Hydrocarbon puff experiment in the ASDEX Upgrade divertor

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Introduction Although carbon is a favourite material due to its superior mechanical and thermal properties, its use as wall material in future reactors is under discussion, in particular due to the possible flake formation and the codeposition of tritium [1,2], which are related to the chemical erosion of carbon in terms of hydrocarbon molecules.

The spectroscopic determination of the chemical sputtering yield in fusion devices depends in a first step on the values of the photon efficiencies of the emitting species [3]. In the case of hydrocarbons the photon efficiency D/XB represents formally the number of dissociation events per emitted photon, where D is the <u>D</u>issociation rate and XB the e<u>X</u>citation rate times the <u>B</u>ranching ratio. The particle flux is related to the photon flux via Eq.1. The transition used in this study is the CH/CD A-X transition at 431 nm (see Fig.1). D/XB is normally related to the emitting species, e.g. CH. In practice the underlying, eroded hydrocarbon species is of interest. Therefore, taking into account the transport of the intermediate breakup product and, in particular, the wall sticking probability effects, the $(D/XB)_{CH \leftarrow CH_4}$ as defined in Eq.2 is used in the following.

$$\Gamma_{particle_{C_XH_Y}} = (D/XB)_{C_XH_Y} \cdot \Gamma_{photon_{C_XH_Y}} \tag{1}$$

$$\Gamma_{particle_{CH_4}} = (D/XB)_{CH \leftarrow CH_4} \cdot \Gamma_{photon_{CH}}$$
⁽²⁾

The aim of this work is to study the influence of the local plasma parameters (ne, Te) on the values of the photon efficiency $(D/XB)_{CH\leftarrow CH_4}$.

The variation of photon efficiencies with plasma edge conditions is studied by introducing CH₄ and CD₄ in deuterium/hydrogen plasma pulses. To measure the D/XB in situ, a wide field observation ($\Phi \approx 7 \text{ cm}$) of the emitting volume is used to detect all photons emitted during molecular breakup. Arrays of lines of sight ($\Phi \approx 1 \text{ cm}$ each) permit the reconstruction of the intrinsic emission profile and allow to estimate the emitting cloud size in the poloidal direction during the puff ($\Phi \leq 1 \text{ cm}$).

Experiment Different sets of discharges were carried out in deuterium and hydrogen, puffing different hydrocarbon species. Two



Figure 1: Time integrated spectra for three H-mode discharges. The D_{γ} intensity peaks are normalised to 1. The bottom Figure is scaled by 0.1.

sets are presented here: the first set consists of hydrogen discharges in L-mode with 1.4 MW neutral beam injection power, 1 MA plasma current and $6 \cdot 10^{19} \text{ m}^{-3}$ line averaged density (shots:17384,5,6); the second set consists of deuterium H-mode discharges with 5 MW neutral beam injection, 1 MA plasma current and $6.5 \div 8 \cdot 10^{19} \text{m}^{-3}$ line averaged density (shots: 17830,1).



Figure 2: Target profiles of ion flux (top), Te (center) and ne (bottom) for the discharges 17384 (left) and 17831 (right) during the strike-point scan.

To obtain a broad range of temperatures and densities at the puffing location, strike-point scans are performed. The reconstruction of electron temperature, density and flux profiles as function of the distance from the separatrix (S-S_{sep} in Fig.2) permits to check whether the profiles remain self similar during the strike-point scans. Additionally, this permits reconstructing the photon flux profiles of the observed lines with a good spatial resolution (Fig.3).

The ua8 Langmuir triple probe is located near the puff location, and its measured values are assumed to give the local plasma conditions at the emitting region. During the discharges, the puff rate is kept constant and measured via an absolutely calibrated baratron. The diagnostic experimental setup is described in more detail in [4].



Figure 3: Photon fluxes profiles during the strike-point scan for D_{γ} at 433.9 nm, CD at 431 nm, CII at 426.7 nm and BD band at 432.9 nm. The different chords correspond to different divertor poloidal position.

Results and discussion In the L-mode hydrogen discharges CH_4 was puffed. During the downward shift of the plasma column, the relative position of the puff valve moves away from the separatrix in the scrape-off-layer. Therefore the density, flux and temperature at the puff location decrease. During the upward shift the electron density and flux increase at the valve location having although almost constant electron temperature, possibly due to the neutral density increase in the divertor during the upwards shift.

In Fig.4 the D/XB values as function of the electron density (b,e) and electron temperature (c,f) for two L-mode hydrogen- (b,c) and one H-mode deuterium (e,f) discharge are shown.



Figure 4: D/XB correlation plots (a) for two L-mode (top) and one H-mode (bottom) discharges and D/XB as function of ne (b,e) and Te (c,f)

A positive dependence on the density for both data sets is found, although the density dependence is much stronger in the L-mode hydrogen discharges. The L-mode ones show a negative dependence on temperature, whereas in the H-mode only a weak positive Te dependence results from regression analysis. In Fig.4(a,d) the correlation plots from the regression analysis are shown. The functional dependence is reported in (3) for the L-mode and in (4) for the H-mode discharges:

$$(D/XB)_{CH\leftarrow CH_4} = 77.6 + 1.26 \cdot [n_e/10^{19}]^{2.0} - 37 \cdot Te^{0.4}$$
(3)

$$(D/XB)_{CD\leftarrow CD_4} = -55 + 31.9 \cdot [n_e/10^{19}]^{0.2} + 24.2 \cdot Te^{0.1}$$
(4)

In Fig.1 intensity spectra for three different H-mode discharges normalised to the D_{γ} peak are shown, with different y-scales (a,b). In the discharges 17206 and 17430, carried out shortly after a boronization (15÷25 discharges), the BD band intensity is very strong in comparison to the CD band.

The BD molecular band appears during the present campaign much stronger versus the CD band compared to previous campaigns [5]. This can be due to the more direct impact of the boronization on the more open outer divIIb, or a successive long term change of the divertor surface as reported from DIII-D [6].

In Fig.3 the reconstructed D_{γ} , CII, CD and BD photon flux profiles are shown. The profiles obtained from different chords are not fully similar during the scan. This may be caused by the effect of tile edges and gaps or locally different surface coating. The D_{γ} and CII emission profiles are peaked just inside the separatrix while the CD and BD molecular band profiles have strong contributions outside the separatrix.

This can be explained by a chemical erosion dominated area in the private flux region just outside the separatrix and a region dominated by physical sputtering at the location of maximum ion flux, although the application of the D/XB method is questionable in region with low T_e and n_e and long mean free path. Previous comparison of modelling from DIVIMP and B2-EIRENE with target measurements had shown a strong contribution to the carbon source

just outside the separatrix from neutral particles [7]. D/XB values obtained from (4) (Fig.5a) are used to obtain erosion yield profile (Fig,5b). The yield values in the scrape off layer (0.3 \div 0.5 %) are plotted with the yields obtained by direct application of D/XB measured simultaneously during the strike point scan. The values in the private flux region could be not representative due the the low value of T_e and n_e.

Conclusion $(D/XB)_{CH \leftarrow CH_4}$ shows a positive dependence on the density and a negative dependence on the temperature in \square^{20} dence on the temperature in \square^{20} whereas weaker dependences are found in H-mode deuterium discharges. A parametric dependence on just density and temperature is not sufficient to fit all the data sets. The difference between L-mode and H- point mode could be caused by the efect of the ELMs. The spectro-



Figure 5: (a) D/XB from (4) and directly measured during the strike point scan and (b) the respective erosion yields. In Fig.2right the corresponding target profiles.

scopic data are not fast enough to resolve the ELMs temporally and the Langmuir probes values have been time averaged. Typical erosion yield values of $0.3 \div 0.5$ % are found in H-mode deuterium discharge. Short after a boronization yield as low as 0.1% have been observed (Fig.1,shot 17430).

Reconstructed emission profiles for CII, CD and BD show a peaked molecule emission (CD, BD) in the private flux region just outside the separatrix and a CII emission peak more shifted inside the scrape-off-layer. This could indicate a physical sputtering-dominated region in the scrape off layer and a stronger effect of chemical erosion directly outside the separatrix. The low density in the private flux region and the consequent long ionisation path make further investigation necessary.

Temporal variation of target surface conditions related, e.g., to the time after the last boronization and local effects caused by tiles edges or gaps make difficult to derive general intrinsic chemical erosion yields. A full analysis needs a description of the surface structure and composition in addition to the local plasma parameters, so a 3D Monte-Carlo code with molecular physics and surface physics would be needed.

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