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Evaluation Method for Electrical Conductivity of Warm Dense Matter with Isochoric State using Pulsed-Power Discharge

パルスパワー駆動定積 Warm Dense Matter の導電率評価法

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An evaluation method of electrical conductivity in isochoric warm dense state produced by foam ablation has been developed by using pulsed-power discharge. The isochoric state can be achieved to surround the foamed metal with a hollow sapphire capillary as a rigid wall. The temperature and the electrical conductivity of foam/plasma have been evaluated by the emission intensity ratio and the voltage-current waveforms. Observed electrical conductivity is in agreement with previous experiments and predictions. As a result, the electrical conductivity in warm dense state with well-defined temperature and density can be obtained by the proposed method.

1. Introduction

Properties of materials in a warm dense matter (WDM) are of interested to concern an interior of giant planets and an imploded fuel pellet of inertial confinement fusion. The WDM region is defined that the density range is from 10^{-3} ρ_s (ρ_s is the solid density of matter) to 10 ρ_s, and temperature varies from 0.1 to 10 eV. To understand properties of WDM state, effects of the ion-ion correlation and the degenerated electrons can be evaluated by the density-temperature dependence of electrical conductivity. [1-5, 8]. Generating and evaluating WDM state, we should create a well-defined state, i.e. estimative density and temperature condition, in a laboratory experiment.

In this study, we propose a measurement method for electrical conductivity in WDM state by using pulsed-power discharge with isochoric heating.

2. Experimental setup

Figure 1 shows a schematic diagram of the proposed method by a pulsed-power discharge device with isochoric state [8]. To achieve isochoric state, metallic foam was packed into a hollow sapphire capillary (ϕ5×10 mm). The metallic foam is copper with from 50 μm to 600 μm porous size and about 90 % porosity. To avoid the surface creepage on sapphire, turbo-molecular and rotary pumps are set at bottom of chamber. The density of WDM can be controlled by the volume of foam enclosed into the hollow capillary. The capacitors (3×1.87 μF) were charged up to 15 kV to ensure the vaporization of foam. Time evolutions of current

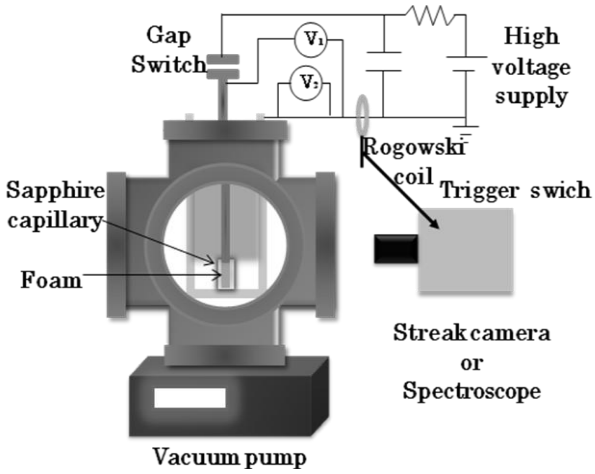

Fig. 1 Experimental setup

I(t) and voltage V(t) in foam/plasma were measured by a Rogowski coil and high voltage probes. The obtained voltage was composed of resistive and inductive parts. The stray inductance L of the discharge device was estimated to be 165 nH from the preliminary experiment with the short-circuit. The electrical conductivity σ(t) of the foam/plasma is evaluated by the following equation;

$$\sigma(t) = \frac{l}{\pi r^2} \frac{I(t)}{\left(V_1(t) - V_2(t)\right) - L\dfrac{dI(t)}{dt}}, \qquad (1)$$

where, l is the length of the foam/plasma, r is the foam/plasma radius, V_1(t) is the voltage between gap switch and ground, V_2(t) is the voltage between the return cable and ground.

To evaluate the temperature without equation-of-state models, the emission from the foam/plasma is measured by the spectroscope mounted on a streak camera. The foam/plasma temperature T is estimated by using line pair method;

$$\ln\left(\frac{\varepsilon_{21}\lambda_{21}}{A_{21}g_2}\right) = -\frac{E_2}{k_B T} + \ln K, \qquad (2)$$

where λ_{21} is the wavelength, A_{21} is the spontaneous emission coefficient, ε_{21} is the emission factor of the spectral line, E_2 is the upper level energy, k_B is the Boltzmann constant, and K is the constant factor, respectively.

3. Experimental results

Figure 2 shows typical results for (a) the voltage and current waveforms, (b) the input energy and foam/plasma temperature, and (c) the electrical conductivity in $0.032\rho_s$. The peak voltage and current are 1 kV and 50 kA, respectively. In case of $0.032\rho_s$, the evaporation energy is estimated to be 300 J. From input energy history, the copper foam is ensured the vaporization at 20 μs from beginning of discharges. The foam/plasma temperature was estimated to be about 5500 K by the input energy and SESAME equation of state (material No. 3333) [7] and spectra of Cu I at 477 nm and 617 nm with eq. (2) [6]. From this comparison, the temperature is almost same between 8 μs and 13 μs. As a result, it is confirmed that the copper foam became the isochoric WDM state by the pulsed-power discharge device. The electrical conductivity of copper foam/plasma is estimated to be 10^4 S/m from the voltage and current waveforms. The observed electrical conductivity is in agreement with previous experimental results [2, 5] and the theoretical predictions [4]. Therefore, it is concluded that the proposed method can produce the well-defined WDM state.

4. Conclusions

We have developed a measurement method for electrical conductivity in isochoric WDM state by using pulsed-power discharge. Achieving isochoric state and avoiding skin effect, we have used the foamed metal surrounded by the hollow sapphire capillary. The result indicated that the foam/plasma temperature obtained by the line pair method is comparable with the temperature estimated by the input energy history with SESAME. It is indicated that the dependence of electrical conductivity obtained by the proposed method is in agreement with the previous results.

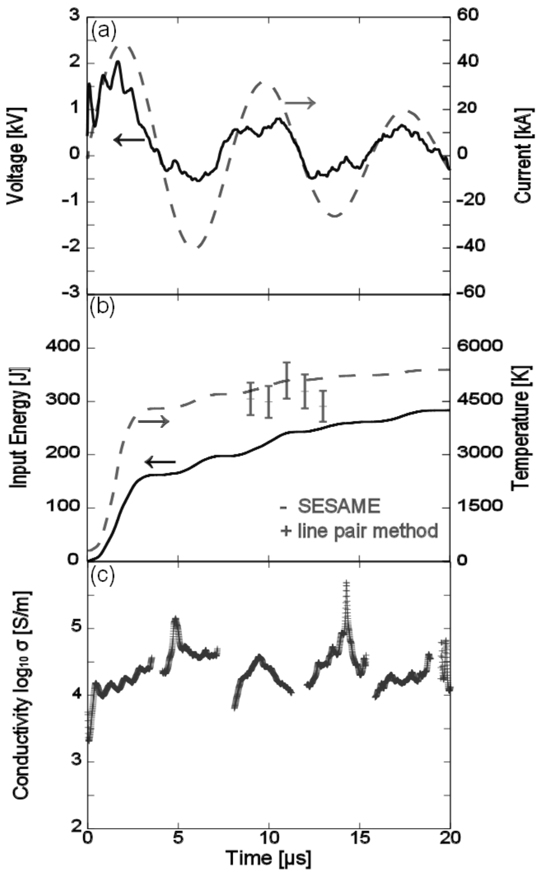

Fig. 2 Typical results for (a) voltage and current waveforms, (b) input energy and typical temperature estimated by line pear method and SESAME equation of state table Cu3333, and (c) electrical conductivity

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