Helium pressure measurement by the penning gauge spectroscopy in the divertor region on LHD

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Introduction. The compression ratio of helium at the divertor region is important for the helium exhaust in a fusion reactor. On the Large Helical Device (LHD), two of ten torus inboard side divertors have the baffle structure in the experiments of 2010 and 2011. Neutral gas pressure in hydrogen plasmas was measured by the ASDEX-type fast ion gauges. It was found that the neutral pressure in the divertor region with the baffled structure is more than 10 times higher than that in the divertor without the baffle structure. [1]. In order to evaluate the helium compression ratio at the divertor regions with and without the baffle structure, two penning gauge spectroscopy systems are newly installed to the torus inner ports of LHD. The penning gauge spectroscopy can measure the partial pressures of neutral gases at each local position from the spectroscopic observation of the penning discharge inside the gauge. This diagnostic was developed at TEXTOR in order to distinguish the partial pressures of deuterium and helium [2, 3]. It is also used for the helium exhaust study on JET [4].

Experimental Setup. Two penning gauges are installed at the torus inner ports of LHD. One is located at the baffle structured divertor and the other is located at the divertor region without the baffle structure. The same type (Leybold PR36) of the gauge heads are used and the high voltage from the same power supply is used for them. Figure 1 shows an example of the penning discharge inside the penning gauge head PR36. Two holes with the diameter of 3 mm are made on the anode ring in order to observe the penning discharge. Although this penning gauge originally has permanent magnets of about 0.13 T in order to make the magnetic field for the penning discharge, the permanent magnets are removed because the magnetic field strength at the torus inside is up to about 2 T when the magnetic field strength at the magnetic axis, B_{ax}, is 2.75 T. It is possible to start penning discharge with the magnetic field of LHD. The dependence of signal intensity on the magnetic field strength is small at the region of $B_{ax} \geq 2$ T.

The light in the penning gauges are transferred to the visible spectrometer by optical fibers. The signals from two different positions are simultaneously detected by a CCD camera. As the wavelength range is about 580 $\sim$ 730 nm, H_α and 4 lines of He I are observed in this range. Figure 2 shows an example of the spectra from the penning discharge in the wavelength range

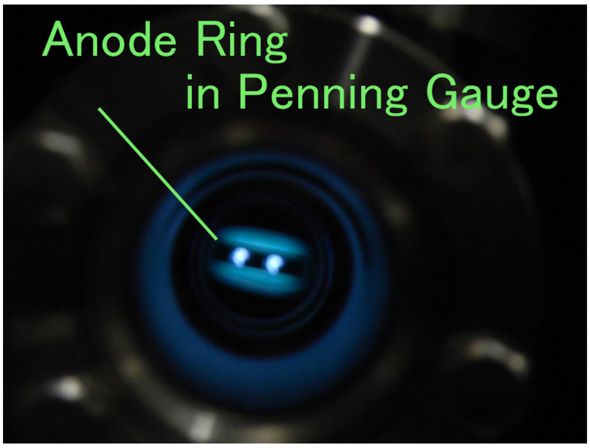

Fig. 1 An exmple of the penning discharge inside the penning gauge head, which is modified with two holes..

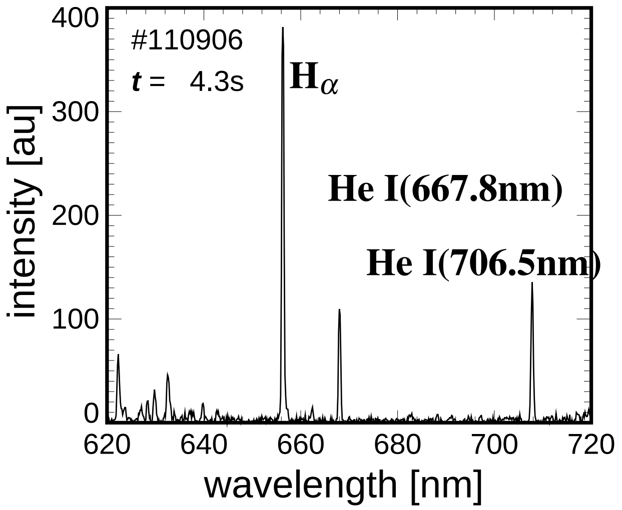

Fig. 2 An example of the visible spectrum from the penning discharge.

of 620 $\sim$ 720 nm. H_α and He I lines of 668.7 and 706.5 nm are observed. For the helium partial pressure measurement, the intensity of He I line at 667.8 nm is used. The time resolution is usually 200 ms for high density plasmas and 500 ms for low density plasmas.

In order to evaluate the partial pressures of neutral gases, calibration is made by filling hydrogen or helium gas in the vacuum vessel and changing their pressures. Figure 3 shows the relation between the intensity of He I line at 667.8 nm and the helium gas pressure under 0.25 Pa. The intensity of each line is derived by integrating in the wavelength range where the line signal appears. Since this calibration was made after the plasma experiment, both helium and hydrogen signals were observed. The helium gas pressure is calibrated by subtracting the calibrated hydrogen pressure. The intensity of H_α is also related with the hydrogen (H_2) gas pressure almost monotonically. The neutral gas pressure was measured by a baratron in these calibrations.

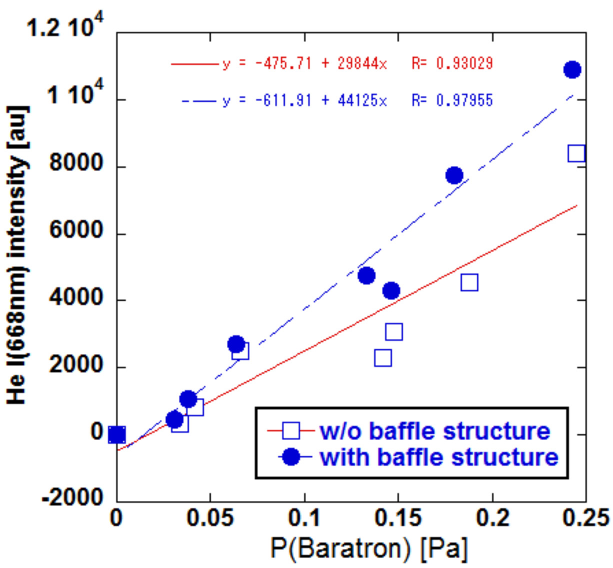

Fig. 3 Relation between the intensity of He I line at 667.8 nm and the helium gas pressure under 0.25 Pa.

Experimental Results. The partial pressures of hydrogen and helium at the divertor regions were measured. Figure 4 shows an example of temporal evolutions of some parameters and signals in a plasma where helium gas was injected at 3.8 s into a hydrogen plasma: (a) ECH and NBI heating pulses, (b) averaged electron density, (c) hydrogen gas-puff, (d) helium super-sonic gas-puff, (e) neutral pressure measured by the fast ion gauge at the divertor region without baffle structure, (f) neutral pressure measured by the fast ion gauge at the divertor region with baffle structure, (g) H_2 pressure in the divertor region without baffle structure, (h) He pressure in the divertor region without baffle structure, (i) H_2 pressure in the baffle structured divertor, and (j) He pressure in the baffle structured divertor. The helium gas was injected by the gas-puff at $t = 3.8$ s (blue line in Fig. 4 (c)) during the hydrogen gas was puffed (black line in Fig. 4 (c)). Two signals of the ASDEX-type fast ion gauges are shown in Fig. 5 (e) and (f). These signals are sum of the hydrogen and helium pressures. For both hydrogen and helium pressures at the baffle structured divertor is higher than those of the position without the baffle structure by about one order. The ratios of P_{H_2}(with baffle)$/P_{H_2}$(w/o baffle) and P_{He}(with baffle)$/P_{He}$(w/o baffle) are shown in Fig. 5 (c) and (d), respectively. For both of hydrogen and helium, the partial pressures which were measured by the penning gauge spectroscopy at the baffle structured divertor is higher than those at the position without the baffle structure by about one order. The ratio of Fig. 5(a) and 5(b) shows the partial pressure of hydrogen and helium. The ratio of P_{He}(with baffle)$/P_{He}$(w/o baffle) is slightly higher than P_{H_2}(with baffle)$/P_{H_2}$(w/o baffle) because of the small signal intensity of

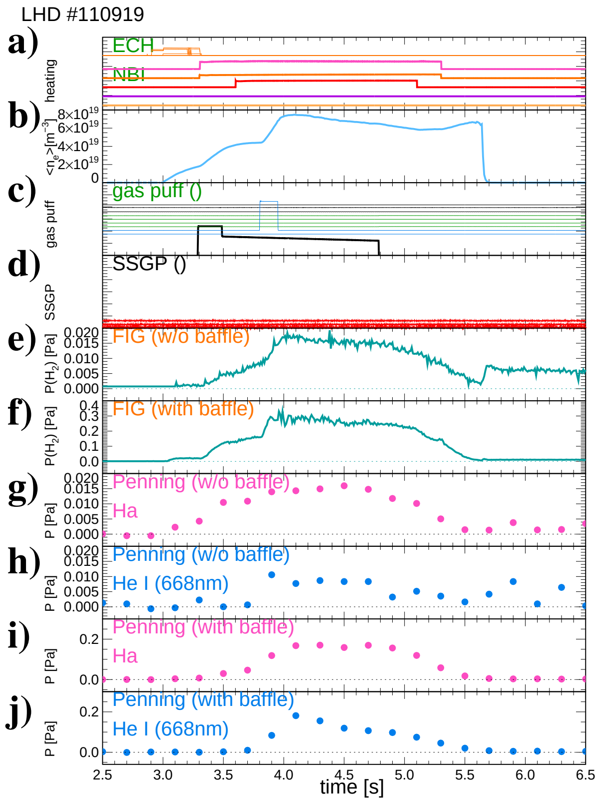

Fig. 4 Temporal evolutions of some parameters and signals in a plasma where helium gas was injected. (a) ECH and NBI heating pulses, (b) averaged electron density, (c) hydrogen gas-puff, (d) helium super-sonic gas-puff, (e) neutral pressure measured by the fast ion gauge at the divertor region w/o baffle structure, (f) neutral pressure measured by the fast ion gauge at the divertor region with baffle structure, (g) H_2 pressure in the divertor region without baffle structure, (h) He pressure in the divertor region without baffle structure, (i) H_2 pressure in the baffle structured divertor, and (j) He pressure in the baffle structured divertor.

He at the position without the baffle structure.

Summary. The penning gauge spectroscopy systems are installed at the divertor regions at the torus inner ports with and without the baffle structure. The initial calibration result shows that the partial pressure of helium at the divertor region with the baffle structure is higher than that at the position without the baffle structure by almost one order.

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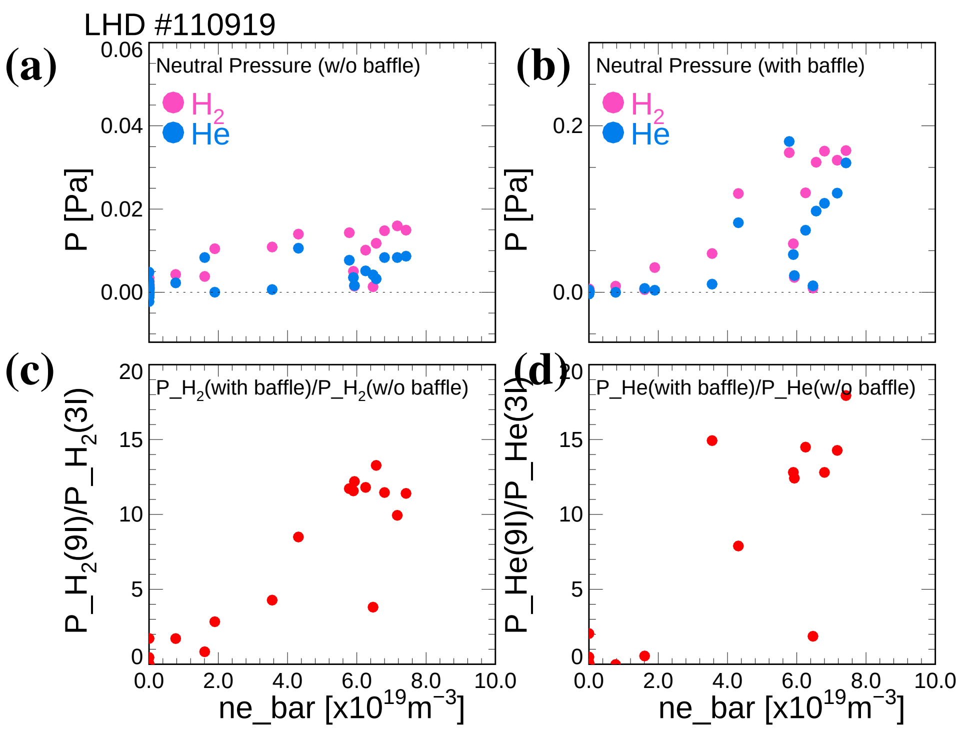

Fig. 5 Density dependence of the ratios P_{H_2}(with baffle)$/P_{H_2}$(w/o baffle) and P_{He}(with baffle)$/P_{He}$(w/o baffle).