31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-2.123 (2004)

Application of the Laser Photodetachment Technique in Divertor Simulator MAP-II

S. Kajita[1], S. Kado[2], A. Okamoto[2], T. Shikama[1], B. Xiao[3], Y. Iida[1], D. Yamasaki[1], S. Tanaka[1]

1. Graduate School of Engineering, The Univ. of Tokyo, Bunkyo, Tokyo 113-8656 Japan
2. High Temperature Plasma Center, The Univ. of Tokyo, Bunkyo, Tokyo 113-8656 Japan
3. Institute of Plasma Physics, Chinese Academy of Sciences, Hefei Anhui 230031, P. R. China

1. Introduction

In the past decade, attentions have been paid to the roles of the negative ions on the divertor region, because a type of molecular activated/assisted recombination (MAR) process, which starts from electron attachment, $H_2(v)$+e- $\Rightarrow (H_2^-)^* \Rightarrow H^- + H$, and ends in mutual neutralization, $H^-+H^+ \Rightarrow H+H^*$, is capable of reducing the heat flux to the divertor plates [1]. Recently, the behaviour of negative ions has been investigated experimentally in linear divertor plasma simulators by applying laser photodetachment technique (LPD) [2,3].

However, three major problems take place when the LPD is applied to high density recombining plasmas. The first one is probe surface ablation due to direct laser irradiation to the probe tip. It may disturb the LPD signal, represented by the change of the electron current ΔI_e. This may lead to a overestimation of the negative ion density n_- [4]. The second one is the reliability of single probe characteristics in detached recombining plasmas in the determination of the electron temperature T_e [5,6], which is necessary to evaluate n_-. The last one is the interpretation of the LPD signal in magnetized plasmas. In the present paper, a developed diagnostic for negative ion density is described and a result for detached plasma in a divertor simulator MAP-II (material and plasmas) is presented.

2. Combined scheme of eclipse laser photodetachment and double probe

For the purpose of avoiding the probe surface ablation, a thin wire is inserted into the laser beam path to form a shadow. Figure 1 shows the schematic geometry of the experimental setup. We have named it "eclipse" laser photodetachment method (eclipse-LPD) [7] after the lunar eclipse in which shadow of the earth protects the moon from direct irradiation of the sunlight. The probe system is equipped with an L-shaped probe for LPD and a double probe for the T_e measurement, as described later.

Figure 2 shows the laser power dependence of excess electron current due to the laser injection for the cases with and without shadow. In the case without shadow, the signal intensity does not saturate even if the laser power exceeds the saturation power of about 50 mJ/cm^2, indicating the onset of the probe surface ablation [4]. On the other hand, the signal intensity saturates and the ablation effect disappears when the shadow is installed.

In order to evaluate the shadow effect on the absolute value of the LPD signals, dependence of the signal intensity on the shadow width d_{sh} is investigated. Time evolution of the excess electron density is numerically obtained using a hybrid fluid-kinetic model for a cylindrical and a slab geometries [8]. The numerical results of the relative peak of the excess electron density are plotted as a function of ρ=r/R_L in solid lines in Fig. 3, where r is the distance from the center of the laser beam and R_L is the laser radius as shown in Fig. 4 (a) and (b). The peak of the excess electron density decreases as the increase of ρ in the cylindrical geometry, while it does not change with ρ in the slab geometry. For the purpose of comparing the eclipse geometry with the cylindrical and slab geometry, we have introduced a function ρ'= $(R_L+d_{sh}/2)/(R_L-d_{sh}/2)$ according to Fig.4 (c). Signal intensity in the eclipse geometry for two different laser radii, R_L=2 and 3.5 mm, are plotted as a function of ρ' in Fig. 3 for the purpose of comparing to the slab and cylindrical geometries. In the eclipse geometry, the relative signal intensity is unity when ρ' is typically smaller than 2, while it decreases as the

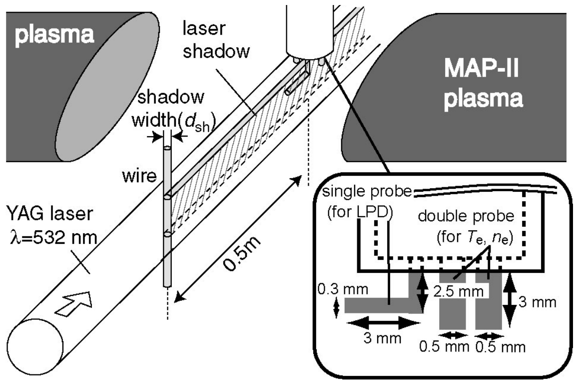

FIG. 1. Schematic of eclipse-LPD arrangement and the probe head: a L-shaped single probe for LPD and a double probe for electron temperature and density measurement.

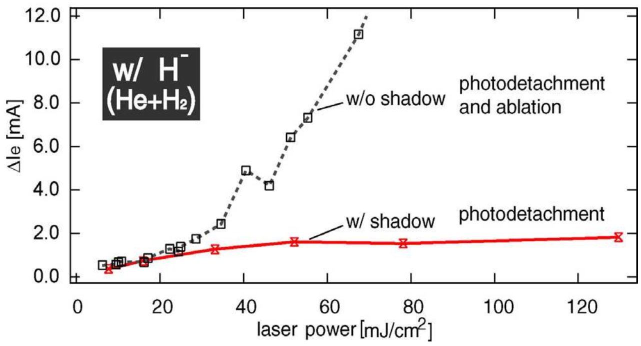

FIG. 2. Laser power dependences of ΔI_e with different shadow width.

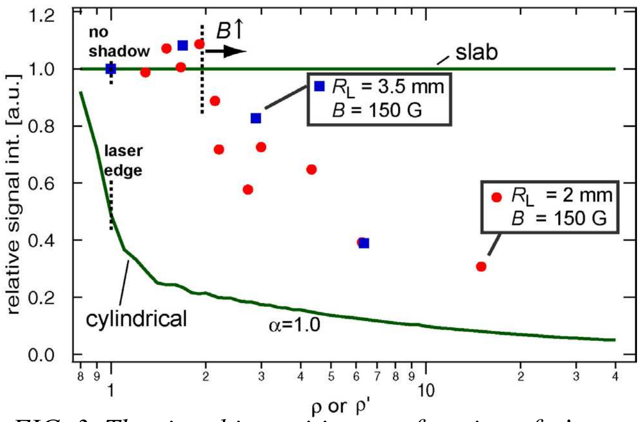

FIG. 3. The signal intensities as a function of ρ' are compared with the calculation in the slab and cylindrical geometries using hybrid fluid-kinetic model. α is a parameter defined as $(\gamma_i T_e/T_i)^{1/2}$.

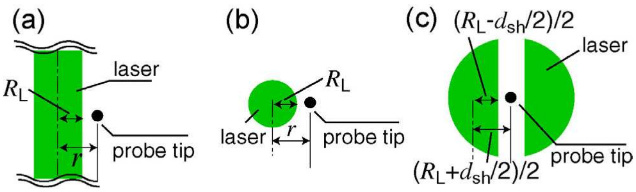

FIG. 4. LPD geometries, (a) slab, (b) cylindrical and (c) eclipse.

increase of ρ' when ρ' is larger than 2. It is supposed that the eclipse geometry is more like a slab one when ρ' is smaller than 2, while it becomes closer to the cylindrical geometry when ρ' is larger. Note that for the value α defined as $(\gamma_i T_e/T_i)^{1/2}$, we take α=1 according to our typical experimental condition (T_e is 1.5 eV, T_i is about 0.5 eV [9]) while γ_i=3 is applied following Ref. [8]. Therefore, it is recommended to apply the eclipse-LPD in the slab like region, namely under the condition where ρ'<2, in our magnetic field, is sufficiently satisfied.

In detached recombining plasmas, conventional evaluation method for negative ion density using $\Delta I_e(V_p)/I_e(V_p)=\Delta n_e/n_e$ [10], can not be applied, where $I_e(V_p)$ is the electron current at the probe bias of V_p, and n_e and Δn_e is the electron density and excess electron density, respectively. Although the absolute value of electron current is unreliable, we can obtain following the relation if the ratio of the electron current at the space potential $I_e(V_s)$ to $I_e(V_p)$ can be assumed to be correct,

$$\Delta I_e(V_p)/I_e(V_p) = eS\Delta n_e\sqrt{8kT_e/\pi m_e}\big/4I_e(V_s)\,, \tag{1}$$

where S is the probe surface area and m_e the mass of an electron. Therefore, the above relation is applicable to the negative ion density measurement in the detached plasmas, when the T_e deduced from the double probe is used, since it gives more proper value than the single probe in the detached plasma [6].

Additionally, in magnetized plasmas, electron collection region may expand along the magnetic field. The signal intensity is disturbed when the collection region is larger than the laser size. We have developed a method for evaluating the effects of the sheath and collection region from the eclipse-LPD signals. It has been confirmed that the collection region is sufficiently smaller than the laser beam size in the typical condition in MAP-II [11].

3. Application to MAP-II [2,12] detached plasmas

The developed eclipse-LPD method combined with a double probe is applied to linear divertor simulator MAP-II. The MAP-II consists of source region and two vacuum chambers, which are a source chamber and a target chamber, connected by a drift tube. The plasmas are generated by a helium dc arc discharge in a source region and terminated at the floating target located in the target chamber. The background helium pressure is about 3.1 mTorr, which is measured by a BARATRON gauge at the target chamber. Additional hydrogen gas is fed into the target chamber. For the purpose of diagnostics, small amount of hydrogen gas is seeded in the plasma source.

The radial distributions of (a) n_e and (b) T_e at 3.1 mTorr and 4.5 mTorr, and (c) negative ion density at 4.5 mTorr are shown in Fig. 5. The n_e and T_e are measured by the double probe.

At 4.5 mTorr, the electron density decreases to about half of the case without additional hydrogen puff. The decreasing rate against the gas pressure is much higher than the case of helium injection [12], which indicates the effect of the MAR. When the hydrogen gas is injected, the negative ions are observed at the peripheral region as shown in Fig. 5 (c), where the electron density and temperature are lower than the central region as can be seen in Fig. 5(b).

We have also performed the hydrogen molecular spectroscopy of Fulcher-α band for investigating the vibrational distribution of H_2. The result indicates that the negative ions are mainly produced in the central region of the plasma column and transported to the peripheral region [13].

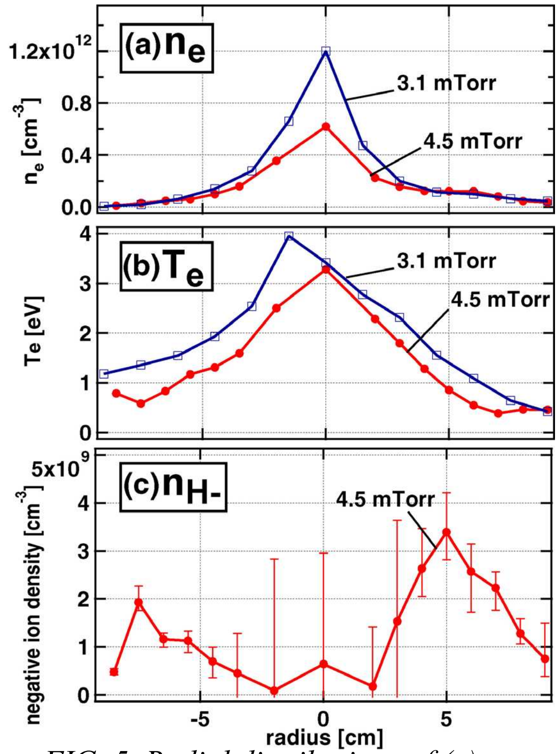

FIG. 5. Radial distributions of (a) electron density (b) electron temperature at 3.1 mTorr and 4.5 mTorr, and (c) electron density at 4.5 mTorr.

Acknowledgement

One of the authors (S. Kajita) was partly supported thorough the 21st Century COE Program, "Mechanical Systems Innovation", by the Ministry of Education, Culture, Sports, Science and Technology.

References

1 S. I. Krasheninnikov, A. Yu. Pigarov and D.J. Sigmar, *Phys. Lett*. **A 214** (1996) 285.

2 S. Kajita, S. Kado, N. Uchida, T. Shikama, and S. Tanaka, *J. Nucl. Mater*. **313-316** (2003) 748.

3 A. Tonegawa, M. Ono, Y. Morihira et al., *J. Nucl. Mater*. **313-316** (2003) 1046.

4 S. Kajita, S. Kado, T. Shikama, B. Xiao and S. Tanaka, *Contrib. Plasma Phys*. in press.

5 R.D. Monk et al., *J. Nucl. Mater*. **241-243** (1997) 396.

6 N. Ohno et al., *Contrib. Plasma Phys*. **41**(2001) 5, 473.

7 S. Kajita, S. Kado and S. Tanaka, *submitted to Plasma Sources Science and Technology*.

8 L. Friedland, C. I. Ciubotariu and M. Bacal, *Phys. Rev. E* **49** (1994) 4353.

9 S. Kado and T. Shikama, *J. Plasma Fusion Res.* **79** (2003) 841.

10 M. Bacal, *Rev. Sci. Instrum.* **71** (2000) 3981.

11 S. Kajita, S. Kado, A. Okamoto and S. Tanaka, *submitted to Phys. Rev. E*.

12 S. Kado, H. Kobayashi, T. Oishi and S. Tanaka, *J. Nucl. Mater*.**313-316** (2003) 754.

13 S. Kado, S. Kajita, D. Yamasaki et al. to be published in *J. Nucl. Mater.*