H/He ratio as a function of wall conditioning and plasma facing material during past 9 years in LHD

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A simple method for monitoring the wall conditioning is presented for analysis on the flux ratio of hydrogen to helium ions, which is determined from intensity ratio of Hα (6563Å) to HeI (5876Å) visible spectral lines. The density and temperature dependences of the emissions, which are calculated with collisional-radiative model, can be mostly deleted by taking into account the ratio. The H/He ion flux ratio in LHD has been thus calculated from toroidally integrated Hα and HeI signals. All discharges during past 9 years since the LHD experiment was started have been analyzed. As a result, the effect of the discharge cleaning as wall conditioning, especially H_2 and He glow discharges, on LHD experiments becomes clearly visible. The history of the wall conditioning in LHD is presented with the analysis of the H/He ion flux ratio and results are discussed as a function of wall conditioning method and plasma facing materials.

Keywords: Hα, HeI, H/He ratio, wall conditioning, plasma facing material, visible spectroscopy, LHD

1. Introduction

Wall conditioning in fusion devices is one of important experimental techniques in order to improve the plasma performance. The edge temperature rise based on the reduction of the particle recycling is the main purpose of the wall conditioning. In LHD the wall conditioning becomes more important because the baking temperature of the plasma facing components is limited to 95° due to a narrow space between the superconducting helical coils and the vacuum vessel. In LHD, therefore, a variety of the wall conditioning techniques such as Ti gettering, low magnetic field ECR discharge, boronization and H_2, He and Ne glow discharges have been attempted until now and the He glow discharge has been finally selected as the main method. Although the He glow discharge was very effective to remove the hydrogen from the wall and divertor plates, a large amount of He was unexpectedly appeared as the influx in the H_2 discharge. It becomes then important to study the status of the plasma facing components after glow discharge cleaning.

Toroidal distributions of Hα and HeI visible emissions have been measured in LHD to monitor the uniformity of the hydrogen and helium influxes. In order to determine their influxes the edge n_e and T_e profiles are always required for the analysis in addition to the absolute values of the Hα and HeI emissions. However, it is really difficult to check all discharges in shot-by-shot basis. Therefore, a new method with more simple technique was required to monitor the status of the wall conditioning.

The Hα/HeI intensity ratio was then adopted for the purpose. The discharge conditions over past 9 years have been analyzed using ion flux ratio of hydrogen to helium evaluated from the Hα/HeI ratio. In this paper the history of the LHD discharge condition is reported as a function of the wall conditioning method and plasma facing component in addition to the description of the H/He ion flux ratio measurement technique.

2. Flux ratio calculation of H^+/He^+

The emission rates of the Hα and HeI lines are generally functions of T_e and n_e, and then the population of excited levels in neutral hydrogen and helium is calculated using a collisional-radiative model [1]. We need the ionization events per photon for calculating the hydrogen and helium influxes in addition to the emission intensity. Here, the ionization events per photon give the conversion rate from the emission to the ion flux. Result for the Hα ($2p^2P$-$3d^2D$: 6563Å) is shown in Fig.1 as a function of electron density. In the figure the calculation is done for four different electron temperatures as a parameter. The radial profile of the Hα emission has been measured in LHD. It is then confirmed that the electron temperature at the location where the Hα line is emitted generally ranges in

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10-100eV except for the recombining phase after turning off the heating devices. Seeing Fig.1 it is understood that the temperature dependence of the ionization events per photon is really weak in the 10-100eV range. However, the density dependence becomes considerably large, especially at higher densities greater than $1\times10^{13}cm^{-3}$, whereas the ionization events per photons for Hα have been frequently used to be constant [2].

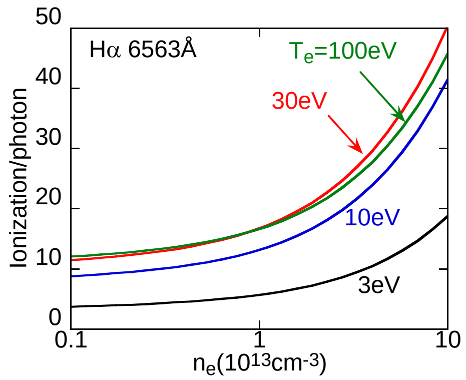

Fig.1 Ionization events per photon for Hα emission as a function of electron density. Calculation is done for four different electron temperatures.

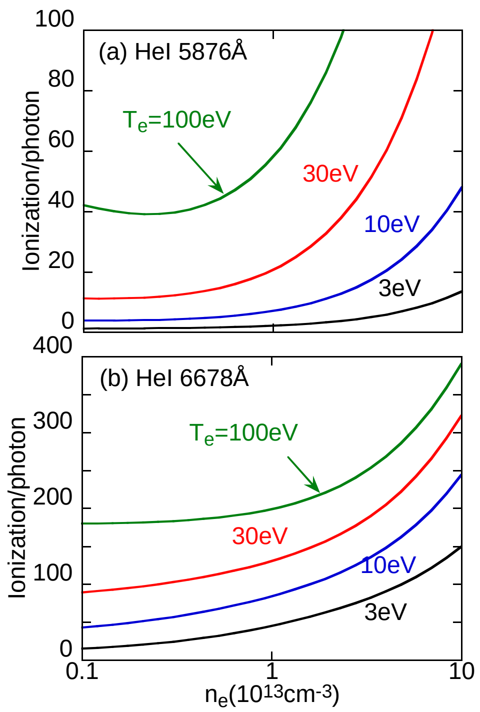

Fig.2 Ionization events per photon for HeI emissions of (a) 5876Å and (b) 6678Å as a function of electron density. Calculation is done for four different electron temperatures.

Results calculated for two neutral helium transitions of $2p^3P$-$3d^3D$ (5876Å) and $2p^1P$-$3d^1D$ (6678Å) are shown in Figs.2 (a) and (b). The ionization events per photon of HeI 5876Å have a large density and temperature dependences compared to HeI 6678Å. In particular it is emphasized exceeding the density of $1\times10^{13}cm^{-3}$.

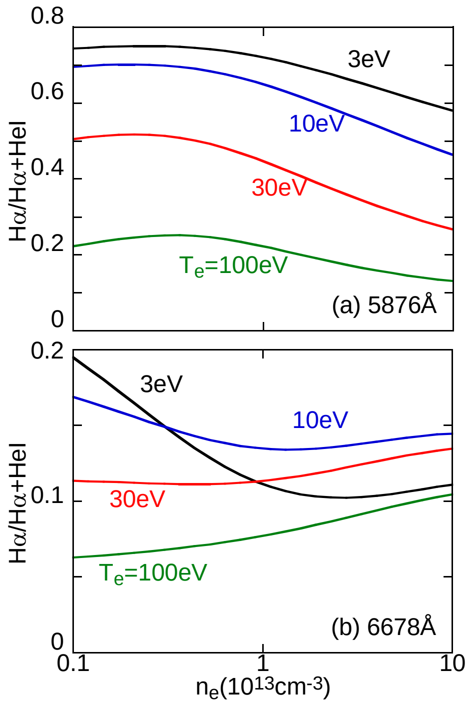

Fig.3 Ratio of hydrogen ion flux to total ion flux as a function of electron density; (a) HeI 5876Å and (b) HeI 6678Å. Calculation is done for four different electron temperatures.

The ratio of hydrogen ion flux to the total ion flux (≡sum of the hydrogen and helium ion fluxes) is shown in Figs.3 (a) and (b) for HeI5876Å and 6678Å, respectively. The calculation is done at the same photon number for both of the Hα and HeI. It is understood that the edge parameter dependence can be considerably reduced when the ratio of Hα to HeI emissions is taken into account. Especially, the disappearance of the parameter dependence tends to be favorable to the HeI 6678Å case. The low T_e of 3eV as seen in the figure is not realistic in normal LHD discharges except for the recombining phase. Thus, the analysis on the ratio can be practically done without consideration of the edge parameters.

The triplet transition (HeI 5876Å) of neutral helium is really strong compared to other singlet transitions like HeI 6678Å. The intensity of HeI 5876Å is always 5-10 times stronger than other lines in LHD. However, the ratio of hydrogen ion flux to total ion flux has a little large density and temperature dependences compared to HeI 6678Å case. Taking into account only the ratio itself, the use of HeI 6678Å is of course better than

5876Å. In the wavelength range near 6678Å, however, other weak emission lines exist in addition to the Hα emission. The HeI 5878Å is used in the present measurement in order to increase S/N ratio of the signal.

3. Measurement of Hα/HeI ratio

The Hα and HeI emissions have been measured using a combination of optical fibers, an interference filter and photomultiplier tubes. Ten optical fibers installed on each toroidal section, which correspond to m=10 toroidal pitch number in LHD, are set on the interference filter with focusing lenses. Since a large interference filter with diameter of 10cm is used, the transmission rate of the line is a little different for each fiber due to the spatially nonuniform transmission rate. Typical transmission rates of the filters for Hα and HeI are shown in Figs.4 (a) and (b), respectively.

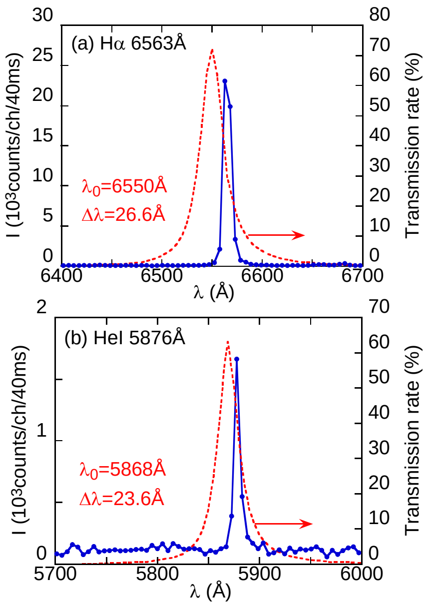

Fig.4 Transmission rates of interference filters and line spectra for (a) Hα and (b) HeI.

The full width at half maximum (FWHM) of the filter is Δλ=26.6Å at Hα 6653Å and Δλ=23.6Å at HeI 5876Å. It is difficult to adjust all the signals to the central position of the filter response because of its nonuniformity. However, the signals keep the transmission rate of, at least, 30-50% against the primary line intensity from the optical fiber.

On the other hand, the present system becomes unavailable to extremely high-density operation with H_2 pellet injection and Ne-seeded discharges. In case of the H_2 pellet injection the increase in the background continuum level mainly formed by the visible bremsstrahlung emission is really large, since the density is enough high and the temperature is considerably low like 0.3-1.0keV. Then, the output signal from the HeI filter involves a large amount of the continuum signal whereas the HeI signal intensity is not changed.

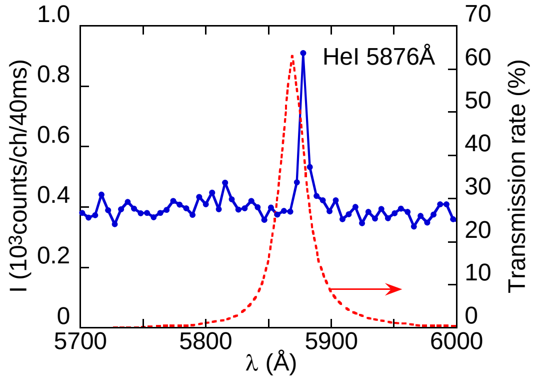

Fig.5 HeI 5876Å spectrum during H_2 pellet injection. Dashed line indicates filter response curve.

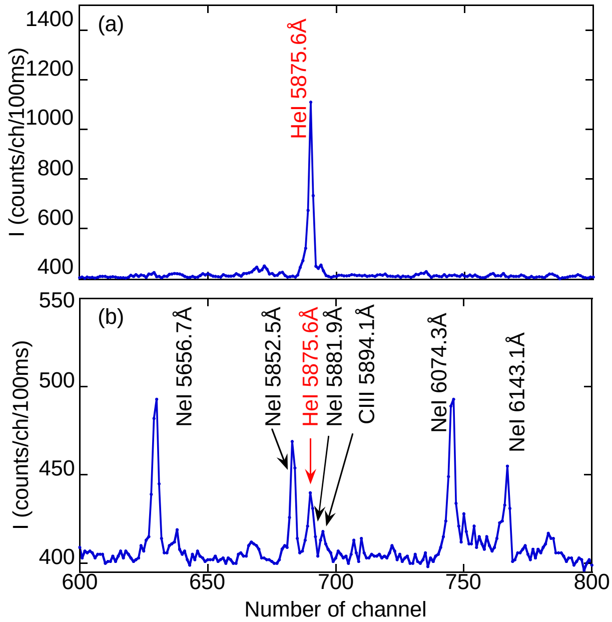

Fig.6 Visible spectra near HeI 5876Å from (a) without and (b) with Ne-seeded discharges.

In case of the Ne-seeded discharges many lines appear near the HeI 5876Å. The Ne-seeded discharges have been sometimes used in LHD for the diagnostic purpose, the increase in temperatures and resultant NBI-driven toroidal current. It is impossible to measure the HeI line using only the interference filter method.

The H/He flux ratio (accurately ion flux ratio of $H^+/H^+ + He^+$) is thus obtained by integrating 10 emission intensity signals from toroidal array observing the Hα and HeI lines.

3. H/He ratio during past 9 years in LHD

The H/He flux ratio has been analyzed in almost all discharges from the 2nd cycle (1998) to the 10th cycle (2006). Typical results are shown in Figs.7 (a), (b), (c) and (d) for the 2nd, 3rd, 4th and 7th cycles. The different wall conditionings were attempted during these 9 years;

2nd: daily He glow (stainless steel divertor)
3rd: daily H_2 or He glow (carbon divertor)
4-5th: daily He glow (carbon divertor)
6-7th: H_2 (He) glow before H_2 (He) experiment
8-10th: He glow only when necessary

The 2nd cycle (1998) had no carbon divertor plates and the discharges were operated with stainless steel wall. In addition, the H_2 and He discharges were repeated alternately. As a result, most of discharges were dominated by He. Before the 3rd cycle (1999) carbon divertor plates were installed on the vacuum wall. Both of the H_2 and He glow discharges were tried after experiments. In contrast to this only He glow discharges were done in the 4th cycle (2000). The difference is clearly visible in the two figures (see Figs.7 (b) and (c)). After He glow discharges any pure H_2 discharge can not be performed, although the He ion flux decreases according to accumulation of H_2 discharges. The additional He flux is mainly released from the carbon divertor plates. In the 7th cycle (2003) the H/He flux ratio was drastically changed as seen in Fig.7 (d). The working gas used in the glow discharge was selected according to the fueling gas in the next day's experiment. Since in the 7th cycle the He experiment was not done so frequently, almost pure H_2 operation became then possible in the H_2 gas fueled discharges.

Recent LHD operation (8th-10th cycles) excellently maintains good H_2 discharges with less He flux. On the contrary the maintenance of the He discharge becomes difficult by the enhanced hydrogen flux, since the number of NBI beam lines (at present NBI#1-#4) increases with further enhancement of hydrogen flux. Then, the increase in the H/He flux ratio is frequently appeared even in the He fueled discharge. It is shown in Fig.8 obtained from the 10th cycle (2006).

Finally, it is summarized that the present diagnostic method using the ratio of Hα to HeI can give useful information on the status of wall conditioning.

Acknowledgements

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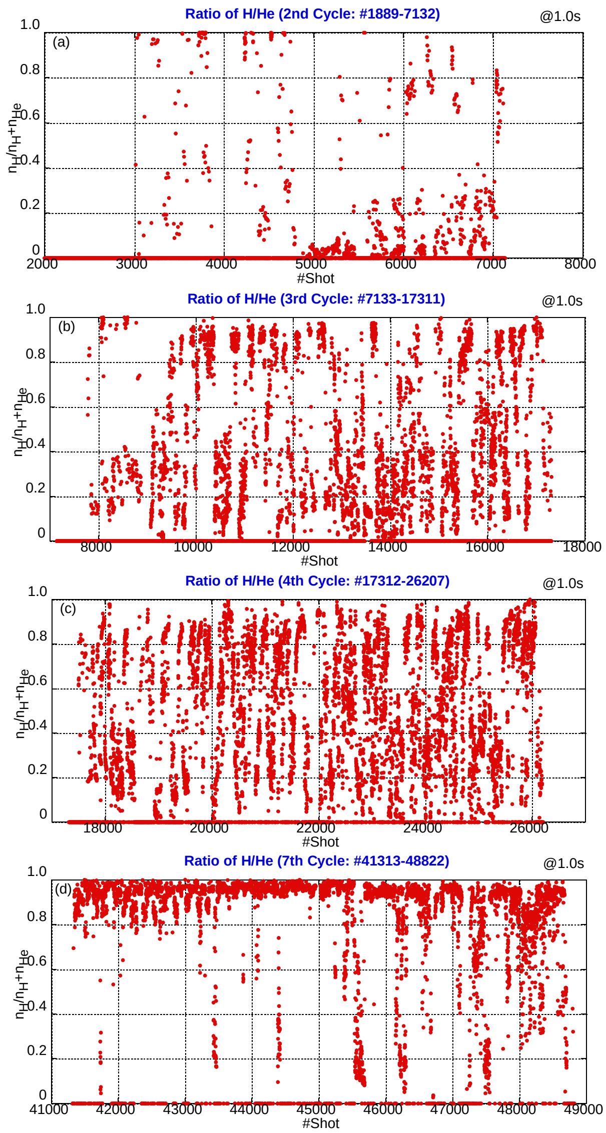

Fig.7 H/He flux ratio in the (a) 2nd, (b) 3rd, (c) 4th and (d) 7th experimental cycles. Repetitive H_2 pellet operation is very few in these cycles.

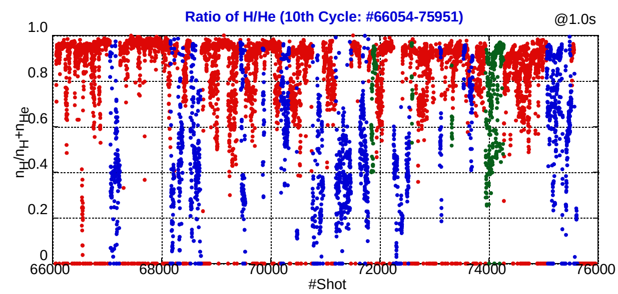

Fig.8 H/He flux ratio in the 10th cycle (2006) with H_2 discharges including H_2 pellet (red), He discharges (blue) and Ne-seeded discharges (green).