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Detached plasma control by H^-/D^- negative ion in divertor simulator

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We have developed a way to stably maintain a detached plasma based on feedback control of the negative ion density of hydrogen (H^-) or deuterium ions (D^-) in the linear divertor plasma simulator, TPD-SheetIV. The detached plasma is steadily maintained in the region of the target plate by varying G_{Div} so as to maximize the value of n_{H^-}, n_{D^-} and keep P_{Div} constant.

I. Introduction

Volumetric recombination in detached plasmas is expected to play an essential role in strongly reducing the heat flux to the divertor plates[1,2]. Stable maintenance of a detached plasma, then, is a key issue associated with reducing the heat flux on to the divertor plates. The most attractive feature of the divertors has been the expected capability to create a dense and cold detached plasma with low neutral back flow to the main plasma. However, the detached plasma is a very complex phenomenon with atomic and molecular collision processes. It is difficult to control the detached plasmas by commonly used diagnostics, such as heat loads, Langmuir probes, etc.

In tokamaks with a divertor configuration, Electron-Ion Recombination (EIR) has been clearly identified in detached plasmas by measurements of high-n Balmer series spectral lines [3]. On the other hand, another recombination process associated with molecular reactions, such as the Molecular Assisted Recombination (MAR) involving a vibrationally-excited hydrogen molecule $H_2(v)$, has been emphasized in theoretical investigation and modeling [4,5]. Recently, we have presented the experimental observation of the spatial structure of MAR in the detached hydrogen plasma at the periphery of the plasma in the linear divertor plasma simulator, TPD-SheetIV[6,7]. At the same time, it is observed that the mutual neutralization in MAR via H^- ion formation, which is produced by dissociative electron attachment to $H_2(v)$, occurs in the periphery of the plasma where cold electrons (~1 eV) are found. In other words, negative ions play an important role in the mutual neutralization of

MAR, providing a new method of controlling detached plasmas.

In this paper, we have developed a method to control a detached plasma based on utilizing H^- or D^- ions which are formed as part of the MAR mutual neutralization process occurring in the periphery of the plasma on the linear divertor plasma simulator, TPD-SheetIV.

II. Experimental apparatus and method

The experiment was performed in the linear divertor plasma simulator TPD-SheetIV. Ten rectangular magnetic coils formed a uniform magnetic field of 0.08 T in the experimental region. The hydrogen or deuterium plasma was generated at a hydrogen gas flow of 50-70 sccm, with a discharge current of 100 A. The neutral pressure P_{div} in the divertor test region was controlled between 0.1 and 20 mtorr with a secondary gas feed. The heat load on the target plate Q was measured by a calorimeter. A cylindrical probe made of tungsten (0.4ϕ x 2 cm) was used to measure the spatial profiles of the negative hydrogen ion density by a probe-assisted laser photodetachment method[8]. At a repetition rate of 50 Hz, the Nd-YAG laser had an energy per pulse of 160 mJ at its fundamental wavelength of 1064 nm. A combination of spherical and cylindrical optics was used to produce a laser sheet having typical dimensions of 4.0 cm in width and 1.0 cm in thickness at the vacuum chamber. The value of n_{H}^{-} was determined from the photodetached electron current measured with a cylindrical probe.

The concept of control of a detached plasma using negative ions can be illustrated through the following steps; (1) determine the minimum and maximum basic parameters (gas pressure P_{div}, heat load Q) required to control the MAR, (2) control the secondary gas-flow rate G_{div} rapidly so as to maximize the value of the negative ion density n_{H}^{-}, (3) carry out a real time feedback control of n_{H}^{-} in order to maintain a steadily detached plasma in the neighborhood of the target plate.

III. Experimental results

Figure 1 show the dependence of the averaged heat load Q, the density of the negative hydrogen ion n_{H}^{-} on hydrogen gas pressure P_{div} with increasing the discharge current I_d. The

H^- ions of the periphery are localized in a circumferential region of about 10-20 mm distance from the center in the direction of thickness of the sheet plasma. Using a small amount of secondary hydrogen gas puffing into a hydrogen plasma, n_{H^-} has a maximum value of $3.0\text{x}10^{17}$ m^{-3} at P_{div} 4.0 mtorr. By defining Q_{att} as the heat load in attached plasma and Q_{pm} as the heat load at the maximum negative ion density for a particular pressure n_{H^-max}, we can express the reduction of the heat load as the ratio of Q_{att} to Q_{pm}, that is, $\Delta Q = Q_{pm} / Q_{att}$.

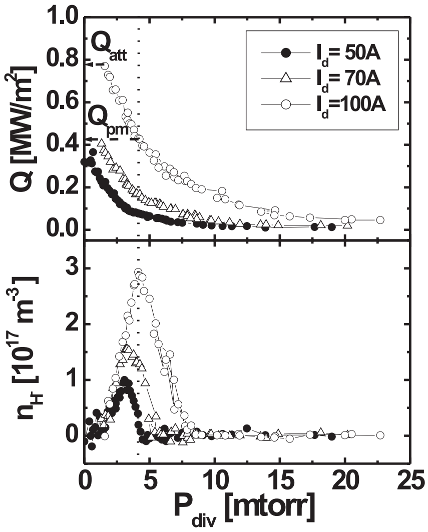

Fig.1 The variations of n_{H^-max} and the heat load Q with the gas pressure P_{div}.

The variations of n_{H^-max}, n_{D^-max} heat load Q_{att}, Q_{pm}, and the head load radio ΔQ with the discharge current I_d is shown in Figs. 2 and 3. In the hydrogen plasma, as I_d changes from 50 to 100 A, Q_{att} increases from 0.32 to 1.1 MW/m^2. At the same time, n_{H^-max} increases linearly from 1.0 to 3.0 $\text{x}10^{17}$ m^{-3} and Q_{pm} increases from 0.1 to 0.4 MW/m^2. Therefore, ΔQ remains nearly constant at around 30-40 % with increasing heat load to the target. In the deuterium hydrogen plasma, Q_{att} increases from 0.1 to 0.58 MW/m^2 as I_d changes from 50 to 100 A. However, n_{D^-max} is nearly constant value of ~

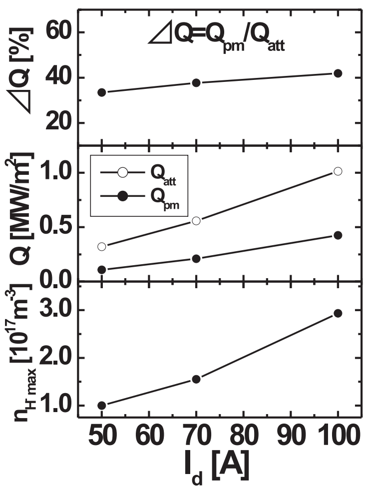

Fig.2 The variations of n_{H^-max}, heat loac Q_{att}, Q_{pm}, and the heat load ratio ΔQ witl the discharge current I_d.

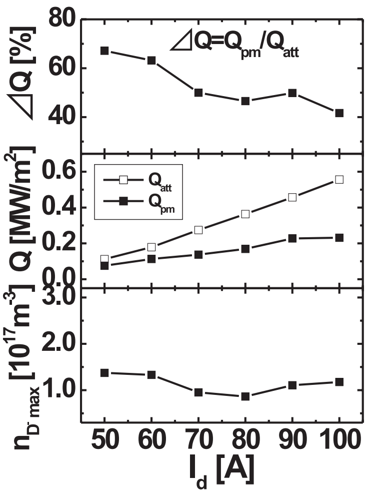

Fig.3 The variations of n_{D^-max}, heat load Q_{att}, Q_{pm}, and the heat load ratio ΔQ with the discharge current I_d.

1.3×10^{17} m^{-3}. On the other hand, ΔQ gradually decreases from 60 to 40 % with increasing heat load to the target. These results indicate that this new way of controlling a detached plasma, based on the feedback control of the negative hydrogen ion density in the high density part of the plasma, is promising.

IV. Summary

We have developed a new way to stably maintain a detached plasma based on the feedback on the level of H^- or D^- which is produced in the course of the mutual neutralization of MAR in the periphery of the plasma on the linear divertor plasma simulator, TPD-SheetIV. The new system has achieved the goal of reducing the target heat flux while simultaneously minimizing the amount of gas puffed in a detached plasma.

Acknowledgments

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