Development of Laser Ion Source at RIKEN

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Abstract

In MUSES project at RIKEN, a pulsed ion source for highly charged heavy ions is required. Laser ion source is expected to satisfy MUSES requirements and is chosen from several types of pulsed ion source. A test bench at RIKEN is now being developed to investigate ion yield from laser produced plasma. We obtained some results by YAG laser on the test bench.

1 Introduction

MUSES (Multi-USe Experimental Storage rings) project is being planed at RIKEN[1]. This new facility consists of an Accumulator Cooler Rings (ACR), Booster Synchrotron Ring (BSR) with an electron linac, and Double Storage Rings (DSR). To accelerate heavy ions effeciently under this MUSES, the ion source has to produce highly charged ions ($M/q \leq 10$). The pulsed ion beam is also required. The repetition rate and the pulse length of the pulsed ion beam are required 10Hz and 10~20 μsec from the injection system and the number of the beam bunch in DSR, respectively. The beam current of 100pμA at the target point is required. Therefore, according to an estimation that the transmission from ion source to the fragmentation target point is a order of 10%, the ion source must produce the current of 1pmA per 1 pulse. The good stability of the beam for a long term operation is also required. The requirements described above are listed at the Table.1.

M/q	$\leq$10
Beam Intensity	$\geq$1pmA
Beam Pulse Length	10~20μsec
Repetition Rate	10Hz

2 Selection of Ion Sources

Major pulsed sources of highly charged ions are listed as follows

1. pulsed ECR (Electron Cycrotron Resonance) ion source[2].
2. MEVVA (MEtal Vapor Vacuum Arc) ion source[3].
3. EBIS (Electron Beam Ion Source)[4].
4. LIS (Laser ion source)[5].

The pulsed ECR ion source is applied by means of the after glow current. The pulse current intensity under the after glow current operation is 2~10 times stronger than the current intensity under the CW operation. However, the beam intensity under pulsed mode operation and the pulse length are only several pμA and the order of 100μsec at the present stage, respectively. Therefore, it is difficult to satisfy the requirements menin the point of view of the beam intensity. At CERN, highly charge state heavy ion Pb^{+27} is obtained about 100eμA (4~5pμA)[6].

The MEVVA ion source applies the metal vapor vacuum arc which occur between the hot cathode and the cold anode in the vacuum. The arc is pulsed with 0.1~0.5 msec and up to 100Hz, and vaporize the cathode metal material and produce the metal vacuum arc plasma. The metal ions are extracted from the vacuum arc plasma. The beam intensity is in proportion to the applied arc current[7]. An axial magnetic field maintaines the plasma confinement and is available to obtain relatively highly charge ions[8]. MEVVA ion source has some excellent advantages for the reproduce of pulses and for a long time operation. However, charge states are not high enough to satisfy the MUSES requirements for the ion source.

The dense electron beam is focused in a solenoidal strong magnet field and is closed to axially by potentials applied to cylindrical electrodes around the beam axis. Atoms are ionized by electron impact inside the electron beam, are trapped in the potential, and undergo stepwise ionization until the stripping limit of electron energy is reached. Then, ions are extracted by a change of the axial potential distribution. At BNL, Super-EBIS is planed for a Au^{+32} ion beam (1.7emA, 10μsec) [9]. It is noted that EBIS type ion source is a one of the candidates.

In the case of the laser ion source (LIS), ions are extracted from laser-produced plasma. The high power laser beam focused on the metal target vaporizes the target material and produces a plasma. The laser ion source at CERN using a 29J, 100nsec, CO_2 laser, generates 7mA of Ta^{+20}, ~5μsec ion pulse[10]. These values meet MUSES requirements for M/q and close to the ion current. ITEP LIS produced for highly-charged medium mass ions will be used in Terra Watt Accumulator (TWAC) project[11]. It is noted that LIS is also a one of the candidates.

3 Laser Ion Source

In the previous section, it seems that the laser ion source has an advantage to meet MUSES ion source requirements compared to other ion sources. Therefore, we decided to start the development of the laser ion source as the pulse ion source for MUSES project at the present stage.

The laser ion source consists of four main components: the pulsed laser, rotatible metal target inside the vacuum chamber, plasma expansion region , and extraction system. The electron temperature and the critical plasma density are important parameter to produce highly charged ions from the laser plasma and can be estimated from following equations[12]:

$$T_e \simeq 1.25 \times 10^{-6}(\frac{A}{Z})^{1/3}(\lambda^2\phi)^{2/3} \tag{1}$$

$$n_{cr} = \frac{\epsilon}{e^2} m_e \omega^2 \tag{2}$$

where A, Z, λ, and ϕ are the mass of atom, the average charge state in the laser plasma, the wavelength of the laser radiation, and the laser power density on the target, respectively, and ϵ is the dielectric constant, m_e is the mass of electron, ω is the frequency of the laser radiation, e is electric charge unit. In these expressions, it is evidently that $\lambda^2\phi$ is the most important value for the production of highly charged ion. Therefore, the high power density and the long wavelength are required. However, longer the wavelength, less the critical plasma density.

3.1 Test Bench at RIKEN

We are now developping the test bench to investigate ion yield from laser-produced plasma, which is shown in Fig.1. TEA CO_2 laser and YAG laser are installed. The maximum energy and the pulse duration of TEA CO_2 laser (λ=10.6μm) are 10J and 100nsec, respectivily. In order to construct the unstable resonator, a convex BeCu mirror (20ϕ, 5t, R=5m) and a concave BeCu mirror (50ϕ, 10t, R=10m) are used as resonator system for CO2 laser. We have obtained the output energy of 5.7J by this resonator system under the gas mixture condition (CO_2:N_2:He=1:1:8). On the other side, Nd:YAG laser (INDI-50, Spectra-Physics) has the maximum energy of 500mJ and the pulse duration of 6~7nsec at λ=1.064μm. The repetition rate is up to 10Hz for both lasers.

The aluminium target is located in the center of the vacuum chamber. The focused laser irradiate on the target with an incident angle of 35°. The diameter and the height of the vacuum chamber are a 290mm and 90mm, respectively. The laser plasma expands perpendicular to the target surface. With using a set of the streak camera and the CCD camera, one can obtain the data of the plasma expansion as a function of time.

3.2 Results

We obtained some results by using the Nd:YAG laser. Laser-produced plasma image in the case of 250mJ laser pulse is presented in Fig.2. After about 100 shots the creater shape became the ellipse with the long axis (700μm) and the short axis (500μm). The power density on the target surface can be estimated as 10^{10} W/cm^2. From this value, it is expected that the charge state of aluminum ions will be at least +3~4.

4 Future Plan

In the next step, we will use ion charge state and energy analyzer and Faraday cup to measure the ion current. Rotatable target will be used instead of present fixed target. In order to inject into the accelerator, the beam energy have to be more than 20 qKeV, where q is the charge state of ions..

Summary

Ion source requirements for MUSES Project were mentioned from the accelator complex. The present performance of some types of pulsed ion source (Pulsed ECRIS, MEVVA, EBIS, and LIS) were examined for MUSES requirements. Then, we selected and studied LIS. We developed the test bench and obtained the power density of 10^{10} W/cm^2 on the aluminum target by using 250mJ Nd:YAG laser. The charge state of the extracted aluminum ion was estimated to +3~4. The future plan for RIKEN LIS development was presented.

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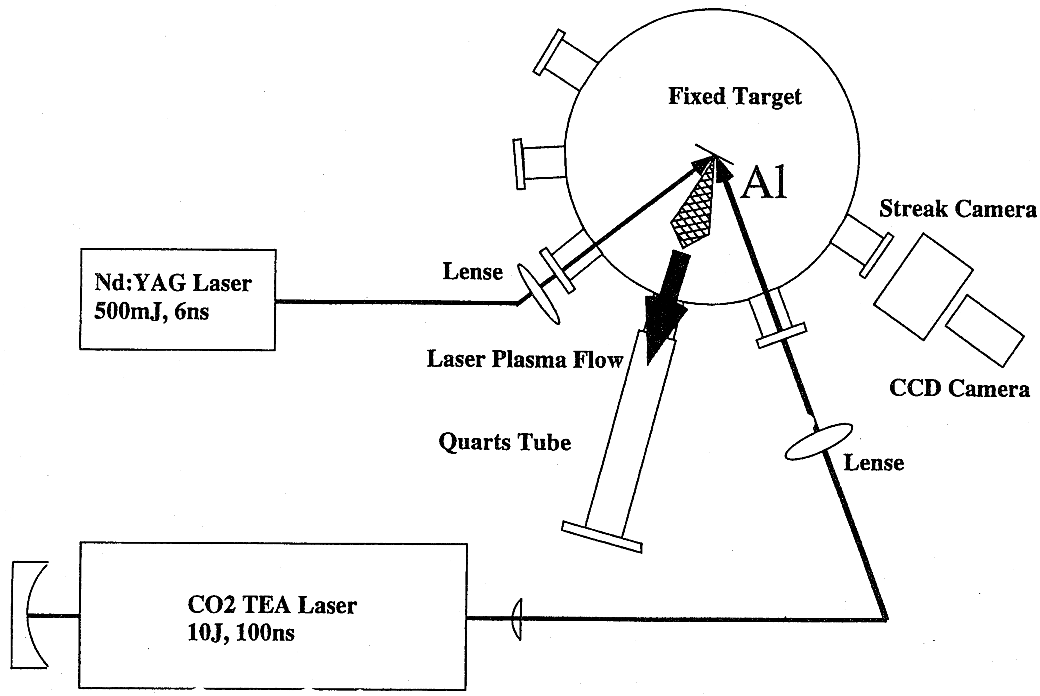

Figure 1. Scheme of the test bench of the Laser Ion Source at RIKEN

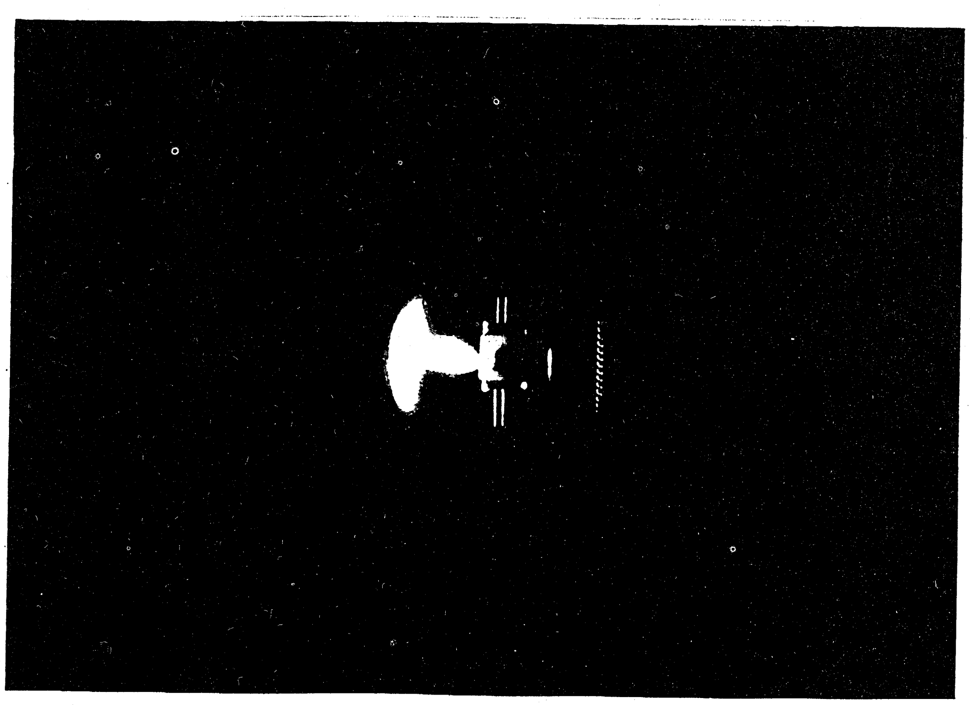

Figure 2. Photograph of the laser plasma on the aluminum target