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Evolution of carbon content in ASDEX Upgrade during the transition to a full W machine

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Introduction During the last years tungsten has stepwise replaced carbon on plasma facing components (PFCs) as plasma facing material (PFM) in ASDEX Upgrade. Chemical erosion of carbon surfaces by hydrogen isotopes is a major issue in future fusion reactors due to the tritium trapping in redeposited layers. Therefore the operability of a carbon-free machine is being investigated at ASDEX Upgrade and is also a strategical target of JET during the ITER-like-wall project.

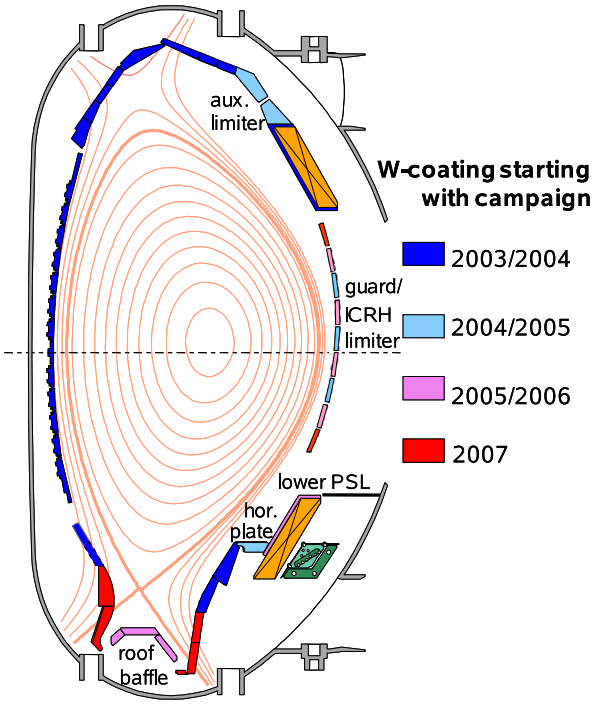

Figure 1: ASDEX transition to full W machine.

Since 2002 a stepwise approach has been followed to minimise the operational risks and learning about the impact of the different components, where more and more of the PFM surfaces have been coated with tungsten. To investigate the operation of a pure full tungsten wall machine, without low Z PFC coatings or oxygen getter, no boronizations/siliconizations were done in 2007. The only conditioning technique used during the 2007 campaign was He-glow-discharge. The transition to a full first W wall started, after some preliminary tests, with the replacement of the inner wall (2002/2003 and 2003/2004), followed by the upper divertor (2003/2004), the low-field-side limiters (2004/2005 and 2005/2006), the roof baffle (2005/2006) and finally with the lower divertor strike point regions (2007), as shown in Fig.1. More details on the transition to full tungsten PFC can be found in [1]. The present work focuses on its effects on the carbon content and recycling. In the following analysis, it must be always kept in mind that the spectroscopically observed carbon is an indication of the carbon gross sources (net source plus recycling) and not of the net carbon sources. As it will be shown the net carbon source has been reduced but the recycling has increased.

Deposition analysis Since the beginning of the transition to tungsten, the divertor tiles were post-mortem analysed to measure the total carbon erosion/deposition at the end of each campaign [2]. While the outer divertor has been a net carbon source with 2.8 g eroded per campaign until its transition to tungsten, the carbon found at the deposition-dominated inner divertor decreased drastically from 14 g to 2.2 g in 2005/2006, following the tungsten coating of the low field side (LFS) limiters. The removal of the last carbon PFC in 2007, the divertor target plates, brought a further reduction of the carbon deposition from 2.2 g to about 1 g [2].

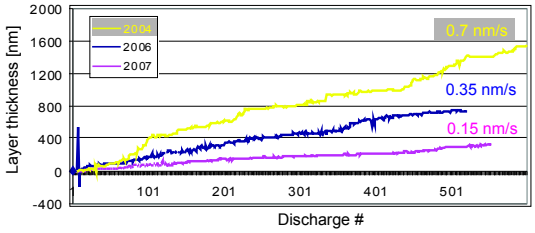

Figure 2: Carbon layer thickness measured by quarz-microbalance at the outer sub-divertor region during different campaigns.For each curve is also indicated the deposition rate in nm/s.

This clearly indicate the role of the LFS limiters as the main net carbon source in ASDEX Upgrade during the past campaigns and of the outer divertor as minority source. Under the divertor roof baffle a quartz micro-balance is installed to measure the redeposition rate [3]. Comparing different campaigns (see Fig.2) the carbon deposition rate in the outer sub-divertor region was reduced a factor 2 after carbon removal from the LFS limiters, from 0.7 nm/s to 0.35 nm/s and another factor of 2 in 2007 with the carbon removal from the divertor to 0.15 nm/s.

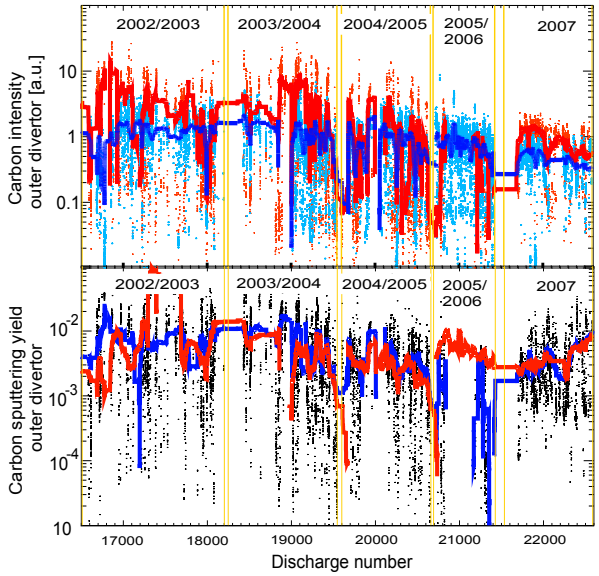

Figure 3: Carbon intensity at the outer divertor (top) and carbon sputtering yield at the outer divertor (bottom). The red datapoints/lines are measured along a single line-of-sight while the blue ones are integrated along the whole target plate.

Spectroscopic data analysis

The deposition is directly correlated with the carbon source but the spectroscopic data analysis is not so straightforward: changing the PFMs modifies the substrate material net source, but also the re-erosion of redeposited material and therefore the recycling characteristics. In [4] is shown that the sputtering yield for light elements on the top of a high Z substrate is much higher with respect to a low Z substrate.

Starting with the 2002/2003 campaign, all discharges have been processed and stationary intervals in density and plasma energy have been extracted. Spectroscopic signal averages in each interval have been calculated and stored in a SQL database (ASDEX Upgrade topical data base). The time slices have a time length from 30 ms up to 1 s. No selection has been done for the data shown in the figures: all the data, independently on discharge power, density, configuration or plasma position, are plotted and the data scatter is in most plots more of two order of magnitude, as a consequence of the different plasma parameter/configurations. Therefore the plots can give a general idea of the trend but cannot be taken individually. In each plot a median filtered curve is over plotted to emphasise the trend of the signal.

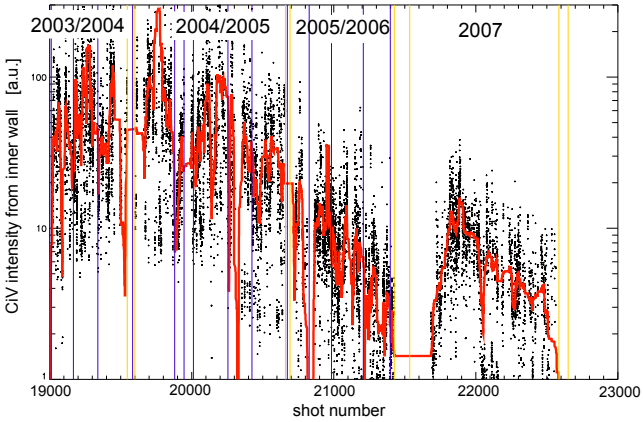

Figure 4: CIV line intensity at 38.4 nm integrated along an horizontal line-of-sight in the midplane.

In Fig.3-top the evolution of the outer divertor carbon during the different campaigns is shown. The red symbols/line show the intensity of the survey spectrometer CIII line at 464.7 nm, integrated along a single line-of-sight looking from the sub-divertor through the separatrix to the center of the outer strike point plate. The intensity is therefore strongly dependent on the strike point position. In the same figure, the blue symbols/line show the integrated intensity along the target plate of the same carbon emission line, measured by a fiber array coupled to a CCD camera with an interference filter. The localized measurement (red) shows a reduction of about one order of magnitude whereas the target integrated one shows only a reduction by a factor of three. The sputtering yield obtained from the ratio of the CIII 464.7 line and the deuterium balmer beta (alpha for the array), multiplied for the photo-efficiency coefficients (0.8 for carbon, 15 for D_α and 150 D_β), is shown in Fig.3-bottom. The yield decreased by about a factor of three from the 2002/2003 campaign till the beginning of the 2007 campaign. At the end of 2007 it increased again to values similar to 2002, possibly due to the lacking of boronization and the corresponding increased effect of

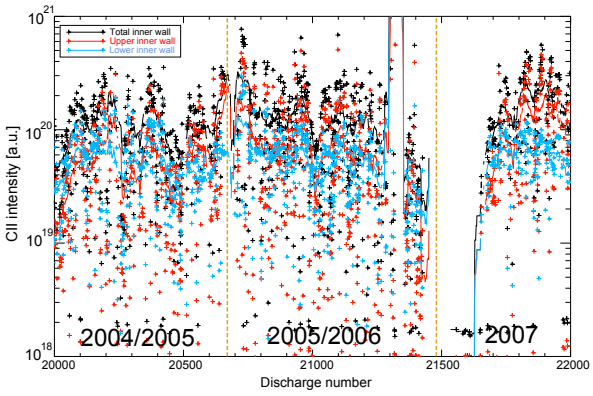

Figure 5: The CII line intensity at 514.5 integrated along the inner wall is shown in black. In red and blue the contribution from the upper and lower part of the inner wall.

carbon erosion by oxygen.
In Fig.4 the CIV intensity (Li-like) at 38.4 nm from an horizontal line crossing the plasma in the midplane is shown. This indicates the carbon source to the separatrix from the inner wall. A clear reduction starting from 2004 can be seen, corresponding to the removal of the carbon LFS limiters. The integrated CII at 514.5 nm from the inner wall is shown in Fig.5. The intensity does not show any reduction over the different campaigns. CII is more an indicator of the strong carbon recycling at the inner wall, differently from the CIV, which radiates nearer to the separatrix and is a more global indicator of the carbon flow to the separatrix.

Discussion and conclusion The moderate reduction of carbon signals after the full removal of carbon plasma-facing components can be attributed to the stronger recycling of carbon in the vessel and to the limited carbon pumping capability. The ASDEX Upgrade pumping system can remove up to 0.4 g carbon per campaign [5]. This amount is comparable to the amount of carbon originating from micro-sources, which are now dominant after all macroscopic carbon sources have been removed. These micro-sources could be e.g. the carbon deposited in remote areas and mobilized by photo-oxidation[6], or the bulk carbon accessible by the plasma after arcing erosion removed the tungsten coating at the inner divertor baffle [7] or also the un-coated tile sides exposed to recycling neutrals. The estimated carbon mobilised by photo-oxidation is some 10^{18}molecules$\cdot$MW^{-1}s^{-1}m^{-2}[6]. Considering an experimental campaign of 3000 s and an average radiated power of 2 MW we obtain 0.1-0.3 g m^{-2} per campaign each metallic square meter exposed.
ASDEX Upgrade although has no more carbon PFC has still considerable amount of carbon radiation. This should not be surprising as ALCATOR C-MOD, running as a pure molybdenum machine and no carbon components, reported carbon concentration of 1-2 % [8]. The carbon removal is dominated by carbon deposition and more pumping capability would be necessary to further reduce the carbon contents in ASDEX Upgrade.

References

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