IMPACT OF ION TEMPERATURE ON DETACHED PLASMA IN GAMMA 10/PDX DIVERTOR SIMULATION PLASMA

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Utilizing the high-temperature feature of the largest tandem mirror device, GAMMA 10/PDX, we have investigated the dependence of ion temperature on the processes of detached plasma formation by varying RF heating power. In the detached plasma formation experiment that leads to hydrogen molecular activated recombination (MAR) [1], we compared the differences in the detached plasma in three different diamagnetism (DM) of the central cell in the range of 0.1 to 0.5 x 10^{-4} Wb. The spatiotemporal distribution of the Balmer H_α and H_β emission intensity ratios observed by a high-speed camera with image quadrant optics and the measurements of the electrostatic probe array on the target plate show that the recombination region is shifted downstream for higher DM plasmas.

Plasma-gas interactions involving high-temperature ions and electrons are critical for managing heat and particle flux to the plasma-facing components of magnetic fusion devices, including ITER and a DEMO reactor. Specifically, the effect of ion temperature on the formation of detached plasma remains unclear. We have explored the fundamental processes of high-temperature plasma during detached plasma operations in the divertor simulation experimental module (D-module), utilizing a variable angle V-shaped target plate at the end-loss region of the tandem mirror plasma device GAMMA 10/PDX [2-4]. The heated plasma from the central, anchor, and plug/barrier cells flows through magnetic mirrors into the open field region in the device's end region. The plasma in these end regions, called "end loss plasma," maintains high ion and electron temperatures of several hundred eV and several tens eV, respectively. However, the role of ion temperature (T_i) in the detached plasma formation process still requires clarification. Variations stemming from T_i changes are believed to involve a population change of excited hydrogen atoms [5] and a change in the hydrogen molecular excited state. These changes could have a possible effect on MAR and the spatial profile of detached plasma. The recombination region may shift downstream if neutral gas pressure remains constant and parallel ion energy changes. Our research strategy leveraged the high-temperature characteristics of GAMMA 10/PDX, allowing us to examine the influence of ion temperature on detached plasma formation processes. This is achieved by systematically varying the RF heating power, the effects of which are indexed by the degree of diamagnetism. This paper will aim to clarify the influence of ion temperature on detached plasma with the spatiotemporal changes in the recombination region.

We observed plasma detachment caused by gas seeding in the Divertor simulation experimental module (D-module; see Fig. 1), which is installed in the end region of GAMMA 10/PDX. Three different DM plasmas can be altered by ICRF heating applied at the central cell, as shown in Fig. 2. The V-shaped target plate, equipped with a Langmuir probe array #1-5, received end-loss plasma in an open magnetic field. The aperture angle of the target plate was set at 15 degrees (Note: 45 degrees in a normal experiment). Hydrogen gas was injected through the gas line between probes #1 and #2 on the upper target plate 130 ms after the master trigger. The pressure inside the D-module increases to about 1 Pa. In this study, a high-speed camera (ACS-3) with 4-branch optics, known as the "Arbaa prism [6]," was utilized to observe emissions during detached plasma operations. This system allows the spatial distribution of H_α and H_β to be captured simultaneously. Since the emission ratio of H_α to H_β increases with the dissociative attachment process in MAR, this ratio serves as a reliable indicator of MAR under our experimental conditions [3].

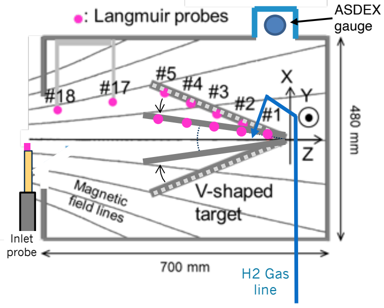

Fig. 1. Schematic of the experimental setup in the divertor simulation experimental module of GAMMA 10/PDX.

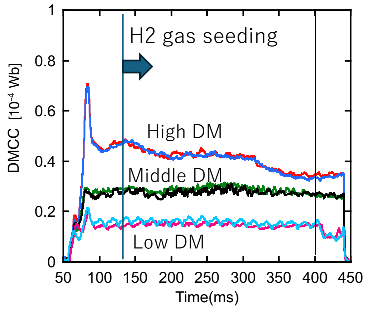

Fig. 2. Variation of DM over time in the plasma discharge being observed.

Figure 3 shows spatiotemporal changes in the intensity ratio of Balmer emissions $I_{H\alpha}$ / $I_{H\beta}$ during the formation of detached plasma. The lower DM indicates that the recombination region is upstream and more extensive, while the higher DM shows that the MAR region is pushed downstream. Downstream from the region where the ratio is high, the ion flux is believed to decrease due to MAR. Indeed, as shown in Fig. 4, data from the target plate probe show that the ion flux upstream rises with gas injection and then remains almost constant, while the ion flux diminishes for the probe located downstream of the MAR region. The electron temperature across all DMs was 20-25 eV before gas injection, and following gas injection, the electron temperature decreased over time (with increasing gas pressure) and fell to approximately 5 eV at 350-400 ms. This trend appears to be nearly independent of the probe's position. In the high DM scenario, the flux increase due to gas injection is significant, yet the flux for the downstream probe #1 reduces to a level comparable to that in the low DM scenario. This is believed to stem from greater momentum loss between upstream and downstream compared to the low DM case. The rates of reduction in flux and electron density are similar, and there is little variation in electron temperature between the probes. Therefore, recombination is thought to contribute to this momentum loss. The MAR region is narrower in the higher DM scenario, but the amount of MAR may be higher. A steep rise in flux and a decline in electron temperature were observed from 150 to 250 ms immediately after gas injection. The changes were more pronounced the higher the DM. Since such a rapid change is not seen further upstream in the divertor simulation region, it is possible that this phenomenon is unique to the interaction between high DM (high ion temperature) plasma and gas and requires detailed analysis. These experimental results are now also being compared with the results of the Collisional-Radiative model analysis that takes ion temperature into account.

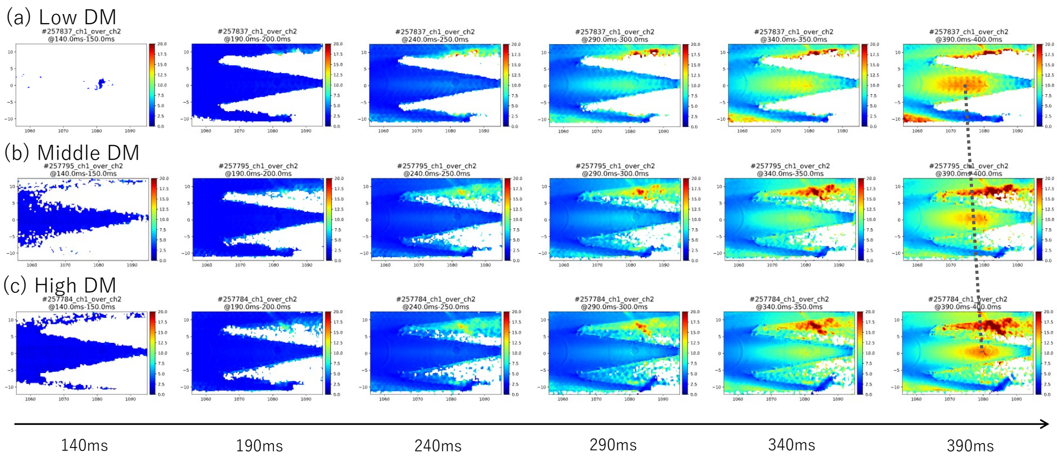

Fig. 3. Spatiotemporal change in $I_{H\alpha}$ / $I_{H\beta}$ in the case of (a) Low DM, (b) Middle DM, and (c) High DM.

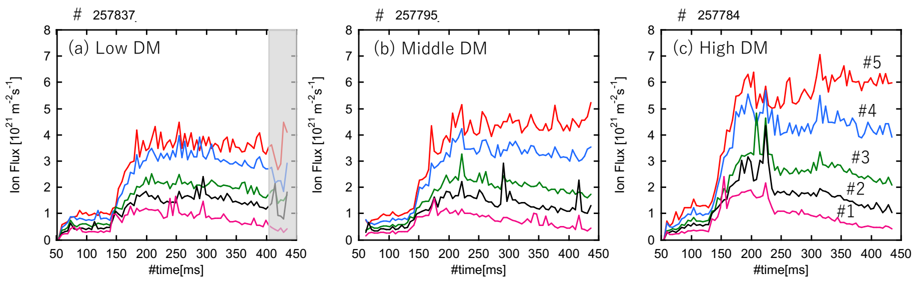

Fig. 4. Time variation of ion flux measured by the electrostatic probe array on the target plate during gas injection. (a) Low DM, (b) Middle DM, and (c) High DM.

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