

Measurement of hydrogen retention in plasma facing surface in TEXTOR by laser induced desorption during plasma discharges

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Introduction

In situ information on the hydrogen content of plasma facing surfaces is essential to estimate the long term tritium retention in future fusion devices. Laser thermal desorption is used for the measurement of the hydrogen content in post-mortem analysis of plasma facing materials [1-5]. Laser induced desorption with a mass spectroscopic detection of desorbed deuterium has also performed in TEXTOR in between discharges [6]. In the present study the hydrogen content of plasma facing elements has been determined during plasma pulses via laser induced desorption and spectroscopic detection of the released hydrogen.

Experimental setup

The diagnostic set up is shown on fig.1. The laser desorption diagnostics was used in the limiter-lock system placed on the top of the TEXTOR torus [7]. A single pulse ruby laser consisting of an oscillator and two amplifiers and operating in a free spiking mode with maximum energy of 5 J and pulse duration of about 0.3 ms

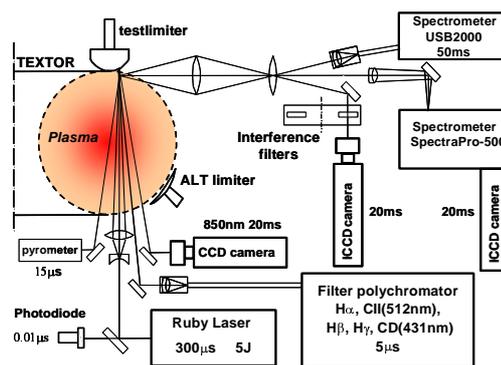


Fig.1. Laser desorption diagnostic set-up.

was used for surface heating. The diaphragm in the oscillator cavity was used to obtain a pure TEM₀₀ beam. The beam from oscillator was amplified by a two pass amplifier and after that by a one pass amplifier. Several diaphragms in the beam pass through the amplifiers were used to remove scattered laser light and improve the beam homogeneity. The laser beam was focused onto the limiter surface by a telescopic lens system to a spot of about 4 – 8 mm diameter. The temperature of the limiter surface in the laser spot was controlled by an optical pyrometer with a time response of about 15 μs and viewing spot diameter of about 6 mm. The light emitted by thermally desorbed particles was detected by a five channel polychromator equipped with interference filters for the wavelengths of CD(430.7 nm), H_γ(434.0 nm), H_β(486.1 nm), CII(514 nm), H_α(656.1 nm) in front of photodiodes. The time response of the photodiode amplifiers was about 5 μs. The collection optics of the polychromator detected light from a volume

around the test limiter with diameter of about 21 cm. In addition to the polychromator, two spectrometers with CCD detectors and integration times of 20 ms and 50 ms were used to monitor the spectra of the desorbed species. The filter polychromator and spectrometers were absolutely calibrated with a standard calibration source. The detection system could not resolve H_{α} and D_{α} , so the total amount of desorbed hydrogen isotopes was measured.

Measurements

The laser desorption experiments have been performed at the tokamak TEXTOR for the following discharge parameters: $B_T = 2.24$ T, $I_p = 350$ kA, $R = 1.75$ m, $a = 0.46$ m (toroidal limiter ALT-II is a main limiter), $\bar{n}_e = 3 \cdot 10^{19} \text{ m}^{-3}$. The measurements were done in deuterium-fuelled discharges with hydrogen NBI heating of 1.3 MW.

The laser was fired close to the end of the plasma discharge. For a graphite limiter the surface temperature of the exposed area during a laser pulse increases up to about 1000°C. The time duration of a single laser spike is about of 0.2 – 0.5 μs and separation between spikes was about 5 -50 μs , therefore the pyrometer could not resolve the peak temperature. The increase of Balmer lines emission during laser pulse heating exceeded the background radiation caused by recycling by about an order of magnitude. The total number of desorbed hydrogen and deuterium atoms was deduced from the number of H_{α} photons emitted during a laser pulse using the S/XB coefficients (photon per ionisation) from the ADAS database. The ratio of H_{α} to H_{β} line intensities was also used for estimation of the plasma density at the location where the desorbed deuterium was ionised. This value is important because in the electron temperature range of 20 – 100 eV the S/XB value depends on the plasma density. For a direct calibration of the spectroscopic detection a flat target made of graphite EK98 and which has been coated previously with an amorphous deuterium rich carbon layer (a-C:D), was placed at the plasma edge ($r = 50$ cm) parallel to the magnetic field. The coating was made in 4 steps with thicknesses of 100 nm, 150 nm, 200 nm and 250 nm. The deuterium content was $3 \cdot 10^{17}$, $4.5 \cdot 10^{17}$, $6 \cdot 10^{17}$ and $7.5 \cdot 10^{17} \text{ D/cm}^2$ respectively. The laser desorption signals were measured at individual

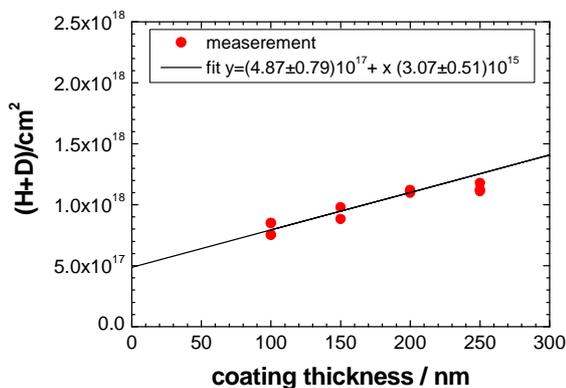


Fig.2. Desorption signal versus the coating thickness

spots (spot area of about 0.16 cm^2) in a series of discharges under consideration of appropriate S/XB values. The result of the calibration is shown in fig. 2. In a second experiment a flat carbon (graphite EK98) target with dimensions of $5.5 \text{ cm} \times 7.6 \text{ cm} \times 0.2 \text{ cm}$ pre-coated with a-C:D film (film thickness of about 250 nm) with a deuterium content of $8 \cdot 10^{17} \text{ D/cm}^2$ was mounted on the ion drift side of a special test limiter. The angle between the target surface and magnetic field was 20° . The target was placed 2 cm behind the LCFS ($r = 48 \text{ cm}$) in a deposition-dominated region of the scrape-off-layer plasma. The duration of the plasma discharge was 6 s with 4 s NBI heating starting from 0.8 s . The laser (spot area about 0.4 cm^2) was fired at 4.5 s . The base temperature of the target rose up to about 330°C during the plasma discharge. During the first laser pulse $5.2 \cdot 10^{17}$ released deuterium and hydrogen were detected. About $1.8 \cdot 10^{17}$ and $2.6 \cdot 10^{17}$ hydrogen atoms were detected during second and third laser pulses, respectively. The hydrogen release from the uncoated part of the target was about the same. Changing the position of the laser spot between the plasma pulses the measurements of the hydrogen content depending on the plasma exposure time shown in fig.3 were made. The total hydrogen fluence onto the target measured from Balmer line intensities was about $1.4 \cdot 10^{19} \text{ D/cm}^2$.

In another experiment, a spherically shaped graphite test limiter with dimensions of $12 \text{ cm} \times 8 \text{ cm}$ and a radius of 7 cm has been exposed 2 cm behind the LCFS ($r = 48 \text{ cm}$) for 21 plasma pulses. The base limiter temperature was about 160°C and the total hydrogen flux on the limiter deduced from the number of H_α photons was about $4.9 \cdot 10^{20}$ deuterium ions. A clearly visible co-deposited layer was formed on the limiter with a thickness of about 150 nm . The laser-induced deuterium desorption from the deposit from the same laser spot (area of about 0.3 cm^2) is shown in fig.4.

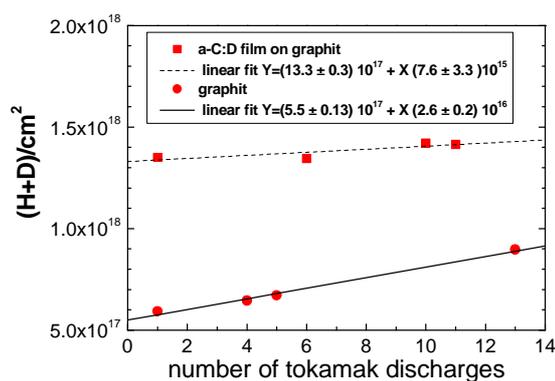


Fig.3. Desorption signal from different spots versus a number of discharges

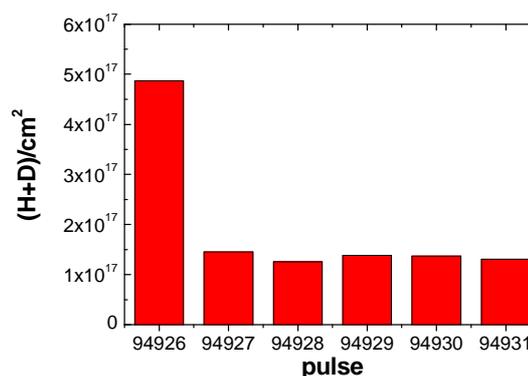


Fig.4. Desorption signal from the same laser spot.

Discussion and conclusion

The results show that laser induced thermal desorption of hydrogen together with spectroscopic detection of the released hydrogen can be successfully used to determine *in situ* the hydrogen content of plasma facing surfaces. The amount of deuterium measured by this method is in a good agreement with the deuterium content expected for an amorphous hydrogen rich carbon film. The deuterium content of a deposited carbon film on a graphite test limiter as shown in fig.4 corresponds to the D/C ratio of about 0.3 as expected for our experimental conditions. As can be seen in fig.3, substantial amount of hydrogen of about $5.5 \cdot 10^{17}$ (H+D)/cm² is desorbed from the uncoated graphite surface exposed to a single plasma discharge. This value includes the deuterium retained in the implantation zone but also the residual hydrogen inherent inside the graphite. This results from the fact that the heat propagates into the graphite during the laser pulse up to a thickness of about 100 µm, which is much thicker than the a-C:D film thickness. The amount of the residual hydrogen depends on the temperature history of the graphite limiter. When the test limiter was heated in previous experiments by plasma up to 1500°C the residual hydrogen content is less than $1.3 \cdot 10^{17}$ H/cm² as seen in fig.4. Practically all the deuterium from the deposited layer is desorbed during the first laser pulse, as shown also in fig.4 and the same behaviour was observed for the a-C:D film deposited on the graphite sample beforehand by plasma assisted film deposition. The development of an ITER diagnostic needs still further improvements that will enhance the performance: modification of the ruby oscillator according to [8] to provide spiking free generation with selectable pulse duration, an imaging of a diaphragm illuminated by the laser beam onto the surface to improve power density homogeneity and to produce a sharp edge of the laser spot, measurements of H_α and D_α lines during laser induced desorption with a high spectral resolution to discriminate H and D retention.

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