu. The RF voltage was set to the design value of the RFQ for accelerating C^{4+} beam. The numbers of particles in the simulation are 3000 for $Al^{9+}$and 1500 for others charge states. We counted the particles which had more than 40 % of energy shift respect to the synchronous particle as lost particles.

Table 1: Initial parameter for PTEQ-HI

Main particle	Al^{+9}
Injection beam current	68mA
Injection energy	540keV (total)

The result of simulation is indicated in Fig.10. It shows the expected current of Al^{9+} is about 42mA (61.4% survive). Some portion of the Al^{8+}, Al^{+7} and Al^{+6} ions will be also accelerated. The simulated current at the end of the RFQ were 54mA, (41.3%), 31.9mA (24.1%) and 4.7mA (8.8%).

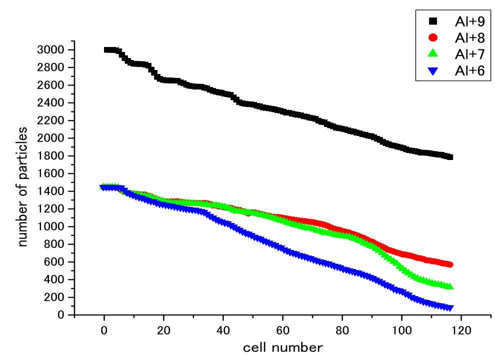

Figure 10: Simulation result.

CONCLUSIONS AND FUTURE PLANS

The contents of the Al plasma induced by the glass laser were measured and we simulated the acceleration performance of the Al beam with our new RFQ. According to the simulation, 42 mA of Al^{9+} will be accelerated.

We plan to try more heavier species up to gold this year to establish the DPIS as intense heavy ion production method.

REFERENCES

[1] M. Okamura et al, Scheme for Direct Plasma Injection into an RFQ Linac, LASER AND PARTICLE BEAMS, (2002), 20, 451-454.

[2] H. Kashiwagi at al, Nd--YAG laser ion source for direct injection scheme Rev. Sci. Instrum. 75, 1569 (2004).