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The Influence of Contamination Layers on Surface Temperature Measurements of Carbon Materials in Fusion Devices

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Introduction

Surface temperature measurements by IR-thermography are supposed for supervision of the heat load arriving at the target plates of the Wendelstein 7-X stellarator presently under construction. However, during plasma exposure, both the surface morphology and the thickness of contamination layers are expected to be continuously modified in an ill-defined manner due to erosion and deposition processes. The involved change of the surface heat conductivity makes it difficult to supervise the thermal load of such surfaces during plasma exposure in real time [1]. Recently, effects of the surface morphology on the accuracy of temperature readings at surface heat loading have been investigated [2]. This paper presents results of experiments demonstrating the influence of contamination layers deposited during the plasma exposure on surface temperature measurements. Moreover the change of the thermal behaviour of this contamination under high heat flux exposure is considered. Therefore contaminated target tiles used in ASDEX Upgrade were post-mortem investigated by surface analysis and their thermal response at the surface to well-defined heat pulses by laser beams was examined. The surface temperature measurements were performed in the far infrared wavelength region (FIR) to reduce morphological effects [2] as well as in the middle infrared region (MIR) to obtain better time resolution.

Experimental

The target tiles were made from the fine grained graphite (FGG) material EK98 and used in the outer or inner divertor I of ASDEX-Upgrade from 1991 to 1995. They were located near the strike lines and are contaminated with deposited material consisting mainly of H, D, B, C. The thickness of the contamination layer on the inner divertor tile varies between 0.5 µm and 4 µm and is less than 0.3 µm on the outer divertor tile. Using laser profilometry the mean surface roughness has been determined to be 1-2 µm for the inner divertor tile and 5-10 µm for the outer divertor tile. The samples have been irradiated by fiber-coupled light from a cw diode laser or a pulsed Nd laser. The heat pulses from the diode laser have a spatial Gaussian profile with a standard deviation σ of 0,36 mm. Heat fluxes with central densities P_o up to 40 MW / m^2 are applied. The surface temperature excursion during and after the laser heat pulses has been measured by a VOx microbolometer camera (240x320 pixels) operating in the wavelength region 8-15 µm. Using a microscopic lens the spatial resolution has been improved to 90 µm/pixel. The thermal images have been taken with a frame rate of 50 Hz. An improved time resolution up to 190 µs could be achieved in other series of experiments with an InSb-camera (3-5 µm) and using a Nd laser with pulse durations up to 20 ms [2].

Results

Figure 1 shows the time history of the temperature excursion for different spots on the contaminated surface of the inner and outer divertor tile, and for comparison the excursion on the uncontaminated machined backside. The laser heating pulse duration is 1 s and the absorbed central power density 28 MW/m^2. The measured values are compared with the analytic solution obtained from the 3D-heat conduction equation [2]

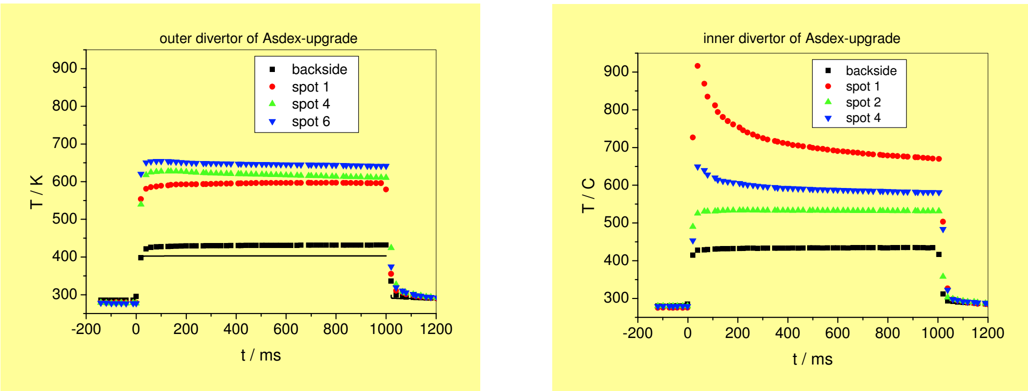

Fig.1 : Temperature excursion measured for different spots on the outer (left) and inner (right) divertor tile; applied heat pulse P_0 = 28 MW/m^2, τ = 1s, σ = 0.36 mm. The solid curve (left figure) is the analytic solution.

For the erosion-dominated outer divertor tile with marginal contamination the spot temperature reaches values between 595 K and 650 K. These values are significantly higher than the temperature of 440 K observed for the unexposed backside. The associated lower mean surface conductivity can be mainly due to morphological effects enhanced by erosion processes indicated by the high surface roughness of 5-10 µm. In fact, the temperature increase on a FGG-surface with a mean roughness of 5.4 µm was found to be 30 % higher than that on the polished backside with a mean surface roughness of 0.4 µm.

The deposition-dominated inner divertor tile shows larger spatial and temporal variations of the spot temperature. In particular the temporal evolution of spot 1 is remarkable. The strong decrease of the spot temperature indicates a change of the thermal properties at the surface during the heat pulse. These properties can be influenced by the thermal conductivity of the layer itself or the thermal contact between the deposit and the underlying bulk material. For the investigated tiles a correlation between the observed spot temperature and the thickness of the contamination is evident. In fig.2 (left) the spot temperature at the beginning and at the termination of the heat pulse across the surface of the inner divertor tile is shown while fig.2 (right) presents the thickness of the contamination.

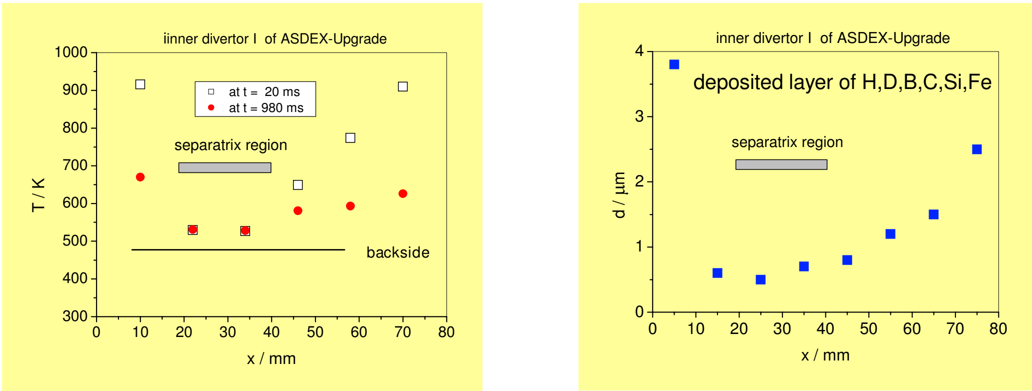

Fig. 2: Temperature values observed at the beginning and at the termination of 1s heat pulses with 28 MW/m^2 and thickness of the contamination (right) in dependence on the coordinate x representing the poloidal position

The lowest values of contamination (~ 0.5 µm) and spot temperature (~ 525 K) are observed in the erosion-dominated separatrix region. With increasing distance to this region both the thickness of the contamination increases up to 4 µm and the spot temperature rises up to 925 K at the beginning of the heat pulse. At this temperature level the deuterium desorption rate was found to be strongly enhanced in thermal desorption measurements using surface heating by electron bombardment [3]. This may indicate that the decrease of the spot temperature and the corresponding increase of the thermal conductivity is correlated to gas desorption.

At increased power density level of 50 MW/m^2 and for a pulse duration of 8 ms the complete removal of a 4 µm thick contamination has been observed as evidenced by surface profiling and surface analysis by SIMS. The thermal behaviour of the heat-treated and uncovered surface is similar to that found for the erosion-dominated areas of the outer divertor.

An increase of the thermal conductivity after ion beam heat pulses of 50 MW/m^2 and duration of 250 ms has also been observed for JET-divertor tiles covered with a contamination layer (H, D, Be, C) of about 50 μm thickness [4]. The surface temperature decreased with the shot number from 2300 C to 1800 C. A similar result is found at successive laser scans for a contaminated JET- divertor sample with a high surface concentration of Be [5]. Here, heating up to 2000 C causes beading of the Be and exposes more of the graphite substrate with a higher conductivity at the surface. In contrast, for other JET-samples the peak temperature raised from 1800 C up to 2100 C on successive laser shots [5]. The decrease of the conductivity to the substrate is explained by gas heating in pores causes the pores to expand.

For the divertor tiles of ASDEX Upgrade the relaxation time of surface temperature effects associated with the contamination is smaller than the laser rise time of 400 μs (see fig.3).

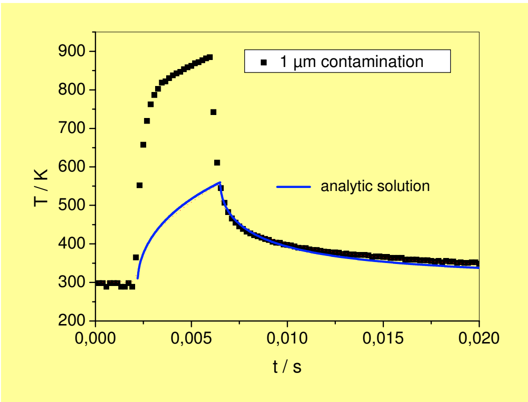

Fig.3: Temperature excursion measured with a time resolution of 190 μs on a inner divertor sample with a contamination of about 1 μm. Applied heat pulse 44 MW/m², τ = 4 ms, σ = 1.5 mm. The solid curve is the analytic solution [1]

With a layer thickness of 5 μm and a supposed thermal conductivity in the order of 10 W/m K one gets a relaxation time of the surface temperature enhancement in the order of 10 μs. Assuming heat exchange between the layer and the underlying substrate with a coefficient of 100 kW/m^{2}K the layer temperature will relax on a time scale of 100 μs. This gives the possibility to recognize modified thermal properties at the surface and to observe temperature values for the underlying substrate after the surface temperature relaxation. Moreover, the observed removal of the contamination at surface heat loading is encouraging and may help to allow supervising of high heat flux loaded components by IR-thermography.

References:

[1] see Proceedings of 16th Intern. Conf. on Plasma-Surface Interaction in Controlled Fusion devices, May 2003, Portland (USA) to be published in J. Nucl. Mater.

[2] D. Hildebrandt et al., 16th Inter. Conf. on Plasma-Surface Interaction, May 2003, Portland (USA)

[3] D. Hildebrandt et al., J. Nucl. Mater. 266-269 (1999) 532

[4] E. Gauthier et al., 16th Inter. Conf. on Plasma-Surface Interaction, May 2003, Portland (USA)

[5] C. Skinner, private communication