Target Design for High Energy Density Physics Experiment using Intense Ion Beams

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Abstract. A new approach for high energy density physics experiments using intense ion beams is presented. To make dense matter plasma as the interior of Jupiter, we use a diamond anvil cell for isentropic compression and the intense ion beams for isochoric heating. Results indicated that the temperature of $10\rho_s$ ($\rho_s$: solid density) pre-compressed target can be achieved 4000 K irradiated by argon ion beams. We also investigated a radiation hydrodynamics (RH) target for understanding optical properties. Making well-defined RH plasma, we calculated the spherical target using intense ion beams. The results indicated that the spherical target plasma could be point-spot like temperature distribution and target size was about 0.4 mm full width of half maximum.

1. Introduction

High energy density physics (HEDP) is of interest in the efficient implosion of the inertial confinement fusion, the originating Solar Systems evaluated by the interior of giant planets as the Jupiter and the Saturn, and the generating process of highly energetic particles in astrophysical phenomena as the Gamma-ray burst, and so on [1]. Understanding these behavior and/or structure, we should have exact data on the equation of state (EOS) and the transport properties of electron and radiation in high energy density (HED) state. HED state of matter, which is categorized as a warm dense matter (WDM), a hot dense matter (HDM), and a radiation dominated matter (RDM), has a potential of abundant scientific discovery including the properties of plasma [2].

Intense ion beams, which are provided by the induction systems, are opening up an attractive branch for HEDP [3, 4, 5, 6, 7, 8, 9, 10]. Accelerators producing opportunely tailored energies of intense ion beams are promising energy drivers for inertial fusion energy and are also expected to be able to provide a useful tool for creating HED matters. Compared to the high power devices, the intense ion beams using induction technology [11] have many advantages; in uniformity of energy deposition, in large volume of the samples compared to diagnostic resolution, in virtue of the long stopping range, in an advantageous environment for diagnostics, in an ability to heat a variety of target materials in a condition with high repetition rate and multiple beam lines.

For the HEDP study based on the ion beams irradiation, the target should be in equilibrium and as well-defined as possible to accurately diagnose the physical parameters. In this study,
we propose a method to make a HED state of matter based on providable beam parameters in KEK digital accelerator. In this paper, low entropy target and spherical point-spot like radiator are discussed using intense ion beams.

2. Low entropy target for condense plasma experiments based on intense ion beams

Low entropy target plasma is expected to be applicable for planetary science. Making a critical parameter for exploring the structure of Jupiter, we have to generate a warm dense hydrogen with 6000 K and 200 GPa. The critical parameter region of hydrogen in Jovian interior is estimated to be about $10 \rho_s$ ($\rho_s$: solid density) from SESAME[12] and QEOS[13]. Generating highly compressed hydrogen, a shock compression driven by ultra short pulse laser or pulsed-power device has been practical method. The shock compression methods are too dissipative to make the state of Jovian interior. A scheme with multiple shock compression may be useful for formation of the WDM state. However, the shock relation intrinsically includes the EOS, that is, the adiabatic constant depends on the state of matters. Then the estimated condition formed by the multiple shock compression should become quite unclear.

Diamond-anvil cell (DAC), which consists of two opposing diamonds with a sample compressed between the culets, can be generated extreme pressure condition, statically. Additional heating method of DAC as laser-heated or electron cyclotron resonance (ECR) heated DAC is also to create extreme pressure ($P > 100$ GPa) and temperature ($T > 3000$ K). However, caused by the broken anvils, approached parameters of both laser-heated and ECR heated DAC depended on the diamonds properties. Pulsed intense ion beams heated DAC, which are programed to heat the sample by the Bragg peak, can provide the uniform samples and the lower damaged anvils compared to the both heating methods in DAC sample.

Figure 1 (a) shows a deposition energy profile of diamond target irradiated by 4.8 GeV argon ion beams, which is providable beam parameter of KEK digital accelerator. As shown, the estimated stopping range is about 4.4 mm and the deposition energy of target is concentrated from 4.2 mm to 4.4 mm. The result indicated that the concentrated deposition energy can heat the compressed sample without the diamond heating. We estimated the temperature of $10 \rho_s$
hydrogen target irradiated by the argon ion beams with $2 \times 10^{10}$ particles as shown in Fig. 1 (b). It reveals that the temperature of compressed hydrogen target can be uniformly about 4300 K with 10 µm in the target length.

3. Quasi-spherical plasma for radiation hydrodynamics experiments based on intense ion beams
The hydrodynamics dominated by radiative energy flux and pressure plays a crucial role in not only for exploring astrophysical phenomena but also for evaluating the efficiency of hohlraum target for ICF driven by HIBs or lasers [1, 14] Especially, the explosion process in supernova is strongly affected by the radiation transfer in a wide range of parameters from optical thick to thin condition. Then, we cannot determine directly the origin of radiation from the astronomical observation due to the unclarified radiative effects. In order to study such processes, we should evaluate the energy transfer in dense high temperature matter. In a region from HDM to RDM, we should consider both the hydrodynamic energy flux and the radiation flux. The focusing beams as KEK Digital accelerator with PS-ring are able to produced both HDM and RDM conditions[2].

We calculated the hydrodynamics of target with two dimensional spherical geometry, which
is assumed aluminum solid target with 1 mm in radius. The detail of calculation is shown in Ref. [10]. In this calculation, the beam radius is set to be 1 mm with a Gaussian distribution. The beam duration is 100 ns, and the beam particle number is $2 \times 10^{13}$ argon ions with monotonic particle energy (1.67 GeV) which is considered to the stopping range in the target.

Figure 2 shows preliminary results of the evolutions of temperature at each time. As shown in Fig. 2, the point-spot like temperature distribution is able to be generated by the light ion beams. The radius of generated point-spot plasma is 0.4 mm full width of half maximum at center of target. It might indicated that the more smaller spherical plasma is created by irradiation of smaller beam radius.

4. Summary

We proposed HED experiment based on intense ion beams as possible parameters of KEK digital accelerator. New target plasmas, which are low entropy target and point-spot like spherical radiation source, were generated by the programed intense ion beams. To make dense matter plasma as the interior of Jupiter, we use a diamond anvil cell for isentropic compression and the intense ion beams for isochoric heating. It indicated that the temperature of $10\rho_s$ pre-compressed target can be achieved 4000 K irradiated by the argon ion beams. We also investigated the radiation hydrodynamics based on the intense ion beams. To generate the well-defined plasma, we calculated the spherical target using intense ion beams with 1 mm in radius. The results indicated that the spherical target plasma could be point-spot like temperature distribution and the target size was about 0.4 mm full width of half maximum.

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