

LASER ION SOURCE FOR RIKEN MUSES PROJECT

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Abstract

CO₂ Laser Ion Source (LIS) for MUSES project is currently being developed at RIKEN. CO₂ laser with the power density of 10¹⁰ W/cm² was used to LIS. In order to minimize the space charge effect of high current of heavy ions, we have a plan to install the connection system of the LIS and the RFQ linac. For this purpose, we measured the velocity and the pulsed distribution of the plasma flow produced by the LIS.

1 INTRODUCTION

1.1 Outline of MUSES project

MUSES (Multi-USE Experimental Storage ring) is designed to make use of a new experimental technique for the radioactive isotope (RI) beams [1]. The MUSES will be constructed at the downstream of the super conducting ring cyclotron (SRC, K=2500) on the RIBF (Radioactive Isotope Beam Factory) at RIKEN [2]. It consists of a radioactive isotope beam separator (RIPS-M), an accumulator cooler ring (ACR), a booster synchrotron ring (BSR), a double storage ring (DSR), and a 300 MeV electron linac (e-Linac). ACR includes the electron cooling system and the stochastic cooling system, and works for the accumulation and cooling of RI or ion beams. BSR works for the acceleration of ion and electron beam. The DSR permits various studies of colliding experiments such as merging or head-on collisions of two beams of stable or RI ions, and electron and stable or RI beams. Wide varieties of nuclei, from light to heavy nucleus, are planned to be accelerated up to 3 GeV for the proton and 1 GeV/u for heavy nucleus. The details of each accelerator are given in elsewhere [3-6].

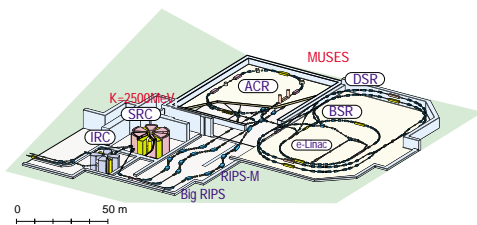


Figure 1: Plan view of RIBF and MUSES

1.2 Ion Source Requirements for MUSES

To accelerate ion beams extracted from the ion source effectively, highly charged ions ($M/q \leq 10$) are required for ion source. A pulsed beam with the beam intensity of at least 100 particle micro ampere is required for producing

the RI beam effectively in RIPS-M. If a typical beam transmission from an ion source to RIPS-M injection point is estimated as 10 %, a primary beam has to be higher than 1 pmA. Produced RI beams are separated by RIPS-M and injected into the ACR by means of a multiturn injection method as shown in Fig. 2. The revolution frequency is nearly equal to 1 MHz, i.e. 1 turn on ACR spends 1 micro seconds. Since a number of ion beam turns in ACR is 20, the pulse duration time for the ion beam has to be longer than 20 micro seconds. The RF stacking time and the cooling time for both of the electron cooling and stochastic cooling are 100 ms. Therefore, the repetition rate for the ion beam requires 10 Hz. The required performances for the ion source are listed at the Table 1.

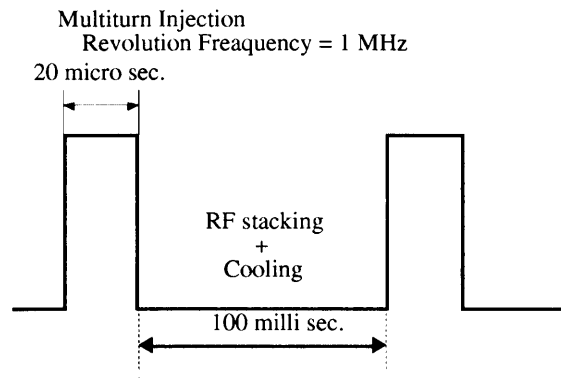


Figure 2: Time chart at ACR.

M/q	10
Beam Intensity	1 pmA
Beam Pulse Length	20 micro sec
Repetition Rate	10 Hz

Table 1: Requirements of ion source for MUSES

1.3 Purpose

To meet requirements mentioned above, we are developing the laser ion source (LIS). However, LIS has the serious problem that causes the strong influence of the space charge for the very high ion current. It is reported that typical value of the transmission through the low energy transport beam line (LEBT) is 25–30 % [7]. To minimize the space charge effect, we are planning to install the production target of LIS at just entrance of the

RFQ linac and pulsed heavy ion beams are accelerated in the RFQ linac. To design RFQ linac for accelerating the heavy ion beam produced from the target by pulsed laser, we have to study the property of plasma produced by high energetic pulsed laser, such as velocity and charge distribution of heavy ions in the plasma. The details of a design and simulation for RFQ linac for the ion extraction are given in Ref. [8]. In this paper, we report the experimental results for measurements of velocity distribution of heavy ions and divergence of plasma expansion

2 APPARATUSES OF LIS

2.1 Operation of TEA CO₂ Laser

It is well known that the laser plasma produced by CO₂ laser is suitable for the laser ion source [9]. We have a transverse electric atmospheric (TEA) CO₂ laser (wavelength = 10.6 micro millimeter), the pulse duration time~100 ns) system with Q-switch. In order to construct the unstable resonator which makes conditions as $L = (\rho_2 - \rho_1) / 2$, a convex BeCu mirror (20 mm diameter, 5t, $\rho_1 = 6$ m) and a concave BeCu mirror (50 mm diameter, 10t, $\rho_2 = 12$ m) are used. The excitation to laser transition level with 10.6 micro meter is provided by glow discharge in CO₂ gas, typically contains N₂ and He. Therefore, the laser output energy and the repetition stability depend on ratio of CO₂, N₂, and He. For our TEA CO₂ laser, we investigated the mean energy for 20 shots and the stability of the energy as a parameter of a ratio of the CO₂, N₂, and He as shown in Table2.

We have obtained the maximum output energy of 12.1 J under the gas mixture condition (CO₂:N₂:He = 1:2:4).

CO ₂ :N ₂ :He	Mean Energy (J)	R. M. S. (J)	(%)
1:1:8	6.71	0.51	7.56
1:1:4	7.41	0.73	9.90
2:1:4	6.96	0.58	8.43
1:2:4	8.16	0.80	9.80

Table 2: The laser mean energy and the stability for 20 shots of TEA CO₂ laser. Total gas pressure is 1.5 Kg/cm², the conductance is 10 liter/min; the flow is about 1800 Torr liter/sec. Air pressure in the pre-spark gap is 1.3 Kg/cm².

2.2 Target Chamber and Detection System

The detection system of the laser plasma and the ion current from the laser plasma is shown in Fig. 3. The diameter and the height of the target chamber are a 290 mm and 90 mm. The aluminum target is located in the center of the target chamber. The focused laser irradiates the target surface with an incident angle of about 45 degrees. The Faraday cup is placed 3250 mm far from the target, which is enough distance to decrease the plasma density. It is used to measure the time of flight by velocity difference of ions of the different charge states.

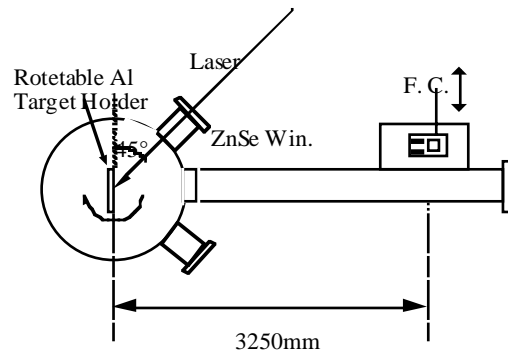


Figure 3: Target chamber and the detection system.

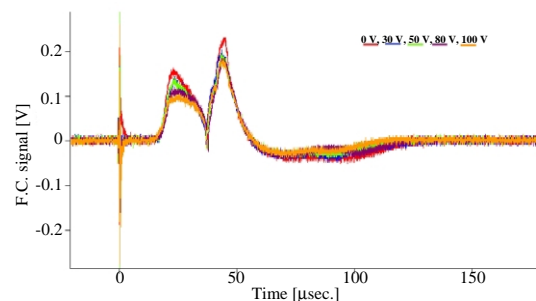


Figure 4: Typical Faraday cup signal.

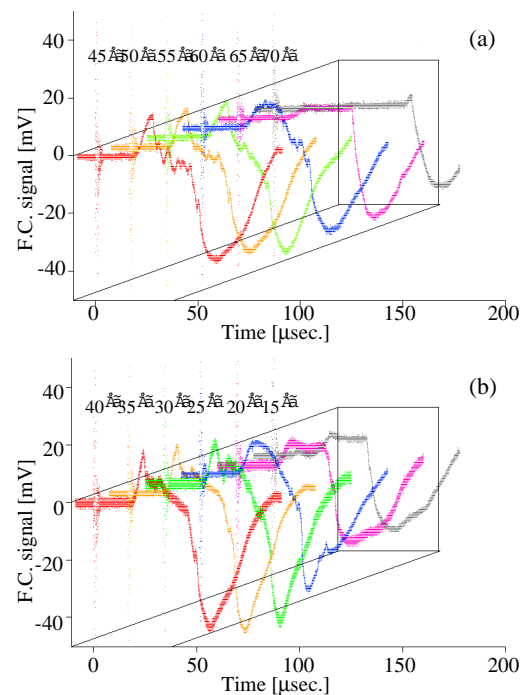


Figure 5: The time dependence of Faraday cup signal for various rotation angles of a target.

3 RESULTS

The power density by CO₂ laser energy is about 10¹⁰ W/cm². The target surface is perpendicular to the direction of the Faraday cup (the rotating angle of the target is 45 degrees), Faraday cup signals as a function of the suppression voltage are shown in a Fig. 4. The first peak at about 0 seconds is the laser system noise in the emission of the laser. It is used as the trigger of the Faraday cup signal measurements. From the measurements of arrival time of a second and a third peaks, it is found that the kinetic energy is about 140 eV/u and 22 eV/u, respectively.

The distribution of the plasma expansion is investigated by means of rotating the surface of the target. Figure 5 shows experimental results. Maximum beam intensities for each angle are plotted in Fig.6. In the case of a laser initiated by an angle of 45 degrees on a target surface It is found that the divergence of the plasma expansion is 15–20 degrees.

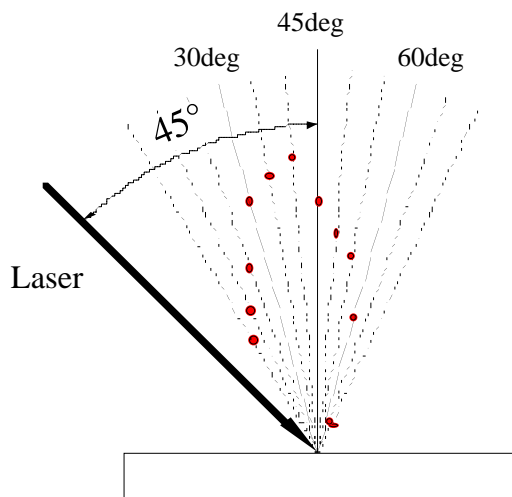


Figure 6: The distribution of the plasma expansion. Solid circles show maximum peak intensities for each angle.

4 SUMMARY

To accelerate the very high beam current of heavy ions effectively, we are designing the new system which consists of laser ion source and RFQ linac. The target of ion source will be installed in the just entrance of the RFQ linac and accelerated directly by it without using the beam transportation system. To design of the new RFQ linac, we surely need the information of velocity and intensity distribution of the plasma and ions. For this purpose, we measured the velocity and intensity distribution of the plasma. From this experiment, we observed that the kinetic energy of the obtained laser plasma was 140 eV and the divergence of the plasma expansion is 15–20 degrees.

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