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Observation of Plasma Fluctuation by a Fast Balmer-α Line Shape Measurement in LHD

高速Balmer-α線形状計測によるLHD中プラズマ揺動の観測

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We have measured the Balmer-α emission spectrum from an LHD plasma with a wavelength resolution and a measurement frequency of 0.14 nm and 70 kHz, respectively. The plasma is generated in the outward shifted configuration having a major axis of 3.9 m with a magnetic field strength of 2.54 T. In synchronization with a magnetic field fluctuation, the intensity increases near the peak of the spectrum while decreases in the line wing. The phenomena suggest that the charged particle flux to the divertor plates and the density inside the last closed flux surface increase with the fluctuation.

1. Introduction

In magnetically confined plasmas, it has been found that the Balmer-α shape has substantial wings which cannot be reproduced by a single Maxwellian velocity distribution [1, 2]. Recently, we reported that the wing reflects the existence of high velocity neutral atoms and its shape changes depending on the plasma parameter inside the last closed flux surface (LCFS) [3]. The high velocity neutral atoms are attributed to those penetrating inside the LCFS and being heated through charge exchange collisions with high temperature protons there. Recently, Goto et al. estimated the penetrating neutral atom density from the Balmer-α line shape [4].

On the other hand, in the magnetically confined plasmas, the line-integrated line intensity of the Balmer-α emission, which is defined as the area of the line shape, is known to be proportional to the neutral hydrogen influx and nearly independent on the electron density and temperature [5]. The influx has been also known to relate to charged particle outflux from the plasma [6]. An increase of the Balmer-α line intensity observed in an edge-localized-mode in Tokamaks is a well-known example. A similar intensity increase has been also observed in Large Helical Device (LHD) in the outward shifted configuration [7].

Here, we report on a time-resolved measurement of the Balmer-α line shape and its line intensity during the phenomenon in LHD.

2. Experiment

A hydrogen discharge in LHD is generated under a confining magnetic field strength of 2.54 T at the magnetic axis. The major radius of the plasma is 3.9 m. The discharge is sustained by neutral beam injections with the heating power of 3.7 MW. The electron temperature and the density are measured to be 900 eV and 6 x 10^{19} m^{-3} at the plasma center, and 50 eV and 3 x 10^{19} m^{-3} around the LCFS, respectively, by the Thomson scattering method [8].

The central region of a horizontally elongated poloidal plasma cross section of LHD is viewed with a single line of sight. The field of view is roughly 150 mm height and 100 mm width. The emission from the plasma is introduced by optical fibers into a high dispersion spectrometer (Jobin Yvon, THR1000, grating: 2400 grooves/mm). The spectrum is focused on the photo cathodes of a multi-anode photo-multiplier-tube (PMT, Hamamatsu, R-5900U-20-L16) which equips 16 channels along the dispersion direction. The linear wavelength dispersion at the photo cathodes is 0.14 nm/ch. The output currents from the anodes of the PMT are amplified by 16 Op-Amps (Texas Instruments, OPA2743) and digitized by a 16-channels analog-digital converter (National Instruments, USB-6251). The cut-off frequencies of the amplifiers are 40 kHz and the sampling rate is 70 kHz. An example of the Balmer-α spectrum measured with the system is shown in Fig 1 with a logarithmic vertical axis. The Balmer-α line intensity can be obtained from the sum of the spectral intensities in the 16 wavelength regions.

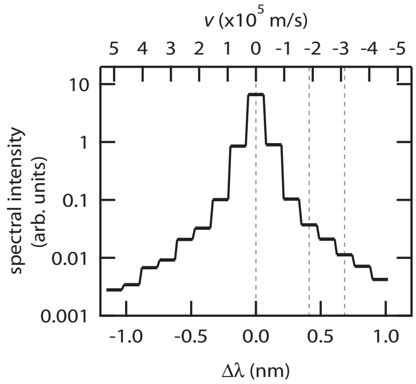

Fig. 1. Example of a measured Balmer-α spectrum. The velocity of the excited hydrogen atoms along the line of sight is indicated in the top axis.

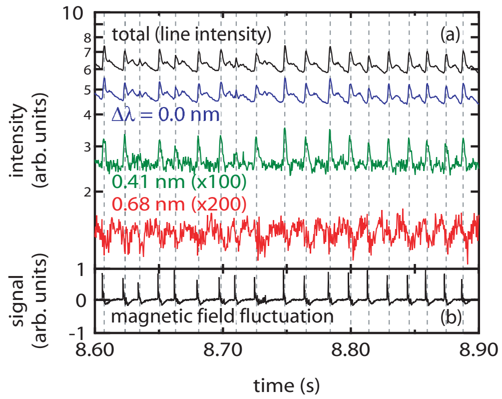

Fig 2. (a) The time developments of the Balmer-α spectral intensity in three wavelength regions. The wavelengths for each trace are indicated. The line intensity of the Balmer-α emission is also plotted. (b) The magnetic field fluctuation measured by a magnetic flux loop.

3. Result and Discussion

Figure 2 (a) shows 400 μs averaged temporal developments of the measured Balmer-α spectral intensities in the wavelength regions of Δλ = 0.0 (line center), 0.41, and 0.68 nm, where Δλ is the wavelength shift from the line center. The wavelengths are indicated with the vertical dotted lines in Fig. 1. For a comparison, the spectral intensities in Δλ = 0.41 and 0.68 nm shown in Fig. 2 (a) are multiplied by 100 and 200, respectively. The Balmer-α line intensity which is dominantly contributed by the spectral intensity in Δλ = 0.0 nm is also shown. In Fig. 2 (b), we plot magnetic field fluctuation measured by the magnetic flux loop located near to the measurement port.

Periodic changes with a cycle of about 15 ms can be seen in the line intensity. In each cycle, the line intensity shows a sharp increase followed by a gradual decrease. In Fig. 2, the local maxima for the line intensity are shown with vertical dotted lines. The increases of the line intensity synchronize to the magnetic field fluctuations. The spectral intensity in Δλ = 0.41 nm also shows a sharp increase in a cycle, while that in Δλ = 0.68 nm decreases and increases gradually.

The increase of the Balmer-α line intensity indicates the increase of the hydrogen atom influx to the plasma [5]. Since the influx depends on the recycling flux of the atoms from a divertor plate and also relates to the charged particle flux to it, the sharp increase in the line intensity accompanying with a magnetic field fluctuation suggests that the charged particles are ejected to the divertor plates by the plasma turbulence [7].

On the other hand, the spectral intensity in Δλ = 0.68 nm represents the number of fast hydrogen atoms having the velocity along the line of sight of 3 x 10^5 m/s. The corresponding kinetic energy is 470 eV, which is much higher than the electron temperature around the LCFS. Such high velocity atoms are mainly generated deeply inside the LCFS. The decrease of the high velocity hydrogen atoms comparing to the neutral influx indicates that the penetration length of the hydrogen atoms decreases. It suggests that the plasma fluctuation triggers an electron density increase inside the LCFS.

Acknowledgments

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