DIRECT INJECTION SCHEME FOR RFQ LINAC

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Abstract

A new injection scheme for RFQ using laser source was proposed and tested successfully. More than 9 mA of Carbon beam was detected after TITech RFQ and an advantage of this scheme, no space charge repulsion force in LEBTs, was verified. A new beam simulation code can reproduce the experimental results well and indicates a capability to build a 100 mA class heavy ion RFQ.

1 INTRODUCTION

It has been difficult to built real high intensity heavy ion RFQs. The difficulty is due to a space charge repulsion force in beam being injected into RFQs. One of the benefits to adopt an RFQ as a first stage accelerator is a simplicity in high voltage terminal where usually an ion source locates. However, for heavy ion acceleration, applicable voltage to the ion source is limited to savor the simplicity and the space charge force, which affects inversely proportional to square of beam velocity, is the serious issue to be solved. In order to overcome the problem, a new injection method, called direct plasma injection scheme, DPIS, was proposed. Plasma is produced from solid material hit by laser light. The induced plasma is transported to the RFQ as in electrically neutral condition. At the entrance of the RFQ, highly charged intense heavy ions are extracted from the plasma and then captured by focusing strength in the RFQ channel.

2 VERIFICATION TEST AT TIT

Verification test has been done using TITech RFQ[2] at Tokyo Institute of Technology. Tested target materials for ion production are Carbon and Boron. In this paper, we like to report results using Carbon beam.

2.1 Experimental Set-up

Design parameters of the RFQ are listed in Table 1. This RFQ was designed to achieve high shunt impedance and the assumed target beam was 10 mA of O^+. It is not entirely appropriate to accommodate the intense beam from the laser source. Then, we focused on proving the principle of the new scheme. A 4.1 J TEA CO_2 laser with 38 ns pulse duration was used as a driver for plasma production. The measured total power was 1.1×10^8 W. The diameter of the laser beam is about 50 mm with hollow 20 mm in diameter. A photo and a figure of the target chamber, which includes focusing mirror and solid target materials, are shown in Figures 1 and 2. The laser light emitted from right side was focused by the concave cupper mirror onto the rotatable target. The induced plasma went through a centre hole of mirror and ϕ4 mm aperture, which is 6 mm apart from RFQ vanes.

Table 1 The main parameters of the TITech RFQ

	Designed Values
Charge to mass ratio	≥1/16
Operating frequency (MHz)	80
Input energy (keV/amu)	5
Output energy (keV/amu)	214
Normalized emittance (100%)(cm·mrad)	0.05 π
Vane length (cm)	422
Total number of cells	273
Characteristic bore radius, r_0 (cm)	0.466
Synchronous phase	-90˚ to -20˚
Inter-vane voltage (kV)	78.9
Maximum field (Kilpatrick)	2.2
Calculated *Q* value	20000
Wall loss (kW)	89
Shunt impedance (MΩ/m)	29.5
Transmission for q/A=1/16 beam 10 mA input	6.84 mA

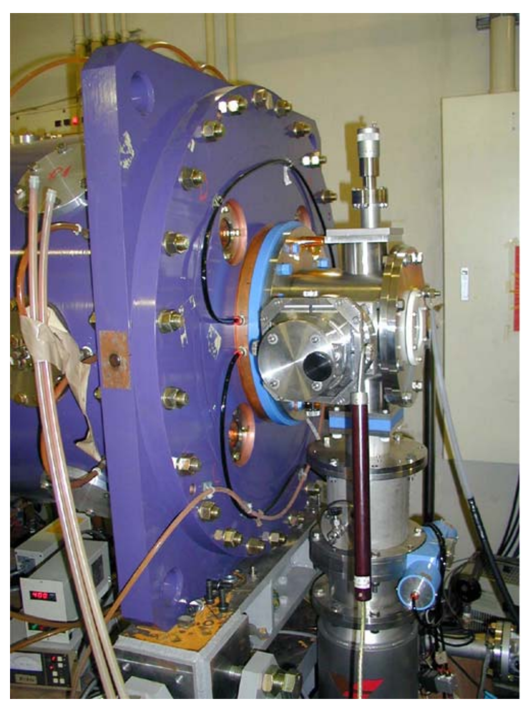

Fig. 1 Photo of the target chamber

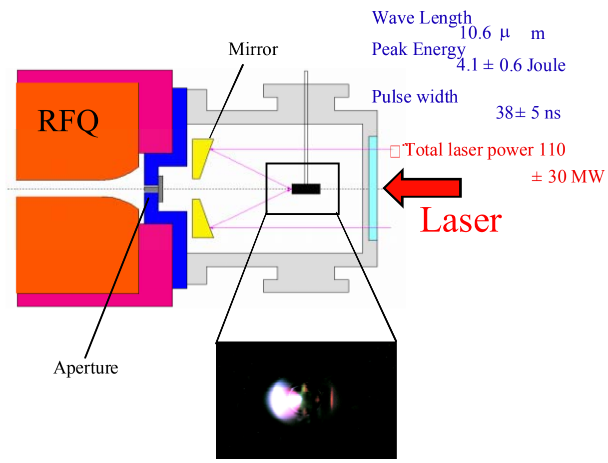

Fig. 2 Schematic view of the target chamber

Table 2 Injected Carbon ions into the RFQ

	C^{4+}	C^{3+}
Current [mA]	20.7	4.3

The injected Carbon beam currents into the RFQ were estimated based on plasma property measurement that was done in RIKEN and indicated at Table 2. A distance between the target surface and edges of the vanes was only 324 mm. The currents were measured by two Faraday cups. The first one was placed several tens mm downstream from the end of the RFQ and another Faraday cup was installed after an analyzing dipole magnet. The transport line after the RFQ was not dedicated to this experiment so that transmission of the line was not satisfactory.

2.2 Measured Wave Form

Figure 3 shows a typical current waveform obtained from the Faraday cup just after the RFQ. The peak current has reached 25 mA.

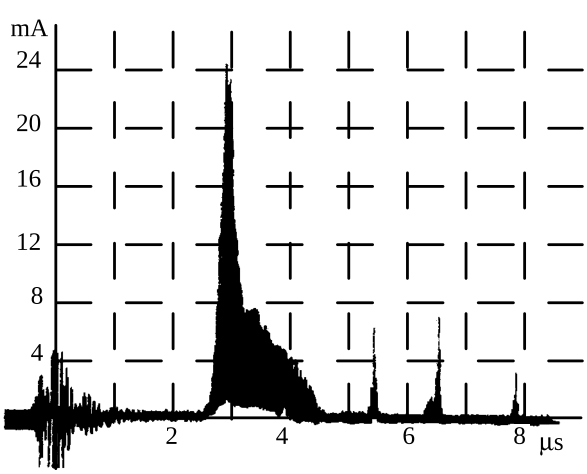

Fig. 3 Measured current just after the RFQ Linac

The observed ion current reflects the bunch structure of the accelerated beam due to short distance between the RFQ and the Faraday Cup. This means that the beam current shape represents the envelope of the peaks that appear at RF cycles of 80 MHz. The observed peak current of 25 mA can be converted into the averaged peak current of 7.8 mA. A start time, t = 0 was triggered by laser light. The flight time proved that the injected beam was accelerated properly.

2.3 Operating Conditions of the RFQ

The RFQ was designed for q/A = 1/16 ions, on the other hand the injected particles are mainly q/A = 1/4 and 1/3. Due to present condition of the RF power amplifier and the Linac, the applicable power was limited. However, required minimum RF powers for these ions were lower than applicable power, so that the fed RF power was scanned. The RFQ vane electrode voltage in the designed condition is +- 39.45 kV (inter-vane voltage = 78.9 kV). As a matter of convenience, we define the designed vane voltage factor as *vfac* = 1.0. Therefore, for example, *vfac* = 0.6 means the vane voltage 47.3 kV. In addition, supplied extraction voltage to the target chamber was varied and optimal conditions were derived.

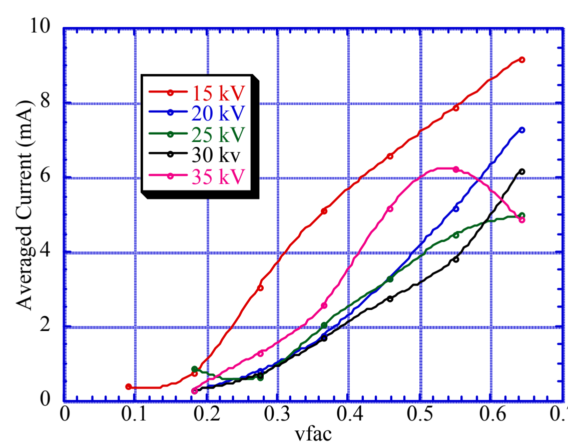

Fig. 4 Total currents vs. *vfac*

Figure 4 indicates the graph with a horizontal axis as *vfac* and a vertical axis as the obtained averaged peak current with the Faraday cup just after the RFQ. The accelerated current increased as increase in RF power and that 15 kV of target chamber voltage was the optimal conditions where the beam current reached to 9.22 mA. At the 15 kV injection voltage, C^{4+} injection energy is 5 keV per nucleon, which exactly matched to the RFQ Linac design value. The current became lower on the condition of 20 kV through 30 kV target chamber voltage. This is because the injection energy of C^{4+} was main particles of the injected beam. The injection energy was deviated very much from the designed value and no longer matched with the RFQ Linac. Over *vfac* = 0.54, the current decreased on the condition of 35 kV. Reduction in

C^{4+} as well as C^{3+} occurred due to being out of the matching condition, while C^{2+} might achieve the matching condition of 30 kV.

2.4 Analyzed Currents

The analyzed currents were detected by another Faraday cup located after the analyzing bending magnet. The currents of C^{4+} and C^{3+} are indicated in Fig. 5.

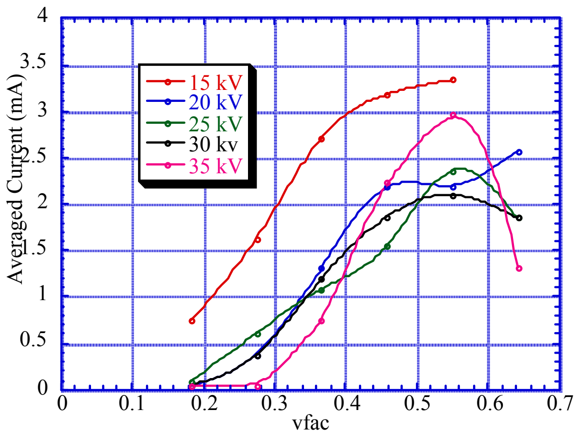

Fig. 5 (a) Analyzed current of C^{4+}

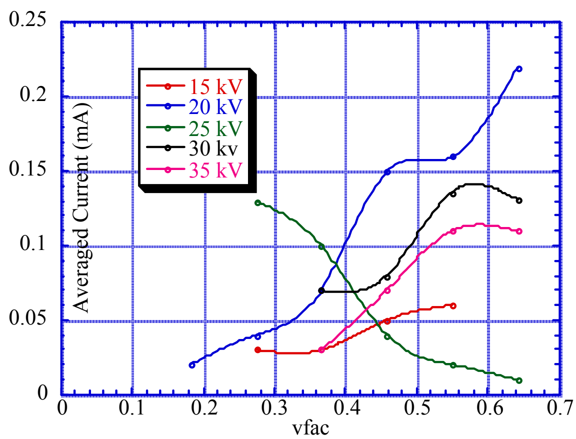

Fig. 5 (b) Analyzed current of C^{3+}

The analyzed currents were maximized to get optimal settings of a triplet magnet that was between the RFQ and the analyzing magnet. However, due to small beam pipe, some amount of the transported beams was lost.

The C^{4+} beam current reached to the maximum at the highest *vfac* at 15 and 20 kV. Findings revealed, however, that the maximum C^{4+} current was larger at *vfac* of 0.54 at 25, 30 and 35 kV. The results also found that C^{4+} beam current was likely to decrease at higher injection voltage for *vfac* of 0.2 and 0.3. The C^{3+} beam current reached to the maximum at the highest *vfac* of 0.64 at 20 kV. The results supported that 20 kV was the target chamber voltage that allowed C^{3+} beam to match the designed injection energy of the RFQ.

3 SIMULATIONS

In case of the DPIS, not only expected uni-charged state particles but also un-wanted multi-charged particles are injected and captured in RFQ. Therefore, we used a code "pteqHI"[3] which was originally refined from the PARMTEQ and modified to handle multiple ion species. The emittance at the RFQ injection plane 6mm from the extraction aperture was computed using a 3D code using realistic 3D RF field map created by TOSCA. Using this emittance as the input to the RFQ, the simulation produced essentially exact agreement with the experimental results at the Faraday cup jus behind the RFQ, Fig. 4, over the full range of injection voltages and vane voltage factors. The excellent agreement between experiment and simulation for the RFQ gives confidence for the design of a new, dedicated RFQ.

4 NEW RFQ DESIGN

The new RFQ is being planned for the next step in developing the new scheme. To demonstrate the possibility of the DPIS, design goal was set to acceleration of 100 mA of C^{4+}. The operating frequency was surveyed assuming very low emittance from the source, about 10 mm mrad, which was predicted by a beam tracking including realistic 3D RF field map. Three frequencies, 40MHz, 80MHz and 120 MHz, were compared with various injection beam energy. We found that higher injection energy will give higher beam transmission. However, 100 kV seems to be practically maximum voltage to the target chamber. The simulation shows 80 MHz is best and more than 95 % of the beam transmission can be expected with 100 kv of the injection energy. For mechanical structure, 4 rods type resonator will be adopted considering low duty factor and cost. We are also testing Nd-Yag laser system as a plasma production driver for higher repetition rate.

5 CONCLUSION

In order to capture the intense ion beams from the laser ion source, the direct plasma injection scheme has been proposed. The first accelerated carbon beam was observed successfully and reached 9.2 mA. This method is quite useful to utilize the intense beam from the laser ion source for various applications. Much more intense beam is expected from the dedicated new RFQ.

6 REFERENCES

[1] M. Okamura, et al., Nucl. Inst. and Meth., B 188 (2002) 216-20

[2] M. Okamura, et al., Nucl. Inst. and Meth., B (1995) 694-96

[3] R. A. Jameson, RIKEN internal reports. (2001, 2002)