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

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In a fusion research plasma, the dynamics of hydrogen or its isotopes in the periphery region is considered to strongly 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] It is, however, difficult to achieve it with conventional spectrometers. Here, we develop a fine-resolution multi-wavelength-range (FM) spectrometer for hydrogen emissions.

Figure 1 shows a schematic illustration of the FM spectrometer. In the spectrometer, the light beam collimated by a concave mirror (M_{col}; focal length: f = 1143 mm, diameter: d = 108 mm) enters a grating (2400 grooves/mm, ruled area: 102 x 102 mm^2) and the diffracted light beams are focused on a CCD camera (1024 x 1024 pixels, 13 x 13 μm^2/pixel, Andor, DV435-BV) by four concave mirrors (M_α, M_β, M_γ, M_{ful}; f = 1143 mm, d = 108 mm) at the locations which correspond to the wavelengths of the Balmer-α (656 nm), -β (486 nm), -γ (434 nm), and Fulcher-α band Q branch (620-622 nm). We set the incident angle to the grating to be 60 degrees. The diffraction angles β are listed in table I. Each light is focused on different region of the CCD camera, which is located just above the grating.

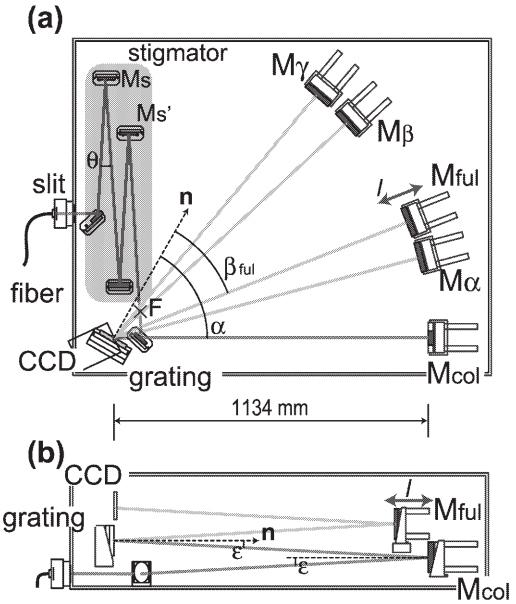

Fig. 1. A schematic illustration of the FM spectrometer. (a): top view, (b): side view.

Table I. The diffraction angles β.

	Mα	Mβ	Mγ	M_{ful}
β [degree]	45.3	17.6	10.2	39.0

The off-axis reflection by the concave mirrors causes astigmatism, which results in the vertical expansion of the focused image of the fiber exit. We correct the astigmatism with a stigmator; the two concave mirrors (M_s, $M_{s'}$; f = 635 mm, d = 63.5 mm) before M_{col}, which is shown in the grey shadow in Fig. 1. We designed the stigmator with ray-tracing calculation. The calculated and measured instrumental functions are shown in Fig. 2(a) and (b), respectively. The astigmatism is well corrected enough so that the images of the fiber exits are clearly separated, and then we can use several optical fibers simultaneously and use all the area of the CCD camera effectively. On the other hand, the measured full width at the half maximum in the horizontal direction ($FWHM_{mes}$) is 5.7 pixels (105 μm), which is much larger than that calculated by the ray-tracing ($FWHM_{cal}$ = 26 μm) at the entrance slit width of 20 μm. In the calculation, we neglect the effect of the diffraction limit of the grating. It is, however, found that it does not explain this discrepancy. Some aberration may be caused by insufficient accuracy in the locations of the optical components used in the FM spectrometer.

The instrumental widths for the hydrogen emission lines are shown in table II. The wavelengths are calibrated with the emission lines of a Th-Ar hollow-cathode discharge lamp (Heraeus, P858A). The absolute sensitivities are also calibrated by a standard-lamp with a standard reflection sphere (Labsphere, USS-600C).

1) F. Wagner, G. Becker, K. Behringer et al., Phys. Rev. Lett. 49, 1408 (1982).
2) N. Ohyabu, K. Narihara, H. Funaba et al., Phys. Rev. Lett. 84, 103 (2000).
3) A. Iwamae, et al., to be published

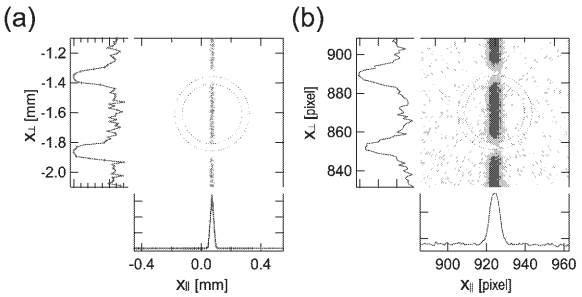

Fig. 2 (a) The calculated instrumental function of the FM spectrometer with the stigmator and (b) the measured one with a Th emission line (622.5 nm). The circles show the size of the core (400 μm) and the crad (500 μm) of the optical fiber. The vertical and horizontal cross sections of the focused image are shown in the left and below side, respectively. Although the scale of the axes in (a) is mm and that in (b) is pixels, the images can be relatively compared.

Table II. The instrumental widths for the hydrogen emission lines.

	Balmer-α	Balmer-β	Balmer-γ	Fulcher-α (2-2)Q0
FWHM [nm]	0.019	0.023	0.030	0.022