Influence of the phase shift between antennas on W sputtering in ASDEX Upgrade

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The ICRF (Ion Cyclotron Range of Frequencies) system is successfully used in the fusion experiments for heating and current drive. During the ICRF operation one of the main problems is the sputtering of the plasma facing material in antenna vicinity. For future fusion devices, high-Z elements are favorable as materials of the first wall [1, 2, 3]. This initiates a growing interest on the compatibility of ICRF antenna operation in the plasma with high-Z facing components (PFCs). One of the negative effects connected to the ICRF antennas operation is due to generation of the strong electric fields along magnetic field lines, that enhances an erosion of PFCs [4, 5]. This electric field ($E_{||}$) is responsible for formation of the high RF potential, $V_{||} = \int E_{||} \mathrm{d}l$, which is rectified in the sheath region [6, 7] and accelerates the ions to the limiters. The effect of the $E_{||}$-field can be partially compensated by choosing the appropriate phase between two neighboring antennas coupled along magnetic field lines. The present experiments continue the early ASDEX Upgrade (AUG) experiments in year 2009, where the effect of the tungsten yield reduction due to an optimization of the antennas phasing was observed [8].

The ICRF system at AUG has 4 two-straps ICRF antennas placed on the low field side. For the standard H-minority resonance heating the standard strap current phasing of $(0;\pi)$ are used. At ASDEX Upgrade only one transmission line per antenna between the ICRF antenna and RF generators is available. The ICRF antennas operate in pairs and in a standard configuration each pair of the neighboring antennas (1-2 and 3-4) is powered through the 3 dB-couplers [9]. In this case, the phase shift between two neighboring antennas is 90°.

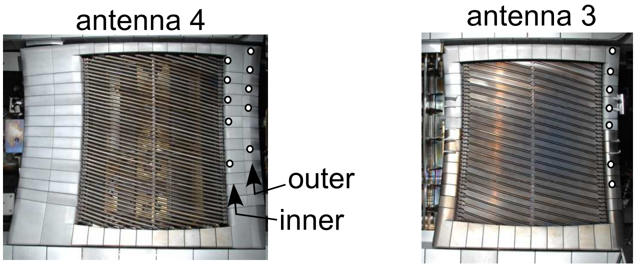

Fig. 1. Antennas 3 and 4 with points of spectroscopic observation

Due to the recent modifications of the transmission line circuit the ICRF system can operate in two configurations with powered independently pairs either of neighboring (1-2 and 3-4) or of opposite (1-3 and 2-4) antennas in the torus. In addition, the direct digital synthesizer for generation and synchronization of the driven frequencies of all generators was added to the ICRF system. In this case the independent control of the phases of each antennas pairs is possible and effect of phase shifts between antennas can thus now be studied in details for a variety of plasma configurations.

During the experiments the antenna limiters of antennas 3 and 4 are monitored spectroscopically. The antenna 3 limiter was monitored with seven lines of sight (LOS) and the antenna 4 with five LOSs on each of the sides (inner and outer) of the limiter (see Fig. 1). The intensities of tungsten and hydrogen are linked directly to the particle fluxes (Γ_W and Γ_D correspondingly) at the points of observation [10]. To characterize the effective sputtering yields of tungsten at each LOS the normalization Γ_W/Γ_D is used [10]. In such case Y_W are independent of the absolute error of the Γ measurements. At the given concentrations and charge states of the light impurities (W sputtering by deuterons alone can not explain the measured sputtering yields [11]), Y_W is linked to a rectified sheath potential drop and theoretically to the plasma RF voltage ($V_{||}$). The total W content during ICRF is characterized by the W concentration C_W measured spectroscopically (see, for example, [12])

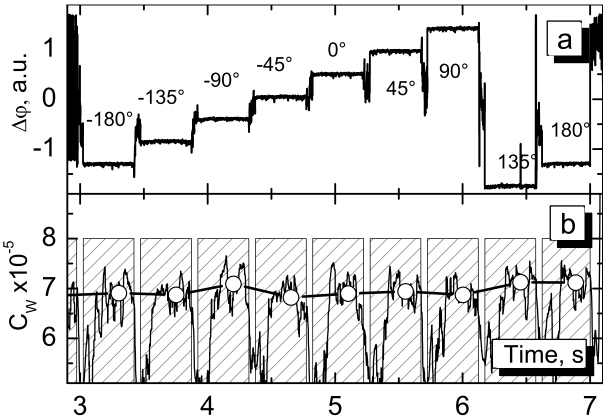

Fig. 2. Variation of the tungsten concentration (b) (C_W) during the antennas phase scan (a). The points correspond to the time average value of the C_W over 60% of the phase scan. Filled area (b) corresponds to ICRF-power on.

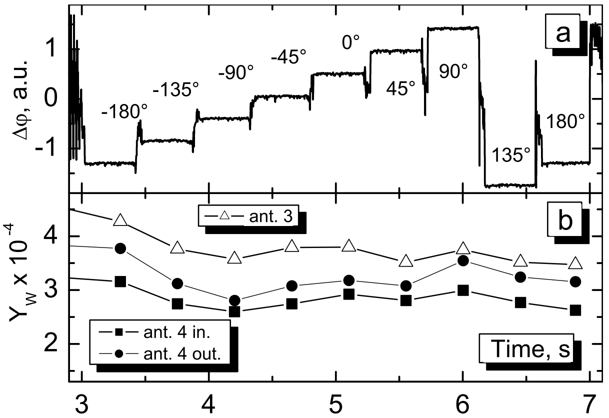

Fig. 3. The time average (over 60% of each pulse) of the tungsten sputtering yield Y_W at a corresponding limiter side of antennas 3 and 4.

The presented below results relate to shot number 27103 (NBI $P = 5$MW, ICRF $P = 3.5$MW at 36.5 MHz from all 4 antennas). The phase shift between antenna pairs 1-3 and 2-4 is scanned "step by step" 45$^{\text{o}}$ every 450 ms. During transition processes at the phase changing the power of the ICRF generator is switched off. On the Fig. 2 are shown the signals of the phase difference between antenna 3 and 4, the signals of the tungsten fluxes and the tungsten concentration C_W in arbitrary units. As it is follows from the curves of Fig. 2, after switching off the ICRF power it is more then half of the pulse duration is necessary for stabilization of the signal. To exclude the error due to transient processes we take into account only 60% of the data at the end of each phase shift pulse.

In Fig. 3 the average value of the Y_W over LOSs at corresponding limiter side are present. Each value of the Y_W corresponds to the time averaging of the Y_W over the 60% of each phase pulse as mentioned above. As we can see there is a certain correlation between the magnitudes of the Y_W and the phase shift. The minimum of the tungsten release from the antenna limiters can be observed in the time range 4-4.5 seconds. It should be noted that the measurements here do not represent a comparison between W sources at antennas 3 and 4. The antenna comparison using more defined conditions will be discussed elsewhere.

In our experiment we also observe a change of the sawteeth crash period during the antenna phasing scan. The time period between the sawteeth crashes shown in Fig. 4. As we can see switching off the ICRF power initiates the sawteeth crash. There is a strong evolution of the crash period during ICRF power pulse. The solid line shows dependency of the crash period at the end of the each pulse. The minimal period coincides with a minimum of the tungsten yield at the antennas 3 and 4.

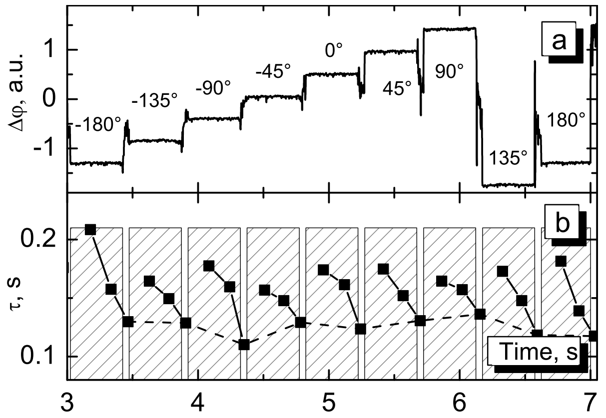

Fig. 4. The sawteeth crash period (b) during the phase scan (a) is shown. The filled area (b) correspond to ICRF-power on.

Observed rates of the tungsten release from the ICRF antennas limiters have not so strong dependencies as in the early experiments in 2009 [8]. In [8] the phase scanning have been done continuously, in contrast to the present experiment, where measurements are obtained in the "stationary case" and 45^o step for phase scan is used. It is possible that we pass the optimal antenna phasing.

One of the interesting issue for future experiments is the study of the effect of the antennas phasing on sawteeth crash. We observe light effect on the period of the sawteeth crash, however at the moment it is impossible to establish whether the antennas phasing directly affects the sawteeth crash or this is a consequence of the impurities concentration change.

References

[1] Philipps V et al 2000 *Plasma Physics and Controlled Fusion* **42** B293

[2] Kallenbach A et al 2005 *Plasma Physics and Controlled Fusion* **47** B207

[3] Lipschultz B et al 2001 *Nuclear Fusion* **41** 585

[4] Wukitch S et al 2007 *Journal of Nuclear Materials* **363-365** 491 – 497

[5] Bobkov V et al 2007 *Journal of Nuclear Materials* **363-365** 122 – 126

[6] Perkins F 1989 *Nuclear Fusion* **29** 583

[7] Noterdaeme J M 1992 *AIP Conference Proceedings* vol 244 (AIP Press, Melville, NY) p 71

[8] Bobkov V et al 2009 *Journal of Nuclear Materials* **390-391** 900 – 903

[9] Noterdaeme J M et al 1996 *Proceedings of 16th International Conference on Fusion Energy* vol 3 (Montreal) p 335.

[10] Dux R et al 2007 *Journal of Nuclear Materials* **363-365** 112 – 116

[11] Dux R et al 2009 *Journal of Nuclear Materials* **390-391** 858 – 863

[12] Neu R et al 2005 *Nuclear Fusion* **45** 209