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

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A requirement for diagnostics in LHD experiments at NIFS 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 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 structure of the Zeeman-split spectrum of the Balmer-α line is masked by the Doppler broadening. The final goal of this work is to develop a technique of Doppler-free spectroscopy (saturation spectroscopy) at the Balmer-α line of atomic hydrogen.

We developed a system of laser absorption spectroscopy shown in Fig. 1. The light source in this system was a diode laser operated at wavelengths around the Balmer-α line. This diode laser had a wide mode-hop-free tuning range of 140 GHz in the case of slow tuning. Rapid tuning for 60 GHz was also possible within a period of 2 ms, which is a sufficient tuning range for this experiment. We used a linear plasma source operated with pure hydrogen. The laser beam was injected from the longitudinal direction, and the intensity of the transmitted laser beam was measured using an avalanche photo diode via an interference filter.

Figure 2 shows the absorption spectra observed at laser powers of 0.13 and 15.7 mW. The vertical axis of

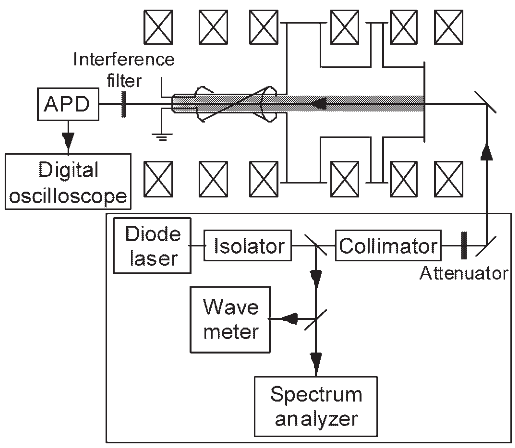

Fig. 1: Experimental apparatus.

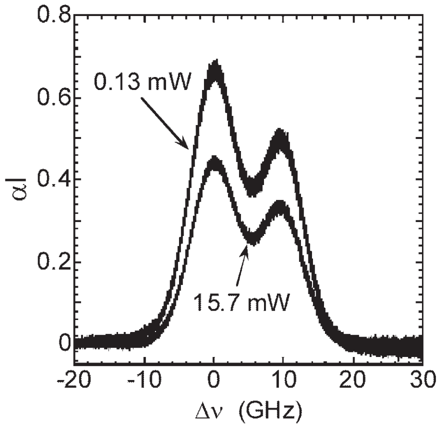

Fig. 2: Absorption spectrum observed at laser powers of 0.13 and 15.7 mW.

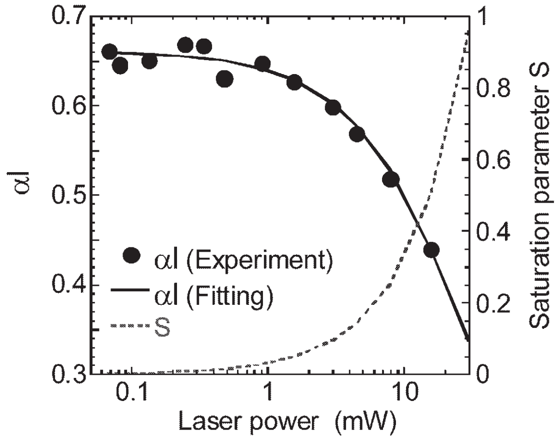

Fig. 3: Relationship between absorption coefficient and the laser power.

Fig. 2 is given by the product between the absorption coefficient α and the absorption length ℓ. As shown in the figure, smaller absorption was observed at a stronger laser power, indicating the saturation of absorption at a high laser power.

We repeated the measurements of absorption at various laser powers. Figure 3 shows $\alpha\ell$ at the wavelength corresponding to the $^2P^o_{3/2} - ^2D_{5/2}$ transition as a function of the laser energy. According to the theory of saturation, a relationship $\alpha = \alpha_0/(1+S)$ is satisfied, where α_0 is the absorption coefficient without saturation and S is the saturation parameter. S is proportional to the laser intensity. The solid curve shown in Fig. 3 shows the fitting between the experimental result and the above equation, and the broken curve represents the variation of S used in the data fitting. According to this result, a saturation parameter of $S = 0.5 \sim 0.6$ is obtained at a laser power of 15.7 mW, which is the maximum power of the diode laser used in this experiment.