Ion Cyclotron Wall Conditioning in KSTAR and ASDEX-Upgrade

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1. Introduction

Ion Cyclotron Wall Conditioning (ICWC) is included into the ITER baseline for in-between plasma shots wall conditioning, i.e. in the presence of the toroidal magnetic field, in order to control impurity or hydrogen recycling, and to mitigate the tritium inventory build-up. In ICWC, high wall fluxes are thought to be responsible for the measured high efficiencies for fuel removal. In particular, extrapolation of multi-machine ICWC experiments shows that ICWC could remove 0.4 gT between two plasmas in ITER [1], which is comparable to a 0.14 - 0.5 gT uptake per nominal 400 s D:T plasma shot [2].

However, neither the interaction of the discharge species with wall surfaces, especially metallic, nor the ability of ICWC plasmas to access co-deposited layers, where most of the retention occurs [3], is well understood. This paper presents results of recent ICWC experiments performed on KSTAR and ASDEX-Upgrade aiming to address these questions.

2. Fuel removal from gaps or castellated structures

The first attempt to estimate erosion inside a castellated structure was done in a He-ICWC experiment in KSTAR. A specially designed mock-up includes a gap of 2.4 mm width and 20 mm deep as shown in Figure 1a. Pre-characterized samples with a-C/B:H films of a known thickness were installed on the sides of the gap, and exposed to multi-pulse He-ICWC (P_{RF}=50 kW, f = 30 MHz, B_T = 2.0 T, p = 10^{-3} mbar feedback controlled continuous gas injection, cumulated duration of 125 s). The sample was mounted on a holder in the mid-plane, the slit being parallel to the toroidal magnetic field. The ion fluxes to the corresponding locations of the wall were measured by means of Langmuir probes. Prior to the experiment the wall was preloaded with hydrogen. In order to minimize re-ionization in the relatively high plasma density He-ICWC discharges (10^{18} m^{-3}), and subsequently re-implantation of wall desorbed species, a RF pulse duration of 1 sec. was chosen. Figure 2 shows the continuous wall desaturation from hydrogen which can be seen on the evolution of the partial pressures of H_2 and HD. The total H recovery amounted is 10.6 monolayers.

Figure 1b shows depth profiles of the film erosion inside the gap installed in the midplane. The film thickness was measured by means of the *ex-situ* ellipsometry.

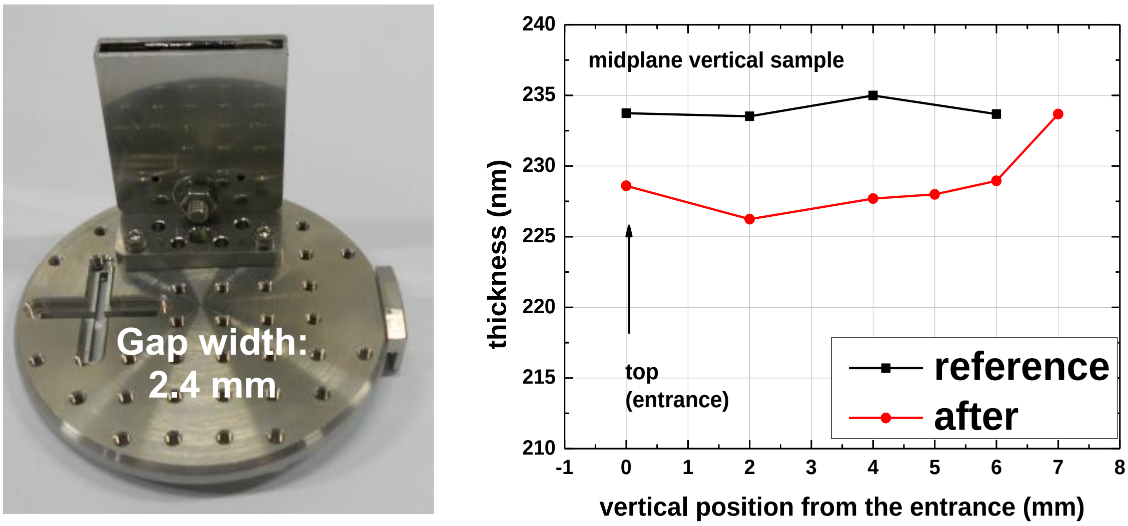

Figure 1. Castellation structure (a) and the depth profile of the a-C/B:H film thickness (b) inside the gap before and after He-ICWC in KSTAR.

A sputtering yield of $Y_{exp} = 0.0013$ is deduced from the average erosion rate of 0.08 nm/s, but it cannot be explained solely by chemical sputtering of the carbon co-deposits by the low energy recycled flux at the room temperature, expected to be $Y_{chem} \approx 10^{-4}$ [5]. Physical sputtering by energetic ions (H, D and He), which is the mechanism of interest for fuel removal from metallic surfaces, e.g. Be/W co-deposited layers in ITER, must intervene.

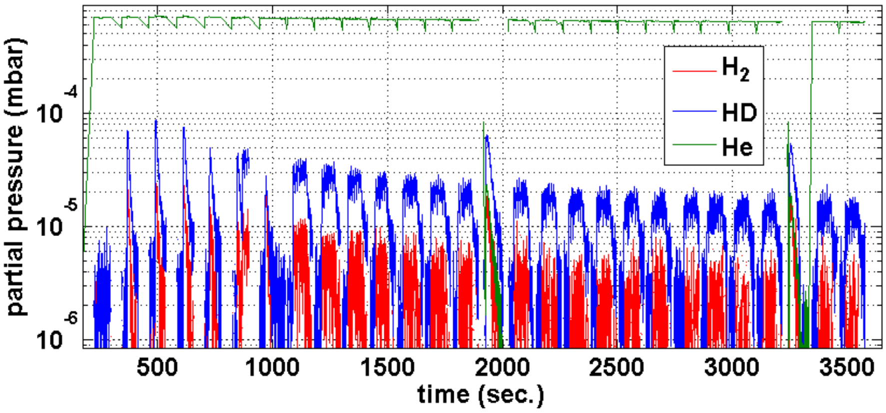

Figure 2. Multi-pulse He-ICWC in KSTAR: evolution of the partial pressures of H_2 and HD.

He ions may penetrate into the gap by diffusion and transport along the magnetic field lines. The yield for physical sputtering expected at these energies ($Y_{phys} \approx 10^{-5}$-10^{-3} for He^+ impinging at 10-100 eV) [6], is lower or comparable to Y_{exp}, indicating in the present

He-ICWC experiment a possible synergetic effect during the simultaneous H and He irradiation, which enhances the sputtering rate, as the energetic He ions activate the surface and break C-C bonds, which leads to a decrease of the sputtering threshold for the H atoms [7].

3. Contribution of fast CX neutrals

Encouraging results for the recovery of metallic wall surface state after massive gas injection (MGI) have been obtained on ASDEX-Upgrade. Six 10 sec. long He-ICWC (f = 30 MHz, B_T = 2.0T, monopole phasing) discharges allowed to remove almost all Ar atoms implanted in the W surfaces by short He:Ar glow discharges beforehand. Comparison between low B_T (0.2T) and high B_T (2.0 T) He-ICWC evidenced a faster decay of the amount of removed Ar atoms at 2.0 T (red circles of Figure 3).

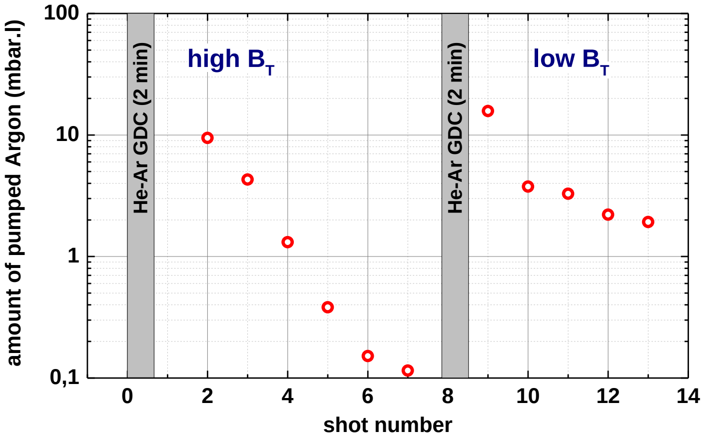

Figure 3. Evolution of the argon partial pressure levels during He-ICWC on ASDEX-U.

In the case of high B_T charge exchange neutral fluxes, measured with a Neutral Particle Analyzer (NPA), were found to have a strongly non-Maxwellian energy distribution function, with a large tail above 1 keV and up to 20 keV, whereas the distribution is Maxwellian at 200 eV at low B_T (Figure 4a). Stronger wall pumping in the RF ON phase and lower Ar post-discharge outgassing of the high B_T ICWC pulse, compared to low B_T pulse (Figure 4b) possibly indicates an interaction deeper into the surfaces in the high B_T case. This result, in contrast with previous findings on JET with D_2-ICWC, may be explained by higher ion cyclotron power absorption per recycled D atom in He-ICWC plasmas compared to D_2-ICWC. Modelling with a 1-D Dispersion Equation Solver [8] shows that in the case of the low B_T scenario RF power is mainly absorbed by the electrons, while in the high B_T scenario ICR is the dominant absorption mechanism, i.e. the ions absorb the energy directly and efficiently clean the wall from argon [9].

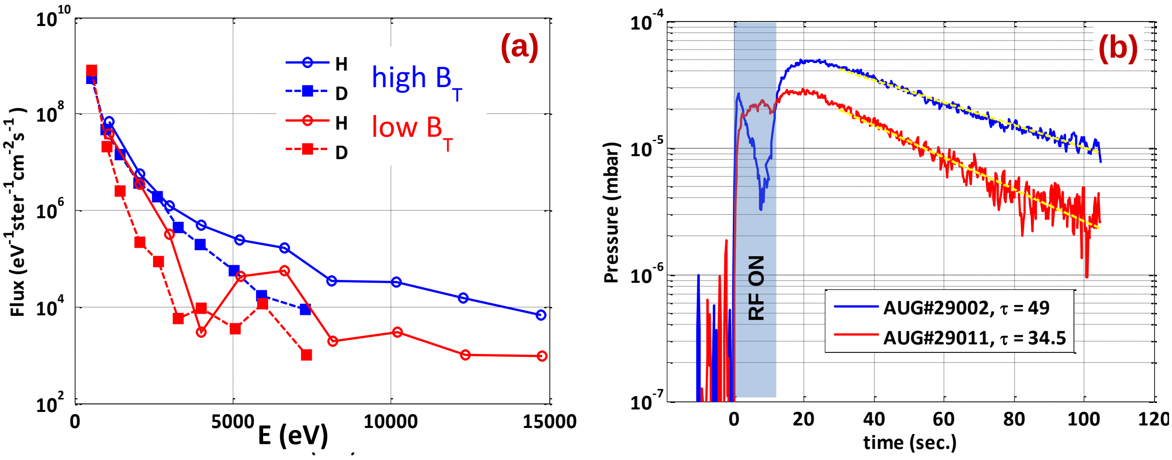

Figure 4. Comparison between low B_T (red) and high B_T (blue) He-ICWC on ASDEX-U: (a) the fast CX spectra measured by NPA during the pulse; (b) outgassing curves after the ICWC shot.

4. Conclusion

The efficiency of ICWC for fuel removal and wall cleaning is discussed in this paper. He-ICWC experiment in KSTAR showed prominent removal of the carbon co-deposits inside the castellated structure, indicating the combined role of both physical and chemical sputtering by H, D and He particles.

He-ICWC in ASDEX-Upgrade clearly evidences the role of the B_T value in the RF power absorption and efficiency of Ar removal from the walls. In the high B_T scenario a significant tail of the energetic *CX* neutrals (E > 1 keV) was observed in the NPA spectra. These particles penetrate deeper into subsurface layers of the first wall, releasing more trapped argon atoms compared to the low B_T case. The stronger interaction between the He-ICWC plasma and the wall in the high B_T scenario is confirmed by mass-spectrometric analysis of the outgassing in the post-discharge.

References

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