20PA-044

Non-Equilibrium and Extreme State Plasma -Experimental study of heat loads and damage to materials under steady/pulsed dual plasma-

非平衡極限 -ELM 模擬試験装置における熱流計測と金属材料への定常・パルスプラズマ照射実験—

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Synergistic effects of steady and pulsed plasma irradiations to materials have been investigated in the NAGDIS-PG (NAGoya DIvertor Simulator with Plasma Gun). The time evolution of the surface temperature of tungsten (W) plate in response to the plasma heat pulse was measured with a photo detector detecting the infrared radiation. The maximum temperature in response to the pulse on the W with a fuzz surface induced by helium plasma irradiation was higher than that of the pristine W plate. This result suggested that formation of W fuzz structure enhances the energy absorption of plasma heat pulse.

1. Introduction

Damages on plasma facing components (PFCs) due to Edge localized modes (ELMs) are a critical issue in fusion devices such as ITER. Huge localized heat loads due to ELMs will determine the life time of divertor tiles in ITER [1, 2].

Tungsten (W) will be used as a divertor tile in ITER, because it has good thermal properties. To investigate the influence of the transient heat loads on W PFCs, a laser [3], an electron beam [4], and a plasma gun [5] have been utilized. The transient localized huge heat loads cause material erosion, cracking, melting, and vaporization [6-10]. Furthermore, it is known that a steady state helium (He) plasma bombardment to W leads to a strong modification of the surface morphology, such as fiberform nanostructure [11].

In this experiment, we have developed a new temperature measurement system using the radiation from the W sample with a high time resolution (a few microseconds) to reveal how the transient plasma heat load deposits to the nanostructured tungsten in time.

2. Experimental Setup

Synergistic effects of steady-state and pulsed plasma irradiations to a material have been investigated in the device NAGDIS-PG (NAGoya DIvertor Simulator with Plasma Gun) [12], which can produce pulsed plasma in addition to steady-state plasma. Figure 1 shows a schematic view of the experimental setup. Nanostructured W was prepared by high density He plasma exposure in NAGDIS-I. The sample size was 65 × 50 × 0.1 mm^3. The incident ion energy was controlled by biasing the sample negatively, and its energy was approximately 100 eV. The temperature of the sample was ~1100 K and the He ion fluence to the sample was 6.8×10^{25} m^{-2}.

The density of the pulsed plasma generated by the plasma gun is in the range 1-10 × 10^{21} m^{-3} and the ion temperature is ~10-30 eV [13]. The pulse duration is about 0.25 ms. He gas was used for the discharge gas in this experiment.

The infrared radiation from the backside of a W sample was used for the temperature measurement. The angle of plasma stream incident to the W surface was 45°. An indium gallium arsenide (InGaAs) photo detector, which has sensitivity in the wavelength range from 800 to 1700 nm, was used to detect the infrared light from the W sample. The minimum measurable temperature is about ~800 K, because the detected signal amplitude of the photo detector at 800 K becomes background noise level. Response time of the photo detector is ~7 μs, which is sufficiently shorter than the pulsed plasma duration of 0.25 ms.

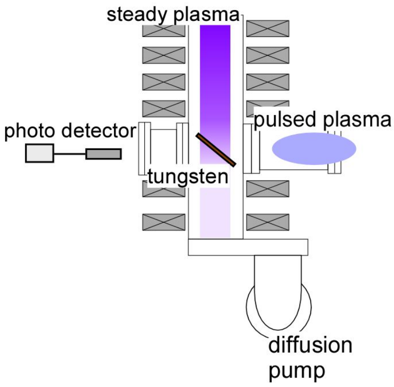

Figure 1. Schematic of the experimental device, NAGDIS-PG.

3. Results and Discussion

The temporal evolutions of the output voltage of the photo detector and the backside temperature were shown in figure 2. The discharge voltage of the plasma gun was 5.0 kV, the ion temperature was ~25 eV, and the electron density was ~3×10^{21} m^{-3}. The base temperature of the W sample before the pulsed plasma irradiation was the room temperature and the maximum temperature became ~925 K in response to the pulsed plasma irradiation. The heat load due to the pulsed plasma irradiation was estimated to be ~0.15 MJm^{-2} from the temperature rise of the W sample by analyzing the equation of heat conduction.

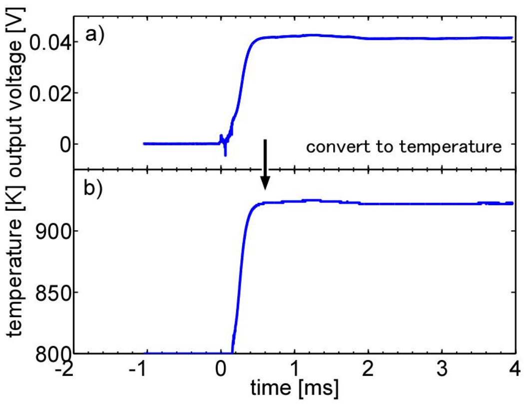

Figure 2. a) Temporal evolution of the output voltage of the photo detector and b) temperature of W sample.

Figure 3 shows the change of the maximum temperature due to the formation of W nanostructures. On the pristine sample corresponding to first 6 shots of the pulsed plasma, the maximum temperature was ~950 K. After the first 6 shots, the W sample was irradiated by a steady-state He plasma to form the W fuzz structure. It is clearly found that the formation of W fuzz leads to larger temperature to reach ~1250 K. After that, the temperature decreased gradually to ~1000 K, which could be attributed to the erosion of the W fuzz by the pulsed plasma heat load. However, the temperature did not return to the same level of the pristine sample since the He induced defects probably still remained in the deeper region. When W fuzz structure was formed again, the maximum temperature was also increased again.

It is thought that the energy deposition of the W sample was enhanced by forming the W fuzz formation. The energy deposition of the fuzz W becomes about 1.3 times larger than that of the pristine W.

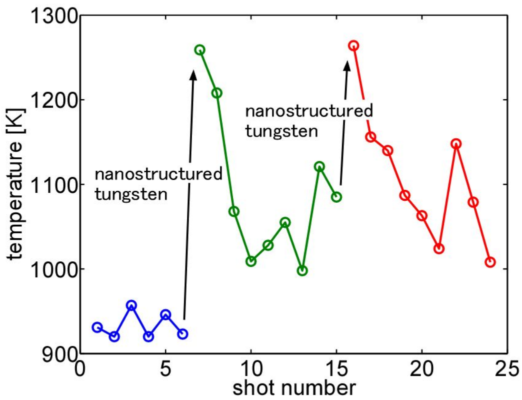

Figure 3. Variation of the maximum temperature by the successive pulsed plasma irradiation

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