06aC12

Thermal response of nanostructured tungsten

Shin Kajita, [1]Gregory De Temmerman, [1]Thomas Morgan, [1]Thijs de Kruif,
[1]Stein van Eden, [2]Noriyasu Ohno

EcoTopia Science Institute, Nagoya University, Nagoya 464-8603, Japan
[1]FOM Institute DIFFER, Dutch Institute for Fundamental Energy Research, Association EURATOM-FOM, 3430 BE Nieuwegein, The Netherlands
[2]Graduate school of engineering, Nagoya University, Nagoya 464-8603, Japan

In future fusion devices, nuclear reaction produces helium atoms. It has been recognized that the helium irradiation to tungsten leads to the formation of nanostructures on the surface. Previously, it was suggested that the thermal conductivity significantly decreased and an anomalous temperature increase occurred in response to transients when the nanostructures were formed on the surface [1]. To investigate the temperature evolution in response to transients, the experiments were conducted in MAGNUM-PSI device with laser and transient plasma [2] using nanostructured tungsten samples that were prepared in the divertor simulator NAGDIS-II. The measurement of the temperature was conducted with a fast framing IR camera.

Figure 1 shows temporal evolution of the surface temperature on (a,c) a pristine sample and (b,d) nanostructured sample. In response to transient plasma irradiation, the surface temperature significantly increased on the nanostructured tungsten surface compared with that on the pristine tungsten sample. Although the surface temperature increased only by ~100 K on pristine tungsten sample, the SEM analysis on the nanostructured tungsten revealed that the nanostructures melted on the same power.

Similar experiments were conducted using laser pulse irradiation in MAGNUM-PSI chamber. The peak temperature in response to laser irradiation to fuzz sample was investigated with changing the laser power. It was revealed that the significant temperature increase and melting traces were also identified for the laser irradiation similar as the pulsed plasma irradiation.

There are several possibilities to lead the phenomena; they are discussed with using the numerical analysis of the surface temperature by solving the thermal diffusion equation. It is found that the decreases in the density of tungsten and thermal diffusivity by the formation of nanostructures could lead to the increase in the surface temperature. The nanostructure decreases the cohesive energy, and the melting point may be decreased consequently. However, it was likely that these effects should be minor, and cannot explain the experimental observation overall. It was likely that nanostructure matrix formed a thermally isolated part near the surface, and non-uniformity in the temperature increase would have been taken place. The locally heated part would increase the thermal radiation and increase the measurement temperature.

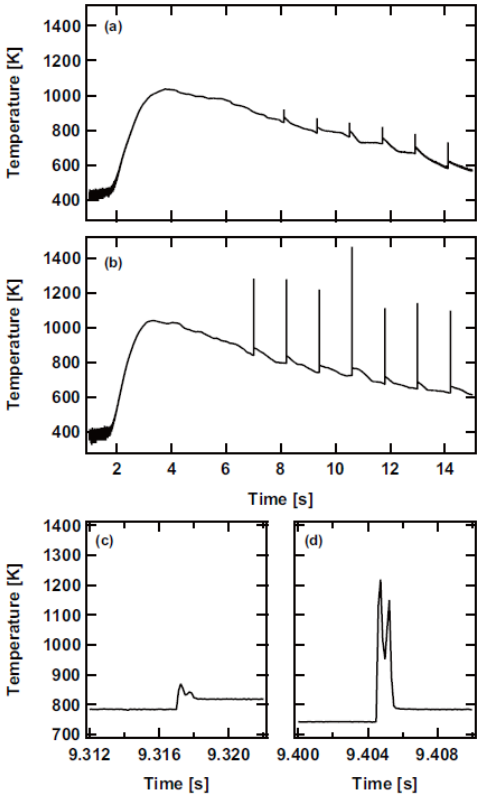

Fig. 1: Temporal evolutions of the surface temperature measured with an infrared fast camera during pulsed plasma irradiation experiments. (a, c) shows the case for the pristine W sample, and (b, d) shows the case for nanostructured W sample.

References:
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[2] G.D. Temmerman, J. Zielinski, S. van Diepen, L. Marot and M. Price, Nucl. Fusion 51, 073008 (2011).