PERFORMANCE OF THE LOW CHARGE STATE LASER ION SOURCE IN BNL*

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Abstract

On March 2014, a Laser Ion Source (LIS) was commissioned which delivers high brightness low charge state heavy ions for the hadron accelerator complex in Brookhaven National Laboratory (BNL). Since then, the LIS has provided many heavy ion species successfully. The low charge state (mostly singly charged) beams are injected to the Electron Beam Ion Source (EBIS) where ions are then highly ionized to fit to the following accelerator's Q/M acceptance, like Au^{32+}. Recently we upgraded the LIS to be able to provide two different beams into EBIS on a pulse-to-pulse basis. Now the LIS is simultaneously providing beams for both the Relativistic Heavy Ion Collider (RHIC) and NASA Space Radiation Laboratory (NSRL).

INTRODUCTION

In 2007, we started to study low charge state heavy ion beam creation using a laser ion has been originally studied for high current highly charged beam production. It was confirmed that by adjusting the laser power density between a few 10^8 W/cm^2 and about 10^9 W/cm^2, the induced ablation plasma contains mostly singly charged ions from various materials [1]. Although highly charged beam has high intensity with short pulse length, the observed low charge state beams had a much longer pulse of more than a few tens μs at a position of 1 m away from the laser target, with moderate beam currents. Also it was found that the damage of the target surface was quite small since the low charge state production mode needs gently focused spot on the target. This enabled us to apply multiple shots on the same target spot. In 2010, the low charge state laser ion source project was funded by NASA. The project was to enhance the versatility of the EBIS pre-injector [2], which provides various heavy ions to NSRL, by establishing fast species switching in a few second. Unlike other ion sources, the plasma created in a LIS is formed independently from surrounding environments including vacuum chamber wall, residual gases, magnetic confinement field or resonant modes of microwave. Thus, in a LIS, by only mechanically changing target material, we can change the ion species provided without any hysteresis effects.

In March 2014, the first beam was delivered to the EBIS and then ten days later, the beam was supplied to NSRL. Since then most of the solid based ions used in NSRL have been supplied by the LIS [3].

UPGRADE FOR RUN15

Upon the successful beam commissioning of the LIS, we decided to install another laser and target in the system to provide beams to the Relativistic Heavy Ion Collider (RHIC) without any interferences in providing beams to NSRL. The over view of the LIS is shown in the Fig.1.

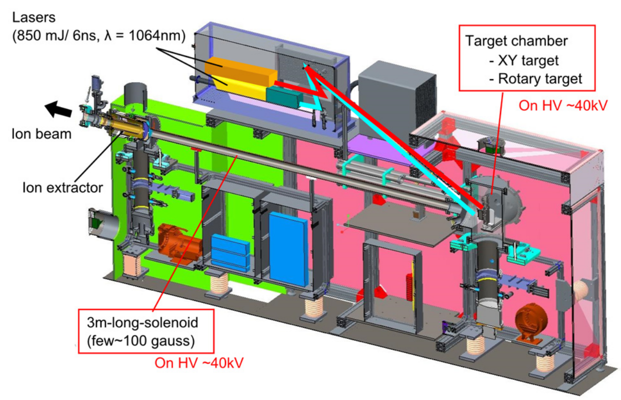

Figure 1: Cut view of the LIS.

In the enclosure made of aluminium on the top of the frame, we have a Quantel Brilliant B Twin laser (6 ns, 1064 nm) which has two independent oscillators [4]. One of the oscillators is used as a backup in case of a failure. In the same enclosure, we added another Quantel Brilliant B laser (single oscillator model). The beam paths of lasers in the enclosure are shown in Fig. 2.

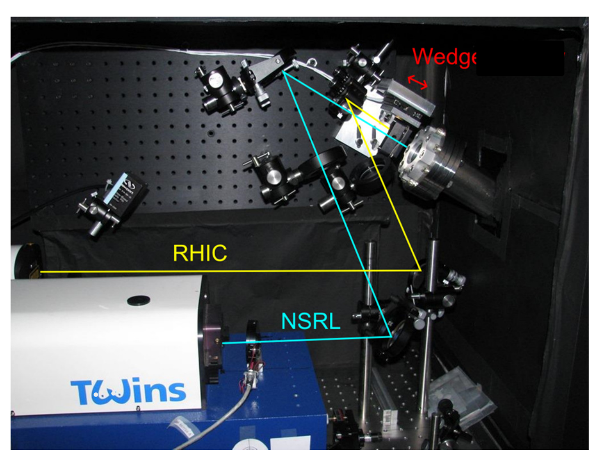

Figure 2: Laser paths in enclosure.

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In RHIC RUN15, aluminium beam was requested in addition to gold beam. To irradiate the both materials, we installed a retractable AR coated wedge in the laser path for the RHIC. By inserting the wedge, the beam direction is deflected by 0.3 degree aiming to an aluminium target which is next to the gold target.

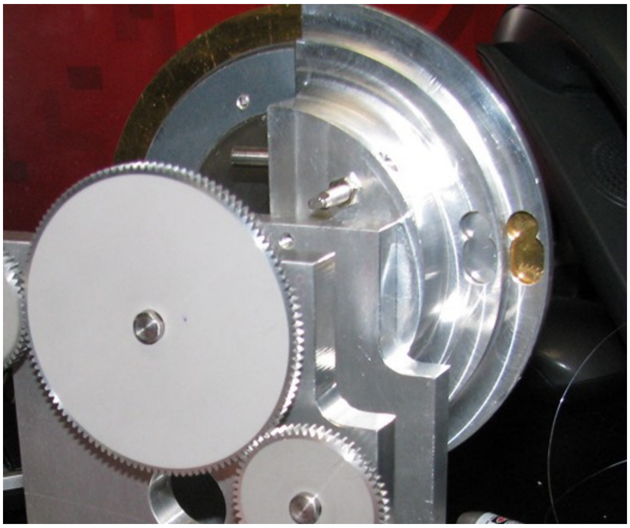

Figure 3: Rotating target for RUN15.

Figure 3 shows a photo of the installed target moving structure. The drive motor was mounted outside of the vacuum and the motor axis is connected to a reduction gear, a magnetic coupling mechanical feedthrough and another gear to drive the gold and aluminium rings. The ring's O.Ds are 120 mm and 100 mm. The laser irradiation surfaces are seen through holes in the aluminium shroud in the photo. The target rotated at least at 5 rpm to avoid consecutive exposures on the same position on the ring surface, when running at 5 Hz.

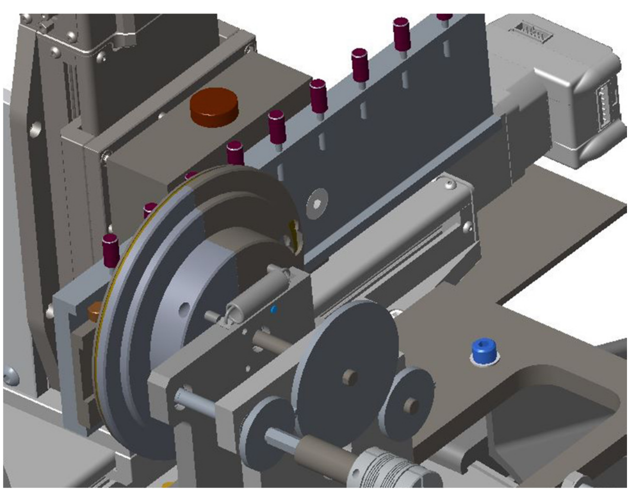

Figure 4: Rotating target and XY target mounted in the vacuum chamber.

Behind the rotating target, as shown in the Fig. 4, we have a XY motorized stage which has 250 mm and 50 mm of movable range in horizontal and vertical directions respectively. The laser irradiation spot on the XY stage was aligned to the common axis of the solenoid and extraction electrode. The laser spots on the gold and aluminium rotating targets were offset 15 mm and 25 mm from the axis. This is because the NSRL beams are mainly lighter ions and require more effective solenoid enhancement, which was explained at [5, 6]. The gold beam for RHIC doesn't need a strong enhancement by the solenoid and can be set at the off-centre position. In the Fig 5 from left to right, aluminium, gold, aluminium, lithium(top), calcium(bottom), silicon, titanium, iron and graphite mounted on the tungsten target holder are shown as used in RUN2015.

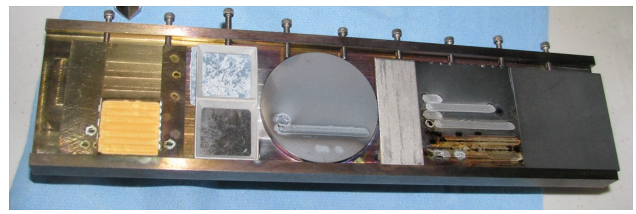

Figure 5: Various materials mounted on the target holder for the NSRL.

OPERATION

The entire hadron accelerator complex is triggered every ~5 seconds and the interval of the triggers is called the supercycle. In a supercycle, the LIS delivers beams to the NSRL only once. This means that the repetition rate for the NSRL beam is ~0.2 Hz and the exposed spot on the target has enough time to be cooled down before having the next laser irradiation. On the other hand, RHIC needs 8 pulses at 5 Hz within a super cycle. The continuously rotating target reduces the degradation of the beam current due to the excessive exposure on the same spot.

Operation for NSRL

Typically beam time for NSRL is 8 hours a day 5 days a week. To optimize other devices, the LIS was operated longer than the beam time. In the RUN, the LIS has provided, Li, C, Ca, Si, Ti, Fe, Ta and Au. Due to strong demands, Si and Fe targets were heavily used.

Operation for RHIC

During a RUN period, RHIC runs 24 hours a day. Once beams are injected and accelerated up to desired energy, the RHIC tunes into storage mode and continues for several hours. This means the LIS needs to provide 8 pulses in every super cycle for around 5 minutes to fill RHIC and then wait for another injection request. However, to keep other devices in a standby state, the LIS provides at least one pulse in a super cycle continuously. Also, tuning optimization of AGS and booster need the beams. In the most of daytime, the LIS was occupied to deliver the beams with 8 pulse mode operation.

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Hours of operation

The total days when the beams were provided by LIS to the users are summarized in Table 1.

Table 1: Species and Number of Days

		Li	C	Al	Ca	Si	Ti	Fe	Ta	Au
Run14	NSRL(days)		2			11	1	18	1	3
	RHIC(days)									33
Run15	NSRL(days)	1	3		1	19	4	30		6
	RHIC(days)			14						42

The days listed in the table show the beam time for NSRL and RHIC. Commissioning or tuning days are excluded. For example, the total days of the LIS operation for multiple species, aluminium for RHIC, and gold for RHIC reached 99, 24, and 96 days respectively.

Failures of the system

Just after the commissioning in 2014, we experienced a failure at one of the stepping motors which is used in the XY stage for the target manipulation. To achieve even target consumption and to stabilize beam condition for a long time operation, the target needs to be scanned with very low speed. Initially we drove the motor continuously and this incessant electric current in the motor induced excessive heat. This was clearly seen in the vacuum monitor and damaged the motor. Then we changed the operation mode of the motor to step motion, like 0.1 mm every several minutes. In the RUN 2015, we had a problem with the moving mechanism in the rotating target system. A ceramic bearing was used to hold the axes of the gears and target. Those bearings were exposed to laser plasmas and evaporated gas from the target. Also the torque control of the drive motor was not optimized. This caused a halt in the target rotation. For the next run, we are developing a new robust mechanism for the gold rotating target.

Deposition in the system

After the RUN15 was finished, we disassembled the extraction chamber, 3 m solenoid pipe and target chamber. The inner surface of the target chamber was coated by target materials as expected. However, we did not find obvious deposition at the extraction electrodes. The beam extraction system seems likely to last for several years without maintenance work.

CONCLUSION

We have developed a laser ion source to provide low charge state heavy ions to the EBIS. In the RUN15, most of the solid based ions provided to the NSRL and RHIC originated in the LIS. The overall performance including beam stability and the fast species switching capability was satisfactory.

ACKNOWLEDGMENT

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