LOW CHARGE LASER ION SOURCE FOR THE EBIS INJECTOR*

M. Okamura#, T. Kanesue, J. Alessi, E. Beebe, A. Pikin, D. Raparia, CJ Liaw, J. Ritter, V. Lodestro, BNL, Upton, NY 11973, USA
Y. Fuwa, M. Kumaki, S. Ikeda, RIKEN, Saitama 351-0198, Japan

Abstract

In March 2014, we successfully commissioned a newly designed low charge high brightness laser ion source (LIS) named as "LION," which delivers various singly charged heavy ions to the electron beam ion source (EBIS) in Brookhaven National Laboratory. Since then, the LIS is used in routine operation for the RHIC accelerator complex and is providing stable, less-contaminated beams into the EBIS. The laser power density was optimized to provide singly charged ions with low material consumption rate. The nominal laser energy on the target is around 500 mJ at 1064 nm wavelength. The plasma produced by the laser is transported through a 3 m pipe to stretch the ion beam pulse length to match the EBIS's requirement, and the degradation of the beam current caused by aging of the laser flash lamps and target surface deformation can be compensated by a longitudinal magnetic field induced by a coil surrounding the pipe. A twin laser system, firing sequentially, is to extend the beam width further. The accelerated beams through the EBIS, RFQ and IH-linac showed a good performance. Also we can now provide relatively lower charge state ion beams from the EBIS, if desired, using fast injection scheme. Before introducing the LION, fast injection was not typically used, since it was difficult to get sufficient injected ion intensity. This mode will be used in the next run to maximize particle number in the relativistic heavy ion collider (RHIC) for running with Al ions.

INTRODUCTION

Since 2010, the EBIS injector has been used to provide heavy ion beams to NASA Space Radiation Laboratory (NSRL) and RHIC[1]. The injector consists of two hollow cathodes ion sources for 1+ heavy ion production, an EBIS for breeding of injected ions to high charge state, a 4 rod 300 keV/u RFQ, and a 2 MeV/u IH-DTL. In the spring of 2014, to enhance the versatility of the injector, a newly designed LIS was installed[2]. After the beam commissioning of the LIS, we have provided beams both from the LIS and the hollow cathode ion source (HCIS) for the RHIC and NSRL runs. In this paper, some operation results of the EBIS injector comparing the LIS and HCIS are reported.

LION

The new LIS was named as LION and the installed apparatus is shown in Fig. 1. The LION comprises three major parts, which are target chamber, 3m solenoid and extraction chamber. In the target chamber, a two dimensional motorized x-y motion stage is installed. In Run 14, carbon, silicon, titanium, iron, tantalum and gold plates were installed, and those beams were provided. The targets were illuminated a by QUANTEL Brilliant-B twin (850 mJ, 1064 ns, Q-switched Nd:YAG) laser system. The laser was placed on the top of the supporting frame and the laser beam was guided into the target chamber.

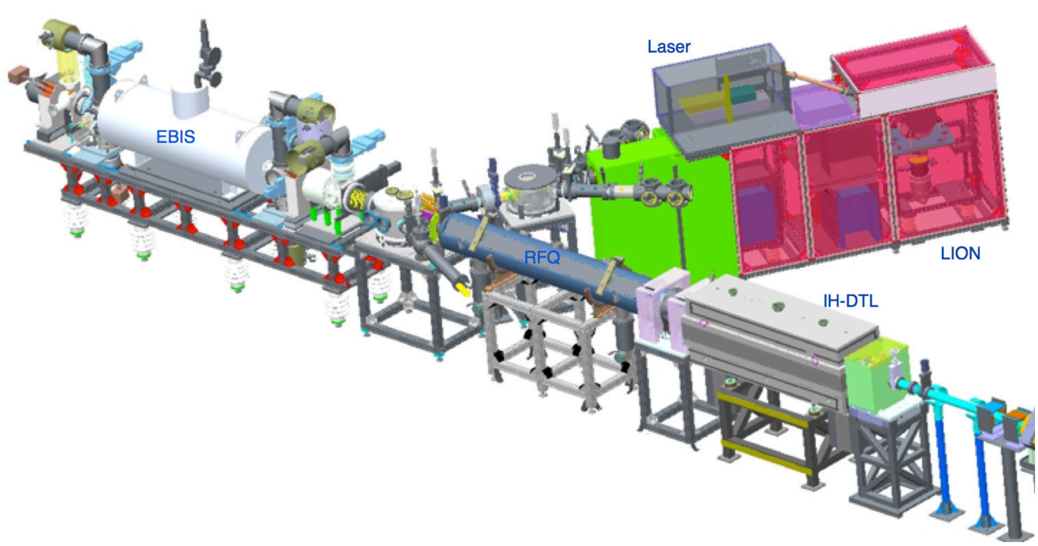

Figure 1: EBIS injector equipped with LION

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The vacuum window for the laser beam was placed about 2 m away from the laser spot to reduce coating from ablated material. The laser incident angle was thirty degrees from the beam axis and the spot size on the target was controlled to be about 5.0 mm in diameter. The laser power density was adjusted between 10^8 and 10^9 W/cm^2 by varying the Q-switch timing. The induced plasma goes into the 3 m beam pipe which is wound by a 2 mm diameter copper wire with two layers. This solenoid induces up to 10 Gauss to suppress the expansion of the ablation plasma and can compensate the degradation of beam current caused by the aging of laser flashlamps and deformation of the target surface's flatness. At the end of the solenoid, the extraction voltage is applied between the extraction hole (ϕ=15 mm) and the intermediate electrode as shown in Fig. 2. The platform voltage was design to apply up to 40 kV. By changing the intermediate electrode's voltage, the beam extraction condition can be adjusted.

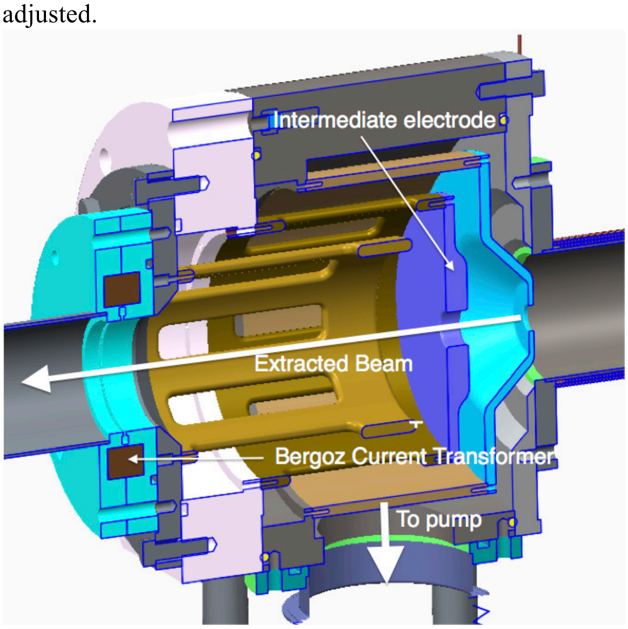

Figure 2: Beam extraction

Under the extraction chamber, excessive plasma and neutral vapour are evacuated by a turbo pump. This helps to stabilize the beam at 5 Hz operation. The entire vacuum condition is kept below 10^{-7} Torr. The extracted singly charged heavy ion beams are delivered into the EBIS trap. The beam pulse is regularly monitored by the current transformer[3].

BEAM INJECTION INTO THE EBIS

In an EBIS, the transverse confinement is done by a potential of the electron beam and the drift tube voltages control the longitudinal confinement. With "slow injection", at the both ends drift tubes of the trap have higher potential than the centre region. When a singly charged ion beam is injected longitudinally into the trap, the beam must climb over the voltage barrier of the first drift tube. The injected beam travels in the electron beam and is reflected by the higher potential at the other side and then gets out from the trap. While traveling in the electron beam, some particles are ionized and cannot come out from the trap. These ions remaining in the trap are ionized further until reaching the desired charge state. The capacity of the trap is determined by the number of electrons in the trap region, and the total ionized particle's charge cannot exceed the corresponding capacity. In other words, to maximize the EBIS performance, the injected singly charged ions must be more than the electron charge in the trap divided by the desired charge state. To fulfill this requirement, the injecting beam pulse needs to be long enough, since the initial ionization probability in the trap is limited. A HCIS provides typically a few tens of μA beams with a long pulse, and is good for the EBIS injection. However, this "slow" injection scheme has a disadvantage when the confinement time is not long compared to the injection time. The earlier injected particles have more chances to be ionized than later beam and the charge states of the EBIS output may have broader distribution. Since the trap capacity is limited, the broader distribution reduces the particle number of the desired charge state ions. If the required confinement time is shorter than the injection time, the target charge state ions may rarely be obtained.

The LION can provide more than 1 mA of singly charged bright beams. The required number to singly charged ion can be injected to the trap in a short time and the voltage of the first drift tube is elevated just after the injection to prevent these ions from escaping. This scheme is called fast injection. All the injected particles start to be ionized simultaneously and a narrower charge state distribution can be expected.

BEAM ANALYSIS USING THE LINAC

To confirm the charge state distribution of the output beam from the EBIS, a bending analyser is needed. However, the current setup of the injector doesn't have an analysing section between the EBIS and RFQ. We decided to use the bending magnet[4] which is at after the RFQ and IH-DTL. All the quadrupole magnets and the RF cavities were scaled to accommodate the target charge state beam. The injection voltage into the RFQ was also scaled. Only the pulsed solenoid magnet, which is used to shape the injection beam into to the RFQ, was tweaked to maximize the detected current after the bend. Let us note that the RFQ and IH-DTL were designed to accelerate Au^{32+} and the lower charge state particles (q/A ≤ 1/6.2) cannot be analysed due to the discharge limits in the IH-DTL.

COMPARISON OF GOLD BEAM

Using the parameters used in Run 14, a comparison test between the HCIS and LION was performed. Figure 3 shows the electron current profile in the EBIS trap and injection timing of the singly charged gold beam from the HCIS. The slow injection required 35 ms of injection beam pulse width. The HCIS was biased at 12 kV. Figure 4 shows the case of LION. At that time the platform

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voltage of the LION was 18 kV. The injection time was only 200 µs. The detected charge state distribution after the bend is shown in Fig. 5. Unfortunately we could not observe an obvious improvement, however we achieved similar performance using the LION, compared to the well-optimized operation condition of the HCIS. We plan to explore this further, to find a better tune for the LION beam in the next run.

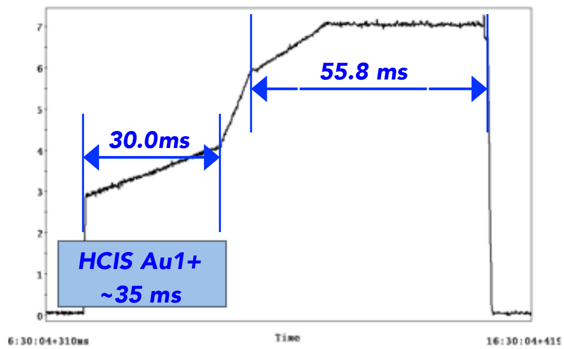

Figure 3: Injection timing using the HCIS

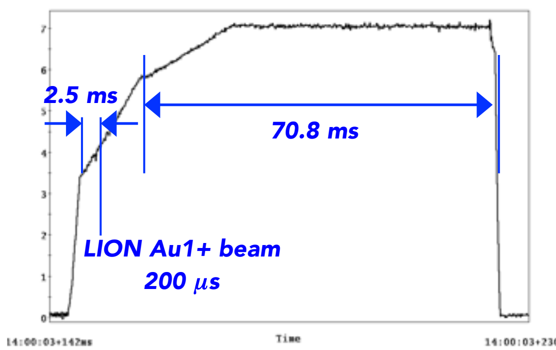

Figure 4: Injection timing using the LION

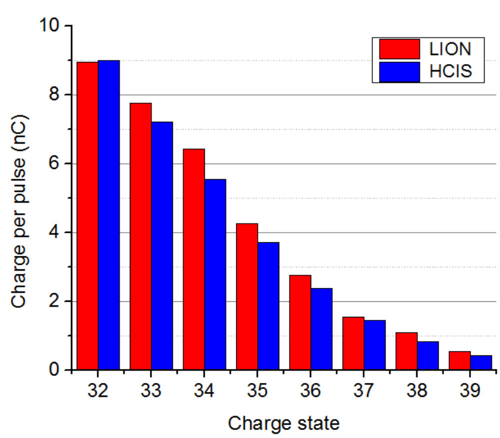

Figure 5: Charge state distribution of gold beam

LOW CHARGE ALUMINIUM BEAM

We tested Al^{8+} beam acceleration. It was difficult to obtain the optimized condition using the HCIS within the limited time, so only the results with the LION are reported. Figure 6 shows the injection and confinement timings for Al^{8+} production. The measured charge state distribution is plotted in Fig. 7. We could demonstrate lower charge state acceleration in the EBIS injector. To obtain the maximum particle number, we also confirmed Al^{5+}. The confinement time was reduced from 31 ms (shown in Fig. 6) to only 5.5 ms and this reduction agreed well with our simulated result. The detected charge per pulse reached 14.2 nC (1.77×10^9 particles).

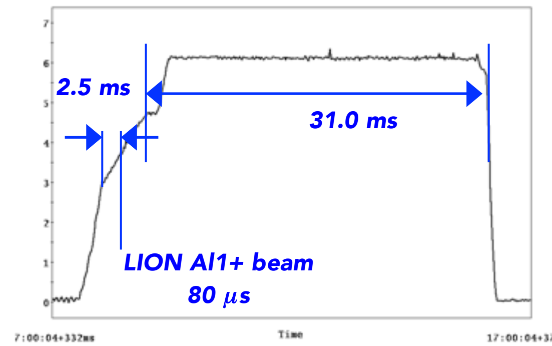

Figure 6: Injection timing for Al^{8+}

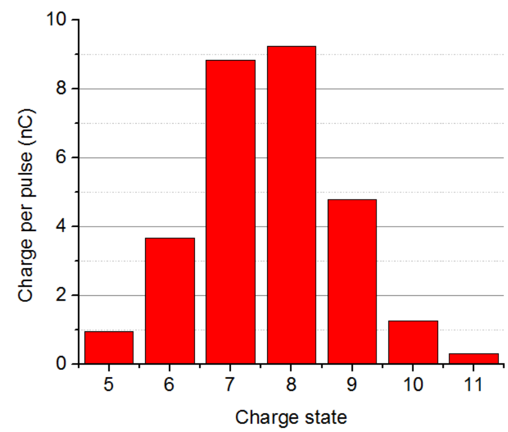

Figure 7: Charge state distribution for Al^{8+}

CONCLUSION

The LION was successfully commissioned and is reliably providing many stable beams into the EBIS injector. We confirmed the reasonable charge state distribution for Au^{32+} production. Also we could supply Al^{8+} and Al^{5+} beams that were previously unavailable using slow injection scheme. For the next RHIC run, we plan to provide Al^{5+} beam using the LION.

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