RFQ LINAC COMMISSIONING AND CARBON4+ ACCELERATION FOR AG15+ ACCELERATION VIA DIRECT PLASMA INJECTION SCHEME

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Abstract

Various species of high intensity highly charged state heavy ion beams with small emittance are required in many fields including particle physics, medical uses, inertial fusion, and simulator of space radiations. Direct Plasma Injection Scheme (DPIS), we have developed for several years, is a unique scheme to provide heavy ion beams to meet the above requirements. A high-density plasma created by a laser ablation with an initial drift velocity flies to entrance of a Radio Frequency Quadrupole (RFQ) LINAC; ions will be separated from plasma via high voltage at the inside of the RFQ LINAC. Then ions are captured by the RF buckets and are accelerated remaining high current over 10mA. In the past, we had accelerated carbon4+, carbon5+, and carbon6+ using a RFQ with partially modulated vanes. Due to the un-modulated section of the electrodes, accelerated beams were not bunched. In 2011, we replaced the vanes with a newly designed one. The designed charge to mass ratio (q/A) is 1/6 and the output energy is 270 keV/u. The beam commissioning with carbon 4+ was successfully carried out. In the next step we'll try to accelerate carbon 2+ (q/A=1/6), which is to demonstrate the feasibility of the Ag+15 ion acceleration.

INTRODUCTION

We are studying high current highly charged beam acceleration using direct plasma injection scheme (DPIS) which has been developed for several years [1]. We established how to capture and accelerate intense carbon beams with carbon beam. Using a table top small Nd-YAG laser system, carbon can be easily ionized up to fully stripped condition and the vanes in the RFQ was designed to accelerate more than 4/12 of charge to mass ration. We had tested carbon 4+, 5+ and 6+ acceleration. In the next step, we plan to accelerate heavier species like silver, bismuth or uranium, newly designed vanes were demanded. Currently we are testing laser irradiation conditions. In parallel, we modified the RFQ to accelerate lower charge to mass ratio particles. In this paper we describe the beam-commissioning test with a new set of vanes.

LASER ION SOURCE

High power laser irradiation on the solid target makes laser ablation plasma. A laser power density of more than 10^10[W/cm^2] is required to induce high charge state ions, therefore laser light is needed to be focused by an optical lens. The plasma contains a stream of high brightness highly charged ion flux. By extracting ions from the plasma, intense ion beams can be easily provided.

Since the ablated plasma is emitted from a target material, the plasma moves away from the target. Simultaneously, the plasma expands three dimensionally. So the plasma plume volume expands longitudinally and transversely in a free space. The longer length of the plasma in the space gives a longer ion beam pulse width and thinner ion current density. These relations are shown in equations (1) and (2). The τ is a pulse length, and the j is a current density of generated ion beam. The L is a plasma drift distance, the length from target to the ion extraction position.

$$\tau \propto L \tag{1}$$

$$j \propto L^{-3} \tag{2}$$

In a conventional laser ion source, however, once high intensity ion beam is extracted, the beam quality is suffered by its own repulsion forces called space charge effect. Due to severe non-linear force of the space charge, the emittance of the extracted beam grows immediately. This is a common issue of a Low Energy Beam Transport (LEBT) line with high current beams.

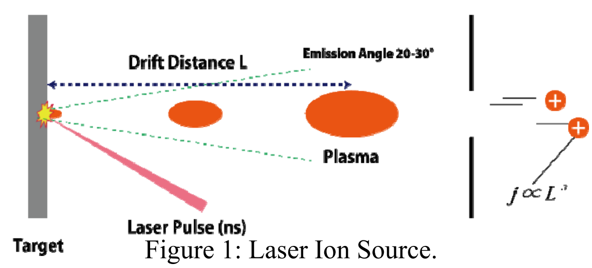

Figure 1: Laser Ion Source.

DIRECT PLASMA INJECTION SCHEME

The DPIS was developed to mitigate the problem of the strong space charge effect. The ablation plasma is created in a high voltage region and is transferred to an RFQ with its initial expanding velocity. At the entrance of the RFQ, the contained ions by the plasma are extracted from a nozzle which is connected to the plasma expansion high voltage region. Then the beam is captured by the RFQ electric field, and is accelerated efficiently. The ion beam is not exposed by the strong space charge effect in the transport line.

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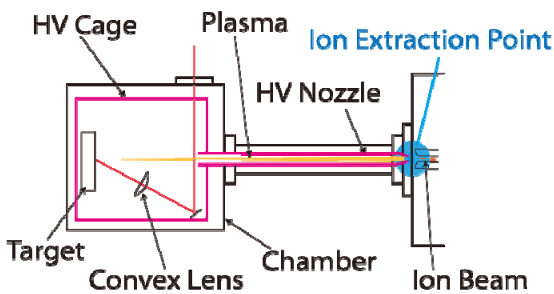

Figure 2: DPIS settings.

RFQ LINAC

Radiofrequency Quadrupole Linear Accelerator (RFQ LINAC, Figure 3) is accelerator for low energy ion beam. The quadrupole electric field excited by the modulated quadrupole electrode can accelerate ions on longitudinal axis with focusing on transverse axis (Figure4).

On the longitudinal axis, ions follow a synchrotron oscillation, and on the transverse axis, ions follow a strong focusing.

The RFQ parameters we used in this experiment are shown in Table1.The output energy and Beta is calculated from the input energy by the PteqHI, and the Q value is measured using a network analyzer.

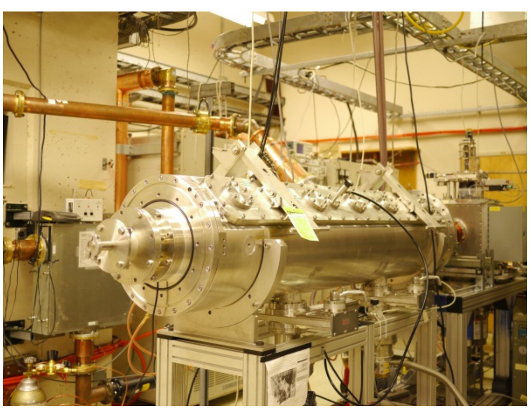

Figure 3: RFQ LINAC.

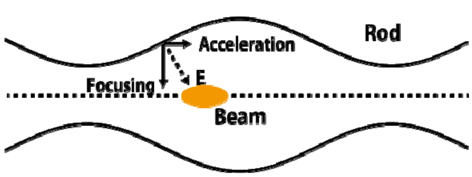

Figure 4: Electric field in RFQ LINAC.

INJECTION STRUCTURE ALIGNMENT

Since the extracted ion beam starts from the nozzle at the entrance point of the RFQ, the alignment of the nozzle and vanes are important. We measured 3D coordinates of the beginning section of the RFQ vanes by a FARO gage.

Table 1: Parameters of RFQ LINAC.

Parameter	Value
RFQ Type	4 rods
Charge to Mass Ratio [q/A]	1/7.19
Length [m]	2.0
Cell number	143
Input Energy [keV/u]	8.26
Output Energy [keV/u]	270
RF Frequency [MHz]	100
Rod Voltage [kV]	73
Unloaded Q Value	4500
Loaded Q Value	2250
Beta	0.024

The obtained shape data were input to OPERA 2D and the electric quadrupole center of the vanes was simulated (Figure 5). Because the positions of the electrodes were slightly off from the ideal positions, the field simulation is useful to define the accurate center coordinate. Then the end wall of the RFQ tank and the extraction nozzle were placed. The accuracy is 10μm. The nozzle radius at the injecting position is 4mm, and a radius of the RFQ vane is 8mm.

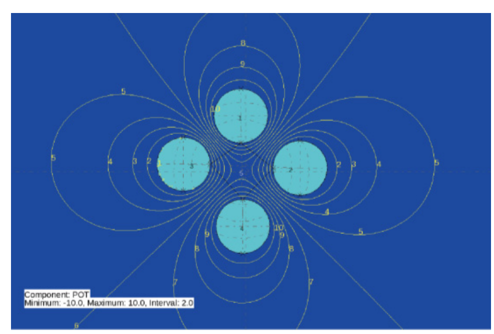

Figure 5: Electric field at injecting position.

CARBON ION BEAM ACCELERATION

After the alignment of the apparatus, we tried the first beam acceleration. We chose a carbon target for the trial. A Nd:YAG (1064nm) laser was set to provide 1.0J per shot. The laser beam was focused on the target by a plano-convex lens and the laser power density on the target was about 10^{10} W/cm^2. The high voltage applied to ion extraction form the plasma was 25kV which is fit to the injection energy of carbon 4+ beam. Figure 6 shows the settings.

Figure 7 shows the signal of the accelerated beam. The RF input power is 23.4kW. The peak current is 6 mA, and the pulse length is 2μs. As seen in the figure, the beam was clearly bunched and this indicated the ion beam was

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accelerated. The ions were captuerd by longitudinal buckets.

Figure 8 is the result with 19.7kW RF input power and 25kV extraction voltage. The carbon 4+ ions are completely accelerated, and the other charge state ions were not accelerated. We tried to scan the RF input power, the peak current is highest at the around 19.7kW.

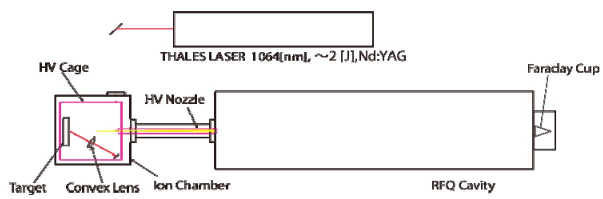

Figure 6: Acceleration Settings

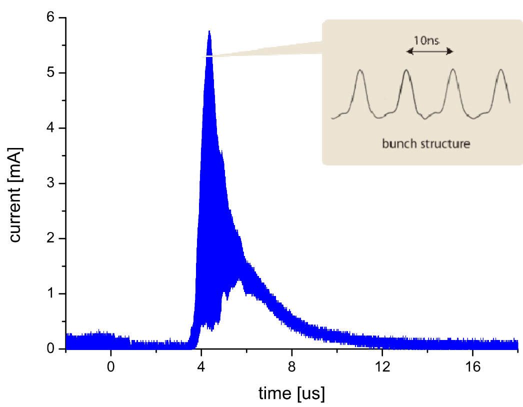

Figure 7: Carbon beam signal and the bunch structure.

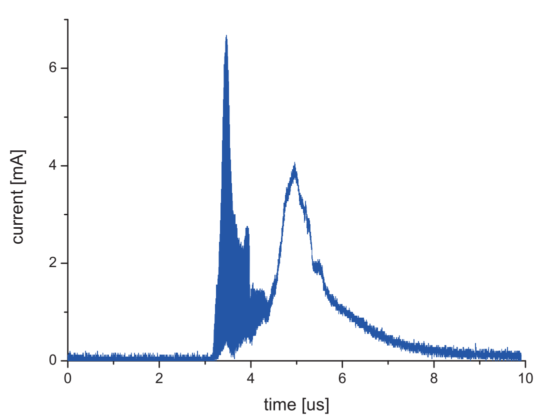

Figure 8: Accelerated and Non-Accelerated Beam.

SUMMERY AND FUTURE PLANS

We succeed the commissioning the new vanes of RFQ LINAC with a carbon beam. The alignment the RFQ vanes and the extraction nozzle were done with direct measurement using a coordinate measuring machine. The detected beam was clearly bunched and this indicated that the carbon beam was accelerated as expected. The beam current reached 6mA, and the pulse length was 2µs.

We plan to accelerate Ag15+ beam this summer. For this purpose, laser plasma production experiment is in progress.

ACKNOWLEDGEMENT

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[1] T.Kansesue, M.Okamura, K.Kondo, J.Tamura, H.Kashiwagi, and Z.Zhang, “Drift Distance survey in direct plasma injection scheme for high current beam production,” Rev. Sci. Instrum. 81, 02B723 (2010); doi: 10.1063/1.3298845.

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