Edge spectroscopic characterization of RFX-mod after Li wall conditioning

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Introduction In the reversed field pinch experiment RFX-mod [1], in common with many fusion devices, development is aimed at improved performance of the plasma discharge. RFX-mod (R/a=2.0/0.46m) has a full coverage of graphite tiles. While advantageous in terms of low Z should C impurities enter the plasma, graphite can become loaded or even saturated with H and is then an important source of hydrogen influx due to the high recycling of H on graphite. High current operation – up to 1.8MA – is achieved in RFX-mod with optimised error field control at the edge [2]. In these conditions, the fluxes of hydrogen from the wall increase and wall recycling can dominate the plasma fuelling. The ability to control the total particle content and plasma density through filling/puffing (rather than being slaved to the wall status) is an essential tool in performance optimisation and hence, particularly for high current discharges, control of the wall recycling is of great consequence.

Conditioning of the plasma facing graphite surfaces to reduce the potential for H recycling is one method for the realisation of density control. A number of methods have been proposed and are utilised, including He discharges, wall baking and wall boronisation or lithisation [3,4]. In RFX-mod, we have in late 2009 initiated a programme of wall conditioning by means of lithisation. In the primary phase of this project, pellets of lithium have been injected into the RFX-mod plasma. The pellets are injected at ~100m/s into either H or He discharges where they are fully ablated. A series of discharges with Li pellet injection is carried out to ensure the optimum conditioning of the wall. The use of Li pellets is an established technique that has the advantage of being a simple procedure and allowing control of the amount of injected Li.

Spectroscopic pattern The RFX-mod plasma, in particular the edge, is investigated by analysing the emitted spectroscopic pattern. A number of diagnostics are utilised to characterise different aspects of the edge plasma. Spectrum measurements demonstrate the presence of Li spectral lines following the instigation of the lithisation procedure. The presence of Li in the spectral signal of the RFX-mod plasma indicates that all of the Li does not stay on the surfaces, some is removed and released into the plasma through the actions of plasma wall interaction. Lines from B, C, O and H are also visible. Evidence of higher ionisation stage ions of Li are also observed, for example in the 135Å XUV feature of LiIII.

Influx The influx of Li ions is studied in more quantitative detail with the use of interference filters. Light emitted by the plasma on particular lines-of-sight is collected and the filter allows only that within specific narrow wavelength band covering the spectral line of interest (for lithium the 6707Å of LiI) to pass to the PMT measurement. Similar interference filters are also arranged to measure the light from H, C and O spectral lines [5]. The particle influxes are calculated using the calibrated brightness measurements together with atomic ionisation per photon coefficients S/XB from [6], scaling the edge (n_e, T_e) from line averaged interferometer measurement.

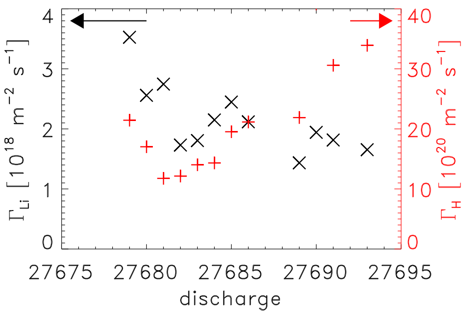

Figure 1: Average influxes of Li (black x) and H (red +) in discharges following a Li wall conditioning (averaged 170-190ms).

In figure 1, we show the progression of the Li and H influxes in a series of similar discharges following lithisation. The influx of H (red) increases whilst that of Li (black) decreases indicating that the effectiveness of the conditioning gradually reduces.

Three sets of high current discharges are considered and depicted in figure 2: discharges far from either boronisation or lithisation conditioning are in black; discharges following boronisation are in green; and discharges following lithisation are in red. As is clear from figure 2(a), at comparable densities the influx of H (from Hα) is reduced in the lithised case compared to boronisation. It seems that the lithisation is more effective at conditioning the graphite wall of RFX-mod than boronisation alone. It should be noted that a couple of lithisation series separate the set of Li points from the previous boronisation. The figure also demonstrates the clear relation between the electron density n_e and the H influx, more H is released into the higher density plasma.

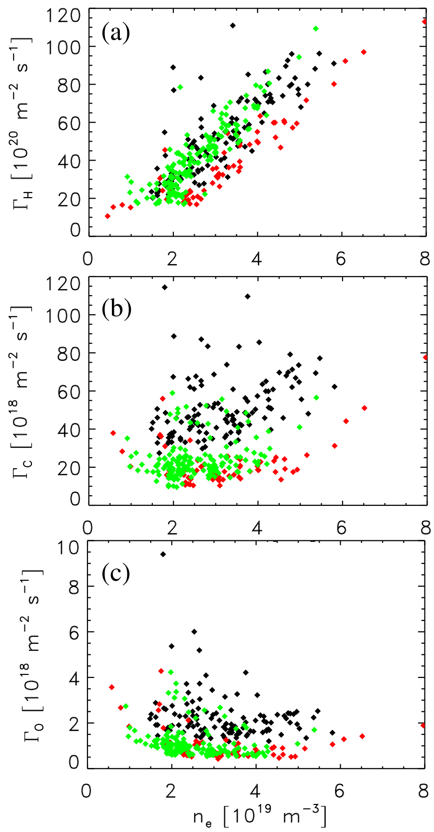

Figure 2: Variation of influx of (a) H, (b) C and (c) O with n_e for 3 sets of discharges: far from wall conditioning (black); with boronised wall (green); and with lithised wall (red).

Control of, and in particular a reduction in, the impurity content of the plasma is generally beneficial for performance and operation of fusion plasmas. The influx of C particles is seen to be affected by the lithisation procedure. Here the line examined is the CII line at 6578Å. The source of the C impurities in the RFX-mod plasma is from interaction of the plasma with the graphite tiles. Coating the graphite surfaces with a different substance causes the plasma to be less able to interact directly with the graphite and the influx of C is reduced. Figure 2(b) shows that whilst both lithisation and boronisation techniques reduced the C influx; a small additional benefit is seen with the Li treatment, probably related to the small dependence of C influx on H. The effect is not as clear as for H and there is less correlation between the influx and n_e. A reduction in the influx of O (OII line at 4415Å) is also seen with the application of either wall conditioning technique – figure 2(c) – although the effectiveness of the two cannot be distinguished.

Influx and magnetic shift The influx of H can be correlated to the geometrical shift of the magnetic surface at the edge due to the m=1 n=-7 magnetic perturbation. The time evolutions of the shift and of the H influx are shown in figure 3 for two cases, far from wall conditioning (black) and with lithisation (red). The connection between $\delta_{m=1}$ and H influx is clearly seen in the time oscillation of the influx. Also clear from the figure is that a similar m=1 deformation produces smaller excursions in the H influx following lithisation. This result implies that the lithisation may be a calming influence on the plasma edge.

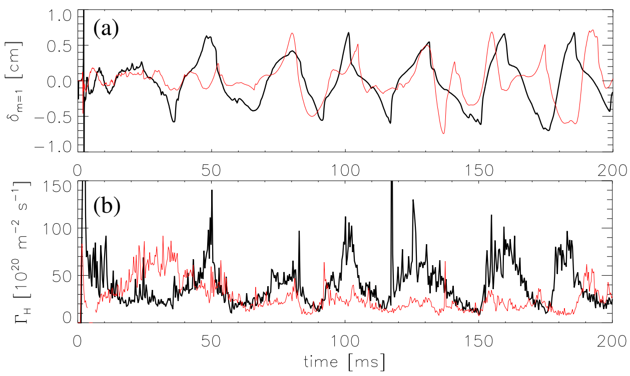

Figure 3: Time evolution of (a) shift due to m=1, n=-7 and (b) H influx for a discharge far from wall conditioning (thick black) and one after lithisation (red).

Confinement time The quality of the plasma performance can be quantified through the energy and particle confinement times with higher confinement a mark of increased performance. The particle confinement is calculated from the influx measurements averaging over the plasma volume. For the same three high current discharge types discussed above – no wall conditioning (black), boronised wall (green) and lithised wall (red) – figure 4(a) shows how the particle confinement time τ_p is increased for the Li case compared to the standard discharges and

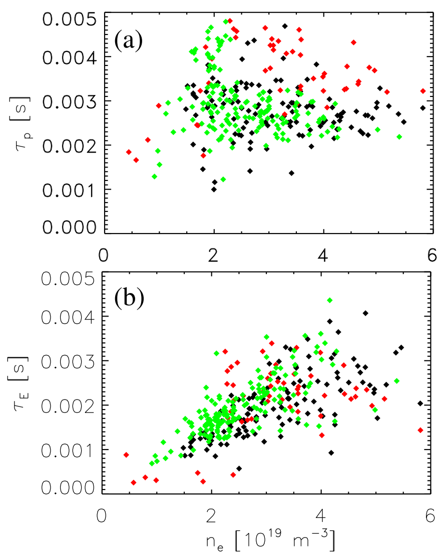

Figure 4: Particle (a) and energy (b) confinement times for 3 cases: far from wall conditioning (black); with boronised wall (green); and with lithised wall (red).

those with a boronised wall. There is no clear dependence of τ_p on n_e, however figure 4(b) shows that there is a n_e dependence of τ_E, the energy confinement time, with increased energy confinement for higher density plasmas. The τ_E is more or less unaffected by the wall conditioning in RFX-mod.

Edge profile Measurements of the edge electron temperature and density profile show an increase in T_e and decrease in n_e with wall conditioning whilst although n_e profiles away from the edge do not show large differences, statistically the Li cases typically have a higher peaking factor [7].

Radiative Power The total radiated power P_{rad} is linked to the influx (and hence the plasma particle content) and to the edge conditions. However, plotting line-averaged P_{rad} for the three discharge sets in figure 5, no clear change can be seen with lithisation.

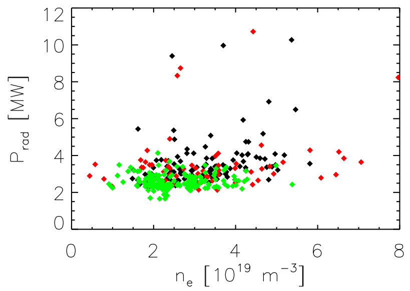

Figure 5: Radiated power for: far from wall conditioning (black); boronisation (green); and lithisation (red).

Conclusions Examination of the spectroscopic pattern of the RFX-mod plasma has been carried out to investigate the effect of the Li wall conditioning on the operation and performance. A decrease in the influx of H is observed with the lithium coated walls (more than with boron), indicating the technique is successful in control of the H inventory in the graphite walls of RFX-mod. A small decrease in impurity influxes (C and O) is also suggested by the results. The particle confinement time seems to be slightly increased by the lithium conditioning however, at present, no corresponding improvement in energy confinement is observed. The profile of temperature and density of the edge plasma is affected by the lithisation of the graphite tiles, however, the effect is not clear in the total radiated power. The lithisation by pellet injection does not have a long-lasting impact on the plasma performance, at best its effect remains for a number of discharges. The desire to improve on the need for regular and frequent renewed lithium application is behind the forthcoming RFX-mod experiments with a liquid lithium limiter.

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