§2. Development of Doppler-free Spectroscopy for Plasma Diagnostics

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A requirement for diagnostics in LHD experiments is the development of high-resolution spectroscopy at the Balmer-α line of atomic hydrogen. If the high-resolution spectrum of the Balmer-α line with Zeeman splitting is measured, one can estimate the place of electron impact excitation of atomic hydrogen with the help of the knowledge of the distribution of the magnetic field strength. The place of electron impact excitation roughly represents the place of electron impact ionization. The knowledge on the place of electron impact ionization is helpful for investigating the particle balance in LHD. However, the Zeeman-split spectrum of the Balmer-α line is masked by the Doppler broadening. The goal of this work is to develop a technique of Doppler-free spectroscopy (saturation spectroscopy) at the Balmer-α line of atomic hydrogen, with the intention of applying it to LHD experiments.

In this year, we continued examining the characteristics of saturated absorption spectrum at the Balmer-α line using a test plasma device, which was a linear machine with a uniform magnetic field along the cylindrical axis. The system of saturation spectroscopy employed an oscillator-amplifier system of diode lasers, which yielded tunable, single-mode, cw radiation with a power of 200 mW. A part of the laser beam obtained from the master oscillator was picked up using a beam splitter and was used as the probe beam. The other part of the master oscillator beam was injected into the amplifier to obtain the intense pump beam. The probe and pump beams were launched into hydrogen plasmas from the counter axial directions. The probe and pump beams were overlapped carefully.

Figure 1 shows examples of saturated absorption spectra observed at three magnetic field strengths of 60, 300, and 1300 G. The absorption spectrum of the probe beam in the absence of the pump beam was composed of two Doppler-broadened peaks. We observed many dips in the absorption spectrum of the probe beam in the presence of the pump beam. The vertical axes of Fig. 1 are given by $\Delta\alpha/\alpha$, where α is the absorption coefficient of the probe beam in the absence of the pump beam and $\Delta\alpha$ is the difference between the absorption coefficients with and without the pump beam. The magnitude of the Zeeman splitting at a magnetic field of 60 G was smaller than the resolution of the saturated spectrum, and the spectrum shown in Fig. 1(a) is composed of seven fine-structure components and their cross-over signals. The spectra shown in Figs. 1(b) and 1(c), which were observed at magnetic fields of 300 and 1300 G, respectively, are complicated ones with many peaks, but all the peaks were assigned successfully as fine-structure lines of the Balmer-α transition with Zeeman splitting and their cross-over signals.

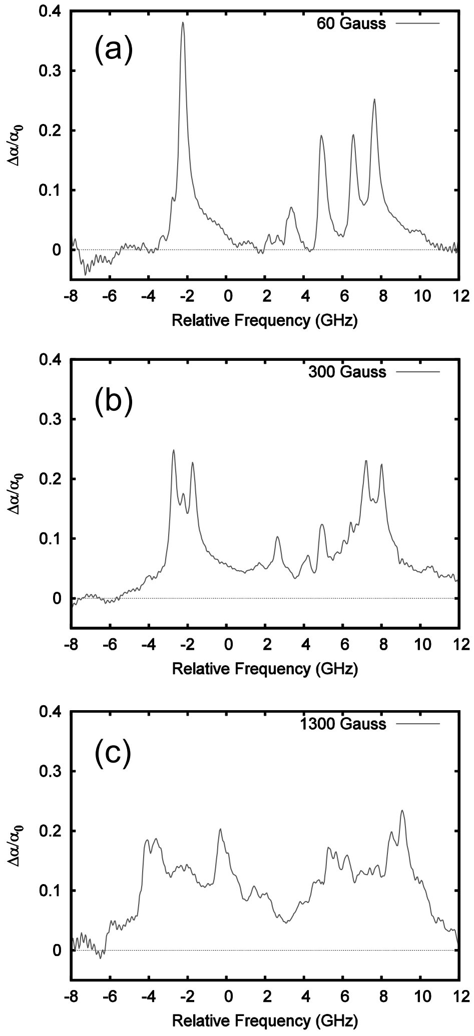

Fig. 1: Saturated absorption spectra of the Balmer-α line of atomic hydrogen observed a magnetic fields of (a) 60, (b) 300, and (c) 1300 G.

An mysterious point that could be seen in Fig. 1 is the existence of broadband components at the bottom of the spectra. The broadband components are not explained by the simple theory of saturation spectroscopy. They were observed more remarkably at strong magnetic fields, high gas pressures, and high plasma densities. We constructed a two-wavelength saturation spectroscopy system employing separated probe and pump laser sources to examine the mechanism of the broadband component. We are measuring the velocity distribution function with hole burnings, which are induced by the pump beam, by scanning the wavelength of the probe laser independently.