§10. Development of Simultaneous Measurement System of High-resolution Spectra of Hydrogen Emissions for the Study of LHD Edge Plasma

Hasuo, M., Fujii, K., Mizushiri, K., Nishioka, T., Shikama, T. (Dept. Mech. Eng. Sci. Kyoto Univ.),
Goto, M., Morita, S.

In a magnetically confined plasma, the dynamics of hydrogen and its isotopes in the periphery region is known to have strong influence on the core confinement[1,2] A simultaneous measurement of line shapes of more than one hydrogen emission line is demanded for the spectroscopic diagnostics of the edge plasma by comparison with the collisional-radiative model of hydrogen.[3]

In the last year, we developed a multi-wavelength-range fine-resolution (MF) spectrometer for hydrogen atomic and molecular emissions in a scheme of this project.[4] With the spectrometer, the line shapes and intensities of hydrogen atomic Balmer-α, -β, -γ lines and molecular Fulcher-α band $v' = v'' = 2$ lines were measured. Here, v' and v'' are the vibrational quantum numbers of the upper and lower states, respectively. The spectral resolutions for these lines were 0.02-0.03 nm. In this year, we refined the alignment of optical components in the spectrometer to increase the instrumental resolution and to measure another vibronic transition line of hydrogen Fulcher-α band.

Figure 1 shows a schematic illustration of the refined MF spectrometer. In the spectrometer, light introduced by optical fibers are collimated by a concave mirror (M_c, focal length: 1143 mm, diameter: 108 mm) and incident on a grating (2400 groves/mm, 102 x 102 mm^2). The diffracted light beams are focused by five concave mirrors (M_α, M_β, M_γ, $M_{ful}{}^0$, $M_{ful}{}^2$) at the location corresponding to the wavelengths of Balmer-α, -β and -γ lines and the Fulcher-α band $v' = v'' = 2$ lines and $v' = v'' = 0$ bands. The light beams are focused on different regions of a charge coupled device (CCD, Andor, DV-435BV, pixel size: 13 x 13 μm^2). For reducing aberration, we minimize the off-axis reflection angle of the M_c to be 4.1 degree, and we optimize the location of the CCD using a ray-tracing calculation. The achieved instrumental width for these lines is less than 0.01 nm at the entrance slit width of 20 μm.

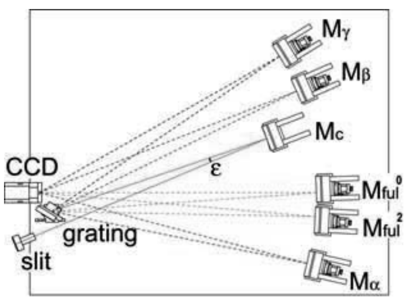

Fig 1. Schematic illustration of the refined MS spectrometer

We applied this spectrometer to the polarization resolved spectroscopic measurement of hydrogen emission from a LHD plasma heated by the ECH of 3.7 MW. The central electron temperature and the line averaged electron density are 4 keV and 1 x 10^{19} m^{-3}, respectively. Fig. 2 shows the poloidal cross section of LHD and the line of sight we used. Fig. 3 shows the observed spectra.

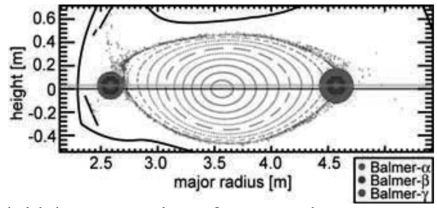

Fig 2. Poloidal cross section of LHD and measurement line of sight. The emission locations and intensities obtained for the Balmer-α, -β and -γ lines are indicated by the centers and areas of the circles, respectively.

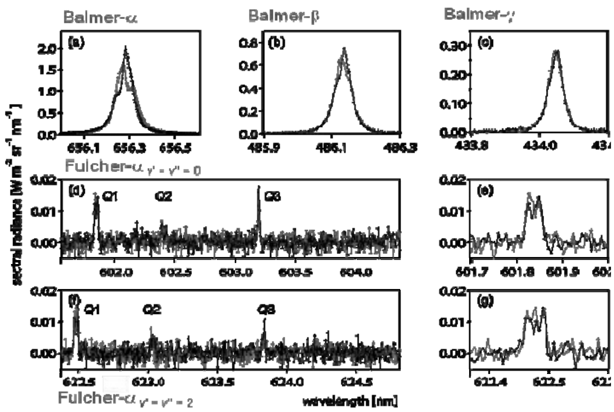

Fig 3. The observed emission spectra of the LHD plasma. (a), (b), (c), (d), and (f) show the hydrogen Balmer-α, -β, -γ lines and Fulcher-α $v' = v'' = 0$ and $v' = v'' = 2$ bands, respectively. The spectra of ordinary polarization are shown by the red lines while the black lines show those of extraordinary polarization. The expanded spectra for the $Q1$ emission lines of the Fulcher-α bands are shown in (e) and (g).

The polarization dependence on the line shapes is clearly seen in the Balmer-α and Fulcher-α $Q1$ lines, which is due to the strong magnetic field of LHD at the emission location. The dependence can be also seen in Balmer-β and -γ lines. We adopted a least-square method to fit the observed atomic spectra assuming the emission locations to be localized in two positions; inner and outer edge regions. From the analysis, the emission intensities of the atomic lines for each location are estimated together with the positions. In Fig. 2, the estimated intensities of the Balmer-α, -β and -γ lines are shown by the areas of the circles. The analysis of the intensity ratios between these lines with the collisional-radiative model are now in progress.

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2) N. Ohyabu, K. Narihara, H. Funaba et al., Phys. Rev. Lett. **84**, 103 (2000).
3) K. Sawada, K. Eriguchi, and T. Fujimoto, J. Appl. Phys. **73**, 8122 (1993).
4) K. Fujii, K. Mizushiri, T. Nishioka et al., Rev. Sci. Instrum. **81**, 033106 (2010)