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Introduction

Iron coming from the poloidal limiter or the stainless steel vessel is an important intrinsic impurity in the FTU tokamak discharges, and X-ray and VUV spectroscopy provide useful information about the impurity behaviour. The iron ion charge state distribution, as usual for tokamaks, is analysed assuming a collisional radiative model and an anomalous perpendicular diffusion. In our experiment the iron ionization level depends, as it is expected, on central electron temperature (fig. 1), but the ion charge state distribution shows a different behaviour when the first wall material or the iron source are changed.

The iron injection experiment

In the time resolved high resolution iron K_α spectra, the relative intensity of the Li-like q and Be-like β inner-shell satellite lines with respect to the He-like w resonance line depends on the Li-like/He-like and Be-like/He-like ion charge state ratio respectively [1].

In discharges having I_p = 0.5 MA, B_T = 6 T as plasma current and toroidal field and the magnetic configuration defined by a TZM (Molybdenum) internal toroidal limiter and an inconel poloidal limiter, the q/w and β/w line intensity ratio are not consistent with either the electron temperature measurements from ECE and Thomson scattering (TSC) diagnostics or the transport parameters usually assumed in FTU, implying a core ionization level of intrinsic iron lower then expected.

However, when small amounts of iron were injected during laser blow-off (LBO) experiments [2], the temporal evolution and the radial profiles of both the X-ray lines and the L-shell $\Delta n = 0$ transitions in the VUV spectrum are correctly simulated (with the exception of the initial inflow of the the lower charge states in the plasma edge) assuming the "usual" transport parameters (S = 1 as peaking factor, $D_\perp$ = 0.5 m^2s^{-1} as perpendicular diffusion), and using a time dependent temperature profile from ECE and TSC.

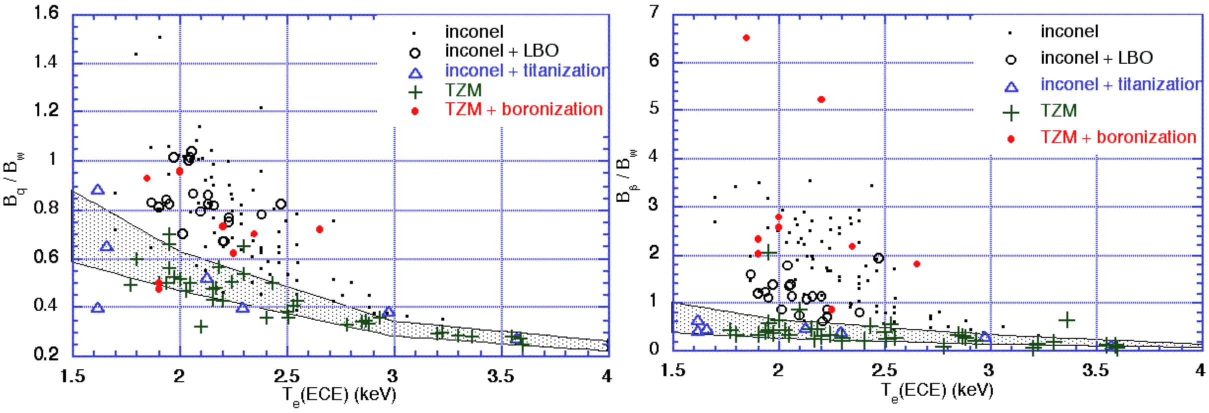

Fig. 1: q/w (left) and β/w (right) line intensity ratio in different experimental conditions. Dots: intrinsic iron in the campaign with the inconel poloidal limiter. Open circles: injected iron in the same campaign. Triangles: campaign following titanization. Crosses: campaign with the molybdenum poloidal limiter. Full circles: campaign following boronization. Shadowed area: line intensity ratio with usual FTU transport parameters.

The injection does not alter significantly the main plasma parameters. On the contrary, the scrape off layer (SOL) studied by an array of reciprocating Langmuir probes shows after the injection a decrease of n_e and T_e evident at all the radial and poloidal positions. In the unperturbed SOL, at the last close magnetic surface (LCMS), n_e~0.7 10^{19} m^{-3} and T_e~25 eV are measured. After the injection, a drop of n_e and T_e lasting 40-80 ms is found, and the effect is stronger at the poloidal position corresponding to the poloidal limiter, where n_e(LCMS)~0.3 10^{19} m^{-3} and T_e(LCMS)~10 eV are measured (fig. 2).

The scrape off layer was then analysed with the 2-D multifluid SOL code EPIT [5]. Considering the plasma parameters 3 ms after LBO injection and assuming constant transport parameters, the electron temperature drop is well reproduced as the effect of additional cooling, but, in contradiction to the experimental observation, the plasma density increases. Moreover, when the temporal behaviour of the plasma after injection is considered, all the parameters are expected to follow the typical SOL time scale (few ms), one order of magnitude shorter than the perturbation observed. This supports the conclusion that the transport parameters in the SOL and/or in the edge are in some way reduced by the LBO injection, perhaps as the consequence of the establishment of a radiating layer that prevents the inward convection and decreases the temperature and density at the LCMS by means of a lower input power in the SOL. Nevertheless, no difference in the iron K_α spectrum is found when impurities different of iron are injected.

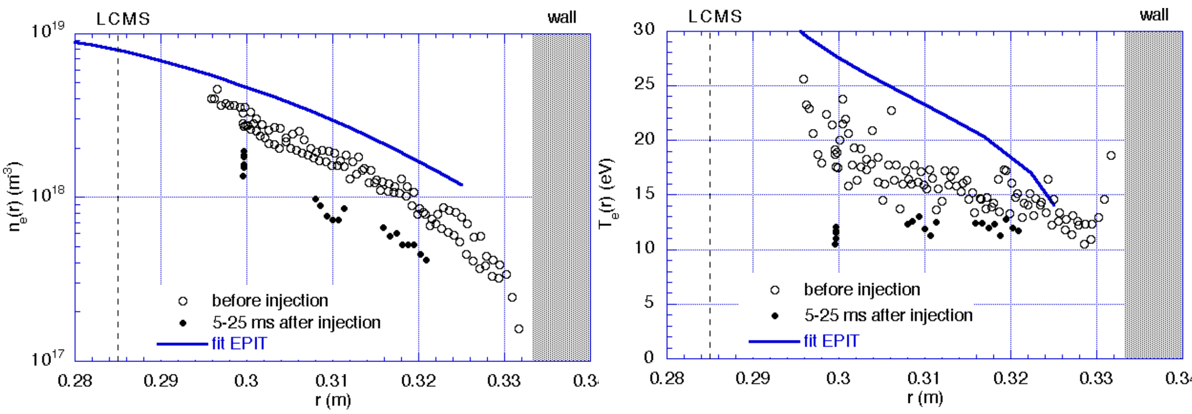

Fig. 2. n_e (left) and T_e vs. minor radius. Before (dots) and 5-25 ms after injection (circles). EPIT simulation of the scarpe off layer before injection (line)

The ion charge state distribution of intrinsic iron in different experimental conditions

The simulation of the intrinsic iron X-ray and UV spectra requires a higher inward convection velocity. $S = 2.5$ reproduces the UV spectra, but is not enough to reproduce the X-ray spectra [2]. In order to find a mechanism that could explain the discrepancy, the effect of the energy of neutral iron produced at the wall on the iron charge state radial distribution is studied by an impurity transport code with various neutral iron inward velocities and transport coefficients, but no difference at the plasma center is found by the code.

Without any apparent reason, after the titanization of the main chamber the X-ray spectra of intrinsic iron become consistent with both the electron temperature measurements and $S = 1$ and $D_\perp = 0.5$ m^2s^{-1} as transport parameters. This situation persisted when molybdenum replaced inconel as poloidal limiter. Finally, when the main chamber was boronized [6], a core ionization level of intrinsic iron lower then expected was found again, effect that gradually disappeared in approximately 200 plasma discharges after boronization. Fig. 3 shows the K_α spectrum of intrinsic iron before and after a boronization. The increase of the relative intensity of the inner shell q and β satellites is evident, whereas the satellites j, k and r, produced mainly by dielectronic recombination and that are very sensitive to the electron temperature, show only minor changes.

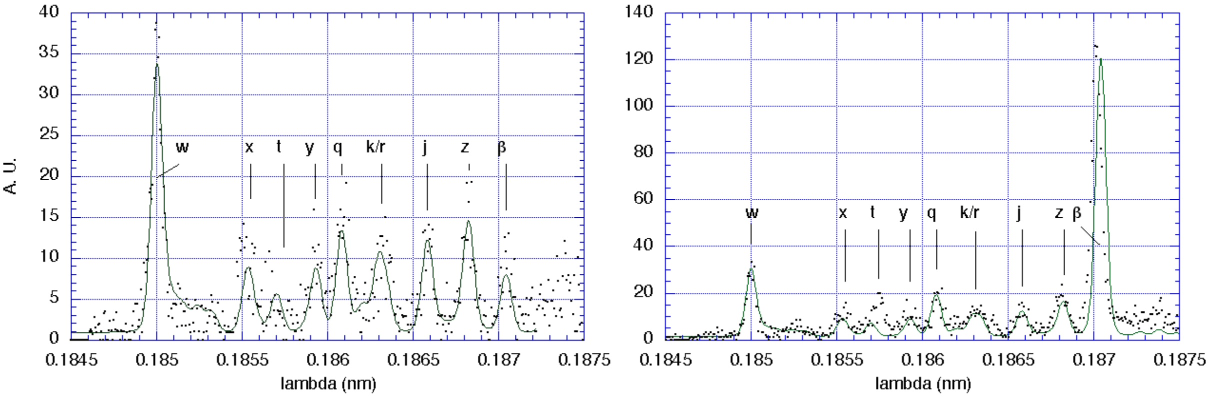

Fig. 3: He-like spectrum before (shots 20327, left) and after (shots 20543, right) a boronization. Line: simulation with the atomic data from [1], [3] and [4] with parameters T_i=1.1 keV, T_e=2.2 keV, $n_{H\text{-like}}$=0.02, $n_{He\text{-like}}$=1, $n_{Li\text{-like}}$=0.6, $n_{Be\text{-like}}$=0.35 (left) and parameters T_i=0.9 keV, T_e=2.1 keV, $n_{H\text{-like}}$=0.03, $n_{He\text{-like}}$=1, $n_{Li\text{-like}}$=1, $n_{Be\text{-like}}$=7 (right)

Conclusion

In the FTU tokamak discharges, the joint analysis of high resolution X-ray spectra, VUV spectra and Langmuir probe measurements showed a different behaviour of the iron ion charge state distribution when the first wall material or the iron source are changed, whereas no effect is expected with the usual impurity transport scenario. The simple (and simplistic) assumptions, usual for tokamaks, concerning diffusion and convection fail in describing the iron impurity behaviour in FTU; the experimental results indicate that a more complex dynamics of the interaction among core iron ionization level, iron production, influence of other impurities and SOL plasma parameters should be considered in order to describe the intrinsic impurity particle transport.

References

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