Concept for Generation of Warm Dense Matter of Insulator due to Flyer Impact Accelerated by Electron Beam Irradiation using Intense Pulsed Power Generator

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Abstract. We have proposed a concept for generation method of warm dense matter (WDM) by using flyer impact accelerated by intense electron beams. To generate the warm dense matter by using flyer impact, the output current of electron beams generated by the intense pulsed-power generator as ETIGO-II is evaluated. The results denote that the beam current and the pulse duration are 11 kA and 50 ns, respectively. The achievable parameters of WDM by using flyer impact are estimated by the simplified model. It indicated that the sample temperature achieves the provided electron beams with lower conversion efficiency.

1. Introduction

Properties of insulators in warm dense matter (WDM) are interested in an optimization of cone material for the fast ignition [1], evaluating interiors of giant planets [2], and so on. For example, diamond-like-carbon (DLC) is expected as one of effective cone materials, and the accurate properties in WDM are required to increase the coupling efficiency.

The WDM region is in dense ($10^{21} - 10^{24} \text{m}^{-3}$) and moderate temperature ($10^3 - 10^5 \text{K}$). To understand the properties of WDM, effects of ion-ion correlations and degenerate electrons are analyzed by studying the dependence of equation of state (EOS). To generate WDM for conductive materials, several experimental approaches by using pulsed-power discharge have been demonstrated [3-6]. However, it is difficult to generate the WDM from insulators by the method, because insulators are quite low conductivity. To generate WDM of insulator needs high energy density and another method besides the isochoric heating of Joule heating. Thus, we consider a different approach for generation of WDM from insulator with well-defined plasma parameters. To solve the problems, we focus on the flyer impact method by using intense pulsed-power system. The method of flyer impact by using an intense ion beams has been demonstrated [7,8]. The results indicated that the flyer generated from an aluminum foil was 7.7 km/s in the velocity and 13 GPa in the ablation pressure at ion beam energy density of 2 kJ/cm$^2$. Thus, the method of flyer impact provides the heating insulator samples and the well-defined material state from the shock relations.
In order to consider the method of flyer impact, we propose the flyer acceleration and impact on an insulator target with intense electron beam by the intense pulsed power supply “ETIGO-II”[9].

2. Intense pulsed power generator “ETIGO-II” as experimental setup

The normal output parameters from ETIGO-II in the case of impedance matching at a load are 1MV, 590kA, 50nsec (FWHM), respectively. In this experiment, the load as an electron beam diode consists of a cathode made of a SUS plate having φ 105 mm in diameter and an anode made of a SUS mesh having φ 210 mm in diameter. The output voltage of pulse-transmission line in ETIGO-II was measured using a capacitive voltage divider located at upstream of the electron beam diode. The output current of pulse-transmission line in ETIGO-II was measured by pick-up coil located at between the voltage divider and the electron beam diode. The output currents at the cathode and the electron beam current were measured using Rogowski-coils.

Figure 1 shows typical output waveforms of ETIGO-II with electron beam diode. The output voltage is 1 MV at the peak with 50 ns of the pulse duration. The output current of pulse-transmission line in ETIGO-II is 30 kA. The output current of cathode is also 30 kA with 30 ns delayed from the current of pulse-transmission line. The electron beam current is 11 kA at the peak with the duration of 50 ns.

3. Evaluation of sample temperature in WDM for insulator

To evaluate the EOS of WDM for insulator, we consider the achievable parameter by using flyer impact. From the beam-flyer conversion efficiency obtained by the previous experiments as the intense ion beams, we estimate the achievable temperature of WDM sample for silicate.

Figure 2 shows the processes of energy conversion by using flyer impact. The electron beams heats the flyer with the ablation. The flyer collides and heats the silicate sample. These processes have several energy conversions. The increase of temperature ΔT for the silicate is estimated by the following equation,

\[
\Delta T = \frac{E_s}{\rho_s C_v S_s L_s} \cdot \frac{\eta_{e-f} \eta_{f-S}}{\rho_s C_v S_s L_s} \cdot E_e,
\]

Figure 1. The typical output waveforms from ETIGO-II with electron beam diode.
Figure 2. Processes of energy conversion by using flyer impact

Figure 3. Achievable temperature of the sample as a function of the conversion efficiency $\eta_{e-f}$ from the electron beam energy to the kinetic energy of flyer and the transmission efficiency from the kinetic energy of flyer to the sample. The initial sample temperature is 300 K for these estimations. The sample temperature $T_s$ is over 3000 K at $\eta_{e-f}=0.1$ and $\eta_{f-s}=0.5$. It means that the sample temperature and the input energy are enough to generate WDM at lower efficiency of conversion from the electron beam energy to the sample heating.

4. Design for flyer experiment to generate WDM of insulator

Figure 4 shows the design of the load for flyer acceleration. The flyer target is located on the focal point of the spherical electrodes because of focussing electron beam and irradiating intense electron beam. Figure 5 shows the measurement systems for the flyer and the sample. The electron beam current is measured by the Rogowski-coil to estimate the input power to flyer. Flyer velocity as the flyer energy is measured by time of flight method using optical fibers with photo diodes. The sample temperature and propagation shock velocity trace are observed with the spectroscopic observation and VISAR.
5. Summary
We have proposed a concept for generation method of WDM by using flyer impact accelerated by the intense electron beams. To generate the WDM by using flyer impact, the output current of electron beams generated by the intense pulsed-power generator as ETIGO-II is evaluated. The results denoted that the beam current and the pulse width are 11 kA and 30 ns, respectively. The achievable parameters of WDM by using the flyer impact are estimated by the simplified model. It indicated that the sample temperature achieves the provided electron beams with low conversion efficiency. The design of the flyer impact driven by the intense electron beams is considered. We will make the system and demonstrate the experiment of generating WDM for insulator.

References
[1] Fujioka S et al 2012 Plasma Physics Controlled Fusion 54 124042
[2] Kurosawa K et al 2012 J. Geophys. Res. 117 E04007
[3] Amano Y et al 2012 Rev. Sci. Instrum. 83 085107
[4] Renaudin P et al 2002 Phys. Rev. Lett. 88 215001
[5] Sasaki T et al 2010 Phys. Plasmas 17 084501
[6] DeSilva A W and Katsouros J D 1998 Phys. Rev. E 57 5945
[7] Kashine K et al 2002 Jpn. J. Appl. Phys. 41 4014
[8] Kashine K 2013 2nd IGCN SO-6
[9] Jiang W et al 1993 Jpn. J. Appl. Phys. 32 L752