22P085-R

Spectral characteristics of saturation spectroscopy at the Balmer-α line of atomic hydrogen in magnetized hydrogen plasma

有磁場水素プラズマにおける水素原子バルマーアルファ線の飽和吸収分光スペクトル特性

Koichi Sasaki[1], Renge Asakawa[2], Motoshi Goto[3], and Nader Sadeghi[4]
佐々木 浩一[1]，浅川 れんげ[2]，後藤 基志[3]，サデギ ナダー[4]

[1]*Division of Quantum Science and Engineering, Hokkaido University, Kita 13, Nishi 8, Kita-ku, Sapporo 060-8628, Japan*
[1] 北海道大学大学院工学研究院量子理工学部門，〒 *060-8628* 札幌市北区北 *13* 条西 *8* 丁目
[2]*Department of Electrical Engineering and Computer Science, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan*
[2] 名古屋大学大学院工学研究科電子情報システム専攻，〒 *464-8603* 名古屋市千種区不老町
[3]*National Institute for Fusion Science, 322-6 Oroshi-cho, Toki 509-5292, Japan*
[3] 核融合科学研究所，〒 *509-5292* 岐阜県土岐市下石町 *322-6*
[4]*LIPhy, Universite Joseph Fourier & CNRS, Grenoble, France*
[4] ヨゼフフーリエ大学グルノーブル校およびフランス国立科学研究センター，フランス

We developed a system of saturation spectroscopy at the Balmer-α line of atomic hydrogen with the intention of applying it to the diagnostics of LHD plasmas. The spectrum was composed of a broadband offset and many peaks which were assigned as fine-structure components of the Balmer-α line with Zeeman splitting. The saturation parameter or the amplitude of the saturation spectrum was discussed by referring to the theory of saturation spectroscopy. In addition, the physical origin of the broadband offset component was speculated on the basis of the pressure dependence of the saturation spectrum.

1. Introduction

Laser absorption spectroscopy has a much finer resolution than optical emission spectroscopy, and is widely used for investigating the velocity distribution functions of various species in plasmas by measuring Doppler-broadened spectra of their transition lines. On the other hand, studies of the particle balance in Large Helical Device (LHD) at the National Institute for Fusion Science (NIFS) need a spectral resolution finer than the Doppler broadening. A required information for understanding the particle balance is the location of ionization (H + e $\rightarrow$ H$^+$ + e + e). The location of ionization is expected to be almost the same as the location of excitation (H + e $\rightarrow$ H* + e) in the LHD plasma. In principle, the location of excitation is known by measuring the spectrum of the Balmer-α line of atomic hydrogen with Zeeman splitting, since the spatial distribution of the magnetic field strength is known in LHD and the spectrum with Zeeman splitting is a fingerprint of the magnetic field strength. However, because of a high temperature of atomic hydrogen in LHD, the details of Zeeman splitting are masked by the Doppler broadening. Under the aforementioned background, in this work, we developed a system of saturation spectroscopy at the Balmer-α line of atomic hydrogen.

2. Experiment

We examined the performance of a saturation spectroscopy system in a linear machine with a uniform magnetic field of 350 G along the axis. The experimental apparatus is schematically shown in Fig. 1. The light source for saturation spectroscopy was an oscillator-amplifier system of diode lasers, which yielded tunable, single-mode, cw radiation with a power of approximately 200 mW. The wavelength of the master oscillator (New Focus, Vortex II) was scanned for a range of 50 GHz within a period of 5 ms. The power of the master oscillator was approximately 15 mW, and a part of the master oscillator beam (< 1 mW) was picked up using a beam splitter and was used as the probe beam. A collimator was used for avoiding the divergence of the probe beam. In addition, a part of the master oscillator beam was picked up to measure the rough wavelength and the frequency scan using a wavemeter and a Fabry-Pérot spectrum analyzer, respectively. The other part of the master oscillator beam was injected into a diode laser amplifier (TOP-

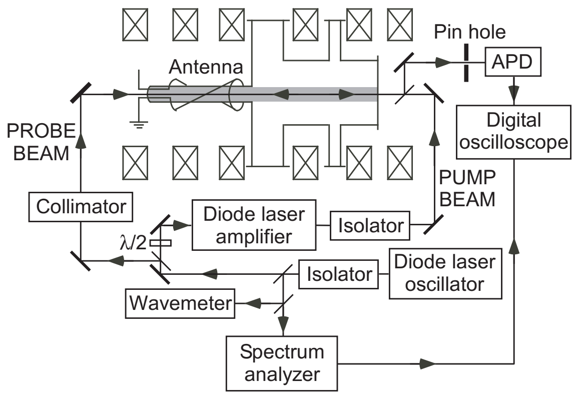

Figure 1: Experimental apparatus.

TICA, BoosTA) to obtain the intense pump beam.

The probe and pump beams were launched into the plasma source from the counter axial directions, and they were overlapped carefully. Therefore, the present experimental configuration was sensitive to the σ transitions between energy levels with Zeeman splitting. A beam splitter was used for detecting the transmitted probe beam using an avalanche photo diode. A pin hole transmitted the probe beam, while it eliminated the optical emission from the plasma efficiently. The electrical signal from the avalanche photo diode was recorded using a digital oscilloscope, together with the signal from the spectrum analyzer.

3. Results

Spectra of the probe beam transmitted through a plasma are shown in Fig. 2(a), which was observed with and without the pump laser beam. The origin of the relative frequency axis corresponds to a wavelength of 656.285 nm. The vertical axis shows the absorbance, which is the product between the absorption coefficient for the probe beam ($\alpha_{\rm probe}$) and the absorption length (ℓ), and is obtained from the intensities of the incident (I_0) and transmitted ($I_{\rm t}$) probe laser beams using the Lambert-Beer law $\alpha\ell = -\ln(I_{\rm t}/I_0)$. The pump laser power in front of the optical window for launching the pump beam into the plasma was 146 mW. When the pump laser beam was switched off, we observed a smooth spectrum with two broad peaks, as shown in Fig. 2(a), which was understood by the overlaps of many Doppler-broadened fine-structure components of the Balmer-α line [1]. On the other hand, when the pump beam was switched on, we observed many dips in the spectrum of the probe beam, as shown in Fig. 2(a).

Figure 2(b) shows a saturation spectrum, which was obtained by dividing the difference between the two spectra ($\Delta\alpha_{\rm probe}$) shown in Fig. 2(a) by the spectrum without the pump laser beam ($\alpha^0_{\rm probe}$). We observed many peaks with high spectral resolutions. The peaks shown in Fig. 2(b) are found to be understood as

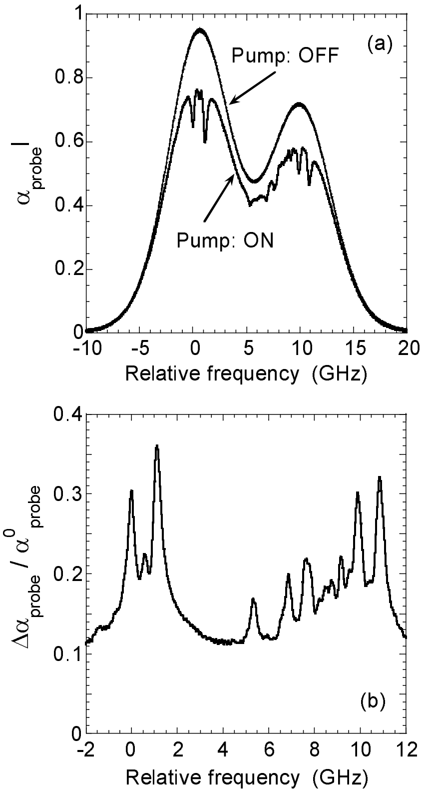

Figure 2: Spectra of (a) simple laser absorption spectroscopy and (b) saturation spectroscopy.

σ transitions of the Balmer-α line at 350 G and their cross-over signals.

4. Discussion

According to a theory of saturation spectroscopy, the amplitude of the peak in the saturation spectrum is directly related to the saturation parameter. From the amplitude of the peaks shown in Fig. 2(b), the saturation parameter was estimated to be less than 0.2 $\sim$ 0.3. On the other hand, the theoretical saturation parameter, which is given by the laser intensity, the relaxation frequencies of relevant energy levels, and the transition probability, was evaluated to be $\sim$ 5. Hence, the amplitude of the saturation spectrum shown in Fig. 2(b) is smaller than that expected by the theoretical saturation parameter. Another experimental result that is difficult to be understood by the theory of saturation spectroscopy is the existence of the broadband offset component in the saturation spectrum. We will discuss the possibility of collisional transport in the velocity space at the conference, by referring the pressure dependences of the amplitudes of the peak and offset components.

References

[1] M. Aramaki, Y. Okumura, M. Goto, S. Muto, S. Morita, and K. Sasaki: Jpn. J. Appl. Phys. **44** (2005) 6759.