AG ACCELERATION USING DIRECT PLASMA INJECTION METHOD

Takeshi Kanesue, K. Ishibashi, Kyushu University, Hakozaki, Japan
Masahiro Okamura, RIKEN, Saitama
Kazuhiko Sakakibara, RLNR, Tokyo
Sergei Kondrashev, ITEP, Moscow

Abstract

We are investigating high current and high repetition rate ion production methods for various heavy ions which can be utilized for an injector of an FFAG accelerator. Direct Plasma Injection Scheme (DPIS) is one of the candidates of the ion production methods and to confirm the capability of the DPIS, we are now preparing for accelerating high intensity Ag^{15+} ions. The DPIS uses a combination of Laser Ion Source (LIS) and RFQ. The plasma goes into the linac directly without transport line and the ions are extracted at RFQ entrance. To determine the specifications of new RFQ electrodes, the plasma properties were measured. With the Nd-glass laser (3 J / 30 ns), we could not obtain high charge state ions. A new Nd-YAG laser (2.3 J / 6 ns) enabled us to observe many highly charged ions and the most produced ions were Ag^{15+}. We completed the plasma distribution measurements. Based on these results, we designed the new RFQ, which will accommodate Q / M = 1 / 8 particles, supposing Ag^{15+}.

INTRODUCTION

Since 2000, to generate and accelerate high intensity highly charged heavy ions, the Direct Injection Scheme (DPIS) which consists of Laser Ion Source and RFQ and then connect them directly without Low Energy Transport Line have been investigated [1]. The DPIS is the candidate of the heavy ion injection methods of a future project in Kyushu University which will have a FFAG accelerator transferred from KEK. The first experimental results were 9 mA of Carbon beam after RFQ [2]. With a new RFQ dedicated for the DPIS and continuous improvements, in 2004, 35 mA C^{4+} beam was accelerated successfully with CO_2 laser and 17 mA C^{6+} beam with Nd:YAG laser [3]. In 2005, we obtained over 60 mA of Al beam [4]. As the next step to accelerate heavier species, we investigated the laser ablation plasma property of many ion species and determined Ag as the acceleration material. This paper will show laser ablation plasma property of Ag using 2.3J / 6ns Nd:YAG laser and acceleration simulation results.

EXPERIMENTAL SETUP

Figure 1 shows a photo of whole plasma measurement line and Fig. 2. is a schematic view of the experimental setup using Nd:YAG laser (THALES LASER SAGA230). This laser has a 1064 nm wavelength, 17 mm spot size and maximum repetition rate is 10 Hz. The laser light transported in the air flying about 2 m distance with two flat mirrors went into target chamber in vacuum through a BK7 window from the incident angle of about 30 degrees to the target. These mirrors and windows were for high power laser. One convex lens (100 mm focal length) focused the laser beam onto the target surface. The residual gas pressure was about 10^{-6} Torr. The maximum power density on the target was estimated as 5.2×10^{12} W/cm^2. The shape of the target plate was 50 mm by 20 mm and 1mm thick and it was placed inside the chamber and aligned the surface perpendicular to the measurement line. The 3D manipulator allowed moving the target with minimal step of 10 μm. The laser ablation plasma mainly expanded to normal direction to the target surface. The 3D manipulator moved the target to transverse direction enough to provide fresh surface after each laser shot. The total plasma current emitted from the target was measured by the Faraday Cup (FC) at 2.4 m far from the target. The aperture size and suppressor voltage of the FC were 10 mm and -2 kV, respectively. The ions which had the proper charge to energy ratio corresponding to the Electrostatic ion analyzer (EIA) applied voltage could go through the EIA. The Secondary electron multiplier (SEM) at 3.7 m far from the target detected ions after the EIA.

Figure 1: photo of whole experimental setup.

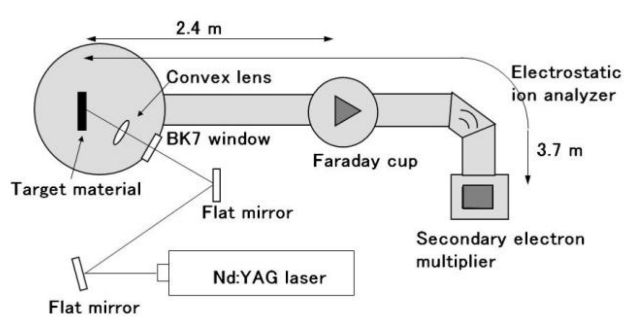

Figure 2: schematic view of the setup

EXPERIMENTAL RESULTS

To generate the highest charge state, we set the target best position for highly charged intense ion generation by shifting the longitudinal target position with the 3D manipulator. Changing focus position about 0.25 mm step, we measured the total ion current by the FC. We confirmed the best target position where realized fastest ion arrival time to FC and the highest peak current. After determined target longitudinal position, we measured separated ion signals at the SEM changing the EIA applied voltage until ion signal disappeared. Figure 3 was the typical SEM signal (Ag ions).

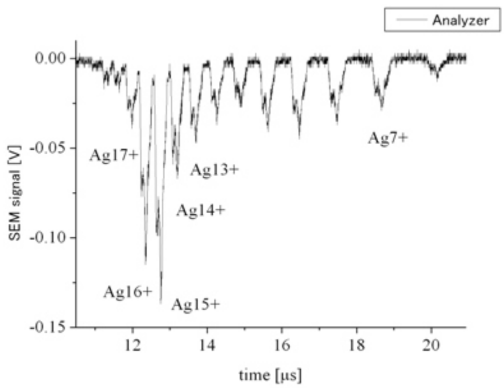

Figure 3: typical ion signal at SEM separated by EIA

We distinguished charge states in the spectrum of each applied voltage and made table of signal voltage to time to each charge state. This value had the information of the number of particle and was multiplied value by SEM, so we should calibrate using the ion total current by the FC. The plasma current was proportional to L^{-3} (L : drift distance) in case of only considering adiabatic bunching. Converted the obtained the SEM data to the FC position value applying this relation and compared the sum of each charge state signal multiplied by its charge state with the FC total current, we achieved the charge state distribution of plasma with mA scale (Fig.4. was the Ag charge distribution at RFQ entrance position). The number of particles was calculated by integrating this data and being divided by electric charge (Fig. 5.was the number of particles of Ag).

We investigated the plasma of C, Al, Ag and Ta target. The brief result is shown in Fig. 6. In this figure, the charge to mass ratio at the maximum charge state and the highest yield charge state are shown.

Following is the description of the results of Ag plasma analysis. Figure 4 shows the charge state distribution of Ag over Ag^{14+} at RFQ entrance position (30 cm far from target material and 6 mm diameter). The vertical axis is in mA. The trigger of horizontal axis is laser shot. Smaller charge state ions had similar time structure with Fig.4. The charge states spreads widely in Ag plasma from Ag^{2+} toAg^{20+}.

Figure 5.shows the total number of particles of each charge state at RFQ entrance position per one pulse. The

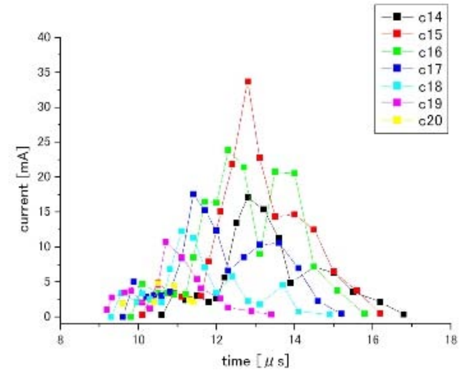

Figure 4: charge state distribution at RFQ injection condition (300 mm far from target and 6 mm diameter)

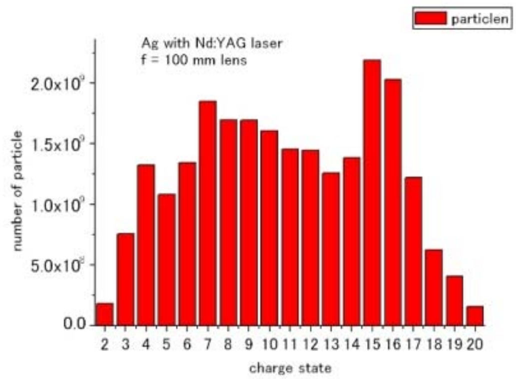

Figure 5: The number of particle per one pulse injected to RFQ

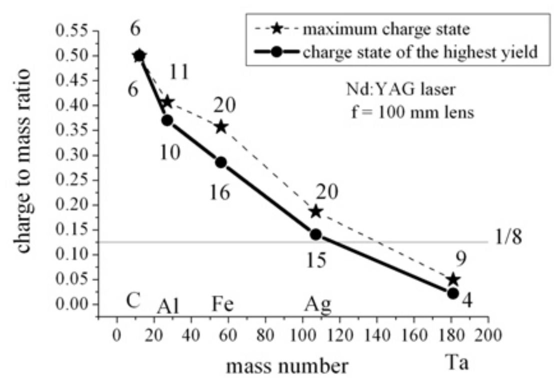

Figure 6: results of other ion species with 2.3J / 6ns Nd:YAG laser

Ag^{15+} had the highest yield and the number of Ag^{15+} particles was 2.2×10^9. We aimed to high intensity acceleration. Taking the balance of intensity and acceleration efficiency (charge state) into account, we selected Ag^{15+} as the next acceleration target ion. Towards the acceleration experiment, we are preparing to set new RFQ electrode designed for the DPIS of charge to mass ratio 1/8. In this case, over Ag^{14+} ions will be accelerated.

Mentioned about the result of Nd:glass laser, the generated Ag ions were up to Ag^{15+} and the highest yield was around Ag^{3+}.

SIMULATION STUDY

Based on the plasma property data as mentioned before, simulation study was done with a multi species beam tracking cord Pteq-HI. We took 6 time slices of charge state distribution converted to RFQ entrance condition (Fig. 4.). These time slices were 0.81μs, 0.92μs, 1.04μs, 1.12μs, 1.23μs, 1.33μs. Ag^{15+} is the main particle, and we included existing charge state to Pteq-HI up to 10 around Ag^{15+} at each time slice, respectively. The example of initial parameters is shown in Table.1. The RFQ operation frequency is 100 MHz and the extraction energy is 270 keV/u.

Table 1: the initial parameter at 1.04 μs where the peak of Ag^{15+}

main particle	Ag^{15+}
injection beam current	32.4 mA (total)
injection energy	900keV (total)

The result of simulation is shown in Fig.7. It shows the peak current of design particle Ag^{15+} was 14.4 mA which is 47% of initial current. Many of Ag^{16+} and Ag^{17+} ions are also accelerated in this simulation. The survived current of Ag^{16+} and Ag^{17+} ions at 1.04 μs are 5.1 mA (30 % of initial current) and 2.0 mA(22 % of initial current), respectively. The survived Ag^{17+} ions at 0.92μs and Ag^{16+} ions at 1.12 μs was 10 mA (64 %) and 14.0 mA (69 %).

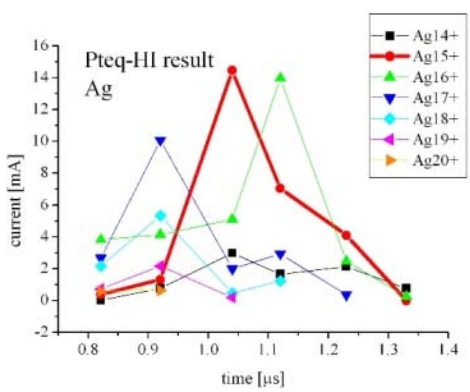

Figure 7: Pteq-HI result

CONCLUSION

The charge state distribution and the number of particle of Ag plasma generated by 2.3J/6ns Nd:YAG laser was measured. It contains Ag^{2+} to Ag^{20+} ions and the observed largest peak was Ag^{15+} where the total number of particles was 2.2×10^9. The simulation result shows 14.4 mA of Ag^{15+} ions will be accelerated using new RFQ which charge to mass ratio is 1/8. In this year, we try to do Ag acceleration experiments to confirm efficiency of the DPIS.

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