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On the formation of a-C:D layers and parasitic plasmas underneath the roof baffle of the ASDEX Upgrade divertor

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Abstract

The key problem for the use of carbon in a future fusion device is the formation of tritium containing a-C:H layers. ASDEX Upgrade offers the possibility to investigate these layers at ITER relevant divertor conditions. Long term probes show, that the layer growth under the structure of the new divertor (Div IIb) is very similar to Div II. Additional quartz microbalance monitors offers measurements on the layers growth on a shot-to-shot base. The layers are found to grow continuously during the campaign. Using similar shots, a proportionality of the growth rate to the divertor neutral pressure is found. A Langmuir probe, installed below the divertor structure, measured a strongly variable plasma with electron densities up to 1×10^{18} m^{-3}. The density of this parasitic plasma is correlated to the divertor radiation and neutral density, which point to photo ionisation or photo emission as the origin of the plasma.

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1. Introduction

The optimal plasma facing material for future fusion devices is still not found. Today most fusion devices use carbon, which offers excellent thermal and mechanical properties. For a fusion reactor the amount of carbon is restricted due to the formation of a-C:H layers, which will contain a significant amount of tritium [1]. Up to now the mechanisms, which form the layers are not completely understood. While alternative materials are available at most locations, only carbon seems to be applicable at positions with high transient loads such as ELM's. Most of the investigations on layers, found at tokamaks, were done with post-mortem analyses of probes [2,3,9]. In ASDEX Upgrade additional quartz microbalance monitors (QMB) are installed, offering data on the layers formation on a shot-to-shot basis. The deposition pattern beneath the divertor structure indicates the presence of charged atoms in that region [4]. To investigate this, a Langmuir probe was used. This paper is divided into three parts: (i) comparison of divertor configuration (Div II and Div IIb) (ii) new results of the QMB and (iii) plasma measurements underneath the divertor.

2. Long term deposition

During 2001 the divertor of ASDEX Upgrade was changed from Div II to Div IIb. This new divertor provides more flexibility on the strike point position and plasma shape. Details on the behaviour of Div IIb are given elsewhere [5]. Deposition probes are installed at equivalent positions with respect to the roof baffle as in the Div II (Fig. 1). The results are compiled in Table 1. During the 2001 campaign an average carbon deposition rate of 2.0×10^{15} at cm^{-2} per sec plasma discharge was measured. Compared to 2.2×10^{15} at cm^{-2}/s in Div II no

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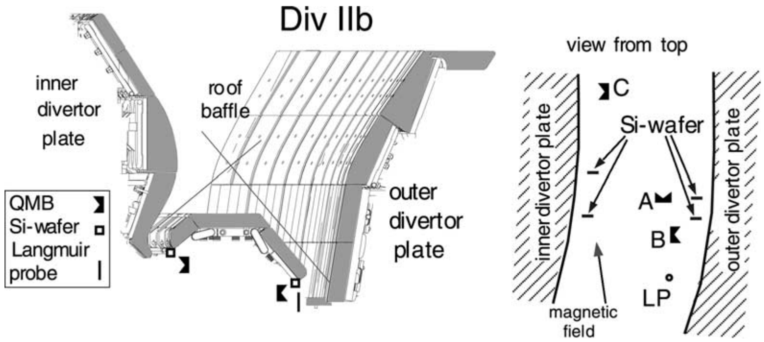

Fig. 1. Sketch of Div IIb showing the positions of the probes. Si wafer, used as deposition probes are indicated as open squares, QMB as filled symbols and the Langmuir probe as a line. The insert clarifies the orientation of the probes.

Table 1
Comparison of properties of redeposited layers in Div II and Div IIb

Divertor	D/C Facing towards strike point	D/C Facing away from strike point	C ratio Inner/outer divertor	D ratio Inner/outer divertor	C deposition (atm $^{-2}$s^{-1})
Div II	0.42	0.84	3.0:1	2.4:1	2.2e19
Div IIb	0.74	0.92	2.8:1	2.1:1	2.0e19

significant difference is found. The amount of carbon deposited at the inner divertor is a factor of 2.8 larger than at the outer divertor, which again is very similar to Div II. In Div II the type of layers depends on the orientation of the probe. Probes facing the magnetic field direction towards the strike point, showed brownish layers with a lower D/C ratio value, whereas probes facing into the opposite direction showed transparent layers with a higher D/C ratio value. At Div IIb, such pronounced differences were not observed. Optical inspection of the divertor structure again reveals brownish layers, but only very localised. Details of the data analysis and layers characterisation are given in [6].

3. Layer growth during single shots

The deposition monitor technique allows only measurements on a campaign-to-campaign basis. Very different scenarios are used for plasma operation, which restrict dramatically the interpretation of the observed layers. Obviously time resolved measurements are necessary to identify the mechanism, which causes the layer growth. For this reason QMB, which are commonly used as monitors in industrial applications, were installed. These instruments measure the resonance frequency of a quartz crystal inside an oscillation circuit. The frequency is related to the density of the quartz crystal and the mass deposited onto its surface. Because of the distance from the vacuum flange to the monitor position, modified instruments with an oscillator inside the vacuum had to be applied [4]. Thermal load onto the crystal changes its density and, by this, the resonance frequency. The pulse length in ASDEX Upgrade is too short to reach thermal equilibrium, which makes measurements during a pulse impossible and restricts data evaluation to a shot-to-shot base. Using ion beam techniques and ellipsometry of the dismounted quartz an absolute calibration of the deposited layer thickness was obtained.

Three monitors are operating during the present campaign. Two monitors are installed at the outer divertor. QMB B is as close as possible to the divertor slits and orientated in the toroidal direction, i.e. typically at 10° with respect to the magnetic field direction. Another unit, QMB A, was mounted perpendicularly to the first one, but further away from the slits. A third one, QMB C, which is orientated as QMB B, was installed at the inner divertor slits (Fig. 1).

The layer thickness as measured during the campaign in 2001–2002 are shown in Fig. 2(a) for the three monitors. The growth rate is almost constant, i.e. each shot contributes to the increase of the layer thickness. Variation in the slope of the curve represents different plasma scenarios, with different deposition rates. Typically several similar shots were combined during the experiments. The two dips at shot 15 070 and 15 220 are related to ICRH high power conditioning, which seems to remove the layers. The gap in the data at shot number 15 500 is due to a venting of the vessel, which resulted in an increase of the mass of the layers, presumably by water uptake by the film. The two monitors at the outer

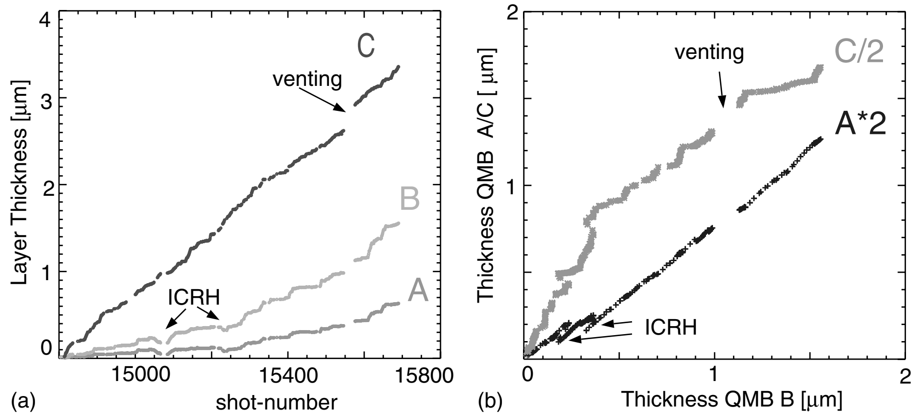

Fig. 2. The actual layer thickness versus shot-no of the QMB's. QMB A and B were located in the outer, QMB C in the inner divertor (a). Correlation of the layer thickness of QMB A, C to that of QMB B (b). The data are scaled for comparison.

divertor are very closely correlated, indicating the reliability of the measurement (Fig. 2(b)). On the contrary the monitors B and C show only poor correlation, reflecting the different plasma conditions at the inner and outer divertor. The integral deposition at the inner divertor (QMB C) is about 2.2 times thicker than at the outer divertor (QMB B). This ratio is lower than that found by the long term deposition monitor technique, but it seems to be changing during the campaign.

The monitors at the outer divertor allow estimation of the e-folding length of the deposition. Using a simple model: $\Gamma_a = \Gamma_0 \times \sin(\alpha)e^{-x_a/\lambda}$ and $\Gamma_b = \Gamma_0 \times \cos(\alpha)$ $e^{-x_b/\lambda}$, with α the angle of the magnetic field direction and x_i the position of the probes, $\lambda_a = 21$ mm is found for uniform deposition and $\lambda_b = 8$ mm for deposition only in the magnetic field direction. Both estimates result in very steep gradients of the material deposited and agree with the finding of almost no carbon deposition at the ASDEX Upgrade pumping ducts [6]. If we assume that the precursor of layer formation is the sticking of hydrocarbon radicals [10], then this steep gradient hints at molecules with high sticking coefficients or to other mechanisms, which prevent the diffusion of C_xH_y molecules.

For identification of the mechanisms, which are involved in the formation of a-C:H layers underneath the divertor, the growth rate was compared with typical plasma parameters and signals of different diagnostics. The position of the QMB below the divertor inherently separates the plasma ramp up and ramp down phases, which use the limiter in the main chamber, from the flat top phase. For comparison, the signals of other diagnostics are time integrated during the divertor phase. Up to now, no simple correlation of the layer growth rate with one of these signals was found for all discharges. This shows that the layer growth depends on a complex interaction of different parameters.

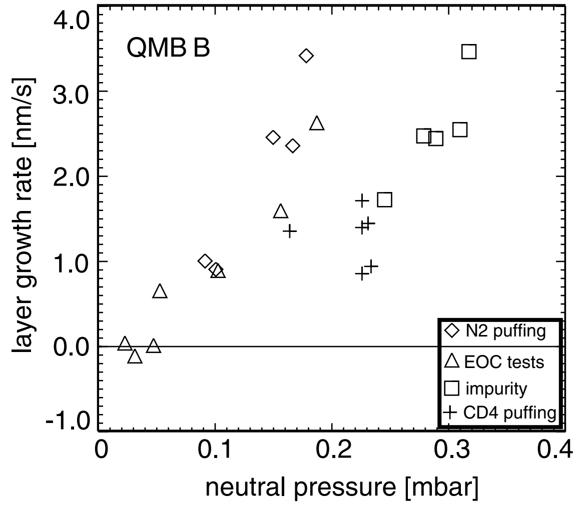

Fig. 3. Layer growth rate versus the shot integrated neutral density below the roof baffle for a different shot series using the same plasma edge shape.

To isolate the critical parameters only shots which use the same plasma shape at the SOL where compared. Fig. 3 shows the layer growth during similar shots with the same edge configuration. Although the series used different heating scenarios, core densities, impurity inlet and pumping scenarios, correlation of the growth to the neutral flux Γ_{neutr} below the divertor is found. For one series, shown with identical symbols, the correlation is even better.

4. Parasitic plasma beyond the divertor

The deposition pattern in Div II showed pronounced shadows behind obstacles. This points towards the existence of a plasma beyond the divertor structure. To verify this hypothesis a Langmuir probe was installed at the divertor support structure below the dome baffle (Fig. 1). The probe characteristics were evaluated using the double probe model [7]. Because ELM's affect the measured probe characteristic, these time slides were not used for evaluation. Indeed, a plasma was found just after the transition from the start-up limiter configuration to the divertor operation (Fig. 4). Typical data of a standard H-mode discharge show an electron density up to $n_e = 1 \times 10^{18}$ m^{-3} and an electron temperature up to $T_e = 15$ eV. An unexpected high variation of the electron density of almost 3 orders of magnitude during the same shot is observed. The electron temperature shows at 4.3 s a transition from 15 to 5 eV, which is correlated with the onset of divertor detachment.

The position of the probe is not connected via magnetic field lines with the divertor plasma. For this reason, the electrons found at the probe must be created underneath the divertor structure. Because of the strong magnetic field and the mechanical structure beyond the divertor the typical distance for electrons to reach the walls is only some meters, which results in a typical loss time of $\tau \approx 100$ μs. So the plasma must be produced very effectively on the same field line, which hits the probe position. To get an idea on the origin of the parasitic plasma, its density was fitted to experimental signals. To reduce the data scatter all signals were averaged for 300 ms. A test data set for 12 discharges, covering different scenarios was used. A subset of the raw data and the fit is shown in Fig. 5. Although the electron density varies by three orders of magnitude a good fit was obtained using only two input signals. For this fit the radiation at the outer divertor and the neutral flux below the divertor were used. A dependence of $n_e^{div} \approx \mathrm{Radiation}^{2.7} \times \mathrm{Pressure}^{0.7}$ was found. This result supports the assumption that the plasma is created by photo ionisation. From the data it is not possible to distinguish between photo emission on metallic surfaces or ionisation of impurities such as C_xH_y or D. Because all surfaces are covered with a-C:H layers the cross section for photo ionisation is unknown. An estimate of the ionisation cross section of the neutral gas below the divertor requires the knowledge of all cross sections for all C_xH_y species expected.

The existence of a plasma below the divertor has direct consequences for the deposition of C_xH_y species. On their way to the pumps hydrocarbon molecules have to cross the plasma, which may result in ionisation of the species. Ionised molecules are directed along the magnetic field lines to the walls, where they have a high sticking probability due to their high energy. This may result in a high deposition below the roof baffle and short decay lengths, as observed in [6]. The appearance of the hard, brownish a-C:D layers can be explained only by the presence of plasma ions [8]. On the other hand, there are indications that the layer growth rate below the roof baffle parallel and perpendicular to

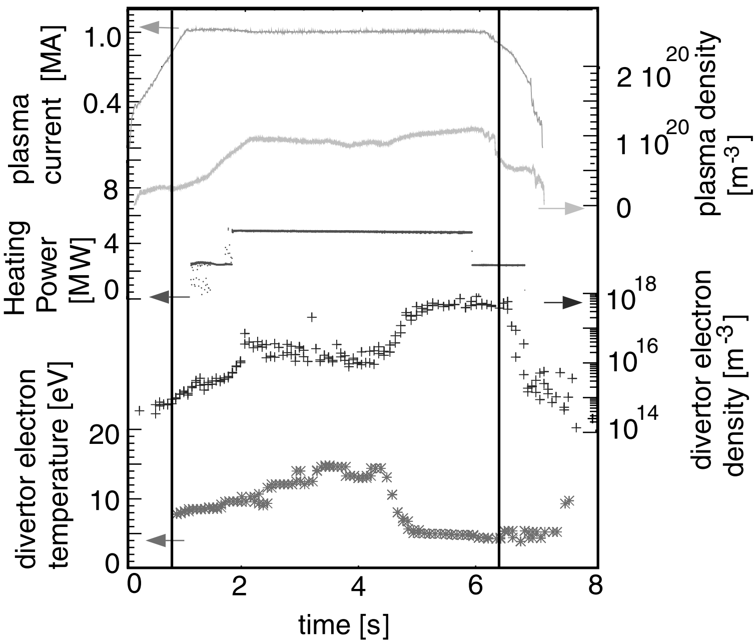

Fig. 4. Density and temperature of the parasitic plasma measured by a Langmuir probe underneath the divertor for a typical H-mode discharge. The lines indicate the divertor phase.

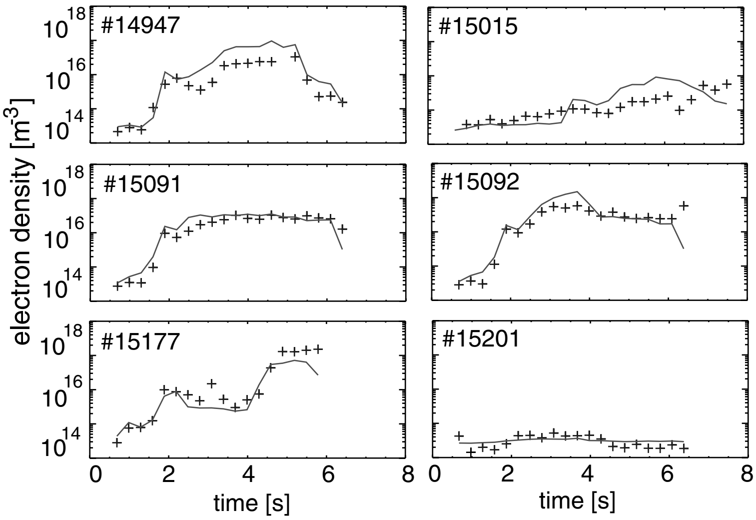

Fig. 5. Correlation of the measured plasma density (+) with the fit (solid line).

magnetic field lines is identical [6], indicating a major contribution of neutral particles. This is confirmed by the presence of very soft a-C:D layers [6], which are formed only in the absence of ion bombardment. A quantitative understanding of layer deposition below the roof baffle is still missing, but the plasma below the divertor may play a crucial role.

5. Summary and conclusions

Regarding the deposition, only small differences are found between Div II and Div IIb configurations. The main difference is the lack of brownish, hard a-C:D layers with lower D/C ratio. The QMB technique offers reliable measurements on a shot to shot base. The layers are found to grow continuously. For shots with similar edge configuration, the growth rate is proportional to the divertor pressure. A typical low temperature plasma is found below the roof baffle structure. This plasma seems to originate from photo emission or photo ionisation.

References

[1] G. Federici et al., J. Nucl. Mater. 290–293 (2001) 260.
[2] J.P. Coad et al., J. Nucl. Mater. 290–293 (2001) 225.
[3] M. Rubel et al., J. Nucl. Mater. 266–269 (1999) 1185.
[4] V. Rohde et al., J. Nucl. Mater. 290–293 (2001) 317.
[5] R. Neu et al., Plasma Phys. Control. Fusion 44 (2002) 1021.
[6] M. Mayer et al., Characterisation of deposited hydrocarbon layers below the divertor and in the pumping duct of ASDEX Upgrade, these Proceedings.
[7] M. Weinlich, A. Carlson, Phys. Plasmas 4 (1997) 2151.
[8] W. Jacob, Thin Solid Films 326 (1998) 1.
[9] M. Mayer et al., J. Nucl. Mater. 290–293 (2001) 381.
[10] A. von Keudell et al., Nucl. Fusion 39 (1999) 451.