Unraveling the coupling of divertor closure and impurity radiation in the first impurity seeding experiments in the SAS divertor at DIII-D


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The first impurity seeding experiments in the Small Angle Slot (SAS) divertor in DIII-D have been carried out to study the interplay between divertor closure and impurity-induced dissipation. Future reactors will require high divertor radiation by impurity seeding [1, 2] and operation with some degrees of detachment to limit power loads on divertor components. It has been shown in a number of tokamaks [3, 4, 5, 6, 7] that detachment onset can be influenced by variations in divertor target and baffle geometry. At DIII-D the role of divertor closure and target shaping for a highly dissipative divertor is currently being evaluated with the recently installed SAS slot [8, 9]. The SAS includes a number of divertor design features combining a gas-tight slot geometry with a small target angle to bootstrap power and momentum dissipation of recycling neutrals [10] for achieving plasma detachment more compatible with core performance. The SAS slot is located near the main upper, outer divertor of DIII-D and is equipped with a comprehensive set of boundary diagnostics such as Langmuir probes (LPs), divertor Thomson scattering (DTS) system, ultraviolet wavelength spectrometer (DivSPRED), near infrared spectrometer (NIRS), and in-tile pressure gauges (PGs) (fig. 1 left). Experiments were performed in H-mode with $I_p = 1.0$ MA, $B_t = 2$ T with ion $B \times \nabla B$ directed into the SAS (toward the X-point in the upper divertor), and $P_{NBI} = 4.5$ MW and 8MW with related density scans. In order to study the detachment dependence on strike point location, matched discharges with the same set of plasma parameters but with two different strike point locations were considered. In one case the strike point was located at the inner surface, and in the other case at the outer corner of the SAS (fig. 1 right). Impurities were injected at both the inner and outer corners of the SAS from two independent gas valves located at the same poloidal location but
at different toroidal locations (fig. 1 right) with the impurity flow split evenly between the two valves.

Figure 2 shows time traces of input power (fig. 2a), radiated power (fig. 2 b), electron density (fig. 2c), nitrogen puff (fig. 2d), and neutral pressure (fig. 2 e-f) for a discharge in which N$_2$ is injected at t=3.0 sec in the plasma from the corner valves and then its level is further raised at t=4.0 sec to invoke full detachment. As expected, the radiated power increases with N$_2$, while the discharge keeps a very stable behavior throughout. As soon as nitrogen is injected, a significant neutral pressure rise (p$_0$ > 10 mtorr), which has been shown to correlate with the detachment onset [10], is detected by both the pressure gauges, hence in two different locations in the SAS. Langmuir probes measurements show the roll-over of the J$_{sat}$ profile at the outer target and T$_e$ of only few eV during the highest N$_2$ level. The eroding thermocouples detect a roll-over in the surface temperature suggesting a reduction of the heat flux. A clear reduction in T$_e$ with N$_2$ seeding is also detected by the different DTS channels which show a clear drop starting at t= 4.0 sec with T$_e$ ~ 0.5 eV (fig. 2 right). Spectra from the DivSPRED shows the bright resonance N$_2$ emission lines, the widening of the Lyman alpha and the appearance of the Lyman beta all features which indicate that T$_e$ is below 2 eV. The NIRS spectrometer registers the appearance of the Paschen series of D lines which also coincides with T$_e$ < 2 eV. The simultaneous observation of plasma cooling on the multiple diagnostics listed above suggest that the detachment front is not a highly local phenomenon but it rather extends through the entire slot. Interestingly, in matched nitrogen discharges with different strike point locations, the detachment onset requires different N$_2$ levels highlighting an important dependence of detachment on strike point location in the SAS as demonstrated, among other diagnostics, by
LPs measurements (fig. 3). When the strike point is located at the outer corner of the SAS (red), the $J_{\text{sat}}$ (fig. 3 left) and $T_e$ (fig. 3 right) drops occur only in correspondence of the highest N$_2$ puff rate (N$_2$ flow rate = 5 TorrL/s from each valve for a total flow rate of 10 TorrL/s), but when the strike point is located at the inboard side (blue), $J_{\text{sat}}$ and $T_e$ react promptly to even the lower N$_2$ rate (N$_2$ flow rate = 2.5 TorrL/s from each valve for a total flow rate of 5 TorrL/s).

![Figure 2. Left: Time traces of injected power (a), radiated power (b), electron density (c), nitrogen puff rate (d), neutral pressure (e-f). The dashed lines mark the time windows with the small N$_2$ puff (3.0-4.0s) and the high N$_2$ puff (4.0-6.0s). Right: Electron temperature from the DTS channels looking into the SAS as shown in fig1.](image)

Such strike point dependence is also confirmed by the different nitrogen content reaching the core as indicated by both the core CER and SPRED measurements.

![Figure 3. Left: Time traces of $J_{\text{sat}}$ (left) and $T_e$ (right) for two matched N2 discharges with different strike point locations.](image)

The two strike point locations considered in these experiments correspond to different wetted target shapes and thus different distribution for the recycling source. When the strike point is located on the inboard side, the recycled ion flux is directed towards the outer SAS surface where it is reflected back to the strike point to enhance recycling. The results obtained with these two different strike points demonstrate that target shaping can affect dissipation by
redistributing the recycling source [10, 12] and hence affecting divertor detachment. In addition to N₂, the effect of Ne seeding in the SAS was also investigated. The neon discharge was designed such to match the input parameters, \( n_e \) and total \( P_{\text{rad}} \) from a selected N₂ discharge. Comparison of these two matched discharges reveals that while N₂ seeding does not significantly impact the core, Ne leads to higher pressure gradients than the unseeded cases as shown in fig. 4. A detailed pedestal and divertor analysis for the N₂ and Ne matched cases is ongoing. In conclusion, the first impurity seeding experiments in the new SAS divertor at DIII-D have shown the simultaneous observation of detachment on the entire boundary diagnostic suite viewing the SAS with stable discharge behavior and unchanged or improved pedestal performance. The dependence of detachment on strike point location suggests that the neutral and impurity distribution in the divertor can be controlled through variations in strike point location in a fixed baffle structure with important consequences for divertor dissipation.

**References**

12. B.M. Covele et al. to be submitted to Nucl. Fusion (2019)

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