*29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. **26B**, P-3.216 (2002)*

Detached Plasma Control by Negative Ion in Divertor Simulator

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I. Introduction

The reduction of the plasma heat flux to plasma-facing components, that is, divertor plates, is one of the important issues for in the fusion reactors. The control of the detached plasma, then, is thought to be a key issue in order to reduce the heat flux at divertor plates. In tokamaks with a divertor configuration, continuum and series of visible line emissions from highly excited levels due to the radiative and three-body recombination(EIR) were clearly observed in detached plasma[1]. On the other hand, another recombination process associated with molecular reactions, such as the molecular activated recombination (MAR) involving a vibrationally excited hydrogen molecule, has been emphasized in theoretical investigation and modeling [2-4]. There are two main paths for MAR: (1) $H_2(v)$ + e=> H^- + H followed by H^- + H^+ =>H + H(n=3) (mutual neutralization), and (2) $H_2(v)$ + A^+ => $(AH)^+$ + H followed by $(AH)^+$ + e => A + H (dissociative recombination) , where A^+(A) is a hydrogen or an impurity ion (atom) existing in divertor plasma. The MAR is expected to enhance the reduction of ion particle flux, and to modify the detached plasmas because the rate coefficient of MAR is much greater than that of EIR at relatively high electron temperature above several eV. Especially, it was noted from the theoretical consideration that the formation of negative ions due to the successive breakup of molecules might take place new plasma recombination under certain conditions [5]. In other words, the negative ion plays an important role in the mutual neutralization of MAR [6,7], providing a new method of controlling detached plasma.

We have developed a new way to control detachment plasma based on the negative ions formation of hydrogen atom in the linear divertor plasma simulator, TPDSHEET–IV (Test Plasma produced by Directed current for SHEET plasma).

II. Experimental apparatus and method

The experiment was performed in the linear divertor plasma simulator

TPDSHEET–IV as shown in Fig.1 [8,9]. The sheet plasma was terminated by the electrically floated and water-cooled target plate, which was made of stainless steel at the axial position of z = 0.7 m from the discharge anode electrode. The hydrogen plasma were generated with the hydrogen gas flow of 70 sccm at the discharge current of 50 A. The neutral gas pressure P_{Div} in the divertor test region was able to be changed from 0.1 to 20 mtorr by feeding a secondary gas.

A cylindrical probe made of tungsten (ϕ 0.4 × 2 cm) and the laser sheets was used to measure the spatial profile of the negative ion of the hydrogen atom H^- by a laser photo-detachment method [10]. The maximum power of fundamental (1064 nm) radiation of the laser was 120 mJ at 50Hz. A combination of spherical and cylindrical optics were used to produce a laser sheet having typical dimensions of 4.0cm × 1.0cm at the vacuum chamber. The negative ion density was determined from the photodetached electron current. The Balmer spectra of visible light emission from hydrogen atoms were detected at the axial position of 3 cm apart from the target plate. The brightness of the Balmer series, such as the 5-3 (H_γ), is directly related to the recombination rate of EIR. Therefore the ratio of the H_γ to 3-2 (H_α) line intensities can be used as EIR indicator[1]. The heat flux onto the target plate W was measured with the calorimetric method.

The concept of control of detached plasma by negative ion can be shown in as following step; a)to measure the experimental data related to the basic parameters (gas pressure P_{Div}, heat load W) in order to determine a threshold values of upper limit, b)to control a rotated valve so quickly as to keep the maximum value of the negative on density, c)to carry out a real time feedback control the

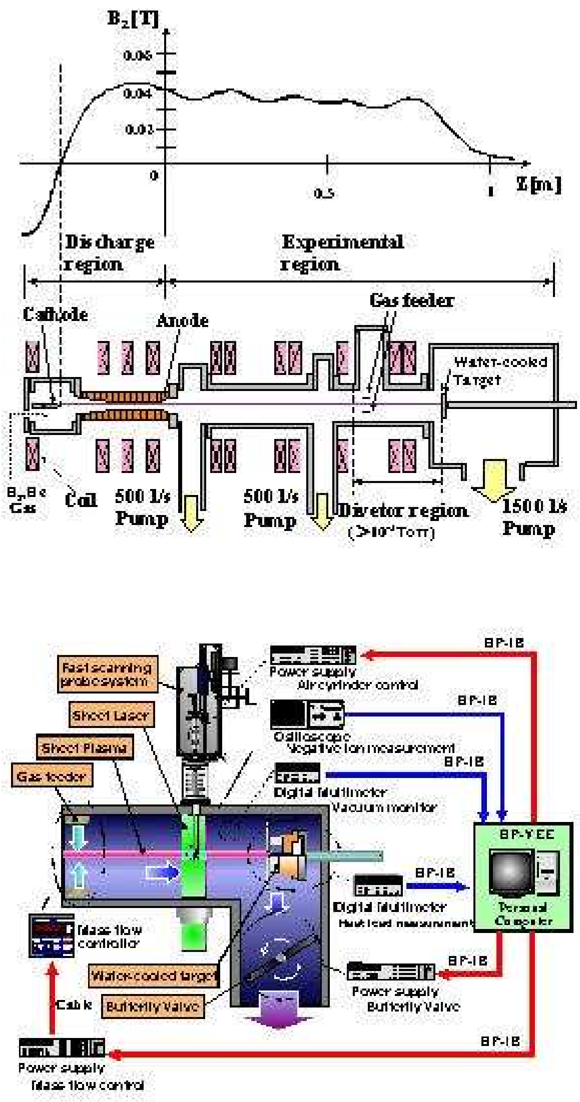

Fig.1 Schematic diagram of TPDSHEET-IV and measuring and control system.

constant in order to maintain the steadily detached plasma in the neighborhood of the target plate.

III. Experimental results

Figure 2 shows the dependence of W to the target plate, the hydrogen Balmer spectrum ratio H_γ / H_α of visible light emission and the maximum value in the thickness profile of the negative ion density of hydrogen atom H^-_{max} on hydrogen neutral gas pressure P_{Div}. The negative ion is localized in the outer region where cold electrons come from the circumference of the plasma exist. At a small amount of secondary hydrogen gas puffing into a hydrogen plasma H^-_{max} have a maximum value of 1.2×10^{17} m^{-3} until P_{Div} ~ 3.5 mtorr. With an increase in P_{Div}, the value of W is found to decrease rapidly, being an less than 30% of the initial value until P_{Div} ~ 3.5 mtorr, while the hydrogen Balmer spectrum ratio H_γ / H_α of visible emission remains to be constant. After P_{Div} ~ 6 mtorr, H^-_{max} disappears and visible light emission strongly very bright visible light emissions of the Balmer spectrum ratio H_γ / H_α were observed in front of the target plate. The photon ratio H_γ / H_α rapid increases above P_{Div} ~ 6 mtorr. At the same time, the intensities of the hydrogen Balmer series from n=7 to 16 due to the EIR were observed in front of the target (full detachment region). It is found that the recombination with negative ion is the only process allowing the reduction of the heat flux onto the target without strong radiation loss of EIR.

Figure 3 shows the typical

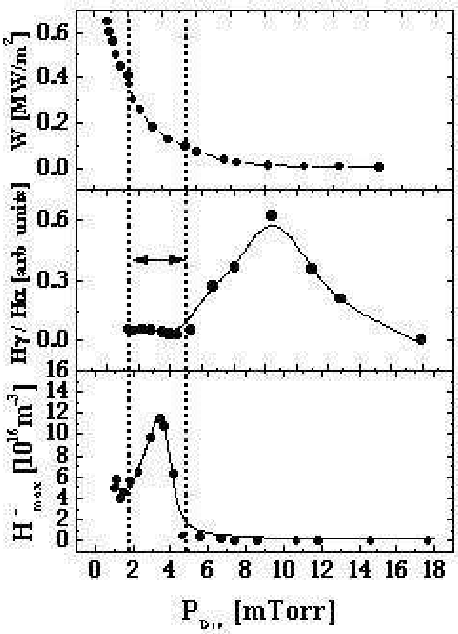

Fig.2 The dependence of W, H_γ / H_α and H^-_{max} on hydrogen gas pressure P_{Div}.

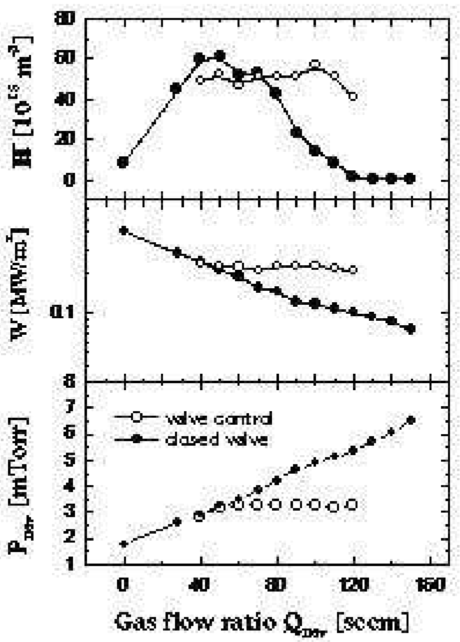

Fig.3 Typical characteristics of P_{Div}, W and H^- on the gas flow ratio Q_{Div}.

characteristics of the neutral gas pressure P_{Div}, heat load W and the negative ion density H^- on the gas flow ratio of the secondary hydrogen gas Q_{Div}. The solid circle is for feedback control of the neutral gas pressure at closed valve and the open circle is for the feedback control of the neutral gas pressure by rotated valve. Without the neutral gas pressure by rotated valve, the density of H^- in the circumference of the plasma increased rapidly and the heat load onto the target plate is reduced with increasing the secondary hydrogen gas puffing. The detached plasma is maintained steadily in the neighborhood of the target plate by the control of rotated valve so quickly as to keep the maximum value of the negative ion density and the constant neutral gas pressure, while the radiative and three-body recombination processes were disappeared. The new system has permitted the establishment of both a reduction of heat flux and the minimum amount of gas flow ratio in detached plasma.

IV. Summary

We have developed a new way to control detachment plasma based on the negative ions formation of hydrogen atom in the linear divertor plasma simulator, TPDSHEET–IV (Test Plasma produced by Directed current for SHEET plasma). It is found from the experiment that the detached plasma is maintained steadily in the neighborhood of the target plate under the feedback control of the neutral gas pressure by the rotated valve so quickly as to keep the constant of the maximum value of the negative ion density and the constant neutral pressure. The new system has permitted the establishment of both a reduction of heat flux and the minimum amount of gas puff in detached plasma.

Acknowledgments

This work is part of a program supported by the LHD Joint Project, the National Institute for Fusion Science.

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