THE COMMISSIONING OF THE LASER ION SOURCE FOR RHIC EBIS*

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Abstract

The LION source is a new laser ion source (LIS), which was installed and commissioned at Brookhaven National Laboratory (BNL) for low charge state heavy ion production as an external source of primary ions for RHIC-EBIS. This is the first LIS for low charge state ion production to be combined with an Electron Beam Ion Source type heavy ion source for long term user operation. After short term of commissioning, the LION started to provide various ion species for NASA Space Radiation Laboratory (NSRL) since March, 2014, and Gold beam has been provided for RHIC since June, 2014.

INTRODUCTION

The Electron Beam Ion Source (EBIS)-based heavy ion preinjector (RHIC-EBIS) is used for RHIC and NASA Space Radiation Laboratory (NSRL) at Brookhaven National Laboratory (BNL) [1]. The NSRL is a facility to simulate the effect of Galactic Cosmic Radiation (GCR), which is highly energetic heavy ions of various kinds, and solar particles, which are highly energetic protons, in space. The RHIC-EBIS is required to provide fast switching between many heavy ion species for this purpose. However, the existing two Hollow Cathode Ion Source (HCIS) based external sources cannot satisfy this requirement. The LION source is funded by NASA to enlarge available ion species for fast switching. A laser ion source (LIS) can generate ions from any solid materials. Fast switching can be accomplished by switching laser irradiation position on different target materials. In addition, a cleaner vacuum condition in EBIS with less residual gas can be achieved with LIS, which produces plasma by a high-power pulsed laser irradiation while HCIS uses discharge with discharge gas. This improved vacuum condition could enhance the ion beam intensity of interest. The other difference between the use of HCIS and LIS is the injection scheme. Because the LIS can supply much higher current such as hundreds of microamperes rather than a few tens of microamperes of HCIS, so called fast injection scheme is applied. Ions from an external source are trapped by EBIS in a short period. The efficiency can be high and a narrower charge state distribution can be achieved [2].

At BNL, we have studied a LIS for low-charge state ion production for many years [3, 4]. Based on the study, the LION source for RHIC-EBIS was designed and installed. Figure 1 shows a layout of the LION.

LASER ION SOURCE

The LION consists of a high-power pulsed laser, a target chamber, a 3-m-long plasma drift region with a solenoid magnet, and an extraction chamber. The target chamber, the plasma drift region, and the extraction chamber sit on a high voltage platform, which is designed to hold up to 40 kV.

Laser

Key laser parameters are shown in Table 1. This laser is equipped with two identical Q-switched Nd:YAG laser oscillators (850 mJ/6 ns at FWHM, 1064 nm wavelength). A built-in laser combiner merges the two laser beam into one laser path to aim at the same position. The laser is focused on a solid state target plate. The laser spot size on

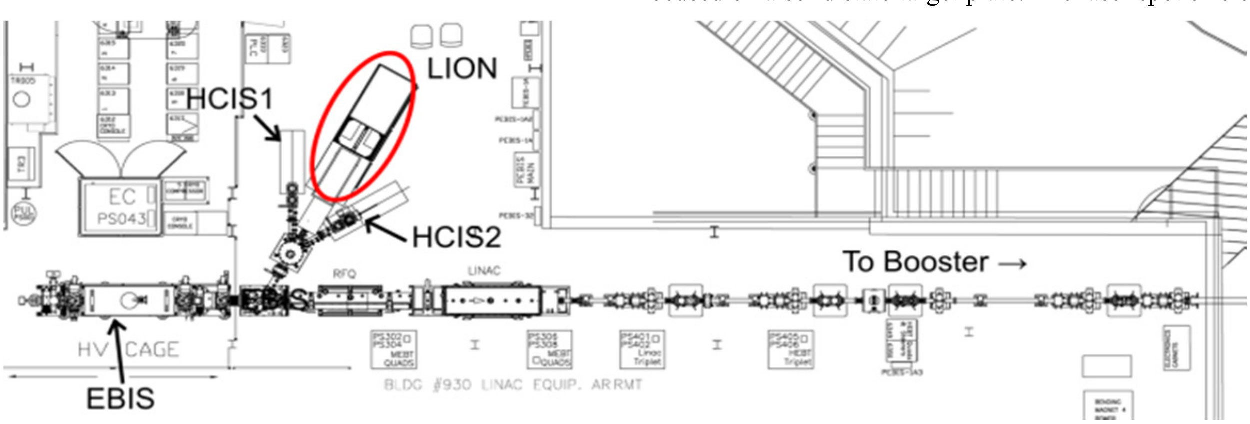

Figure 1: Layout of the Laser ion source and the RHIC-EBIS.

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the target is 5 mm in diameter. The different laser energy of 500 ~ 700 mJ is used depending on the species to achieve singly charged ions.

Target Chamber

In the target chamber, several targets are held on a tungsten target holder. Figure 2 shows the target holder with Au, C, Fe, and Ta targets from right. The target holder is mounted on a x-y linear stage, which has the maximum travel range of 250 mm and 50 mm in horizontal and vertical direction, respectively. The x-y stage allows the laser to hit different target materials.

Table 1: Laser Specification

Name	Quantel laser Brilliant Twin B
Wave length	1064 nm
Energy on target	500 ~ 700 mJ
Pulse width	20 mm (0.79 in)
Rep. rate	5 Hz

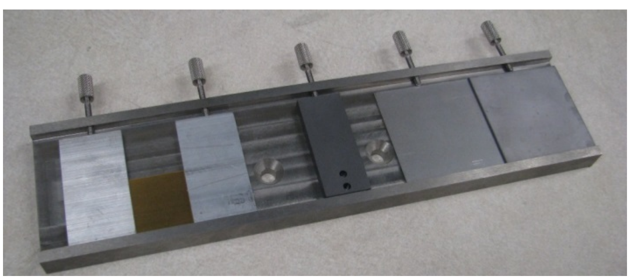

Figure 2: Target holder with Au, C, Fe, and Ta targets from left. Aluminium plates are used to hold Au target.

Plasma Transport Line and Extraction Chamber

A 3-m-long solenoid magnet guides laser-produced plasma to an extraction chamber. The solenoid magnet is used to reduce the diverging angle of expanding plasma. Typical magnetic field to be used is a few Gauss. With this drift length, ion beam with pulse width of a few hundreds of microseconds is achieved. Ions are extracted at the extraction chamber, and transported to EBIS. The beam current at the exit of the LION extraction chamber is measured by a current transformer (Bergoz ACCT-S-082) [5].

EBIS

Singly charged ion beam from an external ion sources are trapped by EBIS. Ions are confined radially by the potential of an electron beam focused by a superconducting solenoid magnet. As the ions are confined in the trap, they are ionized step-wise. After the desired charge state is reached, the ions are extracted and transported for further acceleration. The EBIS can change species and charge state distribution on a pulse-to-pulse basis. The combination of LIS and EBIS realizes very flexible operation in terms of species and charge state.

At RHIC-EBIS, the extracted beam from the EBIS is accelerated by a RFQ accelerator and a linear accelerator to 2 MeV/u, and injected into AGS Booster synchrotron for use for NSRL and RHIC.

To accommodate all requirements for RHIC facility, EBIS provides one species at the rate of roughly once per 5 sec for NSRL, plus 8 pulses of a second species during the same 5 sec period for RHIC injection, or 1 pulse in the 5 sec period during RHIC storage mode to keep the machine warmed up.

INSTALLATION

The LION source was preassembled in a building different from RHIC-EBIS because of the limited space in the RHIC-EBIS area. The preassembled structures were moved to EBIS area on Dec 3, 2013. After a vacuum leak test, a high voltage platform was conditioned to 36 kV. During the conditioning, discharges tripped several EBIS equipment interlocks. The discharge resulted from normal conditioning process, but to prevent further interruptions, the full conditioning to 40 kV will be done during the next shutdown. The platform voltage up to 20 kV is used for this run. Figure 3 shows the LION at RHIC-EBIS.

Timing requirements of the LION was implemented in the accelerator timing system. The major requirement is for a laser flash lamp trigger signal, which should be operated at as close as 5 Hz to keep good laser stability. The laser will be interlocked when the trigger signal is out of 1 ~ 5.5 Hz.

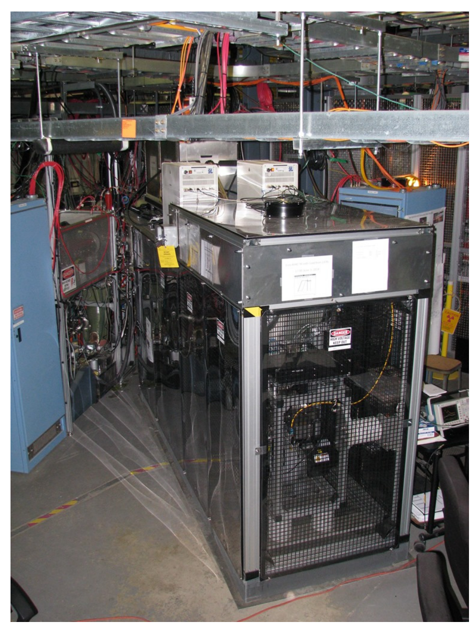

Figure 3: Laser Ion Source at RHIC-EBIS.

BEAM COMISSIONING AND OPERATION

The commissioning with beam was started on March 7 with Fe target. The LION was isolated from EBIS beam line to prevent interruption of RHIC Gold running. The platform voltage was set at 12 kV, which is the voltage

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used for HCIS. The Fe beam extracted from the LION was very close to what was expected. No breakdown caused by the generated plasma was observed.

From March 14, after RHIC low energy Au-Au run was finished and high energy Au-Au run was started, the commissioning with EBIS was started. Au beam was used so that the existing setting of HCIS was applied as a baseline setting. The EBIS was adjusted for fast injection. The transport line between LION and EBIS, and the EBIS injection timing were investigated to capture ions. The first beam extracted from the EBIS was observed on March 16.

On March 26, the first beam at the NSRL target room was observed with Ta beam. The beam intensity was high enough for NSRL operation. We decided to use the LION for NSRL run. The user operation with the LION was started from March 27, and has been very successful. Since that time, the LION has provided most beams for NSRL. This is way beyond our initial plan to use the LIS only for several days for commissioning purpose.

The progress of the commissioning with beam was satisfactory as shown above. The major problem we had was related to stepper motors for x-y linear stage. The motor, operating in vacuum, was burned out several times when the target was moved at a very slow constant velocity such as 0.001 mm/sec. This problem was solved with a step-and-stop scan mode. After this mode was introduced on April 9, no motor has failed.

The lower vacuum pressure in EBIS was clearly observed compared to HCIS. This should increase the beam intensity of interest. The start-up time of the LION is very quick. We demonstrated the fast species switching at 1 Hz at the exit of the LION.

Beam for NSRL

Since March 27, C, Si, Ti, Fe, Ta, and Au beams have been provided for NSRL user runs. Table 2 summarizes NSRL running with LION. Figure 4 shows the NSRL performance of Si beam on April 29. The effect of increased pressure in EBIS can be seen at 15:30 to 16:00 when HCIS started to operate at 8 pulses per cycle. The beam intensity of Si beam was decreased during this time.

As we predicted, lighter species has less tolerance of the number of shots on a same spot to keep long term stability. The scan step of 0.1 mm/80 sec was used for C while 0.1 mm/540sec was used for Fe. These numbers are conservative and should be investigated more for efficient use of target material.

Beam for RHIC

The EBIS injection efficiency and the EBIS settings have been improved continuously. Since June 3, the LION with an extraction voltage of 18 kV has started to provide Au beam for RHIC, since the beam intensity of LION has reached the same intensity as the maximum of HCIS. The LIS has been working continuously. The scan step was set at 0.5 mm/20 sec. With a 1-mm-thick 25 x 25 mm Au plate, laser irradiates the same spot more than hundred times. As of June 10, Au beam remains very stable.

CONCLUSION

The LION source was installed to provide singly charged ions as an external ion source for RHIC-EBIS. The commissioning was very successful. The LION was used to provide C, Si, Ti, Fe, Ta, and Au beams for NSRL user operation for more than 400 hours so far. Since June 3, the LION has been used for RHIC injection. Further optimization is planned during the next shutdown since the available time and resources are limited when RHIC and NSRL are in operation.

Table 2: NSRL Beams from LION

Species	Days	Total hours
C	2	43.5
Si	11	97
Ti	1	10.5
Fe	18	214.5
Ta	1	8
Au	3	49.5

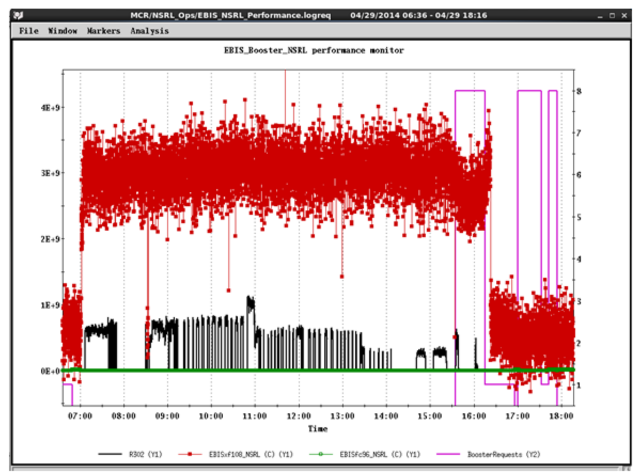

Figure 4: Si beam for NSRL on April 29. Beam was sent to NSRL from 7:00 to 16:20. (Red: Beam intensity at Booster injection, Black: Beam at NSRL target room, Pink: HCIS shots in a supercycle.)

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