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Design study of primary ion provider for RHIC-EBIS

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Design study of primary ion provider for RHIC-EBIS[1][2]

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Brookhaven National Laboratory (BNL) has developed the new pre-injector system, Electron Beam Ion Source (EBIS) for Relativistic Heavy Ion Collider (RHIC) and NASA Space Radiation Laboratory (NSRL). Design of primary ion provider is an essential problem since it is required to supply beams with different ion species to multiple users simultaneously. The laser ion source with a defocused laser can provide a low charge state and low emittance ion beam, and is a candidate for the primary ion source for RHIC-EBIS. We show a suitable design with appropriate drift length and solenoid, which helps to keep sufficient total charge number with longer pulse length. The whole design of primary ion source, as well as optics arrangement, solid targets configuration and heating about target, is presented.

PACS numbers:

I. INTRODUCTION

The EBIS at BNL will have signicantly better performance than the Tandem Van de Graaff accelerators as the heavy ion pre-injector for RHIC and NSRL science programs. It is required to supply beams with different ion species to multiple users simultaneously for 4-6 months.

Laser Ion Source (LIS) is a candidate as a primary ion source provider for the RHIC-EBIS. In LIS scheme, ions are provided by a solid target which is irradiated by a high power laser irradiates. Low charge state, low emittance and high ion yield LIS with a defocused Nd: YAG laser, is studied[4]. Beam properties, such as current and pulse length, depend on plasma drift length, which is the distance from the target to extraction. Considering these factors is important in designing a viable ion provider for RHIC-EBIS.

II. SUITABLE ION BEAM PRODUCTION

Currently, the LIS is not feasible as a primary ion provider for RHIC-EBIS because the requirements of both limited current in low energy beam transport (LEBT) and sufficient number of 1+ ion injected, cannot be satisfied at the same time. However, LIS experiments with a solenoid show enhancement of the beam current and total ion yield. We show an appropriate condition for RHIC-EBIS using a solenoid.

A. Requirements for RHIC-EBIS

RHIC-EBIS, in Brookhaven National Laboratory, has an ion trap capacity of 1.1×10^{12}. This is sufficient to produce the required total extracted ion charge of 5.5×10^{11}. RHIC asks to provide 1.7 emA of Au^{32+} with 10 μs pulse width and, a second, interleaved beam might be required for NSRL, which could be some ion species such as Si and Fe[5]. For this design, we select 5 ion species: Al, Si, Fe, Ta, and Au, which are typically required species.

Empirical charge distributions of 5 ions are assumed to obtain a ratio of total charge in Interesting Charge State (ICS) to total extracted ion charge and average Charge State (CS) of remaining charge in the Drift Tube (DT) of RHIC-EBIS[4, 6]. Based on the charge distribution and total extracted ion charge of 5.5×10^{11} in RHIC-EBIS, the minimum number of singly charged ions, N_{min}, for a primary ion provider is obtained. These are shown in Table I. Table I also shows limited peak current in LEBT for RHIC-EBIS. We assume that the limited peak current is 25 μA in Au target. In this condition, KOBRA simulations show good beam transmission in LEBT for RHIC-EBIS. The limited current, I_p, is proportional to $m^{-1/2}$, where m is atomic mass[7].

TABLE I: Charge distribution in the DT of RHIC-EBIS and minimum number of 1+ charged ion injected for a primary ion provider

Ion species	Al	Si	Fe	Ta	Au
Interesting CS for beam	13	14	24	30	32
% of total charge in ICS in the DT	50	50	50	20	20
Average CS of remaining charge in the DT	11	12	22	30	32
Min. # of 1+ ion injected N_{min} ($\times 10^{10}$)	4.6	4.3	2.4	1.8	1.7
LEBT Limitied peak current I_p [μA]	68	66	26	30	25

B. Enhancement of ion yield with solenoid in LIS

Previously, we had experiments with a second harmonic, defocused Nd: YAG laser (0.5 J/6 ns and 532 nm wavelength) to produce a charge state 1+ ion dominant plasma[4]. From a solid target irradiated by a laser, the ablation plasma is expanded adiabatically with drift velocity. The total plasma current was measured by a Faraday Cup (FC), which was located on the center of the beam line. Downstream of the FC, we placed a cylindrical 90 degree electrostatic ion analyzer and a Second Electron Multiplier (SEM) for measuring the charge state distribution. Ion signal by SEM was calibrated by comparing the sum of each charge state signal multiplied by its charge state to FC total current. Fig. 1 (a) and (b) represent, respectively, particle number and peak current to laser power density on the solid target. The particle number and peak current were converted per cm^2 at 1 m from the target. The condition of laser power density in Fig. 1 realized that the proportion of singly charged ions was over 95 %.

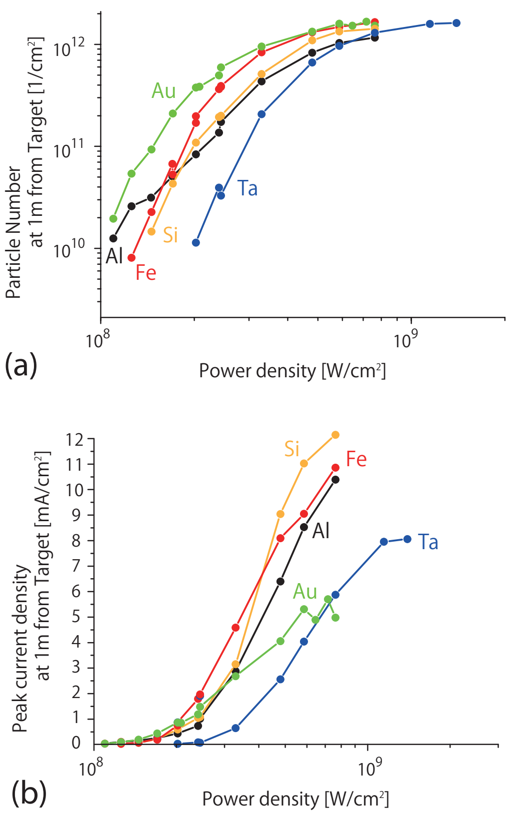

FIG. 1: (Color online). Particle number (a) and peak current (b) to laser power density on solid target

From Table I and Fig. 1, the particle number is enough for RHIC-EBIS requirement, however peak current is too high for LEBT current limit by space charge effect. To obtain appropriate low peak current with adequate particle number, the LIS with solenoid can be a breakthrough. A solenoid magnetic field, which is expected to suppress the expansion of the ablation plasma, was applied at the drift space of the LIS. In experimental condition, a magnetic field of 200 Gauss enhanced the peak current about forty times[8]. Solenoid can provide a low peak current with sufficient beam particle number at longer drift distance of the LIS.

C. Scaling of beam parameters for RHIC-EBIS

In most LIS, we can adapt relationships as below,

$$j \propto L^{-3} \tag{1}$$

$$t \propto L \tag{2}$$

$$N \propto L^{-2}, \tag{3}$$

where j, L, t and N are current denisty, plasma drift length, beam pulse duration and particle number, respectively. Longer drift distance reduces not only current density but also particle number. For requirements of both LEBT limited current and particle number for RHIC-EBIS, we apply the enhancement by solenoid as above. With the enhancement factor α, we can rewrite the relationships,

$$j \propto \alpha L^{-3} \tag{4}$$

$$N \propto \alpha L^{-2}. \tag{5}$$

The relationship of pulse length t does not depend on the solenoid field because no significant change was observed with or without the solenoid. We assume that the drift distance L from solid target to extraction is 5 m for a realistic design and that laser power density is 2.0×10^8 W/cm^2. This laser power density is the lowest of our reliable experimental data. Peak current, pulse width and particle number at 5 m from target without solenoid can be obtained from experimental results at 1 m using Eqs (1), (2), (3). The number of 1+ charged ion injected, N_0, with the solenoid is obtained by the enhancement factor α at drift distance of 5 m, which can be fixed to match the LEBT limited current from Eq. (5). The overall efficiency β, which is defined as the required proportion of number after RHIC-EBIS to number before it, is decided by the ratio of minimum number of singly charged ion N_{min} to N_0. Table II shows beam properties at drift distance of 5 m for 5 ions. We should verify whether sufficient ions could go into the drift tube since the required overall efficiency is higher than ordinary efficiency.

III. DESIGN OF LIS AS PRIMARY ION PROVIDER

For optics arrangement of the target chamber, we have the same laser condition (0.5 J/6 ns and 532 nm wavelength) and the same incident angle of 30° as the previous experiment[6]. As above the laser power density

TABLE II: Beam properties at drift distance of 5 m for RHIC-EBIS

Ion species	Al	Si	Fe	Ta	Au
Pulse length t [μs]	190	180	220	280	430
Enhancement factor α	11	15	6.6	116	3.6
# of 1+ charges injected N_0 ($\times 10^{10}$)	6.1	6.5	5.2	5.2	5.3
Overall efficiency β %	75	66	46	35	32

is 2.0×10^8 W/cm^2. From laser power density, incident angle and laser energy, we can fix a laser spot size of 7 mm on the target.

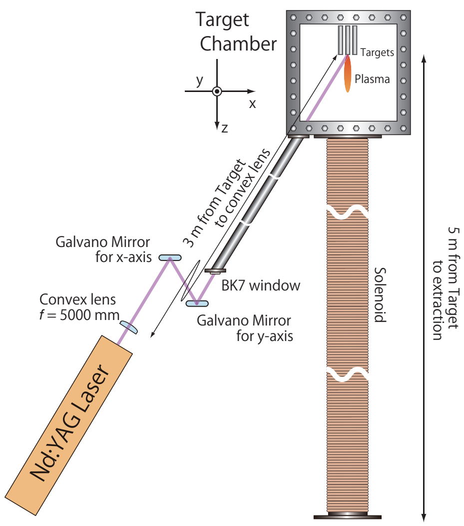

FIG. 2: (Color online). A sketch of LIS with solenoid as primary ion provider for RHIC-EBIS

It is desirable that the location of the optics in LIS is out of and far from the vacuum target chamber to prevent damage of the optics from laser ablation. Convex lens with long focal length ($f = 5000$ mm) is selected for reason and simple design. The distance from the target to the focus lens is 3 m for the spot size. We show the optics arrangement in Fig. 2.

A galvano mirror whose operation time is a few hundred μs is suitable to change the direction of laser irradiation for providing different ion species. As shown in Fig. 2, we need two Galvano mirros for the x and y axis, since targets are arranged concentrically on z-plane to keep a small displacement from targets to center of beam line.

With a laser power density of 2.4×10^8W/cm^2 and laser spot size of 7.6 mm for Fe, the crater depth on the Fe target was about 0.02 mm per 30 minutes at at 5 Hz repetition rate[9]. Target rods of 10 cm size are sufficient for the real continuous operation of 6 months. Heating of the target by laser is not a serious problem in real continuous repetition[9].

A sketch of RHIC-EBIS preinjector with LIS is shown in Fig. 3. To keep the target chamber and solenoid drift tube line of 5 m vacuum, a cryopump is connected with the chamber and a turbopump is located between the solenoid coils.

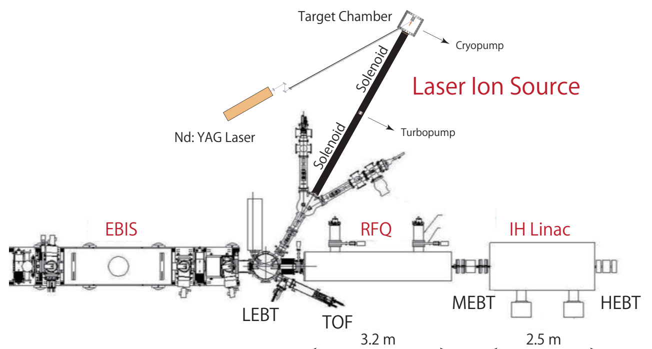

FIG. 3: (Color online). RHIC-EBIS preinjector with LIS

IV. CONCLUSION

We show a design for a primary ion provider for RHIC-EBIS. Solenoid in LIS is useful for the requirement of both low peak current and sufficient particle number. LIS system is suitable as the primary ion source with consideration of singly charged ion beam, optics arrangement, target configuration and heating. It is planned to have a experimental test setup of LIS with a solenoid for RHIC-EBIS.

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