Study of JET conditioning with ITER-Like Wall

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Introduction

Wall conditioning of fusion devices is an effective means for controlling the fuel recycling and the impurity generation due to plasma–surface interactions [1]. Techniques used are baking of in-vessel components, glow-discharge cleaning (GDC) and thin film deposition on plasma facing components (PFCs). The largest existing tokamak JET with its new ITER-Like Wall [2] provides a unique experience to study the wall conditioning in the presence of beryllium and tungsten PFCs [3] and to compare with the extensively studied carbon dominated PFCs. The analysis of the initial conditioning cycle of JET [4] after ILW installation is presented in the first part of this paper. Monitoring of impurities throughout the ILW campaign is analysed in the second part. A study of the poloidal glow discharge wall current distribution as a function of the electrode number, glow current and deuterium pressure is presented in the last part and the results are extrapolated to ITER.

1. Analysis of the initial conditioning cycle of JET.

The overview of the initial conditioning cycle of the JET vacuum vessel in 2011 including the baking temperature, the D_2-GDC sessions (grey stripes) and the pressure from a Penning gauge in the main chamber are shown on Figure 1a. After air leak hunting the vessel was pumped down on the 6th of July. The air leak rate was reduced down to 2×10^{-3} mbar·l/s. The vessel baking was started at 200°C and then maintained at 320°C for almost one month. The analysis of the initial baking is shown in [5]. In total, 70 g of water could be removed, which is comparable to 80 g removed during the 2008 conditioning cycle. About 200 hours of D_2-GDC were then performed before the first plasma.

Figure 1b shows the evolution of partial pressures of water and carbon monoxide as a function of the accumulative duration of the intermittent D_2–GDCs conducted in the first conditioning cycle of JET ILW. Both signals are reduced by one order of magnitude throughout the 150 hours GDC at 320°C. However, once the vessel is cooled down to 200°C, further D_2-GDC conditioning was needed to remove impurities adsorbed at the PFCs, as can be seen on Figure 1b.

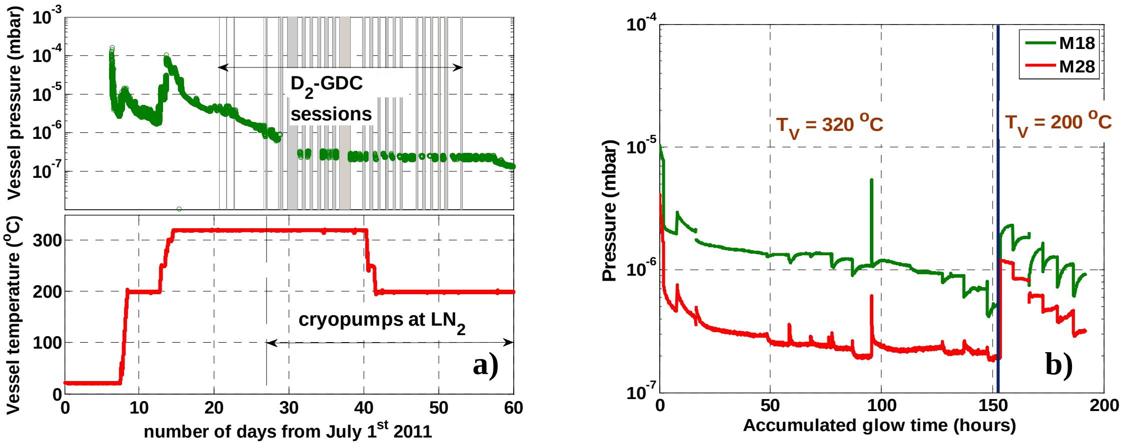

Figure 1. *(a) The initial conditioning cycle of JET with ILW: penning pressure, vacuum vessel temperature and (b) partial pressures of H_2O and CO during the D_2-GDC (p=3.10^{-3} mbar, I=15 A, U=500 V).*

2. Monitoring of impurity content

Levels of impurities in the residual gas in JET vacuum vessel, such as oxygen, water, or carbon dioxide, were monitored by mass spectrometry throughout the experimental campaign with ILW and compared with the restart in 2008. Figure 2a and b shows the partial pressures of impurities one hour before the first plasma pulse of the day. Water and oxygen levels are clearly lower with ILW than in 2008, despite the air ingress which can be seen on the constant N_2 (m/e=28) MS signal. Carbon containing species (m/e=12, 44) are only present at the beginning of ILW campaign, and at a much lower level than in 2008.

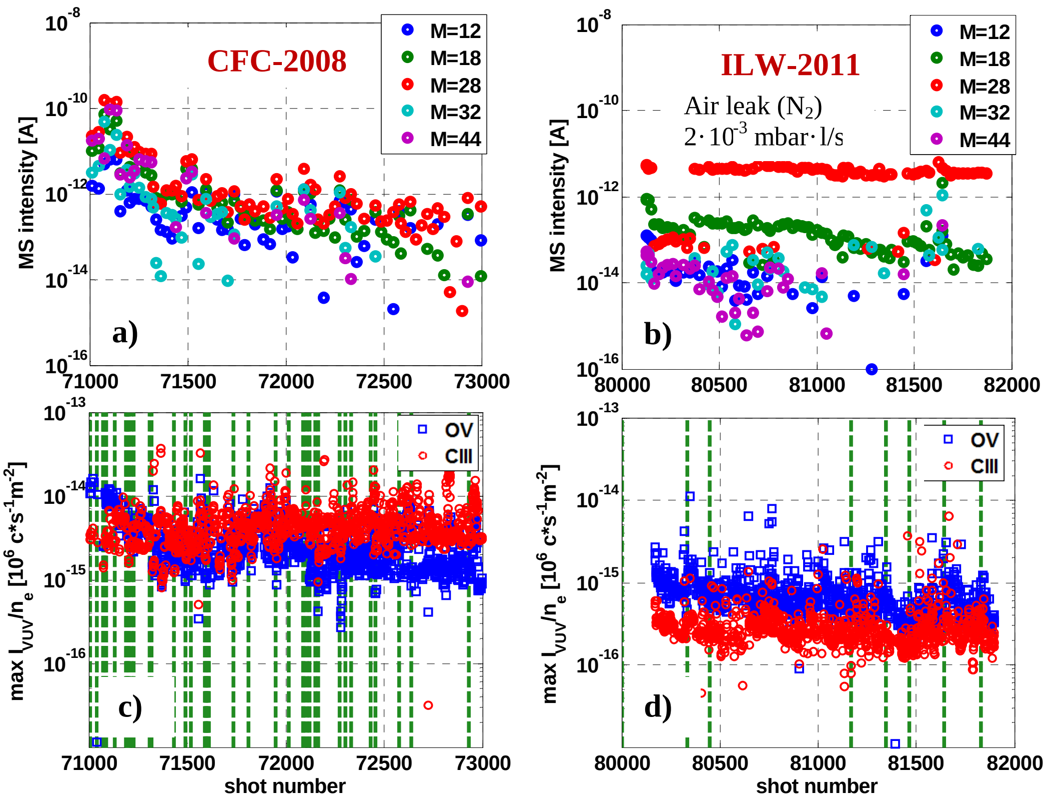

Figure 2. *Residual gas impurity levels 1 hour before the first pulse of the day in 2008 (a) and for the restart with ILW (b). Normalized OV and CIII line intensities in plasmas and GDCs applied (green dashed lines) in 2008 (c) and 2011 (d).*

The intensity of the OV and CIII line after X point formation, measured by VUV spectroscopy on a vertical line of sight and normalized to the density, is plotted as a function of the number of plasma shots for both restarts in Figure 2c and d. Carbon level with ILW is one order of magnitude lower compared to the wall with CFC tiles [2, 4]. Thanks to the getter capabilities of beryllium, the oxygen level also remains lower than in previous restarts with carbon walls, despite the air leak mentioned above, which leads to the formation of one BeO monolayer on the first wall in less than a day. Numerous GDCs were needed to reduce the high O level in 2008, whereas in 2011, after the initial conditioning cycle of JET ILW and despite the air ingress, there has been no further need for any conditioning by D_2-GDC. This is a really dramatic change with respect to the wall with carbon dominated PFCs and very relevant information for the conditioning of ITER.

3. Poloidal and toroidal glow discharge wall current distribution

The originally planned GDC system in ITER is being currently relocated. The question is if the new anode locations (outer midplane and upper lateral ports) and the envisioned range of glow pressures in ITER ensure adequate coverage of the PFCs. Indeed, scale size plays an important role due to the ratio of mean free path for neutral ionization $\lambda = k_B T/(p\sigma)$ to the typical dimensions between the anode and the first wall, where T is the gas temperature, p – the pressure, σ – is the total ionization cross-section. In the low pressure glow plasma λ can be of the order of meters, whereas the distance between the adjacent GDC anodes in JET is 6 m, which is comparable to ITER poloidal dimensions.

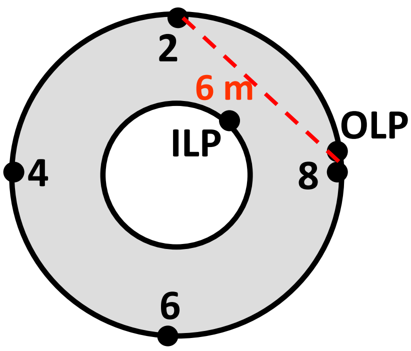

Figure 3. *Toroidal location of GDC anodes and Langmuir probe arrays in JET*

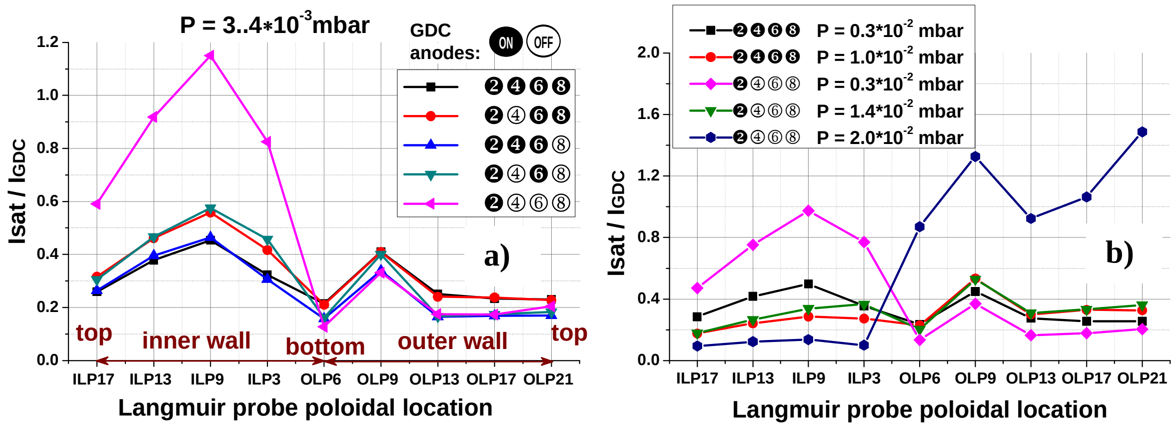

Figure 4. *Poloidal distribution of I_{sat} current normalized to the total GDC current as a function of the number of active anodes and their location (a). Influence of the GDC pressure on the poloidal distribution of the ion saturation current (b).*

Experiments on JET, using the new wall Langmuir probe capability with the ILW, provide a direct way to assess the expected glow current distribution at ITER first wall. The poloidal wall current distribution is studied as a function of the glow current, deuterium pressure, and location of anodes. The four GDC anodes, toroidally distributed in octants 2, 4, 6 and 8 (Figure 3), were switched on and off sequentially, and the homogeneity was assessed from the ion saturation current I_{sat} at the Langmuir probes arrays in the inner and outer limiter of octant 8.

The distribution of the ion saturation current normalized to the total GDC current is plotted on Figure 4a as a function of poloidal coordinates. The plot corresponds to various anode configurations at a fixed pressure of $3\cdot 10^{-3}$ mbar. Operating two toroidally opposed anodes still provides good uniformity (green triangles) within the studied pressure range, whereas switching only one anode on introduces a strong inhomogeneity (pink triangles): the ion fluxes to the inner wall are 3-4 times higher than the fluxes to the outer limiter. The ion flux distribution is strongly influenced by the pressure, as it can be observed on Figure 4b. Increasing the pressure from $3\cdot 10^{-3}$ mbar to $2\cdot 10^{-2}$ mbar while only the anode located in octant 2 is activated shifts locally the glow discharge towards the outer wall, but the homogeneity remains unchanged below $3\cdot 10^{-3}$ mbar. The discharge is poloidally homogeneous if all anodes are active, which, extrapolated to the ITER case, tends to indicate that 6 anodes 6 m apart may provide sufficient toroidal and poloidal homogeneity.

4. Conclusions

The restart and operation of JET with the ITER-Like Wall after its installation in 2010/11 is analyzed. Amounts of water and carbon removed by baking and D_2-GDC during the 2011 restart are comparable with found previously with the CFC wall. Besides water or carbon, the oxygen level is much lower with the ILW than in 2008, despite a vacuum vessel leak rate of $2\cdot 10^{-3}$ mbar·l/s, O being gettered at the beryllium PFCs. Neither GDC nor Be evaporation were necessary for the JET operation, which dramatically contrasts with previous operation with carbon PFCs. The study of the JET glow discharge as a function of the electrode number, glow current and pressure seems to indicate that the envisioned GDC system for ITER will provide sufficient toroidal and poloidal homogeneity.

Acknowledgements

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