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IMPURITY FLUXES IN THE SCRAPE-OFF LAYER OF ASDEX UPGRADE IN THE FULL TUNGSTEN WALL CONFIGURATION

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Introduction

Since 1999 ASDEX Upgrade has been converted in several steps from a device with carbon wall armour to one with an almost complete tungsten wall coverage [1]. The stepwise replacement of the original tiles by W coated tiles allows studying the influence of the increasing fraction of high-Z wall elements. A suitable quantity for the characterisation of the low-Z and high-Z erosion are the ion fluxes of the respective elements in the scrape-off layer (SOL). These can be measured by exposure of collector probes by the outer midplane manipulator of ASDEX Upgrade and quantification of deposited deuterium and impurity elements by ion beam analysis of the retrieved probes. Discharge-resolved and even time-resolved measurements within a particular discharge can be carried out employing rotating cylindrical samples, which are shielded by a 4mm slit aperture extending 88mm in radial direction. For the current campaign a full metallic probe head (TZM shield, Al cylinder) has been constructed to allow the quantitative measurement of the residual carbon flux after introduction of the full tungsten wall in ASDEX Upgrade.

In contrast to previously used long term samples, discharge- and time-resolved measurements allow to correlate impurity fluxes with characteristic plasma conditions and spectroscopic erosion flux measurements. Increased impurity fluxes are observed during the low density current ramp-up phase as well as in plasma configurations with small separatrix-probe head distance and also with increased ion cyclotron resonance heating (ICRH) power [2]. The increase of the impurity flux in the first two cases is attributed to an increased plasma wall flux and correspondingly higher sputtering flux. In the latter case the interaction of the ICRH antenna with the plasma is expected to create a local impurity source increasing with heating power.

Of special interest in the 2007 campaign is the temporal evolution of the residual carbon flux, which is expected to decay strongly during the experimental campaign because all primary C sources have been removed.

Experimental

The used deposition samples are made of highly pure aluminum (Goodfellow, 99.999% Al). Important major impurities are Cu (0.552 ppm), Fe (0.765 ppm), Mg (0.865 ppm) and Ti (0.135 ppm). For these elements, the results of pre-exposure reference measurements are subtracted from the results of sample analysis after plasma exposure. The samples were exposed to discharges using the midplane manipulator system of ASDEX Upgrade (Fig. 1 of [2]), located at z = 0.31 m above the midplane in the shadow of an ICRH limiter and a nearby protection limiter (d ~ 20 cm). To obtain a well defined plasma wetted area, the samples were mounted inside a TZM shield (0.5 % Ti, 0.08 % Zr, 0.02 % C, rest Mo) with a narrow slit aperture defining a viewing cone of 15°. The slit is oriented parallel to the sample in radial direction. The collector sample is usually exposed 13 mm behind the limiter shadow. Inspection of the magnetic field lines ending at the collector sample shows that the connection length stays constant to be ~1.5 m towards the next protection limiter for all presented experiments. Previous exposures were mainly in stationary H-mode discharges in lower single null configuration with a current of I_P = 0.8–1 MA, a toroidal field of B_t = -2.5 T and line averaged densities between $n_e = 5–7\times10^{19}$ m^{-3}. However, results of first experiments during the successful start-up of ASDEX Upgrade in an all W environment have been obtained in stationary H-mode discharges with I_P = 0.8 MA, B_t = -2.067 T and $n_e = 6–7\times10^{19}$ m^{-3} with a flat top phase of typically 3–4 seconds and neutral beam heating of P_{NBI} = 7.5 MW.

After exposure the retrieved probes were analyzed ex-situ using Rutherford back-scattering (RBS), Nuclear Reaction Analysis (NRA), both employing $^3He^+$ ions at 0.8 MeV, and Proton Induced X-ray Emission (PIXE) with a 1.5 MeV proton beam.

Results

In recent experimental campaigns, apart from the dominant first wall element tungsten, the main impurities collected on high purity graphite samples were Ca from ceramic insulation of cables, steel constituents (Fe, Ni) from the vacuum vessel and traces of other elements originating from in-vessel components and from maintenance procedures [3]. Quantification of the deposited deuterium and impurity fluence showed concentrations of $c_{Fe} \sim 10^{-3}$ and $c_W \sim 10^{-5}$ at the plasma edge, which are in good agreement with spectroscopic measurements.

Figure 1 shows the fluence of deuterium and several impurity elements deposited on an aluminum probe. The angular distribution of deuterium demonstrates the system's capability to resolve consecutive discharges. After each exposure the sample was rotated by 40°. For clarity the flux of impurities in Figure 1 is only represented by the respective maximum value

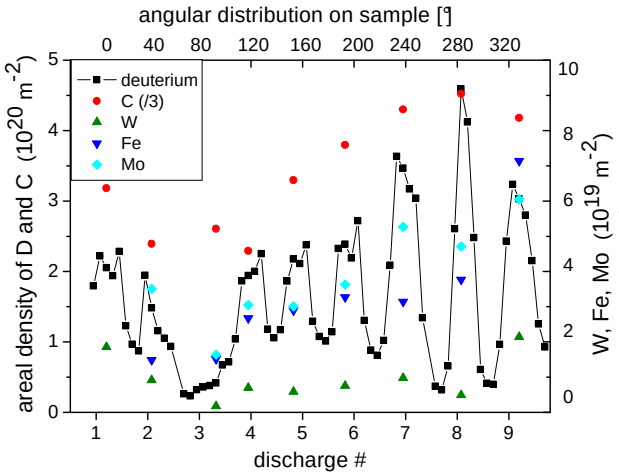

Figure 1: Angular distribution of deuterium and impurities on the collector probe.

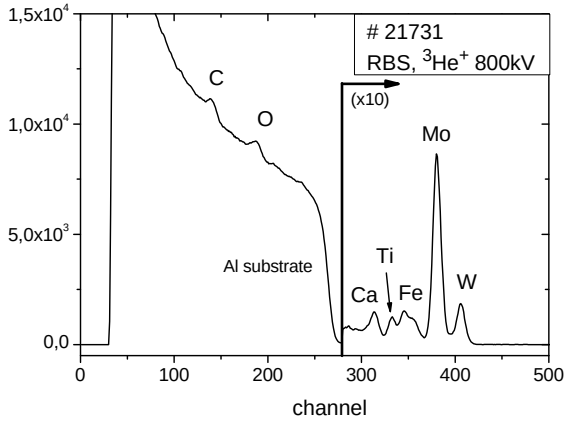

Figure 2: RBS spectrum of impurities on the deposition sample for AUG #21731.

in a given discharge. The deuterium content found on the Al sample exposed in discharges at the beginning of the all W campaign is typically ~4 × 10^{20} m^{-2} after one discharge, which is a factor of 3 – 4 lower than in previous campaigns. This indicates either a lower density of the far periphery plasma compared to previous campaigns or increased D reemission from the Al sample. Additional experiments will be required to clarify this result. A typical RBS spectrum of the sample exposed in # 21731 shows the C and O signals on top of the Al bulk spectrum, see Figure 2. Peaks of heavier elements like Ca, Ti, Fe, Mo and W are enlarged by a factor of 10. Using the RBS cross sections of the respective elements one can calculate the quantity of impurities found on the sample to:

Element	Areal density on sample [m^{-2}]
C	1.1 x 10^{21}
O	5 x 10^{20}
Ca	5 x 10^{19}
Fe	4 x 10^{19}
W	4 x 10^{18}
Ti	3 x 10^{19}
Mo	5 x 10^{19}

The values for Fe and W are comparable to those of previous campaigns. Carbon could be measured for the first time in the ASDEX Upgrade history by a collector sample. Because of the use of a TZM shield around the actual Al sample the quantity of Ti and especially Mo has increased significantly between one and two orders of magnitude. This is clear evidence of sputtering at the probe shield and could possibly be used in future experiments for estimation of local electron and ion temperatures.

The local origin of the Mo source can be deduced from the data shown in Figure 3 presenting radial decay lengths (RDL) of deuterium as well as of W, Fe and Mo. For deuterium a radial decay with a RDL(D) ~ 7mm is found, proving that the D absorption in the Al substrate does not reach saturation level. About 20–30% larger values

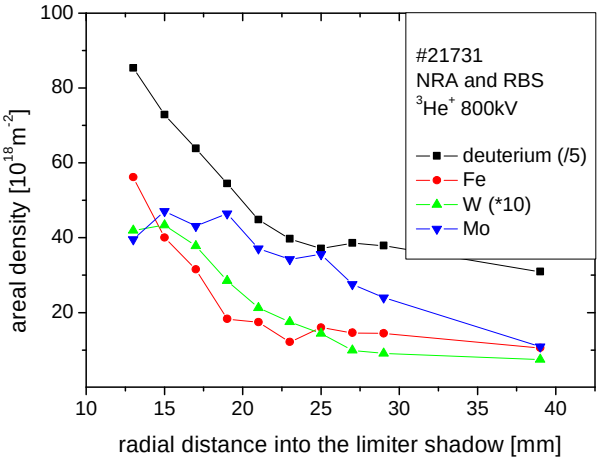

Figure 3: RDL of D, Fe, W and Mo.

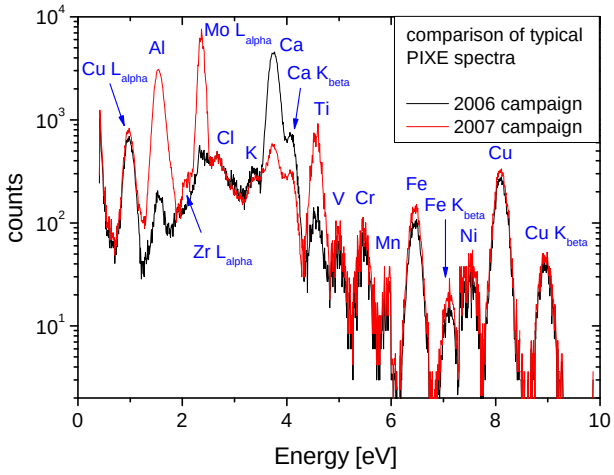

Figure 4: PIXE spectra from 2006 and 2007.

compared to previous campaigns are found for Fe and W (RDL(Fe) ~ 4 mm and RDL(W) ~ 6 mm), whereas Mo shows no exponential but rather linear dependency. The decrease of the W signal towards the limiter edge was identified as a product of Fe sputtering, see [3].

Comparison of typical PIXE spectra in Figure 4 shows some clear changes: Whereas the increase of Al (sample substrate) as well as Zr, Mo and Ti (TZM shield) is explained by technical changes at the probe head the significant decrease of Ca that can be attributed to the exchange of the isolation of electrical cables in parts of the experiment. The quantity of other impurities has not changed significantly. The main contribution to the strong Cu line emission is an inherent signal from the ion beam analyses and is used here as a calibration marker.

Conclusion and Outlook

For the first time in the ASDEX Upgrade history we are able to measure carbon deposition using full metallic probe heads. The C content will be monitored at various times of the all W campaign. The amount of major impurities like W and Fe are comparable to those of previous campaigns, Ca however has decreased significantly due to technical improvements. We plan to monitor and compare impurity behaviour after boronization to the previous campaign and to observe W fluxes in detail by using the midplane and divertor manipulator (including surface and bulk temperature survey) accompanied by spectroscopic measurements.

References

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