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Influence of the negative ion on detached plasma in the sheet plasma

Akira Tonegawa, Isao Shirota, Kenichi Yoshida, Kazutaka Kawamura[*], Kazuo Takayama[*], Tsuguhiro Watanabe[**] and Nobuyoshi Ohyabu[**]

Department of Physics, School of Science, Tokai University
1117 Kitakaname, Hiratsuka, Kanagawa, 259-1292 Japan.
[*]Research Institute of Science and Technology, Tokai University
1117 Kitakaname, Hiratsuka, Kanagawa, 259-1292 Japan.
[**]National Institute for Fusion Science, Toki, Gifu, 509-5292 Japan.

Abstract

We have performed the experiments of the detached hydrogen or helium plasma associated with the molecular activated recombination (MAR) in a linear divertor plasma simulator. The reduction of the heat load to the target plate was clearly observed in hydrogen or helium plasma with the hydrogen or helium gas puff. Measurement of the negative ion density of hydrogen atom observed in the detached hydrogen plasma has been done. These experimental results suggest that the plasma recombination process comes from the negative ion of hydrogen atom.

1. Introduction

The target divertor requires the redistribution of heat load at a surface based on radiation and collisions with neutral particles. It is important to play a rule of the negative ion in the process of the molecular activated recombination involving vibrationally excited hydrogen molecule to reduce the energy of the heat flux of the plasma in front of the target.

In particular, a new recombination process associated with excited hydrogen molecule, that is, molecular activated recombination (MAR), was theoretically predicted in divertor plasma conditions [1-4]. This MAR process is described as follows; (1) $H_2(v)$ + e=> H^- + H followed by H^- + A^+ =>H + A (charge exchange recombination), 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 lead to an enhancement of the reduction of ion particle flux, and to modify the structure of detached recombining plasmas because the rate coefficient of MAR is much greater than that of Electron Ion Recombination (EIR) at relatively high electron temperature above 1.0 eV. The experimental results in linear divertor simulator gave the evidence of MAR, showing the reduction of ion flux in hydrogen/helium mixture plasma by S.Takamura et.al. [5]. However, there are no clear experimental investigations on the detached plasmas with MAR due to the negative ion effects.

To investigate the influences of the negative ion on the detached plasma, we have measured the characteristics of the negative ion on the gas target divertor in a high heat flux magnetized sheet plasma device as the linear divertor plasma simulator [6]. The produced sheet plasma has two regions of the hot plasma (7-15eV) in the center region and the cold plasma (1-2eV) in the outer region. Therefore, it is expected that the two-step of the formation of negative ions is considered to be due to dissociative electron attachment of low-energy electrons to highly excited metastable molecular state producing in a high temperature region in the detached plasma.

In this paper, we will show the characteristics of the negative ion density of hydrogen atom, the electron density, electron temperature, and the heat load to the target plate on the hydrogen or helium detached plasmas with the hydrogen or helium gas puff in linear divertor plasma simulator, high heat flux magnetized sheet plasma device.

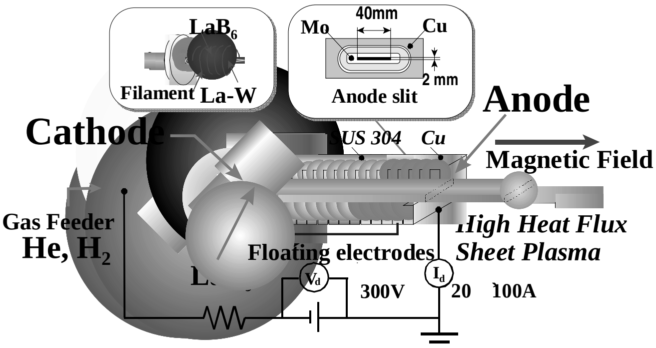


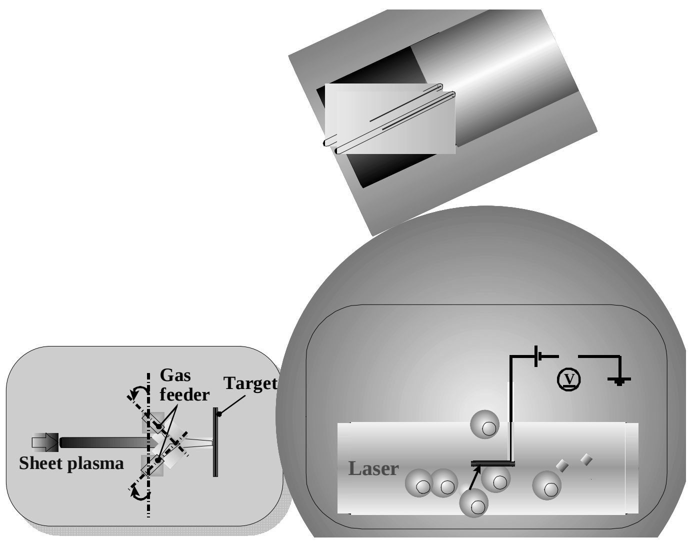
Fig.1 Schematic drawing of the magnetized sheet plasma source.

2. Experimental apparatus

The sheet plasma device is divided into two regions: the sheet plasma source region and the experimental region. The sheet plasma source is composed of a LaB_6 cathode, an anode combined with a floating electrode system having a rectangular hole, through which a discharge path forms, and a rectangular magnetic coil system. The anode slit is 2 mm thick and 40 mm wide as shown in fig.1. The strength of the uniform magnetic field in the experimental region formed by ten rectangular magnetic coils is of 1.0 kG. Since the anode slit is also used to evacuate differentially the two regions of the device, the pressure of neutral gas in the experimental region can be kept low 10^{-4} Torr. Plasma is generated inside the discharge region using a dc discharge between the LaB_6 cathode and the anode electrode at the discharge gas pressure of several Torr. The typical spatial profiles of the electron density in the width and thickness directions of the argon sheet plasma are 40 mm and 10 mm, respectively.

Schematic diagram of the experimental apparatus of high heat flux sheet plasma is shown in Fig.2. The plasma column is terminated by the electrically floated target plate, which is made of stainless steel, with a water cooling at the axial position of z = 1.2 m from the discharge anode electrode. The gas pressure of the experimental region can be varied from less than 1 mTorr to 10 mTorr by introducing the secondary gas to the vacuum vessel.

The electron temperature T_e and electron density N_e at the center of the plasma were measured by rapid scanning Langmuir probe, which was located at 20 cm apart from the target plate. The electron energy distribution function was obtained by differentiating



the I-V curve from the probe experiment. Electron density and temperature were evaluated from the electron energy distribution function. Heat flux onto the target plate W was measured with the calorimetric method.

A cylindrical probe made of tungsten (N 0.4 x 2 cm) is used to measure the spatial profiles of the negative ion density of hydrogen atom by a probe-assisted laser photodetachment method (see Fig.2). The Q-switch YAG laser was driven at a pulse repetition rate of 10 Hz. The maximum power of fundamental (1064 nm) radiation was 65 mJ. The laser width was about 10 ns and the diameter of a laser beam was 3 mm. When the laser beam is injected into the plasma, electrons are detached from negative ions. The detached electrons are collected by the cylindrical probe aligned along the laser beam. The probe is biased at +35 V with respect to the chamber of the earth potential. The probe circuit is used to measure the pulse current by the photodetached electrons and the ordinary electron saturation current by the bulk electrons simultaneously. The currents of the detached electrons are recorded by a digital oscilloscope. The signals are averaged more than 2048 times to reduce the noises. The negative ion density is determined from the photodetached electron current, and the electron saturation current. The spatial profile of the negative ions is measured to move the cylindrical probe with the Laser beam.

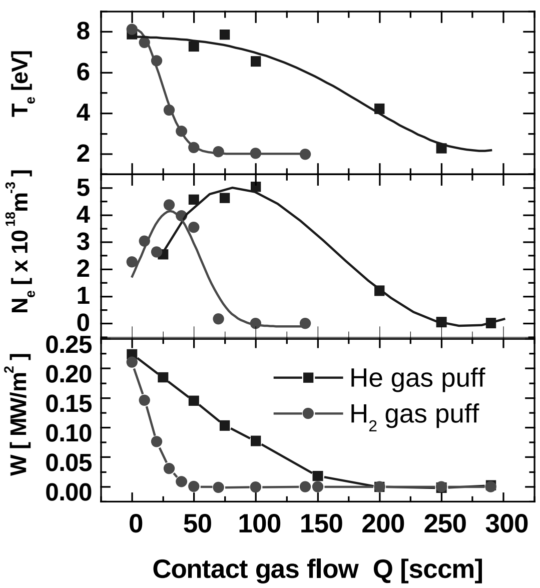


Fig.3 The dependence of the reduction of the ion flux W, the electron density N_e, and the electron temperature T_e in the helium plasma with the helium or hydrogen gas puff.

3.Experimental Results and Discussion

Fig 3 shows the dependence of the reduction of the ion flux W, the electron density N_e, and the electron temperature T_e in the helium plasma with the helium or hydrogen gas puff. The helium plasma are generated with the helium gas flow of 30 sccm at the discharge current of 50 A and the magnetic field of 0.7 kG. In the case of helium gas puff, the value of Ne, Te and W gradually decrease with increasing Q_{He}. On the other hand, in the hydrogen gas puff, these values rapidly decrease with compared to those with the hydrogen gas puff. It indicates that helium detached plasma with hydrogen gas puff leads to an enhancement of reduction of heat flux and to modify the structure of detached recombination plasma.

Fig.4 shows the dependence of the reduction of the ion flux W, the negative ion density of hydrogen atom H^-, the electron density N_e, and the electron temperature Te in the hydrogen and helium plasma with hydrogen gas puff. The hydrogen plasma are generated with the hydrogen gas flow of 100 sccm at the discharge current of 50 A and the magnetic field of 0.7 kG. Negative ions of hydrogen atom are localized in the region of cold electrons (1eV) of the circumference of the sheet plasma. The value of H^- shows the peak value in the radial profiles of the negative ions. When the hydrogen gas is introduced into the both helium and hydrogen plasma, the heat flux W and the electron temperature T_e rapidly decrease (T_e is relatively high value around 3-4 eV). On the other hand, the characteristics of the density of H^-, which is similar to those of the electron density N_e, have a maximum. The density of H^- initially increases with increasing the contact hydrogen gas flow ratio. After that, this value gradually decreases with increasing the gas flow. These experimental results suggest that the plasma recombination process comes from the effect of negative ions of hydrogen atom with MAR.

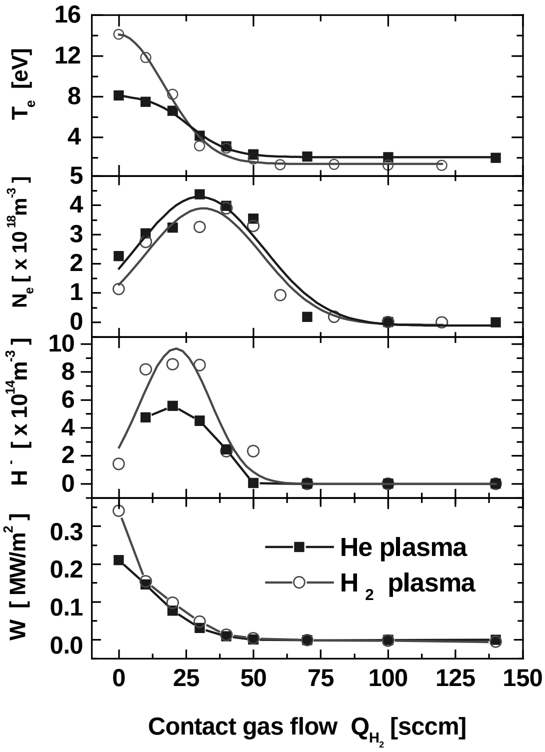


Fig.4 The dependence of the reduction of the ion flux W, the negative ion density of hydrogen atom H^-, the electron density N_e, and the electron temperature Te in the hydrogen and helium plasma with hydrogen gas puff.

Conclusion

We have performed the experiments of the detached hydrogen or helium plasma associated with the molecular activated recombination (MAR) in a linear divertor plasma simulator. The reduction of the heat load to the target plate were clearly observed in hydrogen or helium plasma with the hydrogen or helium gas puff. Measurement of the negative ion density of hydrogen atom observed in the detached hydrogen plasma has been done. These experimental results suggest that the plasma recombination process comes from the negative ion of hydrogen atom.

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