Acceleration Test of the TITech RFQ Using Direct Plasma Injection Method

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Abstract

For heavy ions, a new injection method into RFQ linac was invented. Laser plasma was created by an intense pulsed laser system and can be directly injected into the RFQ without any focusing devises. This method might eliminate complicated difficulties due to space-charge effect within low energy transport systems. Using TITech RFQ, a verification test has been done. From the laser ablated carbon plasma, C^{4+} beam was captured successfully and was accelerated to the designed energy of the RFQ. The observed current of C^{4+} beam had reached to 4 mA which exceeded designed current of the RFQ.

1 INTRODUCTION

At RIKEN, a laser ion source[1] is being developed. Generally, this type of pulsed ion source can provide high intensity heavy ion beams with highly charged states and is well suit for injection to synchrotrons. However, the beams from the laser ion source have wide energy spread, strong space charge effect, and time variation of current, which consists of various kinds of charge states. Also, beam profile changes dynamically[2]. Due to the these complex features, it is extremely complicated to design a low energy transport line between the source and the first stage accelerator, which usually consists of an extraction system and specially made focusing devises[3]. In CERN and ITEP, the design studies of the low energy transport line have been done intensively, however, the satisfactory results weren't achieved yet. In order to accept the pulsed intense beams from the laser ion source, a special attention should be paid to design the injection scheme into the RFQ.

2 THE LASER ION SOURCE IN RIKEN

Using a 4 J TEA CO_2 laser with 70ns pulse duration, the basic parameters of expanding plasma has been measured in RIKEN. The irradiated power density is estimated as 10^{11} W/cm^2 and the measured divergence of expanding ablation plasma was less than 20 degrees[4]. In case of a carbon target, we had obtained several tens mA of C^{4+} beam at 3 m away from the target. For accommodating such a strong current pulsed beam, an efficient method to inject the beam into an RFQ had to be investigated.

3 DIRECT INJECTION METHOD

The beam emittance from the laser source is determined by emittance growth due to strong space charge effect. If we assume only expanding shape of plasma, 0.3 mm radius of the laser spot on the target and 20 degrees of divergence, the normalized beam emittance of ions in the plasma will be only about 0.057 π mm mrad. In order to reduce space charge effect at the initial beam from the source, direct injection method has been proposed. A schematic view of the direct injection system is drawn at Fig.1. The laser target is located in a vacuum chamber, which is directly connected to an RFQ, however electrically isolated. After laser hit the target, ablated plasma expands in the target vacuum chamber which is hooked to a high voltage power supply, and the plasma goes directly into the RFQ channel. At the entrance of RFQ, the electrons in the plasma will be deflected and only the ion beams will be trapped by RFQ focusing force. Finally the injected intense beam will be accelerated up to the designed energy.

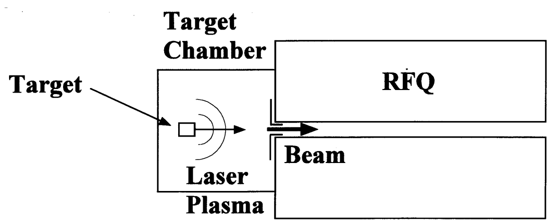

Fig. 1 Schematic view of the Direct Injection Method

4 THE FIRST EXPERIMENT

In order to verify the feasibility of this scheme, the acceleration test was carried out using TITech RFQ[5]. This heavy ion RFQ was originally designed for medium current beams and isn't appropriate for accommodating the intense beam from the laser source. On this experiment, it was focused to prove the principle of the Direct Injection Method.

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°
Transmission	
for q/A=1/16 beam 10 mA input	6.84 mA

The main design parameters of the RFQ are listed in Table 1. A conceptual layout of the experimental set-up is indicated in Fig. 2. The laser beam, emitted from the TEA CO_2 cavity, was guided by two plain mirrors and then focused onto the carbon target by a concave donut shaped mirror, which is installed between the target and the RFQ cavity. The ablation plasma is induced from the target surface and expands passing through the hole of the concave mirror and then a small slit. This slit, (ϕ 4 mm, aimed to scrape the exceeded plasma that cannot fit into the beam channel of the RFQ, and is placed vary close, 6 mm from the electrodes, to the RFQ. The only small portion of the ablated plasma, estimated about several hundreds mA of the beam current, can go into the RFQ. In order to adjust the velocity of the carbon ions to the designed value of the RFQ, high voltage was supplied to the target chamber.

The accelerated carbon beam was observed successfully at the Faraday Cup located just after the RFQ. The measured peak current has reached 25 mA as shown in Fig. 3. 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 shown in Fig. 3 represents the envelope of the peaks which appear at RF cycles of 80 MHz. The observed peak current of 25 mA can be converted into the averaged peak current of 11 mA. On this measurement, the target was at 20 kV. It was expected that the measured current at F.C. 1 contains C^{4+}, C^{3+} and C^{5+} considering injection ion velocities. The analyzed beam current at F.C.2 is shown at Fig. 4. Triplet of quadrupole magnets was optimized to obtain highest current. The measured peak current was 3.9 mA and 1.6 mA for C^{4+} and C^{3+} respectively. The distance between the F.C. 2 and the RFQ is enough to get de-bunched the beam. The effect of the bunch structure to the current isn't needed to be taken into account. The TITech RFQ was designed to optimized to get 6.8 mA of O^{+} beam. In case of C^{4+}, the space charge effect behaves much stronger and the designed optimised current corresponds to about 0.35 mA, which is much smaller than experimentally achieved current. The obtained maximum current was 3.9 mA at 70 % of maximum inter vane voltage. It was found that the Direct Injection Method performs excellent for the laser ion source.

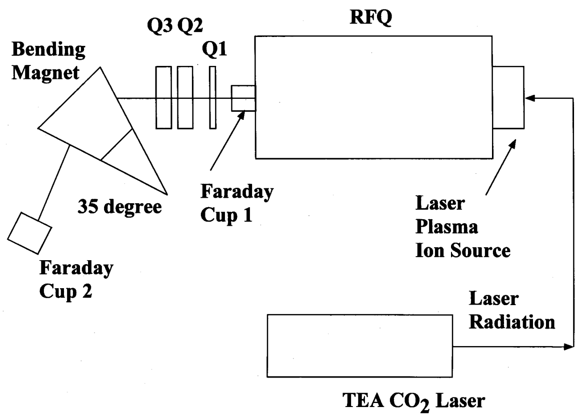

Fig. 2 The layout of the experimental set-up

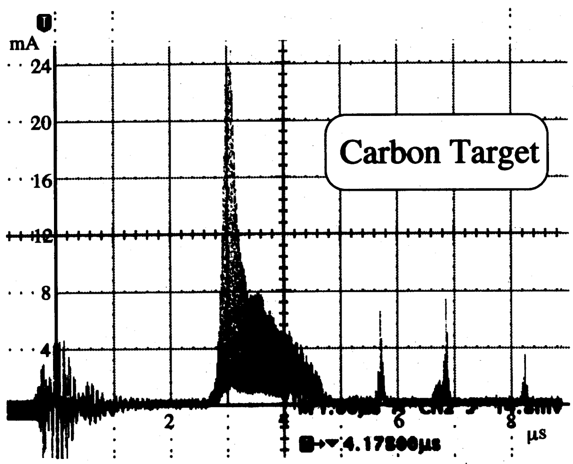

Fig. 3 Measured current at F. C. 1.

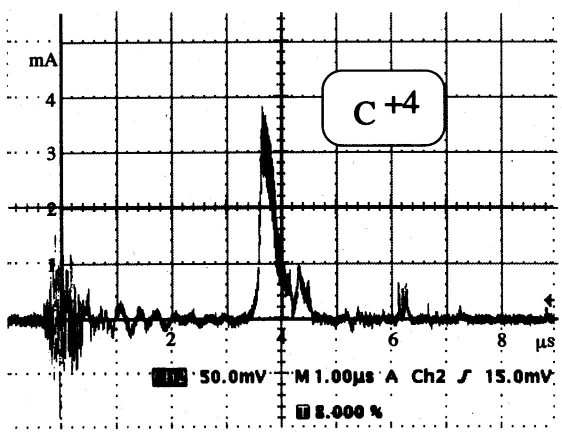

Fig. 4 Analysed C4+ beam.

5 CONCLUSION

In order to capture the intense ion beams from the laser ion source, the direct injection method has been proposed. The first accelerated carbon beam was observed successfully and the obtained current was much higher than expected. This method is quite useful to utilize the intense beam from the laser ion source.

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