Effect of tapered magnetic field on expanding laser produced plasma for heavy ion inertial fusion

Takeshi Kanesue*[1], Shunsuke Ikeda[1], Masahiro Okamura[1]

[1] Brookhaven National Laboratory, Upton NY, 11973, USA
*Corresponding author: tkanesue@bnl.gov

The ion source performance required for heavy ion inertial fusion (HIF) is beyond that used for current operating particle accelerator facilities. Ion sources are required to provide several tens to hundreds mA of low charge state heavy ions (q/A~100-200), such as Bi^{1+} to minimize the difficulty of a final focusing system caused by space charge repulsion force.[1] A laser ion source (LIS) is one of a promising candidate of such ion sources. We already demonstrated more than 60 mA of the accelerated highly charged carbon and aluminum beam by a RFQ accelerator by extracting ion beam inside of the RFQ. [2] This method is called direct plasma injection scheme (DPIS).

Laser produced plasma containing heavy ions are produced from a solid state target irradiated by a high power pulsed laser. The laser power density of below 10^9 W/cm^2 is typically required for the production of singly charged ions [3]. The plasma expands toward the normal direction to the target surface before ions are extracted by extraction potential. The plasma pulse width is proportional to the plasma drift distance. However, in case of free expansion, the ion beam current rapidly decreases as expanding and follows, $j{\sim}L^{-3}$, where j is current density and L is a drift distance, respectively. To avoid a blowup of a beam caused by space charge effect, it is essential to manipulate the shape of the plasma before an intense ion beam is extracted.

The behavior of the expanding laser produced plasma in a magnetic field has been extensively investigated at BNL. So far, we demonstrated that a static solenoid magnetic field confines the plasma in transverse direction. We observed the enhancement of the Cu^{1+} beam current by ~60 times with the solenoid field of 160 Gauss.[4] We also demonstrated that a pulsed solenoid magnet can be used to control the temporal profile of the plasma from the shifted Maxwellian distribution. [5]

In this paper, we will discuss the effect of a tapered magnetic field on the expanding laser produced plasma. The previous studies showed that the plasma follows magnetic field lines to some extent and could be treated as a virtual particle. [6] The solenoid magnetic field of the interest has a wider opening on the target side. This configuration is to collect more area of the plasma to the ion extraction aperture, which could be about 10 mm in diameter slightly smaller than the aperture of a RFQ accelerator. This is highly preferable when a large laser is used. For example, the laser spot radius could be about 40 mm in diameter assuming a 100 J/10 ns laser for the production of singly charged ions. Other advantage is that the option to use multiple small lasers to irradiate different spots on a target for a single ion beam pulse. In this case, we can tolerate multiple failures of the lasers without disturbing the operation of a power plant.

References

[1] I. Hofmann *et al* 1998 *Nuclear Instruments and Methods in Physics Research A,* **415**, 11-19
[3] M. Okamura *et al* 2008 *Rev. Sci. Instrum.* **79**, 02B314
[3] T. Kanesue *et al* 2008 *Proceedings of the 2008 European Particle Accelerator Conference,* 23–27 June, Genoa, Italy, 2008
[4] K. Takahashi *et al* 2013 *AIP Conference Proceedings,* **1525**, 241-244
[5] S. Ikeda *et al* 2015 *PhysicalProceedings of HIAT2015,* September 7-11, Yokohama, Japan, 2015
[6] S. Ikeda *et al* 2015 *IEEE TRANSACTIONS ON PLASMA SCIENCE Review,* **43**, 3456–3460