First detachment studies on COMPASS tokamak using nitrogen seeding

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Introduction

Partial detachment is considered to be a mandatory regime for ITER and next-step devices, as it allows to dissipate a substantial part of the heat flux carried by the plasma particles and significantly reduce the heat fluxes deposited on the divertor target tiles. Despite that, most studies of power deposition in contemporary tokamaks were performed in attached plasmas[1]. Detached regimes tend to be more difficult to access and diagnose - for example the infrared thermography (the principal diagnostics for such studies) suffers from interference caused by increased bremsstrahlung in the infrared spectrum in detached plasmas.

COMPASS has a combination of a relatively short connection length to the target and an open divertor geometry, which was considered unfavourable for detachment access. In order to facilitate access to partially detached regime of operation, impurity seeding in the divertor region can be employed. In this paper, we report on first results from the impurity seeding experiments, which were performed in Ohmic plasmas.

Nitrogen injection

Nitrogen was introduced into the vessel through a pre-programmed piezzo valve in a single toroidal location at the inner divertor leg (R = 469 mm). The valve was connected to a gas reservoir with gas pressure of 2.1 bar. In the first test, the valve was opened on 100% (which corresponds to flow 1.21×10^{21} particles per second) during 10 ms in a low-power Ohmic discharge #13700 (I_p = 200 kA, $n_e = 4\times10^{19}$ m^{-3}, B_T = 1.38 T). The injection was monitored by fast visible camera RIS1, which showed a clear formation of an emissive ring in the divertor (see Fig.

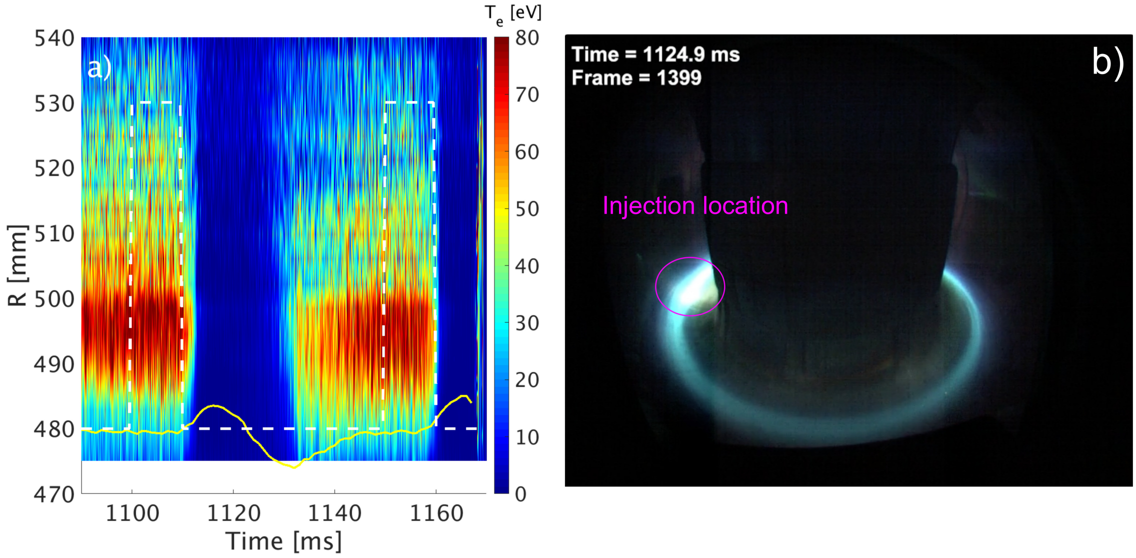

Figure 1: Response to the 10 ms nitrogen injection as seen on divertor probes (A) with the location of the outer strike point indicated by yellow line and valve waveform by white dashed line. Formation of the radiative ring is seen on fast visible camera (B).

1B). An array of Langmuir and Ball-pen divertor probes[3] (dubbed *new divertor probes*) was used to evaluate the effect of nitrogen injection on the target plasma parameters. The response is clearly seen in Fig. 1A, where the radial profiles of electron temperature $T_e = (V_{BPP} - V_{LP}/1.4)$ are plotted. At t=1115 ms (which is approximately 15 ms after start of injection), the target temperature sharply drops from 80 eV to less than 5 eV across the whole outer target and it gradually recovers 40 ms after the valve was closed (t_{stop} =1110 ms).

Following the initial test of injection, nitrogen was injected at varying amount in a series of otherwise identical discharges (with main parameters same as in #13700). The waveform of the gas had two parts: (i) a short 10 ms full opening of the valve, which ensured that the valve was not stuck, followed by (ii) 100 ms injection at varying level of flow at 2.0 (#13729), 3.7 (#13730) and 4.5 (#13731) $\times 10^{20}$ molecules per second (for comparison the deuterium gas puff in the discharge was on average 1.5 $\times 10^{19}$ molecules per second). Fig. 2 shows the evolution of T_e, ion saturation current density j_{sat} and the electron density n_e measured by a set of new divertor probes near the outer strike point (R_{probe} = 484 mm). For comparison, also measurements at the same radial position obtained by an array of 39 Langmuir swept probes (dubbed *old divertor probes*), which were analyzed using the first derivative probe technique[4], is over-plotted.

It can be seen that introduction of nitrogen causes a significant drop of T_e and j_{sat}, where the magnitude of the drop increases with increasing amount of injected gas. For the lowest amount of injected nitrogen, the T_e measured by the new probes exhibits slow quasi-regular oscillations

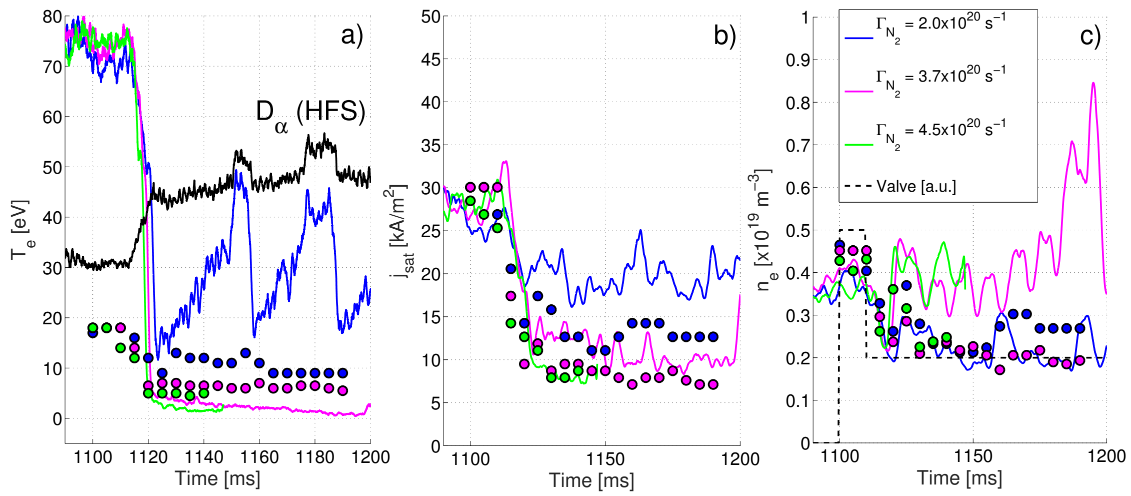

Figure 2: Response to N_2 injection observed by probes at outer strike point - Electron temperature (A), ion saturation current density (B) and electron density (C). Measurements by new probe array plotted as lines, measurements by old probe array by circles.

(also seen on D_α signal, as shown in Fig. 2A), which resemble a behavior seen in the JET divertor [5]. The profiles of j_{sat} measured by the two diagnostics are in good agreement, with differences $< 50\%$. However, the measured electron temperatures are distinctively different. The temperature prior to nitrogen injection differs by a factor of 4x - the new probes are likely to overestimate the T_e as it is higher than the separatrix T_e ($T_{e,sep} \sim 40$ eV) measured by High Resolution Thomson Scattering (HRTS) (see Figure 3A). On the other hand the old probes are unable to capture the slow temperature oscillations at low levels of nitrogen injection (which correlate with HFS D_α signal).

Detachment characterization

Decrease of divertor temperature below 5 eV is one of the indications of detached plasma operation, as well as reduced flow of charged particles to the divertor targets [2]. Low temperature plasma permits formation of considerable neutral pressure in the divertor, which allows the incoming plasma particles to recombine before hitting the divertor tiles. Indeed, the j_{sat} shows a distinct reduction (see Fig. 2B), when nitrogen is injected.

However, the decrease of j_{sat} is only by a factor of three in case of largest injection, which suggests that it is driven mainly by the reduction of divertor temperature, rather than by reduction of the plasma density. Indeed, the density during the second stage of injection measured by the new divertor probes near the outer strike point is practically identical to its value prior to injection (see Fig. 2C). Closer inspection of temperature profiles obtained by HRTS system (see detailed view in Fig. 3) confirms that the plasma is being significantly cooled already inside the

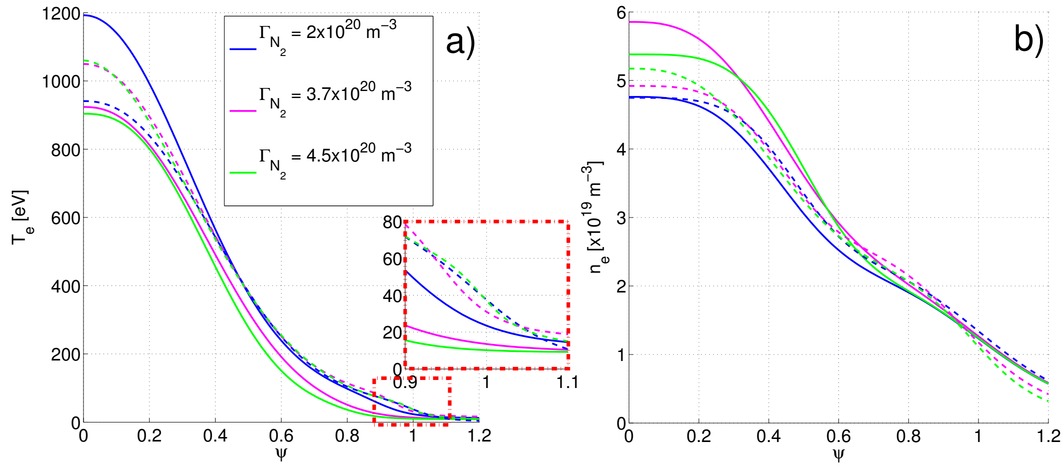

Figure 3: Profiles of electron temperature (A) and electron density (B) observed by Thomson scattering. Dashed line show profiles prior to injection, solid lines during injection (t=1140 ms).

LCFS ($\psi < 1$). In Fig. 3, the dashed lines correspond to profiles prior to injection, while solid lines are during the injection at t=1140 ms.

Conclusions

Nitrogen is usually used to dissipate power in the divertor region on larger tokamaks, which is due to its favourable radiative properties. On COMPASS, however, it can propagate into the confined plasma causing significant cooling in the edge. As a consequence, the electron temperature and ion saturation current density at the outer divertor target diminish, however the presence of significant amount of recombination processes in the divertor was not confirmed. Substantial differences between different divertor probe diagnostics were observed and is currently under investigation.

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