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Experiments of Beam-Induced-Plasma for Basic Study of HIF by RFQ-Linac

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Abstract

An intense heavy ion linear accelerator system is being constructed for basic researches on HIF and heavy ion pumped laser at TIT. This accelerator system consists of an RFQ-Linac, an ECR ion source, a fine-focusing beam transport system and a fast beam pulsing system. At present, the obtained maximum beam current from the TIT-RFQ is 1.6 mA for 4He+. By using this system, An ion beam of $^4He^+$ with an energy of 220 keV/amu was focused onto a small spot area of about $1mm^2$. This beam deposited a specific deposition power of about 0.14 GW/g to the target. The overall status of this linac system and preliminary experiments with beams of $^4He^+$ are discussed.

1.Introduction

Heavy ion beams are one of the favorable drivers for Inertial confinement fusion because of their good efficiency and effective energy deposition in the target. It is important for Heavy Ion Inertial Confinement Fusion (HIF) to make researches on a heavy ion accelerator and a beam-target interaction. At Tokyo Institute of Technology (TIT), a heavy-ion-induced plasma has been studied for basic researches on HIF and heavy ion pumped laser. For these experiments, an energy driver is required to create a high intensity and brightness beam. An intense heavy ion linear accelerator system is being constructed to meet the requirements. Fig 1 shows the layout of the intense heavy ion linac system. This system consists of a four vane type 81 MHz Radio-Frequency Quadrupole Linac (TIT-RFQ), a 2.45 GHz Electron Cyclotron Resonance (ECR) ion source, a fine-heavy ion linac system. The first experiments have been carrying out with 4He+ beams.

2. Intense ion beams from an RFQ-Linac

The TIT-RFQ was designed to accelerate particles with a charge to mass ratio (q/A) greater than 1/16 from 5 keV/amu up to 220 keV/amu. The calculated beam transmission is 68.4% for 10 mA with a beam of $^{16}O^+$. The main parameters of the TIT-RFQ are shown in Table 1 [1].

Table 1.Parameters of the TIT-RFQ

Charge-to-mass ratio	≥1/16
Operating frequency (MHz)	80.9
Input energy (keV/amu)	5
Output energy (keV/amu)	220
Duty factor (%)	10
Q factor	10635
Cavity diameter (cm)	72.5
Cavity length (cm)	425
Expected beam transmission (%)	
0 mA input	91.8
10 mA input	68.4

At present, the beam experiments are being performed with intense $^4He^+$ beams by using a 2.45 GHz Electron Cyclotron Resonance (ECR) ion source. This ECR ion source can produce a beam current of 2.5 mA for $^4He^+$. The maximum productive ratio of $^4He^+$ is more than 99%. The $^4He^+$ beam is extracted by a voltage of 20 kV from the plasma chamber and focused with an einzel lens, and injected into the RFQ. The maximum obtained beam current was 1.6 mA for $^4He^+$ after the acceleration by the RFQ-Linac [2]. By considering the beam acceptance, a transmission efficiency is estimated to be 70%. This result is in good agreement with the calculated beam transmission.

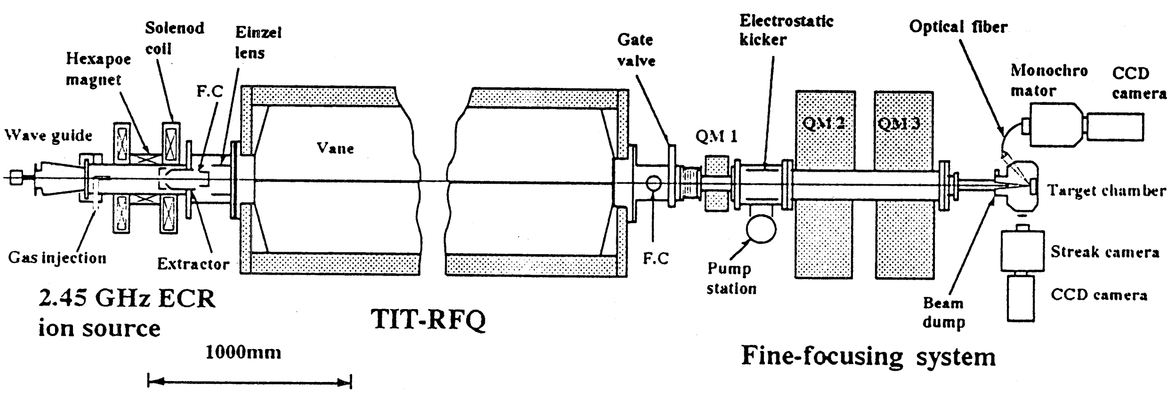

Fig.1. Layout of the intense heavy ion linac system at TIT

3. Fine-focusing system

The fine-focusing system after the RFQ should be designed to obtain minimum beam spot size in order to increase a specific deposition power P (W/g). Because if the beam can deposit enough energy to be evaporated in the target, then the specific deposition power P is the appropriate parameter to estimate the temperature of the beam-induced plasma.

We designed the fine-focusing system that consists of a faraday cup, a gate valve, three magnetic quadrupole lenses and an electrostatic beam kicker. The magnetic quadrupole lenses were made with a bore diameter and a maximum field gradient to be 60 mm and 3 kG/cm respectively. The parameters of RFQ output beams were analyzed by using the computer code PARMTEQ-H. The momentum dispersion is about 0.8 %. The initial phase space occupied by the ion beam is 24.5 mm mrad in the x - and y - directions for the maximum intensity of the RFQ-beams. The beam envelope for the fine-focusing system was calculated by using the computer code MS-TRANSPORT (M. Sekiguchi at INS). The calculated beam envelope is shown in Figure 2. By the result of the simulation, the heavy ion beam of $^{16}O^{+}$ with a current of 7 mA and an energy of 3.5 MeV can be focused onto a spot size of 1.0 mm^2. From this spot size, the beam power density of 2.5 MW/cm^2 - during the macropulse of the RFQ Linac - is expected to be transferred to the target.

At present the ECR ion source for the TIT-RFQ can produce only $^4He^+$ beam. After conditioning the magnetic lenses, we focused $^4He^+$ with a beam current in the macropulse of about 1.6 mA. In this case the beam current corresponds to the ion beam of $^{16}O^+$ with a current of 6.4 mA. To measure the size of the spot, we stopped the $^4He^+$ beam in an aluminum target (0.8 mm in thickness), where the $^4He^+$ beam marked the geometric structures (Fig 3). Table 2 shows the comparison of calculated and experimental spot size. The area of experimental spot size is 1.06 mm^2. This value is in good agreement with the calculated value. A power of 1.4 kW was transferred to the aluminum target. This corresponds to a specific deposition power of 0.17 GW/g.

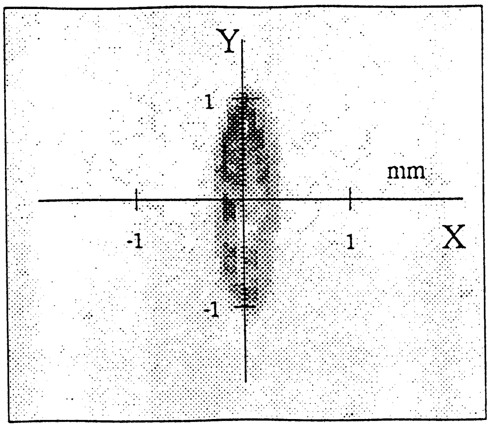

Fig 3. Marked spot size structure by focused 4He+ beam in an aluminum target

Table 2. Comparison of calculated and experimental spot size for $^4He^+$ beam with a current of 1.6mA.

	x (mm)	y (mm)	S (mm^2)
Calculated value	0.26	1.22	1.00
Experimental value	0.30	1.12	1.06

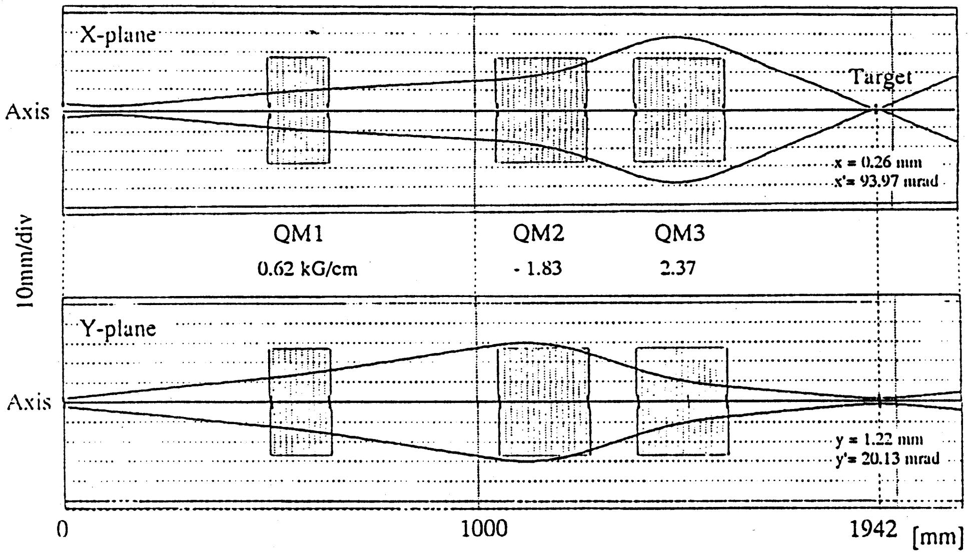

Fig 2. Calculated beam envelope for the fine-focusing system by the computer code MS-TRANSPORT. [16O+:7mA]

4. Expected Parameters of beam-induced plasmas By Simple Scaling Laws

At the first, the beam-target interaction experiments to study the heavy-ion-induced plasma are planned by using a solid target, and then a gas puff target. The gas target is a cylindrical tube of 25 mm length and 10 mm diameter. Table 3 shows the expected parameters of ion-induced plasma for various solid targets. Table 4 shows the expected specific deposition power for various ion beams in H2 gas target (1 atm). The deposition power P (GW/g) is given

$$P = \frac{I \times E}{\rho \times \pi r^2 \times R} \qquad (1)$$

with the total particle energy E (keV), the particle intensity I (mA), the density of matter (g/cm3), the initial radius of the target r (cm) and the range of the ion beam in matter R (cm). The maximum temperature is expressed

$$T_{\max}[eV] \cong 50 \times \left(\frac{3P \times r}{2}\right)^{\frac{1}{2}} \qquad (2)$$

for solid targets [3-4].

By the simulations of simple scaling laws, the beam power amounts to 24.6 kW, and a specific deposition power can be obtained 11.5 GW/g to focus a heavy ion beam of 16O+ with currents of 7 mA and an energy of 3.5 MeV in H2 gas target.

The parameters of ion-induced plasma such as the electron density and temperature are measured with a CCD camera coupled to a streak camera.

Table 3. Expected parameters of ion-induced plasma for the TIT-RFQ Beam
16O+ (3.5 MeV, Imax=7 mA, Wmax =24.6 kW)

Target (solid)	R (10-4cm)	P (GW/g)	Tmax (eV)
Al	2.96	2.93	0.98
Ti	2.54	2.02	0.66
Ag	1.73	1.28	0.53

Table 4. Expected specific deposition power for various ion beams in H2 gas target (1 atm).
[Beam spot size : 1.06 mm2]

ION BEAM	BEAM CURRENT (mA)	BEAM POWER (kW)	P(GW/g)
4He+	2.0	1.76	0.76
14N+	6.1	18.9	9.00
16O+	7.0	24.6	11.5

5. Conclusion

The intense heavy ion linac system for plasma experiments is currently set-up. By using this focusing system, we succeeded that the $^4He^+$ beam with a current of 1.6 mA from the TIT-RFQ focused onto a small spot area of about 1 mm^2. Due to the short range of the ion beams of about 1 mg/cm^2, the beam power of 1.4 kW amounts to a specific deposition power of 0.14 GW/g to be transferred into the target. The first experiment of $^4He^+$ beam-induced plasma will soon be carried out by using a gas puff target.

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