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

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Figure 1: Layout of the Laser ion source and the RHIC-EBIS.
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>
<thead>
<tr>
<th>Table 1: Laser Specification</th>
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<tbody>
<tr>
<td>Name</td>
</tr>
<tr>
<td>Wave length</td>
</tr>
<tr>
<td>Energy on target</td>
</tr>
<tr>
<td>Pulse width</td>
</tr>
<tr>
<td>Rep. rate</td>
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</table>

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.

**BEAM COMMISSIONING 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
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

<table>
<thead>
<tr>
<th>Species</th>
<th>Days</th>
<th>Total hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>2</td>
<td>43.5</td>
</tr>
<tr>
<td>Si</td>
<td>11</td>
<td>97</td>
</tr>
<tr>
<td>Ti</td>
<td>1</td>
<td>10.5</td>
</tr>
<tr>
<td>Fe</td>
<td>18</td>
<td>214.5</td>
</tr>
<tr>
<td>Ta</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Au</td>
<td>3</td>
<td>49.5</td>
</tr>
</tbody>
</table>

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.)

REFERENCES