§14. Static and Dynamical Spectroscopy on Neutral Hydrogen Transport in a Fusion Plasma

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Hydrogen atoms and molecules are dominantly ionized in the peripheral region of the magnetic fusion plasma and therefore their dominant ionizing flux, that is the particle source rate in the plasma, is localized at the plasma edge. Nevertheless, a certain part of the atoms can penetrate deep inside the plasma as neutral through charge exchange collisions with hot protons and they can be the particle source in the core region.

Recently, we found that the far wing part of the Balmer-α line profile is due to such high temperature atoms in the core region while the central part is due to low temperature atoms in the peripheral region of the plasma. [1,2] The emission intensity from the core region can be over 10^5 times smaller than the peak intensity. However, the dynamic-range of a conventional spectrometer is usually less than 10^4.

In this project, we develop a spectrometer having the dynamic-range over 10^5 and keeping the wavelength resolution of 0.031 nm and the time resolution of 0.1 s. We apply the spectrometer to the Balmer-α line observation for an LHD plasma.

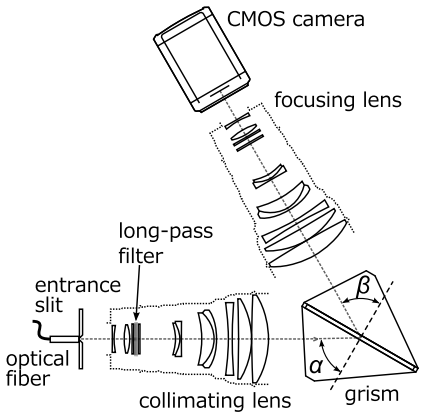

Fig.1. A schematic illustration of the high dynamic-range spectrometer developed in this work.

Fig. 1 shows an illustration of the high-dynamic-range spectrometer developed here. Light introduced by linearly aligned 24 multi-modes optical fibers through the entrance slit is collimated by a camera lens (SIGMA, APO 300mm F2.8 EX). In the collimating lens, a long-pass filter (Hoya, R-60, cutoff wavelength: 600 nm) is set for the purpose of avoiding unexpected stray light. The collimated light beam is incident on a custom-made transmission grating (Wasatch Photonics, groove density, N_g: 4000 grooves/mm, size: 170 x 85 mm^2) sandwiched between two identical prisms (BK7 with visible anti-reflection coating). Such a grating is called as grism. The light throughput with a fully opened slit is estimated to be ~ 30%. The diffracted light is focused on a CMOS camera (Hamamatsu Photonics, Orca flash-4.0, 2048 x 2048 pixels, pixel size: 6.75 x 6.75 μm^2). By the software-based binning of the full-resolution image of the CMOS camera, 11 pixels moving average, and 8 images summation, the dynamic-range of the system is expanded beyond 10^5. The instrumental resolution (FWHM) of the spectrometer is 0.031 nm at the entrance slit width of 30 μm and its bandwidth of wavelength is from 653.5 to 659.0 nm.

We observe the Balmer-α emission from an LHD plasma (#112883) with 16 lines of sight (LOS) as shown in Fig. 2 (a). The time-resolution of the system is 0.1 s. The width of the entrance slit is 30 μm. Fig. 2 (b) shows the Balmer-α spectra observed for LOS1 and LOS8, which see the peripheral and core regions, respectively. It is noted that the vertical axis is logarithmic. The far wings, which are more than 1.5 nm apart from the center, are observed clearly. The corresponding kinetic energy of hydrogen atoms to the wings is more than 3 keV. It is seen that the wing intensity observed for the LOS8 is larger than that for the LOS1. The high temperature atoms generated in the core plasma are quantitatively detected by the developed system.

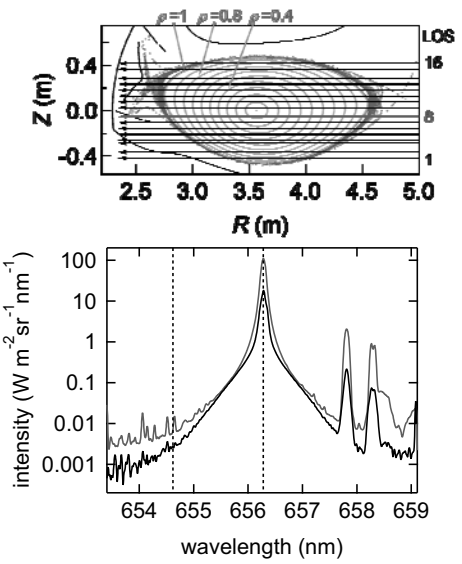

Fig.2. (a) A poloidal cross section of LHD and LOSs for the emission observation. (b) The observed Balmer-α spectra for LOS1 (black curve) and LOS8 (gray curve).

1) Hasuo, M., Shikama, T., Goto, M., Morita, S., Mizushiri, K. and Fujii, K.: "Spatial Distribution and Transport of Neutral Particles in a Fusion Plasma Reconstructed from Emission Observation", ITC-22, Nov. 19-22, 2012, Toki, Japan.
2) Fujii, K., Shikama, T., Goto, M., Morita, S, and Hasuo, M.: "Hydrogen transport diagnostics by atomic and molecular emission line profiles simultaneously measured for large helical device ", *Phys. Plasmas* **20**, 012514 (2013).