Development of Helium Beam Probe for Edge Plasma Measurements

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1. Introduction

There has been a growing consensus that the structure and stability of edge plasma affect the global plasma performance, since particle and energy transport there play an important role in determining the core plasma confinement. Thus it is important to observe edge plasma in detail to reveal the underlying physics.

For edge plasma measurements, the helium beam probe (HeBP) has been developed in liner devices, tokamaks [1,2] and helical devices. The HeBP can measure electron temperature T_e and density n_e simultaneously, using three (667.8, 706.5, 728.1 nm) line emissions from helium atoms injected in the plasma. Owing to its relatively low first ionization potential of 24.6 eV, the target of HeBP is the edge or scrape-off plasma where the Thomson scattering cannot be applied. Since helium is a low Z atom, it is an advantage of HeBP to be free from the plasma contamination during the measurements.

In LHD, a supersonic HeBP with a Laval nozzle injector has been developed and the experiment has just started with a prototype injector. In this paper, preliminary results with a newly installed HeBP in LHD are presented, together with a summary of the development study performed in a test chamber and a linear device.

2. Development of injector

The performance of the HeBP depends on the quality of the beam, i.e. its density and divergence. Therefore it is essential to produce dense (bright) and thin beam to obtain the intense signal and the good spatial resolution. The thick beam always degrades the spatial resolution of the system. The divergent beam is not acceptable in LHD because the distance from the nozzle to plasma is too long (> 3 m). On the other hand, it is generally required for diagnostics not to disturb plasmas during the measurement. To minimize the density increase due to the introduced helium atoms, a pulsed beam injection system with a fast solenoid valve (response time $\tau < 1$ ms) is employed in LHD. For the production of the thin beam, a Laval nozzle, instead of an ordinary conical nozzle or a simple tube, has been developed to minimize the beam width. Although the Laval nozzle is originally used to produce a supersonic molecular beam, it is not necessarily required for our system since the beam cannot penetrate so deep inside the plasma even if it has the supersonic velocity. However, on the other hand, it is favorable for diagnostics because the supersonic beam is so collimated that the resultant beam is very thin. In the experiment performed in a test chamber with a time-of-flight technique, it was know that the beam velocity though the Laval nozzle was about Mach 1.

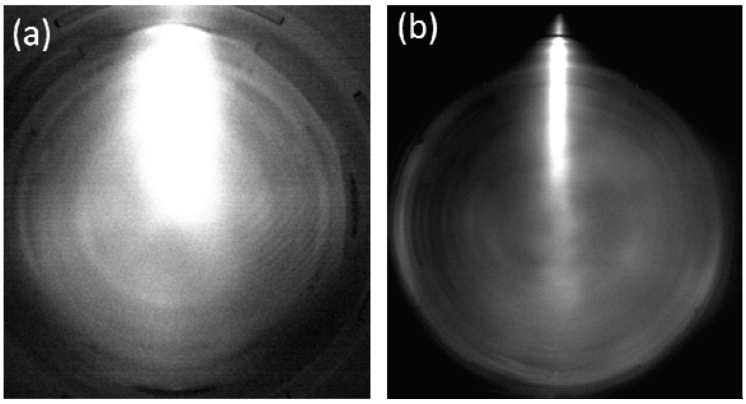

Fig. 1. Beam shapes obtained in ECR plasma with (a) conical and (b) Laval nozzles. Diameter of chamber (plasma) is 30 cm.

Figure 1 shows the beam shapes obtained in the ECR plasma in a linear device called HYPER-1 with (a) an ordinary conical nozzle and (b) a Laval nozzle. The FWHM of the beam with the Laval nozzle was 1 – 2 cm, on the other hand, 7 – 8 cm with the conical nozzle. It is obvious that the Laval nozzle can produce the collimated beam suitable for diagnostics with high spatial resolution. The beam width with various Laval nozzles with different apertures (diameter = 0.1, 0.3, 0.6 mm) was investigated. Measuring the emission profiles of the helium beam excited with the electron beam (100 eV), the FWHM of the helium beam was estimated, changing the plenum pressure from 1 to 7 MPa, as shown in Fig. 2. It is found that there exists a tendency for the Laval nozzle beam to increase with plenum pressure. It is also seen that the smaller aperture produces thinner beam, although difference between dia. 0.3 mm and dia. 0.6 mm is unclear.

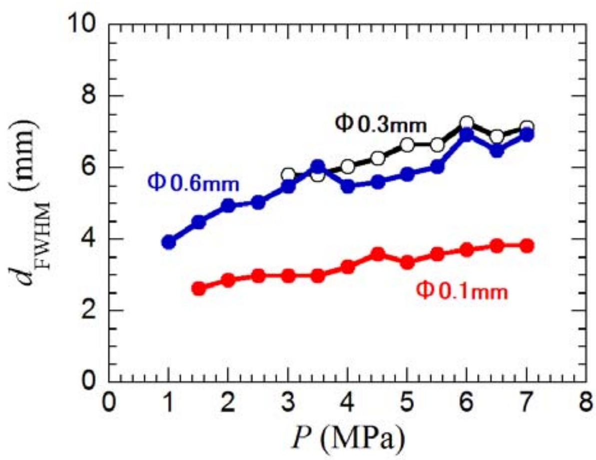

Fig. 2. Beam width with different Laval nozzles with different apertures, as a function of the plenum pressure.

2. HeBP system installed in LHD

The HeBP system is consists of a beam injector and an optical system. In the injector, a fast solenoid valve is directly coupled onto a Laval nozzle to collimate and accelerate the beam, through which the pressurized helium gas at 1 - 3 MPa is injected to the plasma. In order to avoid the unexpected action of the fast solenoid valve due to the strong ambient magnetic field (~ 800 Gauss), it is covered by the magnetic shield made of ferromagnetic materials. To detect the emission profiles of three helium lines along the beam path, a one-dimensional optical fiber array connecting to a spectrometer (f = 25 cm, F = 3.9) is utilized. A back-illuminated CCD detector is attached at the position of the exit slit to acquire the spectra. In the derivation of T_e and n_e from the spectra, the collisional-radiative model is employed.

The beam is injected into LHD almost radially, and the fiber optics is viewing nearly perpendicular to the beam, as shown in Fig. 3. In this configuration, the spatial resolution of the optics is about several cm, which is estimated from the injected beam width.

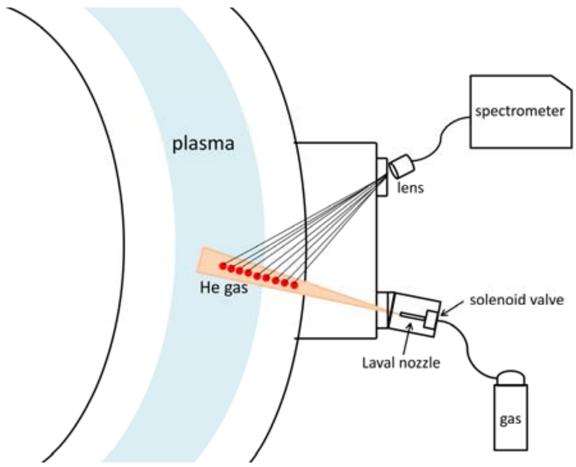

Fig. 3. Schematic of experimental setup.

2. Preliminary results in LHD

Preliminary experiments were carried out with the neutral beam heated plasma in LHD. Two low (n_{e_ave} ~ 1.6 x 10^{19} m^{-3}, #111879) and medium (n_{e_ave} ~ 3.3 x 10^{19} m^{-3}, #111883) density discharges were employed for the edge electron density n_e and temperature T_e measurements with HeBP. In this experiment, the plenum pressure of helium was ~ 1 MPa, and the pulse length of the beam was 1 ms. By the injection of the helium beam, increased

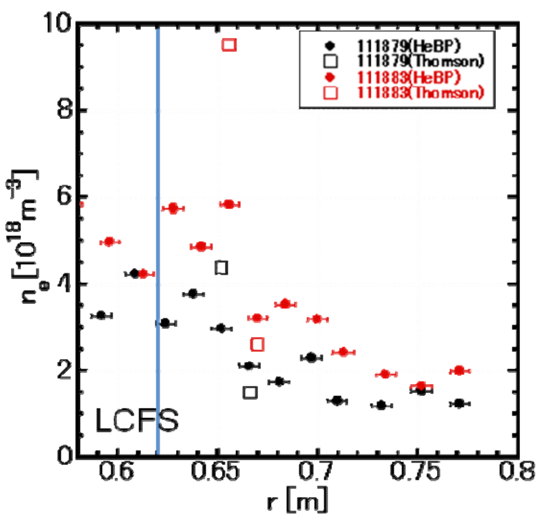

Fig. 4. n_e profiles measured with HeBP (closed circles), together with those with Thomson scattering (open rectangulars). Black and red represent low and medium density discharges, respectively.

density was less than 10 %.

In Fig. 4, n_e profiles measured with HeBP were presented, together with those obtained with the Thomson scattering system. In these experiments, the beam is expected to penetrate near the last closed flux surface (LCFS). It is found that HeBP can observe the response of the edge n_e, following the core density. The quantitative agreement between HeBP and Thomson scattering within a factor of two was also identified.

On the other hand, T_e obtained with HeBP indicates flat profile, and the measured values are so high as 20 – 40 eV. It can hardly be acceptable that such a high temperature plasma spreads far from the LCFS. One of the candidates to be able to explain the reason for this large error in T_e obtained with HeBP is the effect of the radiation trapping (reabsorption) process in the optically thick plasma [3]. Recently the new collisional-radiative model including the process has been developed, and the n_e and T_e reconstructions by using the code have been tried.

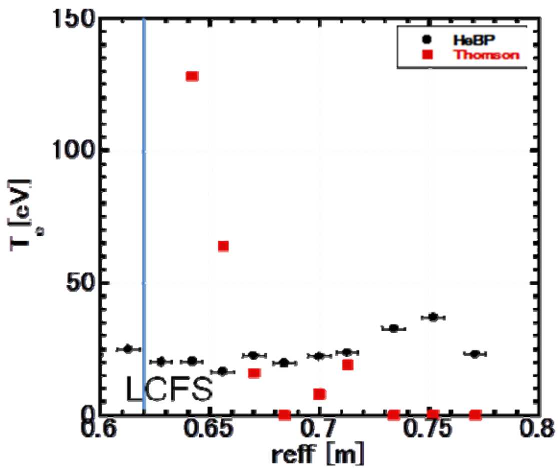

Fig. 5. T_e profiles measured with HeBP (black cirlces), together with those with Thomson scattering (red rectangulars).

In the results shown in Figs. 4 and 5, another error due to the integration effect along the line of sight is included, which degrade the spatial resolution. Near or inside the LCFS, n_e and T_e are not reliable because information of outer plasma property is integrated to the inner plasma. In short, inner n_e and T_e reflect outer n_e and T_e. As is mentioned before, this is caused by the divergent beam at the observing region. It is also known in the development study that a longer Laval nozzle is more effective in collimating the beam, even if it has the same aperture diameter. In order to improve the beam collimation, the new nozzle will be utilized in the forthcoming experimental campaign.

Reference

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