DIVERTOR RETENTION FOR METALLIC IMPURITIES AT ASDEX UPGRADE

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Introduction

Tungsten appears to be a favourable plasma facing material in future fusion devices, at least for those wall components, which are exposed to a high heat flux but have no direct contact to the confined plasma. Possible areas of application are the divertor and baffle regions.

During the tungsten divertor experiment at ASDEX Upgrade, the applicability of W at the strike point region in the divertor could be demonstrated successfully, as no adverse effects on the plasma performance were observed. The high divertor retention R for tungsten was essential in the course of this experiment, in order to achieve plasmas with very low central W concentrations. So far, only estimations for R could be obtained from long-term deposition probes and code calculations [1].

For the determination of R a measurement of the tungsten influx into the divertor as well as a concentration measurement in the main plasma is necessary. The influx measurements of high-Z materials are hampered by the insufficiently known atomic data. To overcome this problem, at ASDEX Upgrade a sublimation probe was developed, which allows the cross calibration of the influx of the metallic impurities with the influx of carbon and oxygen, the atomic data of which are much better known. The tungsten in the main plasma had to be detected by means of a special deposition probe made of pyrolitic graphite since the central W concentrations were below the spectroscopical detection limit.

Sublimation Probe and Observation Optics

The sublimation probe at ASDEX Upgrade (see fig. 1) consists of a heatable cavity in which metal-carbonyls $Me_x(CO)_y$, chemical bonds of one or more metal atoms with carbon monoxide, can be sublimated and then be puffed into the plasma via a controllable valve. The valve itself is attached to a coil which experiences a torque in the toroidal magnetic field, when the electric coil circuit is closed. A detailed description of the probe setup can be found in [2]. The probe has successfully been operated using Fe, Mo and W carbonyl with cavity temperatures of 70 – 110 °C. The impurity influx is measured spectroscopically by an array of 5×5 viewing chords which are projected on the front of the probe head. Fig. 2 shows the pattern and the exhaust hole of the probe.

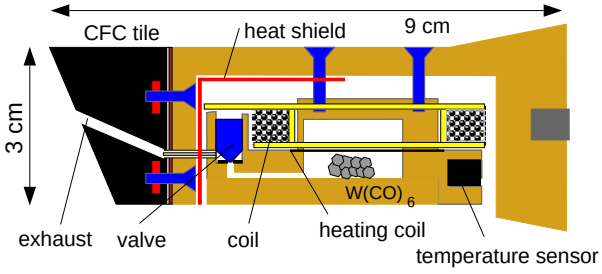

Figure 1: *Setup of the sublimation probe.*

For the spectroscopical observation of the injected impurities a 1 m Czerny-Turner spectrometer was used. The whole optical system was calibrated by means of an integrating sphere.

Due to the relevance of W as plasma facing material tungsten carbonyl was mostly used

with the probe. The observed wavelength range was 396 – 403 nm. Here additionally to the prominent W I line at 400.9 nm a O II line at 397.3 nm can be detected.

Influx Measurements

In the plasma the carbonyls dissociate and the influx of the metal can be cross-calibrated with the influx of carbon or oxygen. For the influx the relation

$$\Gamma = \left.\frac{S}{XB}\right|_{eff} I \qquad (1)$$

was used [3]. Hereby Γ is the flux density of the injected impurity species and I the intensity of a suitable emission line.

$$\left.\frac{S}{XB}\right|_{eff} = \frac{1}{f_\sigma} \left.\frac{S}{XB}\right|_{\sigma}$$

is an effective inverse photon efficiency in which the possible existence of different metastables is taken into account with the fractional abundance f_σ of the metastable observed in the measurements. Fig. 3 shows the intensities of an O II at 397.3 nm and a W I line at 400.9 nm for each line of sight.

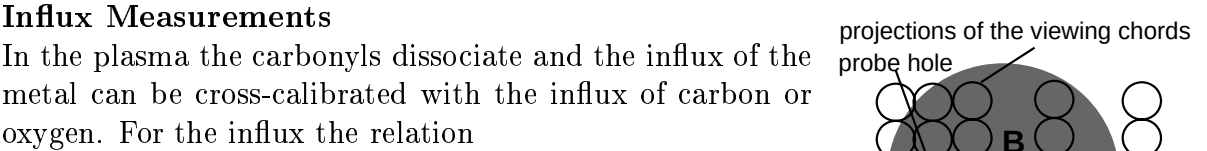

Figure 2: *Projections of the viewing chords for the influx measurements onto the probe head.*

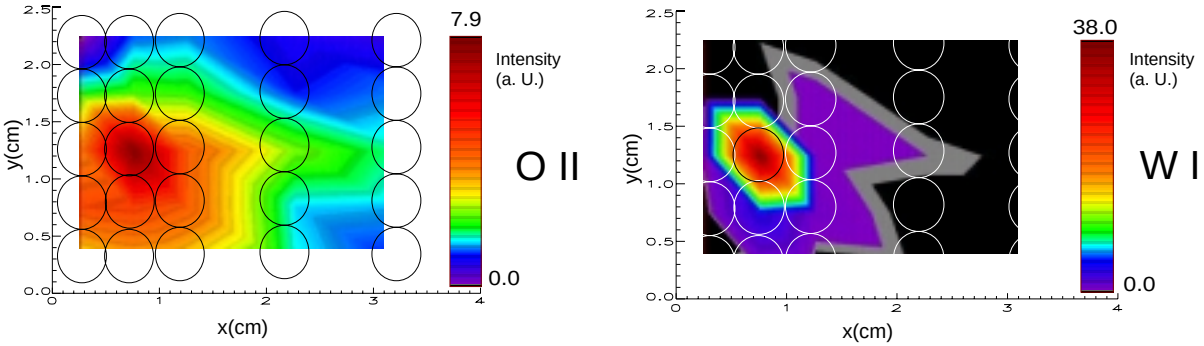

Figure 3: *Spatial distribution of the emitted intensities of the 397.3 nm line of O II and the 400.9 nm line of W I in front of the probe head.*

As expected, the O II cloud is spatially much more extended than the W I emission cloud. The observation of singly ionized O II helps to avoid problems originating from the uncertain dissociation process of the carbonyl. From the bonding relations one would expect that the carbonyls break up into the metal and CO or CO^+. Under electron impact the latter dissociate into the singly charged ions [4, 5, 6].

Using eq. 1, the stoichiometric relation of W and O in $W(CO)_6$ and the relative intensities of the O II and the W I emission clouds one obtains

$$\left.\frac{S}{XB}\right|_{eff,WI} = \frac{1}{6} \left.\frac{S}{XB}\right|_{eff,OII} \frac{I_{OII}}{I_{WI}} = 16 \pm 10$$

for the effective S/XB ratio of of the W I line for an electron temperature of $T_e = 12$ eV as measured by Langmuir probes. This value is in good agreement with measurements by Steinbrink et al. at the Berlin PSI [7] who found a value of about 20 ± 5 at this temperature and confirms their measurements for $S/XB|_{eff,WI}$ under reactor relevant plasma conditions.

Typical fluxes out of the probe are $5 \cdot 10^{16}$ to $1 \cdot 10^{17}$ particles per second.

SOL Penetration Measurements

For non recycling impurities the particle confinement time $\tau_p = p\,\tau_t$ can formally be separated into the product of a penetration probability p and a transport time τ_t. p represents the temporal maximum of the ratio between injected impurity particles and impurity particles found in the main plasma. It has been determined at ASDEX Upgrade at different poloidal positions using laser-ablation [8] and the sublimation probe. p turns out to be about 4 % independent of the poloidal injection position.

For the cases with W injection with the sublimation probe at the midplane position in the main chamber, the decay length of W in the SOL was found to be $\lambda_{sol} = 22$ mm by an RBS analysis of the W deposited on the probe hull.

W Migration and Divertor Retention

The divertor retention potential was originally defined [9] as

$$R_\tau = \frac{\tau_{wall}}{\tau_{div}}$$

where τ_{wall} and τ_{div} denote the particle confinement times of impurity particles originating from the wall and the divertor respectively. Due to the small amount of W actually reaching the bulk plasma it was not possible to determine the different confinement times and consequently we used the ratio

$$R_\Phi = \frac{\Phi_{wall}}{\Phi_{div}}$$

of the influx into the divertor to the outflux from the main plasma for the divertor retention. Assuming $c_W = p\,\tau_t \Phi_{wall}/(n_e V)$ and $c_W = p\,r\,\tau_t \Phi_{div}/(n_e V)$ for W particles originating from the wall or the divertor, where p is the SOL penetration probability and r the probability of the particle to escape from the divertor into the SOL, both definitions for the divertor retention potential are identical. $n_e V$ denotes the product of electron density and plasma volume.

The influx into the divertor was monitored spectroscopically as described above. In the main plasma, however, no W could be detected spectroscopically after $W(CO)_6$ injection in the divertor, only an upper limit for the increase of c_W of about $8 \cdot 10^{-7}$ could be established using a focussing SXR spectrometer.

In contrast to W, Fe could be found in the plasma center after injection of Fe-carbonyl. A probable reason is the much smaller prompt redeposition rate due to the significantly smaller gyro radius of iron ions.

A measurement of tungsten in the main chamber was possible with a special deposition probe made out of pyrolitic graphite which contains far less intrinsic impurities than the usually used fine grain graphite. This probe was exposed during a discharge with $W(CO)_6$ injection in the divertor and afterwards analyzed using RBS with an 1 MeV ^{7}Li Beam. The latter yielded a much larger beam current and a higher scattering cross section than for the typically used ^{4}He beam. The broadening of the backscattering peaks due to the higher beam ion mass is still tolerable for Li. Field line tracing revealed no direct connection between the probes along the magnetic field. This assures that the W is dispersed homogeneously in the SOL before being deposited on the probe.

The measured W surface density $\sigma_W = 2 \cdot 10^{12}$ cm^{-2} on the deposition probe is very small and in the order of 1/1000 monolayer. Fig. 4 shows measured RBS spectra with and

without W injection in the divertor. The W density on the probe was determined by a fit to the W peak and the carbon backscattering edge using SIMNRA [10]. The flux $\Gamma_\perp$ in the SOL can then be calculated from

$$\Gamma_\perp(x) = \frac{\lambda_{lim}\sigma_{W,0}}{tL/2} \exp\left(-\frac{x - x_0}{\lambda_{lim}}\right)$$

Here λ_{lim} is the W decay length in the limiter shade in which the deposition probe was exposed, L is the respective connection length, t the exposure time of the probe and x the large radius. The index 0 denotes the innermost point of the deposition probe.

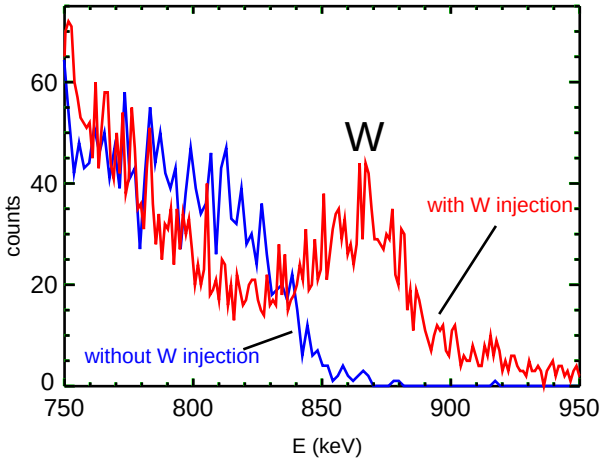

Figure 4: *RBS spectum of the deposion probe showing the W peak.*

There are two possibilities for the W to reach the central plasma. Firstly it is possible, that the W particles flow into the main chamber inside the SOL and penetrate from there into the confined plasma inside the separatrix. The second possibility is, a direct propagation from the divertor into the bulk plasma.
In the first case, for a measured central W concentration, the flux in the SOL is $\Phi_{sol} = c_W n_e V/(p\tau_t)$ while in the second case the respective relation is $\Phi_{sol} = c_W n_e V/\tau_t$. Comparing both cases with the experimental data, one finds that only the first case is consistent with the spectroscopical detection limit. Accordingly the measured divertor retention is $R = 1/r$, i.e. the inverse probability of an injected W particle to escape from the divertor into the SOL. Thus, the value $R = 17$ which was obtained for the divertor retention corresponds to an escape probability of 6 %.

Acknowledgement
The authors thank V. Rohde for his help with the manipulators as well as J. Fink and M. Hien for technical assistance.

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