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# Fusion of Advanced Plasma Spectroscopy and Confinement Research
先進的分光計測と閉じ込め研究の融合

Masahiro Hasuo
蓮尾昌裕

*Graduate School of Engineering, Kyoto University,*
*Yoshidahonmachi, Sakyo-ku, Kyoto 606-8501, Japan*
京都大学大学院工学研究科　〒606-8501　京都市左京区吉田本町

We have demonstrated for an LHD plasma that multi-line of sight and simultaneous observation of polarization-resolved spectra of hydrogen atomic Balmer-α, -β, -γ lines and molecular Fulcher-α ro-vibronic bands offers information about local generation and excitation of hydrogen molecules and transport of hydrogen from the edge region to the confined region. We have also demonstrated that a time-resolved measurement of the Balmer-α line profile offers information about temporal development of hydrogen atom influx and those of electron temperature and density around and in the confined region because the total intensity reflects the atom influx and the wing of the profile reflects the behavior of atom penetration through charge exchange collisions with protons.

## 1. Introduction

Dynamics of the neutral hydrogen has a significant influence on the plasma confinement of magnetically confined plasmas [1,2]. It is demanded to observe behavior of atomic and molecular hydrogen from a wall or diverter boundary to the core region.

Spectroscopic diagnostics is one of the powerful tools. Since emission integrated along a line of sight (LOS) is usually observed in this method, local measurements with the aid of the Zeeman pattern appearing in the line shapes have been developed for the Hα and Dα line emissions from magnetically confined plasmas [3,4,5]. It is known that polarization-resolved spectroscopy improves accuracy in detection of the Zeeman split [6,7]. Recently, a series of work on the Hα emissions from the periphery region of LHD plasmas with this technique were reported [8,9,10].

For the purpose of further improving this technique, we recently demonstrated a method to observe several emission spectra of hydrogen atoms and molecules simultaneously with developing a multi-wavelength high-resolution spectrometer [11,12]. During these researches it has been found that line profiles of the Balmer-series emissions have substantial wings, which reflect the existence of high velocity neutral atoms and depend on the plasma parameter in the confined region [13]. The high velocity neutral atoms are attributed to those penetrating into the high temperature region and being heated through charge exchange collisions with high temperature protons there [14].

In this paper, we briefly review these work reporting our recent progress.

## 2. Simultaneous measurement of polarization-resolved spectra of hydrogen atomic and molecular emission lines

Figure 1 shows an example of the observed spectra of the Balmer-α, -β, -γ lines, and the Q1 lines of the Fulcher-α transition bands for an LHD plasma. The temporal developments of the plasma parameter and heating are shown in Figs. 2(a-1,2) with the exposure time of the CCD detector. The system for the simultaneous measurement of these high-resolution spectra is explained in detail in ref. [11,12]. The polarization dependences are clearly observed for all the spectra, which are due to the Zeeman effect caused by the strong magnetic field in LHD. From the analysis of the line profiles, emission locations, intensities and velocities along LOS can be derived as shown in Figs. 2(b-1,2). The methods of the polarization-resolved measurement and analysis are explained in detail in ref. [7].

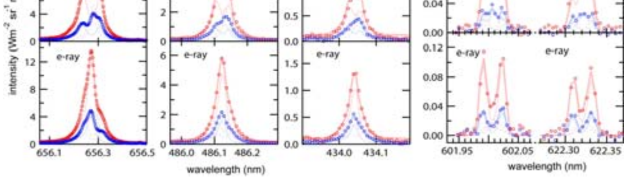


Fig. 1. The observed emission spectra of the LHD plasma. (a-1, 2, 3) show the Balmer-α, -β, -γ lines and (b-1,2) show the Q1 lines of the Fulcher-α $v$: 0-0 and $v$: 2-2 transition bands, respectively. The spectra of orthogonal polarizations are shown in the upper and lower figures. $v$ is the vibrational quantum number.

It is seen in Figs. 2(b-1,2) that the atomic emissions locate in the periphery region, while the molecular emissions locate outside of those. The influence of the divertor leg on the molecular dissociation is suggested. The molecular emissions are also found to be very large near the position where the divertor leg hits the divertor plate. Supply of protons, recombination to hydrogen and molecular desorption are expected to be efficient there. The observed results support this expectation.

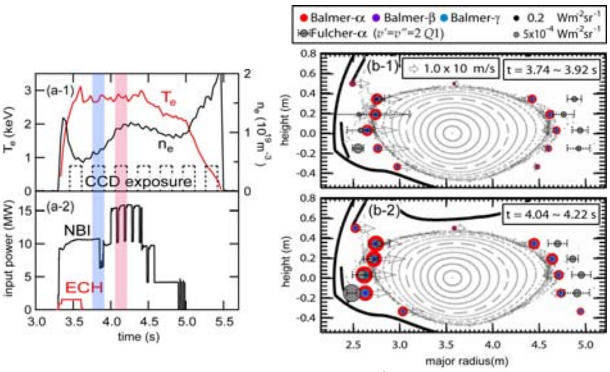


Fig. 2. Temporal developments of the central electron temperature and density (a-1), and those of the ECH and NBI heating (a-2) of the observed LHD plasma. The exposure time of the CCD detector are shown by the dotted squares. The emission locations, intensities and velocities along LOS derived from the observed hydrogen spectra at $t$ = 3.74 - 3.92 s (b-1) and t = 4.04 - 4.22 s (b-2), which are indicated by the center and area of the circles, and the length of the arrows, respectively.

## 3. Time-resolved measurement of Balmer-α line profiles in a large dynamic range

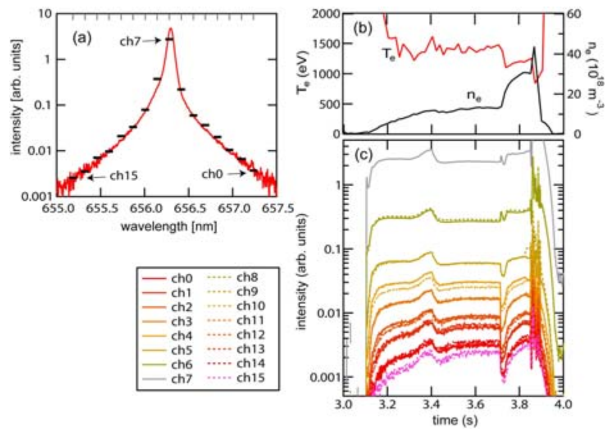


Fig. 3. (a) An example of the Balmer-α emission spectra measured by the 16-channel photo-multiplier system (bars) and the CCD system (dots). (b) Time developments of the central electron temperature and density, and (c) those of spectral components of the Balmer-α line. A hydrogen pellet is injected at $t$ =3.72 s.

Figure 3(a) shows an example of Balmer-α line profiles observed for an LHD plasma. It is noted that the intensity scale is logarithmic and the wavelength range is 6 times as large as that in Fig. 1(a-1). A large wing is seen. This wing is thought to be due to high velocity hydrogen atoms penetrating into the confined region through charge exchange collisions with high temperature protons there [13,14]. On the other hand, the central part of the profile mainly reflects the atom influx as seen in Figs. 2(b-1,2).

By developing a fast line-profile measurement system (measurement cut-off frequency: 40 kHz) with a photo-multiplier linear array, we observe time developments of the profile components shown by the bars in Fig. 3 (a). The result is shown in Fig. 3 (c) with the plasma parameter change (Fig. 3(b)). The effect of a hydrogen pellet injection at 3.72 s is detected as a sudden increase in the central intensity and decrease in the wing intensity.


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