22P087-R

Saturated absorption spectra of Balmer-alpha line of atomic hydrogen observed using a independently-tuned pump laser
独立ポンプレーザーを用いて観測した水素原子バルマーアルファ線の飽和吸収スペクトル

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We developed a saturation spectroscopy system using an independently-tuned pump laser to investigate the absorption spectrum in the whole region of the Doppler-broadened Balmer-α line of atomic hydrogen with Zeeman splitting. The observed saturation spectrum, which was different from that observed in ordinary saturation spectroscopy, was interpreted and discussed.

1. Introduction

In Large Helical Device (LHD) at National Institute for Fusion Science, the particle balance in the plasma edge region is interested to study the high-performance confinement. In helium plasmas, the location of ionization was investigated by analyzing the spectra of He I emission lines [1]. Because the magnetic field strength and direction are vary with the position and known in the LHD plasma, the Zeeman splitting of spectral lines carries the information of the position of excitation, and the position of excitation is almost the same as that of ionization.

In hydrogen plasmas, the emission spectrum of the Balmer-α line was investigated [2]. The analysis of the Zeeman profile was complicated because the Balmer-α line consists of several fine structure lines with a larger Doppler broadening. Therefore, we developed a system of saturation spectroscopy at the Balmer-α line of atomic hydrogen [3]. Saturation spectroscopy achieves a Doppler-free spectral resolution. Our saturation spectroscopy system resolved the Zeeman split fine structure of Balmer-α lines. However, the existence of a broadband offset component was difficult to be explained by the theory of saturation spectroscopy.

A possible mechanism for this broadband offset component is the change in the velocity of atomic hydrogen or the transportation in the velocity space. In this work, we developed a saturation spectroscopy system with an independently-tuned pump laser to investigate the effect of the pump laser beam to the whole region of Doppler-broadened spectra.

2. Experiment

The experimental apparatus is schematically shown in Fig. 1. The plasma source was a linear machine with a uniform magnetic field of 300 G along the axis. The helical antenna was connected to an rf power supply at 13.56MHz. The total length of the plasma was 60 cm. The light sources for saturation spectroscopy were two tunable cw diode lasers. The probe laser was scanned for a range of 50 GHz in 5 ms. A part of the probe beam was picked up to a Fabry-Pérot spectrum analyzer to measure the scanning relative frequency. For the pump laser beam, a handmade tunable diode laser was used as a master oscillator and the master oscillator beam was injected into a diode laser amplifier. The amplified pump laser beam was approximately 80 mW (200 mW maximum). A part of the pump laser beam was picked up to a wavemeter to monitor the rough wavelength. The wavelength of the pump laser beam was fixed. In addition, parts of the pump and probe laser beams were introduced into an optical heterodyne interferometer to detect the frequency difference between the two laser beams.

The probe and pump laser beams were injected into the plasma source on the chord of the cylindrical axis of the plasma from the counter directions. The pump beam was collimated and the two beams were overlapped carefully. The probe laser beam transmitted through the plasma was picked up using a beam splitter, and was detected using an avalanche photo diode (APD). The beat signal of the optical heterodyne

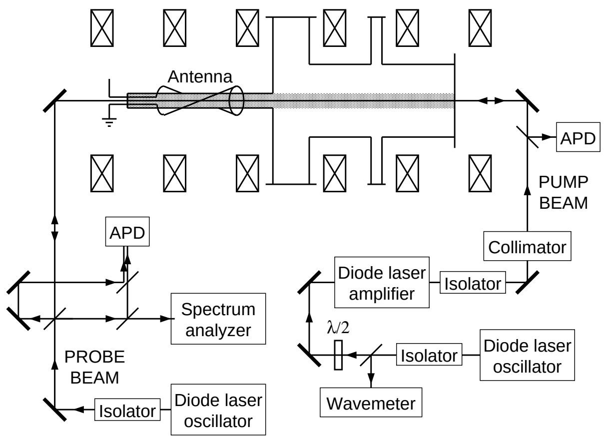

Figure 1: Experimental apparatus.

interferometer was detected using a fast APD. The signals from two APDs and the spectrum analyzer were recorded using a digital oscilloscope.

3. Results

Absorption spectra with and without the pump laser beam are shown in Fig. 2(a). The horizontal axis shows the frequency difference from 656.2819 nm. The vertical axis shows the absorbance $\alpha\ell$ which is obtained by the Lambert-Beer law $\alpha\ell = -\ln(I_t/I_0)$, where I_t and I_0 are the transmitted and the incident probe laser beam intensities, respectively. The dashed curve in Fig. 2(a) shows the absorbance without the pump laser beam. This smooth spectrum is understood as the overlap of Doppler-broadened fine-structure components of the Balmer-α line with Zeeman splitting. The solid curve shows the absorbance with the pump laser beam. This spectrum had several dips because the pump laser beam caused saturation of absorption. The dotted line shows the amplitude of the beat signal of the optical heterodyne interferometer. The peak of the beat signal indicated the wavelength of the pump laser beam.

The saturation spectrum, which is the difference between the solid and dashed curves divided by the solid one, is shown in Fig.2(b). This saturation spectrum was different from a spectrum of ordinary saturation spectroscopy [3] because the frequency of the pump laser was fixed. The narrow negative peaks around 2 and −7 GHz were caused by the instability of the probe laser, and the distortion of the baseline was caused by incomplete compensation of the temporal fluctuation of the probe laser intensity and plasma density.

4. Discussion

Because the pump laser frequency is fixed, the saturation peaks arise at the opposite side of each Doppler-broadened transition line. Therefore the frequency of the transition line is the midpoint between the peaks of the saturation spectrum and the pump laser frequency. Under this interpretation, the two intense peaks in Fig.2(b) were assigned as the transition of $2^2P_{3/2}-3^2D_{5/2}$, consisting of the Zeeman split eight σ components. The amplitude of the valley between the two peaks was not negligible. There are π components of the same transition line at the valley, while the probe laser beam along the magnetic field should not interact with the π components. A possible reason for the considerable amplitude at the valley would be the transportation in the velocity space. On the other hand, the broadband offset component was not clearly observed in this experiment. However, it is difficult to distinguish the offset component from the baseline distortion. For further study, the proper compensations of the fluctuations of the laser and the plasma are necessary. The detailed interpretation of the saturation spectrum will be discussed by referring spectra observed at other plasma conditions and pump laser frequencies.

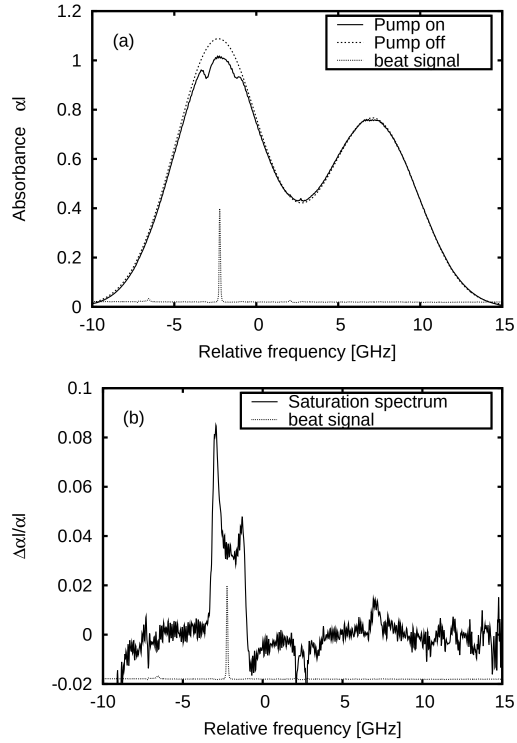

Figure 2: (a) Spectra of absorbance with and without the pump laser, and (b) spectrum of saturation spectroscopy.

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