Laser Ablation at the Inboard Side of ASDEX Upgrade

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Introduction

The production, composition and durability of thin surface layers during plasma discharges has attracted strong attention during the last years because of their importance for the material household in magnetically confined plasmas. Especially the codeposition of Tritium is a major concern in a future fusion device [1]. Usually, such information is gained from deposition or erosion probes. However, these measurements are hampered either by the large technical efforts for movable and retractable probes which restrict the measurements to easily accessible parts in the torus or by the use of fixed mounted probes inside the device, which deliver only largely time integrated information. In the case of the control of surface conditioning colorimetry is used to extract the thickness of the deposited layer [2]. Recently efforts were undertaken to measure the growth of hydrogenated carbon layers by quartz crystal microbalance during plasma operation [3]. In this contribution we will present a method based on in-situ laser ablation of in-vessel components. The injection of impurities by laser-ablation into fusion devices is a common method to study the transport of impurities and their effect on the plasma discharge. Usually a target with the material to be injected is located near the torus wall at the low field side (LFS). Using the laser to ablate surfaces within the device can yield information on the deposited carbon/hydrogen films, the status of Si/B layers from surface conditioning or the coating of the plasma facing component.

Directing the laser repetitively on one ablation spot during one single discharge the sequence of layers on the tile can be determined. Lately a similar method was used in JET to investigate the H-retention in carbon tiles [4]. Additionally, the system can also be used for extended transport investigations: Ablating the same material at different position provides information on the local penetration probability.

Figure 1: *Poloidal cross section of ASDEX Upgrade together with the lines-of-sight for the used diagnostics and the arrangement of the laser beam and the target. The position of the separatrix of a plasma with a standard shape is also shown.*

Experimental Setup

The laser blow-off (LBO) system at ASDEX Upgrade allows ablation in single pulse operation or in pulse series with a repetition rate of up to 20 Hz. It consists of a 0.6J Nd-YAG laser with a pulse-length of 8 ns, a laser beam deflection and focusing unit and a carriage with a target lock to change or replace the targets. The laser beam is focussed onto the target by a combination of movable lenses and fixed mirrors to allow the deflection and focusing of
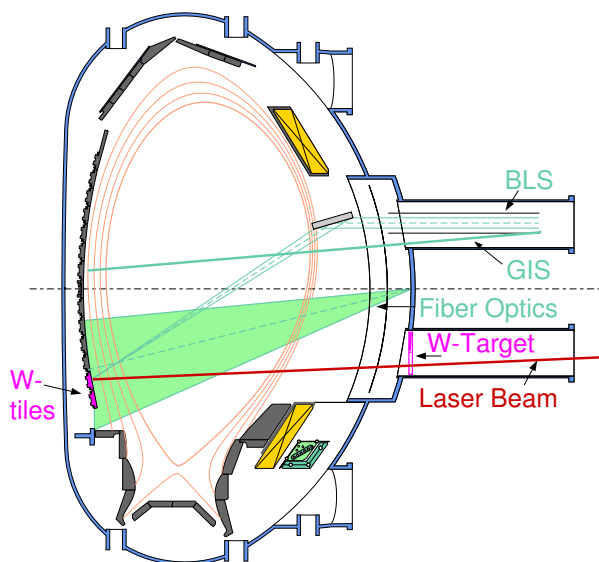
the laser beam. By minor modifications it was also possible to focus the laser beam onto the inner wall of ASDEX Upgrade. An area with the diameter of about 300 mm at the central column can be scanned. The interaction spot of the laser with the surface can be observed by a video camera with filters and a flexible spectrometer-system (BLS) which is sensitive in the visible and the vacuum ultra-violet (VUV) spectral range. Additionally, a dedicated fiber optics was installed, which observes the whole ablation cloud and can be attached to different spectrometers via an optical switchboard. Fig. 1 shows the lines-of-sight of the used diagnostics and the direction of the laser beam in a poloidal cross section of ASDEX Upgrade.

Ablation of Deposited Layers

For the surface conditioning of the vessel walls of ASDEX Upgrade boron or silicon layers with thicknesses in the range of 50 - 100 nm are deposited by a glow discharge (boronization/siliconization) [5]. Ablations with moderate power density on siliconized tiles ($\emptyset_f \approx 10$ mm) only show an influx of Si whereas no carbon desorption above the detection limit is observed. This is demonstrated in Fig. 2, where spectra measured with the BLS shortly before and during the ablation are shown. The intensity of the Si III (456 nm) spectral line is increased during the ablation by almost a factor of 4, whereas the C III spectral line (465 nm) remains almost unchanged. This is confirmed by video observation, where no emission from the spot is seen using a C III filter.

The upper part of Fig. 3 shows the temporal evolution of the Si III and C III brightnesses in the visible spectral range and of a C II-line in in the VUV range for a series of laser pulses with 4 Hz staying on the same ablation spot using a smaller focus ($\emptyset_f \approx 4$ mm). In this case almost no change for the Si-influx is observed whereas

Figure 2: *Spectra measured with the BLS before (dashed line) and during (solid line) laser ablation with moderate power density from a siliconized graphite tile at the central column.*

Figure 3: *Temporal evolution of the Si III (dashed line), C III and C II (solid lines) brightness during repetitive laser ablation with higher power density (see text) at the central column of ASDEX Upgrade. In the lower part the spectra before (dashed line) and during (solid line) the ablation at $t \approx 3.4$ s are shown.*

strong increase of the C lines is found. Some of the ablation signals are lost in the visible channel of the BLS due to the camera triggering which yields a duty cycle of only 40%.
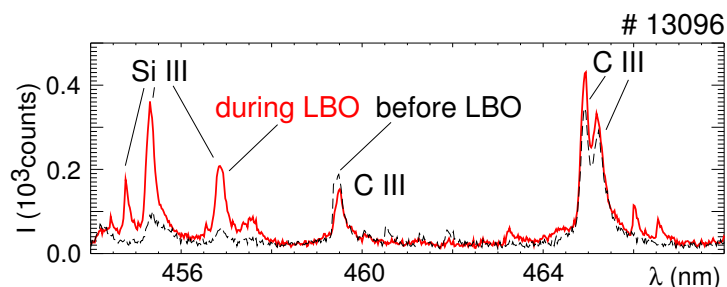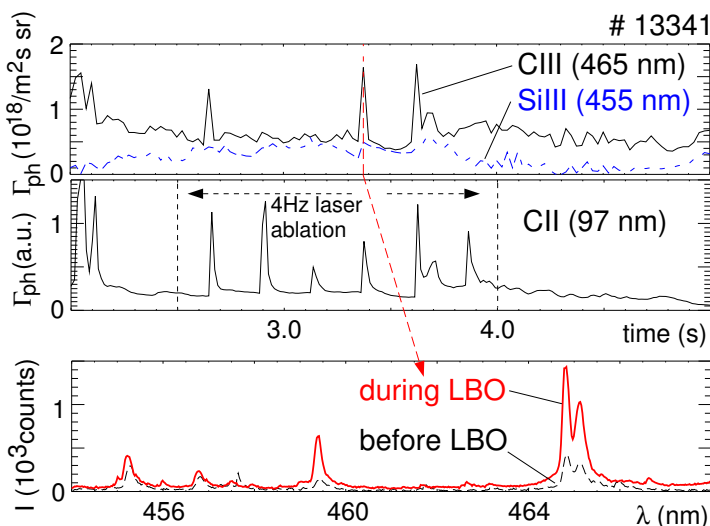
In the lower part of Fig. 3 again the spectra before and during the ablation at $t \approx 3.4$ s are compared. The video observation shows a small bright ablation spot and a cloud penetrating into the plasma. The different behaviour of ablation shown in Fig. 2 and Fig. 3 can be easily explained by the following picture: By reducing the focus size, less silicon is ablated, but at the same time a larger amount of C from the graphite bulk is ablated (see Fig. 4). In the upper part of Fig. 5 the removal of surface layers from the C-tile in the ablation spots is identifiable already by optical inspection. A post mortem analysis of the tiles with a scanning electron microscope (SEM) shortly after the ablation in discharge #13096, using imaging and energy dispersive x-ray spectroscopy (EDX) shows a complete removal of Si in the ablation spots. Also outside the ablation area, only a few percent of Si were found on the surface. Using a larger magnification and smaller areas for the EDX-surface analysis it turned out, that small areas - like valleys - still consist of a major Si fraction, whereas large regions show no signs of Si any more within the scanning depth of about 0.5 μm. These observations are consistent with other investigations [6] which demonstrated, that this part of the inner column of ASDEX Upgrade is a region of net erosion.

Figure 4: *Schematic view of the ablation: virgin surface (a), ablation using a large focus (b), and a small focus (c).*

Penetration Probability of Tungsten

During the present experimental campaign the lower part of the heat shield of the inner column is equipped with tungsten coated tiles, to test their compatibility with the plasma operation [7].

An experimental investigation was performed to get an estimate for the particle confinement time τ_p for W originating from the central column (high field side, (HFS)). For this purpose, the laser was focused onto the W coating. The ablation spot can be seen in the lower part of Fig. 5. The layer is ablated with one single laser pulse and the number of ablated W-atoms was calculated from the thickness of the coating ($d \approx 320$ nm) and the area of the spot (11 mm^2) to be about $2.3 \cdot 10^{17}$ particles. The tungsten penetrating into the plasma was measured in VUV spectral range using a gracing incidence spectrometer (GIS).

For non-recycling impurities the particle confinement time τ_p can be separated (at least formally) in a penetration probability P_f, i.e. the probability to reach the confined plasma and the transport time τ_t within the confined plasma. This penetration probability depends on the impurity species and its energy when it interacts with the SOL as well as on the local properties of the SOL which can vary for different discharge types but also for different spatial locations inside the tokamak. From the comparison of the total amount of ablated W-atoms and the maximum number of W-ions in the plasma, a penetration factor of 0.04 for the HFS is calculated. Performing the same experiment with a W-target deposited via physical vapour deposition (PVD) on a glass
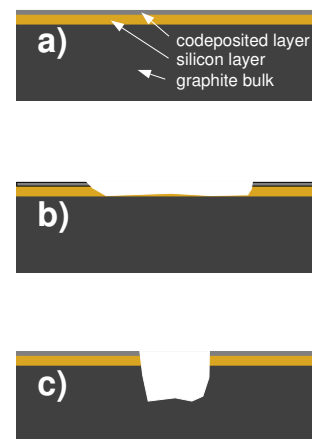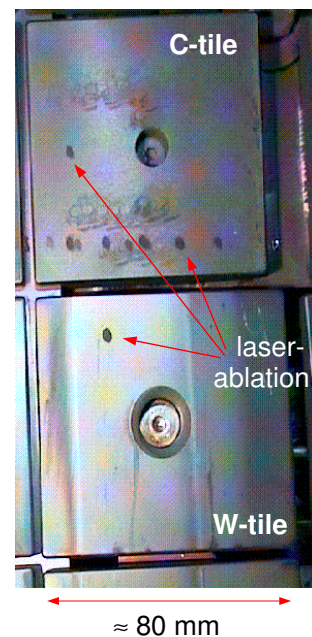

Figure 5: *Tiles at the central column of ASDEX Upgrade. The lower one is coated by tungsten. The dark spots mark the total ablation of surface layers.*

substrate ($d \approx 200nm$), injecting about $1.0 \cdot 10^{17}$ particles from the LFS of the torus (classical laser ablation), a value of $P_f \approx 0.03$ is found, i.e. at least for these poloidal positions there is no significant difference for the penetration of W found. This result is illustrated in Fig. 6 where the temporal evolution of the W-density for HFS-injection and LFS-injection is shown. The injections were performed in two identical H-Mode discharges with 1MA plasma current, 5 MW additional heating and an electron density of $\bar{n}_e = 6 \cdot 10^{19}$ m^{-3}. The W-density resulting from the LFS-injection is normalized to the same amount of W as injected from the HFS. The transport time τ_t is almost equal in both cases and somewhat larger than the energy confinement time.

Summary and Outlook

The use of laser ablation from in-vessel components represents a powerful tool to investigate in-situ the status of their surface.

Thereby the existence of Si-layers from previous siliconizations could be nicely demonstrated. A quantitative evaluation of the surface composition can be gained from the measurement of the absolute brightness of spectral lines using the photon efficiency. The temporal evolution of their intensity during repetitive laser ablation can yield the sequence of the layers. For a known layer thickness or a well diagnosed source strength, the method can also be used for the extension of transport investigation by injecting impurities from different poloidal locations. First results show only minor differences for the penetration of W from the LFS and the HFS. During the next experimental campaign W-coated tiles will be mounted again at the central column. Additionally, a special tile composed of different materials will be installed in the visual field of the system, allowing to refine the analyses.
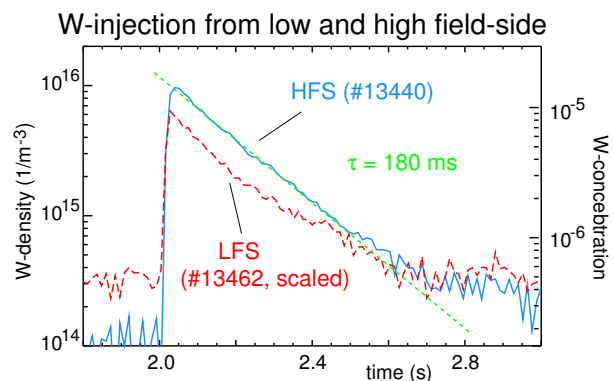

Figure 6: *Temporal evolution of the tungsten density deduced from the GIS measurement, after W-ablation from central column (solid line) and from a W-target at the low field side (dashed line, scaled to the same amount of ablated W).*

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