On the influence of parasitic plasma below the divertor structure of ASDEX Upgrade on the formation of a-C:H layers

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Introduction

Today carbon is the most common first wall material in fusion devices. Its advantages are high tolerable concentration in the plasma core, the tolerability to overheat during transient events, and the favourable radiation characteristics at typical divertor electron temperatures. Due to the formation of carbon deposits and the co-deposition of a significant amount of hydrogen isotopes the use of carbon in a fusion reactor is still under discussion [1]. One key question for a future use of carbon is the understanding of the mechanism, which lead to the formation of carbon deposits. Carbon is typically deposited as a-C:H layer at the divertor plasma facing components (PFC) and the divertor structure. Whereas the deposits on PFC's can be mobilised again during following discharges, material deposited on the structure forms a continuously rising inventory.

The most common picture on layer formation at remote areas is that deposited layers at the divertor plates are eroded during discharges. These produce active hydrocarbon molecules, which act as precursors for layer formation. Long term probes mounted at the divertor structure in ASDEX Upgrade (Fig. 1) indicate steep gradients in the layer thickness [2]. The deposition is obviously due to species with high sticking probability [3]. Comparing these data with the amount of carbon deposited at more remote areas, such as the pumping ducts, indicate that most of the deposits are formed by high-sticking species. Due to different plasma discharges during the normal experimental operation the formation of these layers has to be studied with time resolved techniques. Unfortunately, the locations, where layers are formed, are difficult to access. The expected precursors of the carbon layer formation can not be evaluated by spectroscopy. Up to now the only diagnostic allowing a time resolved local measurement are quartz microbalance(QMB) monitors, which offer reliable data on a shot to shot basis [4,5].

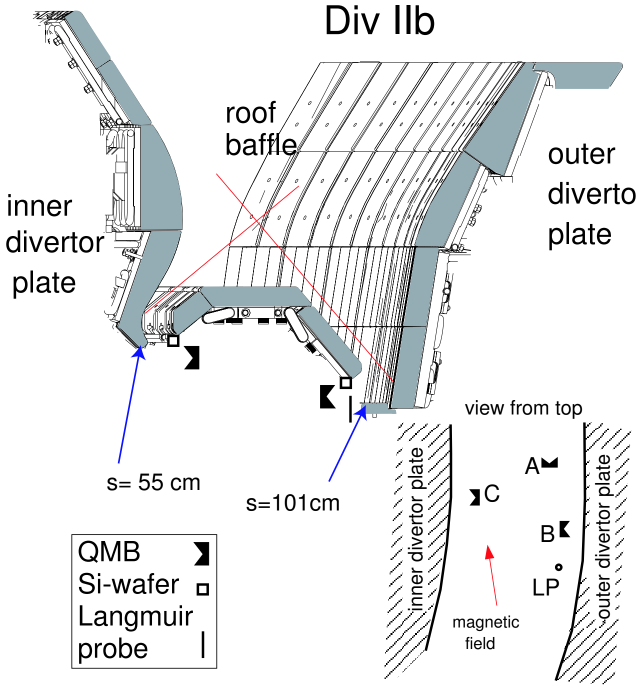

Fig.1: *Position of the QMB monitors below the roof baffle of Div IIb at ASDEX Upgrade.*

Quartz mircobalance monitors

QMB monitors are commonly used in the coating industry to measure in-situ the thickness of layers. This technique uses the resonance frequency of a small crystal on which the layer is deposited. Its resonance frequency depends on the density of the crystal and the total mass of the crystal including layers on its surface. The only modification to use commercial instruments at ASDEX Upgrade is to use a oscillator inside the vacuum, because of the maximum allowed cable length inside the resonance circuit. In ASDEX Upgrade up to 5 QMB are in use since 1999 [4].

During plasma operation the crystal is heated by radiation, which causes a change of the density of the crystal pretending a reduction of the layer thickness. Due to this effect we restrict ourselves on data evaluation on a shot to shot base. The crystals were post mortem analysed using ion beam techniques to get an absolute calibration of the amount of deposited carbon. The installation is shown in Fig.1. The QMB are mounted below the roof baffle as close as possible to the plasma strike points. The QMB at the inner divertor shows a continuos growth of the layer, whereas at the outer divertor also erosion is observed. The deposition rate measured by the QMB was correlated with time averaged values of other signals. A correlation of the deposition with the neutral pressure below the roof baffle was found for identical plasma shape [5]. In Fig 2 all data of the 2003 campaign from one QMB at the inner and one at the outer divertor are plotted against the position of the separatrix on the inner and outer divertor plate. Strong variation of the deposition rate is observed. The envelope of all data shows a significant dependence on the strike point position. This behaviour fits into the picture of erosion at the strike point, and the formation of high sticking precursors or high surface reactivity. The pattern at the outer divertor shows the same behaviour for $s \leq 110$. For lower values there is a direct line of sight from the strike point to the QMB crystal. The deposition rate rises dramatically again indicating the role of high sticking precursors.

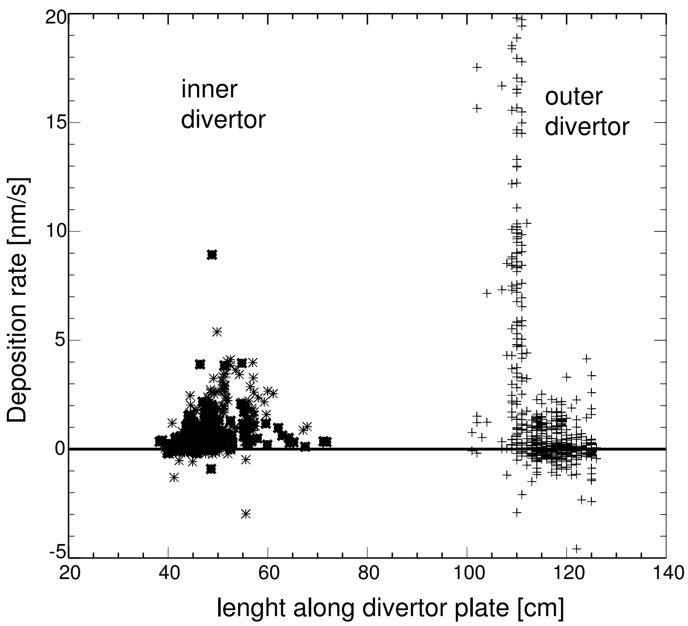

Fig.2: *Deposition rate at the inner and outer divertor during the 2003 experimental campaign measured by the QMB C (*) and QMB B (+) respectively. The x axis coresponds to lenght along the divertor plates (Fig. 1)*

Parasitic Plasma below the divertor structure

A langmuir probe below the divertor structure at the same radial position as QMB B shows a typical glow discharge plasma. Electron temperature of $T_e = 5 - 15eV$ and -densities in the range $n_e = 1 * 10^{13} - 1 * 10^{18} m^{-3}$ are observed. At the position of the langmuir probe exists no connection via magnetic field lines to the main plasma, so that the plasma has to be produced below the divertor As the plasma density depends strongly on the radiation in the divertor the production of this parasitic plasma due to photoionisation or photoeffect was proposed [2]. This assumption is validated by a fit of the electron density versus the radiation in the outer divertor and the neutral density below the divertor structure, which shows a strong correlation: $n_e^{sub} \approx P_{rad}^{2.7} * \Gamma_n^{0.7}$, with P_{rad} the radiation inside the divertor as measured by bolometry and Γ_n the neutral particle flux below the divertor [5]. Simulation calculations on the plasma production are hampered by the uncertainty of the photoionisation cross sections for different hydrocarbon species.

Deposition of carbon

At ASDEX Upgrade primary carbon sources are assumed in the main chamber. The divertor acts as collector for all impurities inside the scrape off layer. During plasma discharges carbon is deposited on the divertor forming thick deposits, which reaches a thickness of $15\mu m$ at the inner and $3\mu m$ at the outer strike point position at the end of a campgain. These layers are eroded by the ion flux of following discharges. In a simple model, we assume that the erosion is due to deuterium ions, the energy is above the threshold for physical sputtering, i.e. the amount of precursors is directly proportional to the ion flux to the divertor, which is proportional to the ion saturation current of the divertor langmuir probes. From long term deposition monitors it is known that the sticking probability of the layer forming species is close to one. Assuming a *cos* distribution of the eroded species at the wall source and a collision free movement inside the divertor, the amount of deposition can be estimated from geometrical factors. Summing up all langmuir probes at the divertor plate the simple formula can be derived:

$$\Delta m_{layer} \approx \sum_{LP} I_{sat}^i / R_i^2 cos\alpha \qquad (1)$$

with Δm_{layer} the deposited mass on the QMB, I_{sat} the ion saturation current on a divertor langmuir probe, R the distance from the langmuir probe to the QMB and α the angle of the divertor plate with respect to the poistion of the QMB.

From laboratory experiments mostly low sticking species are expected to be produced by the erosion of deposited layers. As the divertor layers are eroded by deuterium the precursors are assumed to be saturated with deuterium. These species will form layers below the divertor which will contain much more D than C. Layers with a ratio of $D/C \approx 1$ or $D/C \approx 0.5$ are observed on long term probes. This contradiction can be solved by postulating an additional erosion of the fresh deposited material by atomic D or D ions. Laboratory experiments show that the layer formation can be enhanced by some orders of magnitude by the production of dangling bonds due to atomic H [7]. In a tokamak the production of dangling bonds can be done by the parasitic plasma observed below the roof baffle.

The QMB measurements offer the possibility to check these theory in a tokamak environment. For the QMB B, which is close to the outer divertor, not only deposition, but also erosion during shots is observed (Fig. 2). Erosion effects are not included in the mechanism discussed above. Consequently ,a comparison shows a strong scatter on the data. For comparison QMB A was selected, which shows a continuos growth of the layer.

In Fig. 3 the growth rate of QMB A during the present campaign for the discharges #16500 - #17400 is plotted. In Fig. 3a the abscissa is the expected precursor density as derived from all divertor langmuir probes according to Eq. 1. This simple assumption shows a very good correlation indicating that the main precursor source is ion sputtering at the target plates. No correlation of the divertor layer growth with the main plasma carbon concentration was found. A fit to a polynomial shows a quadratic dependence of the layer growth. This hints on additional effects like surface activation to enhance the sticking probability. A plot of the growth rate to the average density of the parasitic plasma below the divertor structure is presented in Fig. 3b. A fit to a linear dependence is also shown. For electron densities higher than $1 * 10^{16} m^{-3}$ a clear dependence is observed. This hints again to the role of surface activation. Unfortunately the parasitic plasma density is indirectly coupled via the radiation to the ion flux to the divertor. To resolve this dependencies a fit to a more sophisticated model is required.

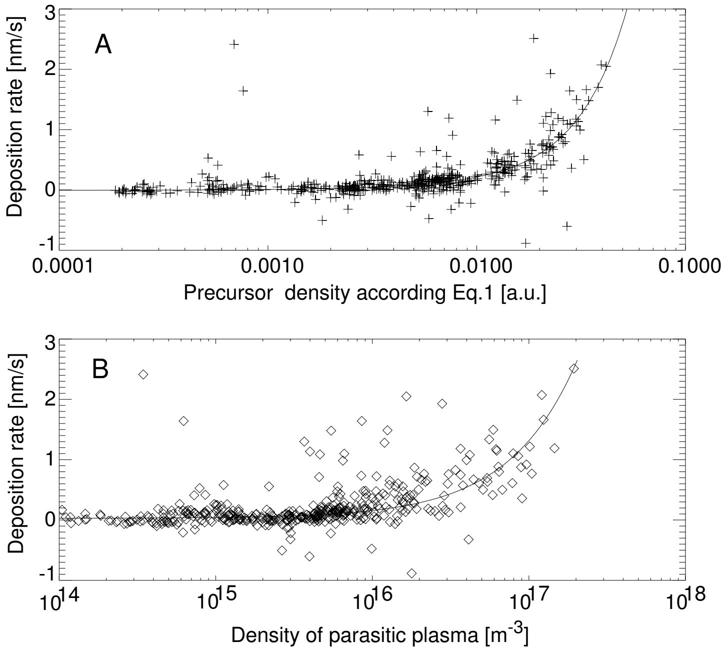

Fig.3: *Deposition rate of QMB A versus Eq.1 (A) and versus parasitic plasma density (B).*

Summary and conclusions

The growth of hydrocarbon layers at remote areas below the divertor of ASDEX Upgrade is studied by quartz micro balance monitors. Whereas at the inner divertor a continuos layer growth is observed, there are additional erosion processes at the outer divertor. The growth rate at the outer divertor rises dramatically, when the strike point is in direct line of sight with the QMB. The deposition can by understand by erosion of hydrocarbons on the target plates due to ion flux producing precursor with a sticking factor close to one. There is evidence that surface activation by parasitic plasma is important in the formation of thick layers.

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