§27. Evaluation of Electrical Conductivity and Heat Conduction for Warm Dense Tungsten Generated between Divertor and Fusion Plasmas

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Type of Tokamak in magnetic confinement fusion such as international thermonuclear experimental reactor (ITER) and DEMO requires a divertor [1]. The divertor is irradiated by the highly energetic particles from the fusion plasmas. Heating load on the divertor is estimated to be 10 MW/m^2 at steady state and 1000 MW/m^2 at plasma disruption and mitigated edge localized modes (ELMs) [2, 3]. To prolong the lifetime, the divertor is going to be made by tungsten. The fusion plasma is sensitive to the ablated tungsten because of high-Z elements. Therefore, we should understand the effect of fusion plasma induced by the ablated tungsten. The ablation plasma evolves through a warm dense state, in which coupled ions, degenerated electrons and the liquid-vapor phase transition should affect the thermal conductivity. The thermal transport and the heat capacity in ablated tungsten should be evaluated by using semi-empirical approaches.

Evaluating thermal conductivity in ablated tungsten such as divertor of the nuclear fusion reactor, we proposed the evaluation of thermal conductivity by using pulsed-power discharge and semi-empirical estimation. The pulsed-power discharge enables us to evaluate electrical conductivities in ablated dense tungsten, directly [4]. We assumed that thermal transport coefficients in ablated tungsten are correlated with them by the ordinary relations.

The experimental layout is the same with previously published studies using exploding wire discharge in water [4, 5, 6] and pulsed-isochoric heating confined by sapphire vessel [7]. The pulsed-isochoric heating is driven low inductance capacitors (3×2 μF) with 15 kV in charged voltage, which is estimated to be enough for vaporization of wire. We used thin wire with 500 μm in diameter and 10 mm in length as the load. The inner diameter of the sapphire capillary is 5 mm. The mass density of vapor/plasma tungsten filled sapphire vessel is estimated to be $\log_{10}(\rho/\rho_s) \sim -2$ (ρ_s: solid density). The electrical conductivity is evaluated by the voltage-current waveforms when the vapor/plasma filled sapphire vessel. The temperature assuming local thermodynamic equilibrium is evaluated by the ratio of radius and the black body emission.

We reconstruct the thermal conductivity using Weidemann-Franz law as the following equation [8],

$$\kappa = \left(\frac{\pi^2}{3}\right)\left(\frac{k_\mathrm{B}}{e}\right)^2 T\sigma, \qquad (1)$$

where, κ is the thermal conductivity, k_B is the Boltzmann constant, e is the elementally charge, T is the temperature, and σ is the electrical conductivity. We estimated the semi-empirically obtained thermal conductivity of tungsten as a function of density at temperature around 5000 K. The result shows that the thermal conductivity obtained by the semi-empirical method is almost the same with that of liquid tungsten at $\rho \sim \rho_s$. Results also indicate that the thermal conductivity reduces more than two orders of magnitude with decrease of the density and the evaluated thermal conductivity has a minimum of 0.1 WK^{-1}m^{-1} at around $\log_{10}(\rho/\rho_s) = -1.5$.

We have done a semi-empirical evaluation for thermal conductivity of ablated tungsten in warm dense region. The thermal conductivity obtained with this method reduced more than two-orders of magnitude with density decrease and it ranged from 0.1 to 100 WK^{-1}m^{-1} at 5000 K. The result indicates that the behavior of thermal conductivity is critically important for understanding the ablation process of tungsten.

This work was partly supported by Grant-in-Aid for Young Scientists (B) from Japan Society for the Promotion of Science (23740406) and the NIFS Collaboration Research program (NIFS1KEMF019).

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