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

N. EZUMI
Plasma Research Center, University of Tsukuba
Tsukuba, Japan
Email: ezumi@prc.tsukuba.ac.jp

T. OKAMOTO, S. TAKAHASHI, K. KOUNO, C. MASUYA, H. SENBOKU, S. TOGO, M. HIRATA, J. KOHAGURA, M. YOSHIKAWA, M. SAKAMOTO
Plasma Research Center, University of Tsukuba
Tsukuba, Japan

A. OKAMOTO
Nagoya University
Nagoya, Japan

Abstract

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

1. INTRODUCTION

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 of eV, respectively. However, the role of ion temperature (T_i) in the formation of detached plasma 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 excited state of the hydrogen molecule. 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, enabling us to examine the influence of ion temperature on the formation of detached plasma. This is achieved by systematically varying the RF heating power, the effects of which are indexed by the degree of diamagnetism. This paper aims to clarify the influence of ion temperature on detached plasma, focusing on the spatiotemporal changes in the recombination region.

2. SETUP OF THE DIVERTOR SIMULATION EXPERIMENT

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 enables the simultaneous capture of the spatial distribution of H_α and H_β. 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].

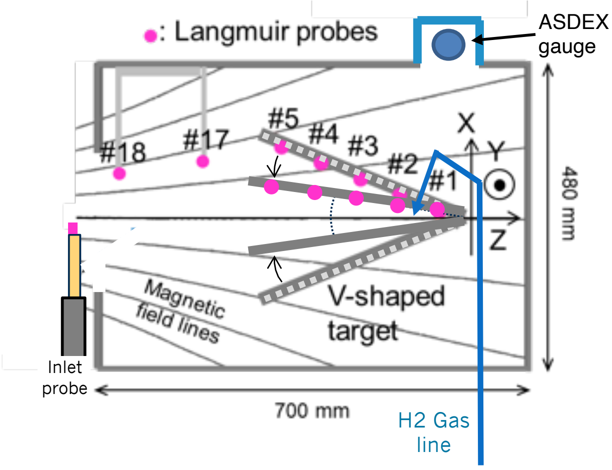

Fig. 1. Schematic of the experimental setup in the divertor simulation experimental module of GAMMA 10/PDX.

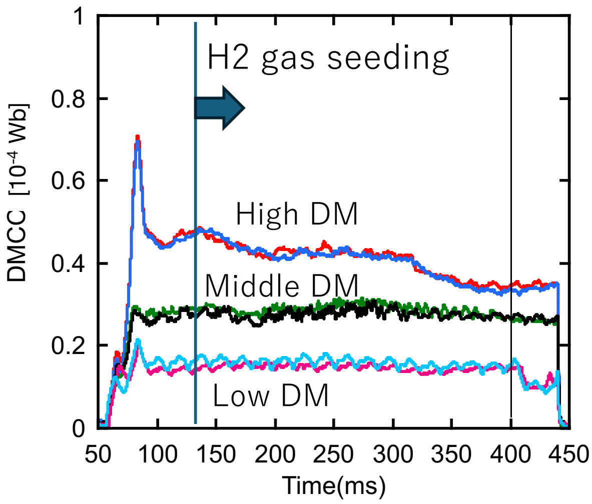

Fig. 2. Variation of DM over time in the plasma discharge being observed.

3. EXPERIMENTAL RESULTS AND DISCUSSION

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 indicate that the ion flux upstream increases with gas injection and then remains nearly constant, while the ion flux is reduced for the probe located downstream of the MAR region. The electron temperature across all DMs was 20-25 eV before gas injection. After gas was injected, the electron temperature decreased over time (as gas pressure increased) and dropped to about 5 eV at 350-400 ms. This pattern seems to be nearly unaffected by the probe's position. In the high DM scenario, the increase in flux due to gas injection is significant, but the flux at downstream probe #1 drops to a level similar to that in the low DM scenario. This is likely caused by 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 believed to contribute to this loss of momentum. The MAR region is narrower in the higher DM scenario, but the MAR amount may be larger. A sharp increase in flux and a decrease in electron temperature were observed from 150 to 250 ms immediately after gas injection. These changes were more pronounced at higher DM levels. Since such rapid changes are not seen further upstream in the divertor simulation region, this phenomenon may be 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 findings of the Collisional-Radiative model analysis that considers ion temperature.

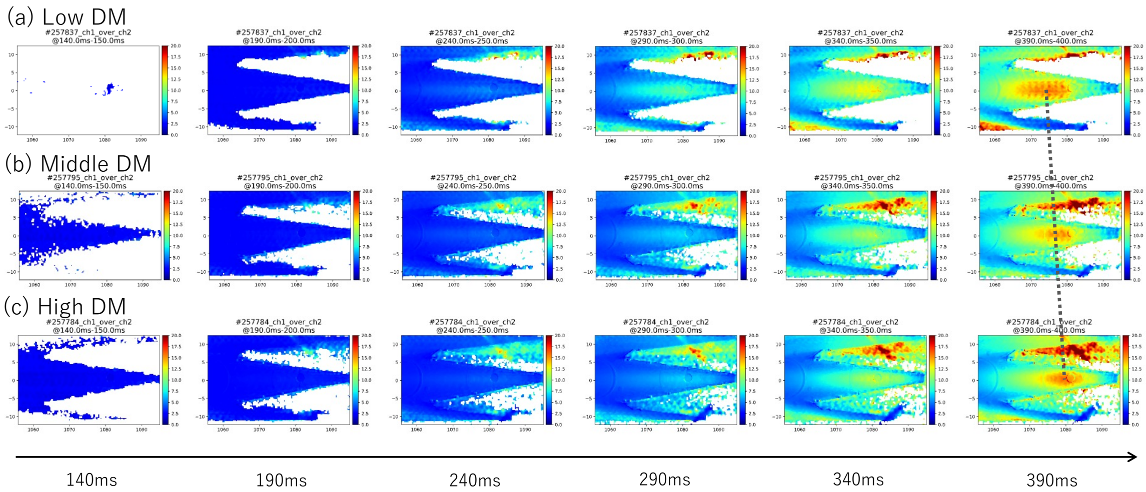

Fig. 3. Spatiotemporal change in $I_{H\alpha}$ / $I_{H\beta}$ in the case of (a) Low DM, (b) Middle DM, and (c) High DM.

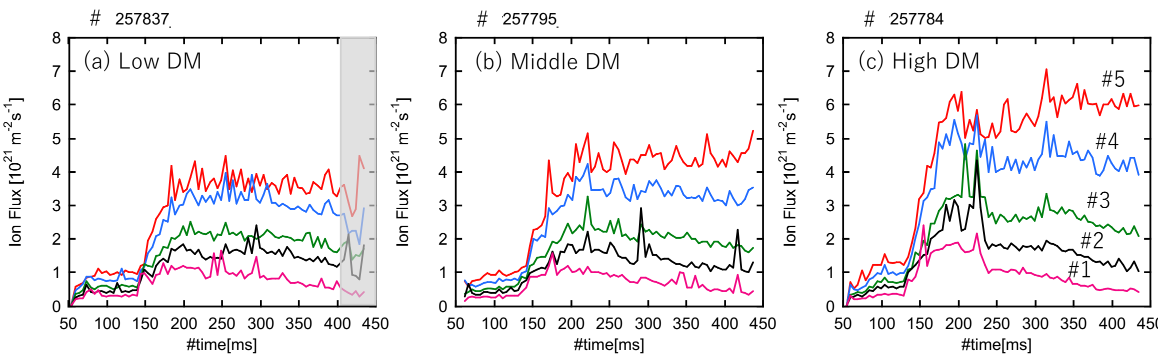

Fig. 4. Time variation of ion flux measured by the electrostatic probe array on the target plate during gas injection. (a) Low DM, (b) Middle DM, and (c) High DM.

4. SUMMARY

We investigated the changes in the spatiotemporal distribution of detached plasma using GAMMA 10/PDX plasma with an ion temperature similar to that of the plasma flowing into the diverter. This was done by varying the ICRF heating power in the central region and examining its effects on the process of detached plasma formation, particularly regarding MAR involving hydrogen molecules. Our results, which included measurements of the hydrogen Balmer line intensity ratio (H_α/H_β), ion flux, electron temperature, and electron density obtained from an electrostatic probe array installed on the target plate, indicated that the recombination region shifts downstream as the ion temperature increases. This shift is associated with plasma exhibiting higher diamagnetic susceptibility.

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