Back-Surface Temperature Measurements of Thin Tungsten Materials during Plasma-Gun Generated Pulsed Plasma Irradiation using a Fast Two-Color Pyrometer

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A fast two-color pyrometer system was developed to measure the back-surface temperature of thin tungsten materials during plasma-gun generated edge localized mode-like pulsed plasma irradiation. The developed pyrometer system had a time resolution of ~5 µs and the lowest measurable temperature was ~1600 K. We observed that the back-surface temperature of the thin tungsten material during the pulsed plasma irradiation reached ~3280 K. The absorbed energy density and the pulse width of the pulsed heat load estimated by the measured time evolution of the back-surface temperature and 3D heat analyses using ANSYS code were ~0.52 MJ m⁻² and ~1.6 ms, respectively.

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Transient heat loads, such as type-I edge localized modes (ELMs), and disruptions are critical problems for lifetime of plasma-facing components in future tokamak devices. In the ITER divertor, the energy density and pulse length of type-I ELMs are predicted to be 0.2 - 2 MJ m⁻² and 0.1 - 1 ms, respectively [1]. Simulation experiments of pulsed heat loads using electron beams, lasers, and plasma guns have been conducted to investigate allowable heat load limits of type-I ELMs in ITER [2]. Furthermore, we have investigated the surface damage of tungsten (W) materials due to ELM-like pulsed plasma heat loads using a magnetized coaxial plasma gun (MCPG) device at the University of Hyogo [3]. The material damage caused by pulsed plasma exposure has been characterized in terms of the energy density absorbed on the material surface, which was measured with a calorimeter. In contrast, a surface temperature measurement during the pulse heat load is also required to clarify dynamic behaviors of plasma–material interactions. In this study, a two-color pyrometer with a fast response time was newly developed to measure a material surface temperature during the pulsed plasma irradiation.

A schematic of the two-color pyrometer developed in this study is shown in Fig. 1. The pyrometer detected thermal emission at 750 and 800 nm wavelengths from the material surface heated by the pulsed plasma load using interference filters with bandwidths of 11 and 12 nm. Si photodiode amplifiers (Tholabs, DET36A/M) were used as the detectors, and output currents of the photodiodes were translated to voltage signals using load resistances (51 kΩ). The temporal resolution of the pyrometer system was ~5 µs, which was sufficient for the temperature measurements in the MCPG experiment.

For the pyrometer system, the absolute temperature T was analyzed as shown in Ref. [4]. The emission intensities I₁₂ at two wavelengths A₁₂ can be described according to Planck’s law

\[ I_{12}(A_{12}, T) = A \Omega K_{12} \varepsilon_{12}(A_{12}, T) \frac{2\pi c^2}{A_{12}^5} \frac{1}{e^{hc/A_{12}T} - 1}, \]

where A, Ω, K, ε, h, c, k are the surface area, solid angle, constant loss term of the pyrometer at the chosen wave-
Fig. 2 Schematic of the sample holder for pyrometer measurements. A thin tungsten (W) sample was mounted, and an optical fiber was installed behind the sample to collect the thermal radiation.

Fig. 3 Time evolutions of (a) \( I_{\text{gun}} \), (b) \( I_{\text{HeII}} \), (c) \( V_{\text{pd}} \) (black: 750 nm, red: 800 nm), (d) \( T_{\text{bs}} \) (black: measured, red: calculated), and (e) \( P_{\text{abs}} \).

The absorbed power density \( P_{\text{abs}} \) on the W disc was estimated by the measured time evolution of \( T_{\text{bs}} \) and 3D heat analyses using the ANSYS code. A spatially uniform heat flux in a circular area was used in the simulation. Furthermore, radial heat transport and the temperature dependence of the thermomechanical properties of W were included. In the simulation, the time evolution of \( P_{\text{abs}} \) was adjusted so that the calculated \( T_{\text{bs}} \) agreed with the measured \( T_{\text{bs}} \). As shown in Fig. 3(e), \( P_{\text{abs}} \) had a steep rise time and a peak value of \( \sim 0.33 \text{ GW m}^{-2} \). The pulse duration of \( P_{\text{abs}} \) defined by the time constant of exponential decay was \( \sim 1.6 \text{ ms} \). The absorbed energy density given by time integration of \( P_{\text{abs}} \) was \( \sim 0.52 \text{ MJ m}^{-2} \). Consequently, measurements of \( T_{\text{bs}} \) of thin W materials during ELM-like pulsed plasma irradiation were successfully conducted using the developed two-color pyrometer.

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