Input Energy Control Using Electron Beam Diode as Impedance Controller to Study Warm Dense Matter by Pulsed Power Discharge with Isochoric Heating

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The characteristics of input energy control with an intense pulsed power device was investigated to explore the properties of warm dense matter in an implosion time scale of inertial confinement fusion. An electron beam diode, which served as an impedance controller and could suppress the prepulse, was placed on the output terminal of the intense pulsed power device. The anode (output) current was regulated by changing the gap distance of the electron beam diode. The input energy into the dummy load representing the sample was controlled with the electron beam diode.

Keywords: pulsed power, warm dense matter, electron beam diode, implosion, input energy control

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In an inertial confinement fusion (ICF) system, the process of implosion is affected by the physical properties of warm dense matter (WDM) [1]. We used a pulsed power discharge with isochoric heating to investigate the characteristics of the WDM [2]. In the setup, the density of the sample (WDM) is well-defined because the volume of the sample is constrained by a rigid capillary wall and the temperature of the sample is controlled by the input energy due to the discharge current. A foamed sample of metal placed inside the rigid capillary wall allows us to control the density and temperature of the WDM. The WDM research at the time scale of the implosion process in ICF was proposed with an intense pulsed power device by using the pulsed power discharge with the isochoric heating [3]. To explore the physical properties such as electrical and thermal conductivities, thermodynamic properties, and equation-of-state, it is necessary to maintain the integrity of the WDM measurement. For this reason, we needed to control the amount of energy entering the sample carefully and easily.

An electron beam diode was used to control the impedance and thus the energy that entered the sample [4]. An electron beam diode consisting of a cathode and an anode in a simple parallel plane configuration was installed onto the output terminal of the intense pulsed power device. The impedance was controlled by changing the gap distance between the electrodes of the electron beam diode.

In this study, the characteristics of the input energy control into the sample with the electron beam diode as the impedance controller is investigated experimentally for the WDM research in the ICF implosion process (several-tens of nanoseconds) [5]. Because the implosion process of the fuel pellet driven by the irradiation of intense lasers and/or high-current ion beams should be finished to cause the plenty nuclear fusion reactions during the inertial confinement phenomenon.

Figure 1 shows the intense pulsed power generator "ETIGO-II" [6], which is used as the pulsed power supply in this study. The nominal parameters of ETIGO-II are

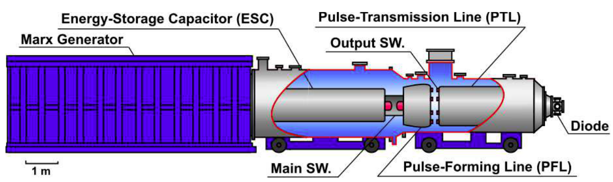

Fig. 1 Overview of intense pulsed power generator "ETIGO-II" as experimental apparatus.

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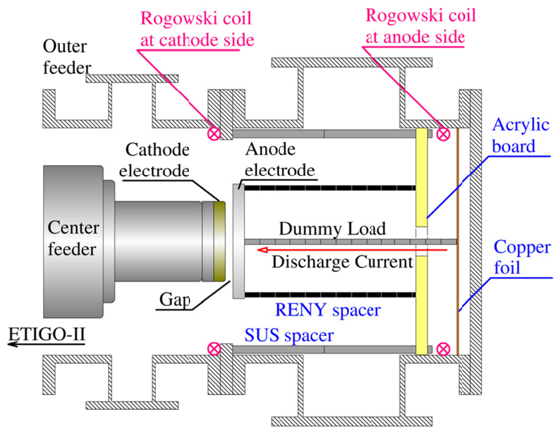

Fig. 2 Experimental setup of dummy load and electron beam diode placed on the output terminal of ETIGO-II.

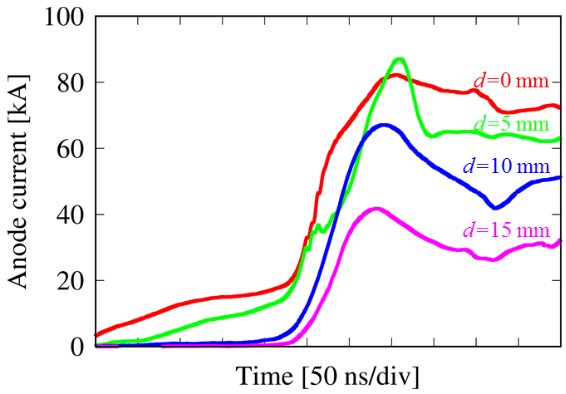

Fig. 3 Typical waveforms of the anode current at each gap distance of the electron beam diode, as detected by using Rogowski coil shown in Fig. 2.

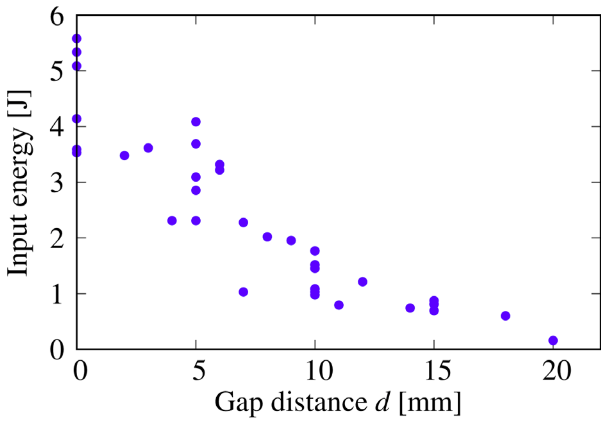

Fig. 4 Input energy into dummy load as a function of diode gap distance.

suitable for this research because of its peak output voltage of 1 MV, an output current of 590 kA, and a pulse duration of 100 nsec.

Figure 2 shows the experimental setup mounted on the output terminal of the ETIGO-II. The electron beam diode serving as impedance controller is the parallel plate, which consists of the cathode (brass, 105 mm in diameter) and anode (aluminum, 150 mm in diameter) disk electrodes [4]. The electron beam emitted from the cathode surface reaches the anode side, and the electrical current passes through the dummy load (stainless steel, 7 mm in diameter) during the discharge of ETIGO-II. The impedance control is varied by changing the gap distance of the electron beam diode [4]. For the WDM research, the dummy load will be replaced by the sample (e.g., a foamed metal surrounding with a rigid capillary) for the pulsed power discharge with isochoric heating [3]. The structure of the setup was carefully arranged to prevent the creeping discharge, excepting inside the diode gap. The pressure inside the vacuum chamber was adjusted to be less than 0.02 Pa, as shown in Fig. 2.

Figure 3 shows the typical output waveforms for the anode current at each gap distance d. As shown in Fig. 3, the prepulse can be suppressed to increase the gap distance of the electron beam diode. The prepulse causes unexpected preheating of the sample. In this study, the input energy should be regulated as a sharp pulse to simulate the target heating during the implosion process.

Figure 4 shows the input energy into the dummy load as a function of the diode gap distance. The input energy into the dummy load is evaluated by $E = \int_{t_r}^{t_r+\tau_p} RI^2\,dt$, where t_r is the rise time of the anode current (at the beginning of the pulse), τ_p is the pulse duration, R is the electrical resistance of the dummy load, and I is the anode current as shown in Fig. 3. The rise time t_r was defined as the crossing time of the horizontal axis ($I = 0$), and the line elongated from 70% to 30% of the peak anode current. The pulse duration τ_p was set as 50 ns in this study, which corresponds to the implosion time scale. This enabled us to study the physical properties of the WDM over the timescale of the implosion (several-tens of nanoseconds) and are the most important for the design of fuel pellets. This technique will enable us to maximize the output of nuclear energy from fuel pellets, allowing us to optimize the structure of the pellet and the manner in which energy is supplied to it. The resistance R was evaluated by the dummy load, including with the skin depth.

In the gap distance $d = 6 \sim 20$ mm, the input energy was controlled as a function of the gap distance d and the tendency was $1/d$, as shown in Fig. 4. When the gap distance is less than 6 mm, the average electric field strength in the gap is estimated as over 1 MV/cm, and the discharge current was unstable. The electron emission condition will consequently be sensitive to the surface roughness of the electrode and the alignment from the viewpoint of the field emission [7], and also the arc discharge will be occurred to reach the ablation plasma emitted from the anode.

In this study, the characteristics of the input energy control with the pulsed power device was investigated to explore the properties of the WDM over the time scale of the implosion. The electron beam diode was placed on the output terminal of the intense pulsed power device ETIGO-II to control the impedance and to suppress the prepulse. The anode current was regulated by changing the diode gap distance, and the input energy into the dummy load, which is the emulated sample for WDM, was easily controlled using the electron beam diode.

By using the system described in this study, we expect to be able to predict the properties of the WDM for a range of energy densities for periods of the order of the implosion timescale of the ICF.

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