LINEAR ACCELERATOR DESIGN STUDY WITH DIRECT PLASMA INJECTION SCHEME FOR WARM DENSE MATTER*

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Abstract

Warm Dense Matter (WDM) is a challenging science field, which is related to heavy ion inertial fusion and planetary science. It is difficult to expect the behavior because the state with high density and low temperature is completely different from ideal condition. The well-defined WDM generation is required to understand it. Moderate energy ion beams (∼ MeV/u) slightly above Bragg peak is an advantageous method for WDM because of the uniform energy deposition. Direct Plasma Injection Scheme (DPIS) with a Interdigital H-mode (IH) accelerator has a potential for the beam parameter. We show feasible parameters of the IH accelerator for WDM.

INTRODUCTION

Warm Dense Matter (WDM) is extremely beyond the ideal condition and the behavior is between a plasma and a solid. The typical temperature is "warm" from 0.1 to 10 eV and the density is "dense" from 0.01 to 1 × solid density with partial electron degeneracy and strong ion-ion correlation [1]. WDM is a key issue to evaluate the effects of the blast wave in the chamber [2] in Heavy Ion Fusion (HIF) and the planet formation process requires the accuracy of hydrogen Equation of State (EOS) in WDM [3]. Many body and disorder system make understanding of WDM difficult.

It is important to establish an accurate EOS in WDM that we should generate uniform WDM. Intense beam with 350 MeV/u is available to study one-dimensional and quasi-isentropic expansion of uniformly heated target material at GSI [4]. On the contrary, lower energy ions (∼ MeV/u) were also proposed [5] as modest-cost drivers for WDM. Using moderate ion beams, maximum energy deposition and uniform heating at Bragg peak require short pulses ($\sim$ ns) to minimize the hydro motion with $\sim \mu$m thickness of target.

Direct Plasma Injection Scheme (DPIS) which can supply high current with heavy ion [6] is a good method for WDM [7]. However, DPIS with Laser Ion Source (LIS) and Radio Frequency Quadrupole (RFQ) can accelerate ions up to only several hundred keV per nucleon. To investigate WDM with higher temperature, we should need an additional accelerator with DPIS. Interdigital H-mode (IH) accelerator, which can accelerate ions with a few MeV/u, resolves the issue and we show typical parameters of IH accelerator for WDM and achievable temperature of WDM by the DPIS with IH accelerator.

* This work was partially supported by the U.S. Department of Energy.
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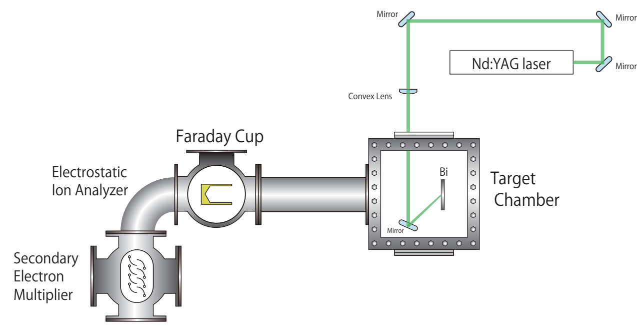

Figure 1: LIS experimental sketch for low charge Bismuth ions. The total current distribution was measured by Faraday Cup (FC). Electrostatic Ion Analyzer (EIA) with Secondary Electron Multiplier (SEM) analyzes the charge state distribution.

LASER ION SOURCE AND DIRECT PLASMA INJECTION SCHEME

LIS is a high current ion source both for low and for high charge state of heavy ion. Laser ablation plasma is produced by high power density laser from a solid target in LIS. The charge state distribution is characterized by laser power density on the target.

Heavy Ion Fusion (HIF), which is a related field for WDM, has a scenario using low charge Bismuth ions [8]. Bismuth ions with low charge state for the scenario was produced by Nd:YAG laser with second harmonic green wavelength of 532 nm as shown in Fig. 1. The power density on the target is 4.7×10^8 $\mathrm{W/cm^2}$. The total current from FC is given by Fig. 2. The current is converted at 1m from Bismuth tarlget per 1 $\mathrm{cm^2}$ and the total peak current density is as high as 10 $\mathrm{mA/cm^2}$. EIA with SEM showed that singly charged Bismuth ions are more than 87 % of total ions. LIS for low charge state is a potential for the HIF scenario.

On the other hand, LIS for high charge state, which is directly connected with RFQ as DPIS, is a powerful tool for WDM. A new RFQ in Brookhaven National Laboratory accommodates q/A = 1/8 particles (q: charge number, A: mass number) supposing Ag^{15+} and a previous LIS experiment results showed ion production of Ag^{15+} with

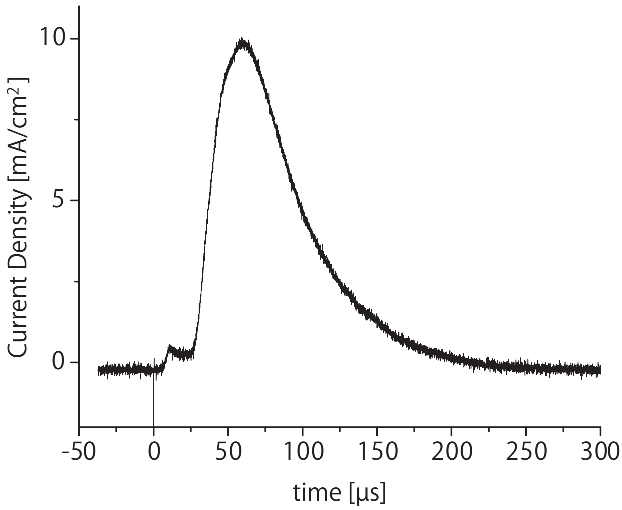

Figure 2: Total current density of Bismuth ions was measured by FC.

peak current of more than 30 mA [9]. We have a plan to have Ag^{15+} acceleration experiment by DPIS. However, the output energy per nucleon of 0.27 MeV/u from the exit of RFQ is not sufficient to investigate WDM with higher temperature. An additional linear accelerator up to a few MeV/u should be required.

IH ACCELERATOR

IH accelerator is advantages of high power efficiency because of longitudinal RF field for π mode. Fig. 3 shows IH accelerator with magnetic flux, current, and electric field. For accelerating Ag^{15+} to 2 MeV/u ($\beta \sim 0.065$), the shunt impedance is high in IH accelerator. Moreover, IH accelerator is more compact than Alvarez type linear accelerator, which is suitable as moderate system for WDM. We show feasible parameters of IH accelerator for WDM using DPIS with Ag^{15+} in Table 1.

Table 1: Basic specification of IH accelerator for DPIS using Ag^{15+}.

Ion	Ag^{15+}
Input/Output Energy	0.27 to 2 MeV/u
Frequency	100 MHz
Effective Voltage	6 MV/m
Cavity length	2.5 m
Cell Number	36
Shunt Impedance	~200 MΩ/m
RF Power	~180 kW

WDM GENERATION BY DPIS WITH IH ACCELERATOR

1 bunched and focused beam should be needed for a well-defined WDM state [7]. Here, a RF Kicker for 1

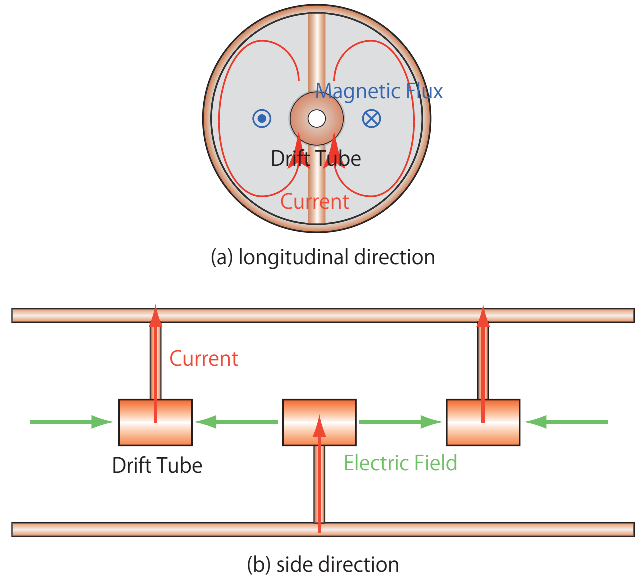

Figure 3: A sketch of IH accelerator for (a) longitudinal and (b) side direction.

bunched beam and a focus system for 0.1 mm beam size after the IH accelerator are assumed.

In order to obtain a estimation of achievable temperature in WDM, it is assumed that the energy density is equal to the energy per the target volume over which the energy is deposited and that a distribution of ion intensity is uniform at the focal plain. When we use Al as a target with Ag^{15+} ion beam, the achievable temperature is shown in Table 2. The energy loss rate (dE/dx) of Aluminum is given from the SRIM code [10] based on 2 MeV/u of Ag^{15+} on Al and we assume the current is same as that from the exit of RFQ by a multi species beam tracking cord Pteq-HI [9]. The temperature is several thousand kelvin with solid density, which is considered to be WDM state. DPIS with a feasible IH accelerator can realize WDM generation.

Table 2: Basic parameters and final temperature of Al in WDM.

Energy loss rate for Ag^{15+} in Al target	1.5 MeV/u μm
Final beam diameter	2 mm to 0.1 mm
Current	15 mA
Bunch width	1 ns
Achievable Al temperature	0.3 eV

CONCLUSIONS

WDM physics is a challenging science and is strongly related to Heavy Ion Fusion science. WDM formation by Direct Plasma Injection Scheme (DPIS) with IH accelerator, which is a compact system, is proposed. Feasible parameters for IH accelerator are shown for WDM state. These represents that DPIS with IH accelerator can access a different parameter region of WDM.

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