Cavity ringdown Lamb dip spectroscopy at Balmer α line of atomic hydrogen for measuring electric field in plasma

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We have reported in a previous work that the sheath electric field can be determined by the Stark spectrum of the Balmer-α line of atomic hydrogen if saturation spectroscopy with a Doppler-free resolution is adopted for measuring the Lamb dip spectrum [1]. However, we needed the pulse modulation of the plasma production to amplify the absorption signal using a lock-in amplifier even in the case that we employed a high-power (1 kW) inductively coupled plasma. The difficulty was caused by the weak absorbance of the Balmer-α line. In this work, we combined saturation spectroscopy with cavity ringdown to measure Lamb dip spectra in low-density cw plasmas.

An inductively coupled hydrogen plasma was generated inside an optical cavity consisting of two mirrors with high reflectivities. A single-mode cw diode laser beam was injected into the cavity. The laser beam was truncated using an acousto-optic modulator when the cavity length was resonant with the laser wavelength. The laser beam transmitted through the cavity was detected using a photodiode, and the temporal decay of the laser intensity after the truncation (the ringdown curve) was recorded using an oscilloscope. As shown in Fig. 1, the ringdown curve was deviated from an exponential curve. The deviation was attributed to the saturation in the initial phase after the truncation because of the high laser intensity inside the cavity. We fitted the experimental ringdown curve with the theory reported by Cancio and coworkers [2]. Based on the fitting shown in Fig. 1, we estimated the ringdown frequency of the empty cavity, the ringdown frequency due to absorption, and the saturation parameter. We obtained the absorption spectrum by repeating the measurement with scanning the laser wavelength. Although the spectrum was seriously noisy, we identified the Lamb dip corresponding to the $2p^2P^o_{3/2}$-$3d^2D_{5/2}$ transition of atomic hydrogen. We observed the Stark splitting of the Lam dip spectrum when we measured it at a distance of 1.8 mm from a planar electrode which was biased at -200 V. We estimated the strength of the sheath electric field from the Lamb dip spectrum with Stark splitting.

[1] S. Nishiyama, H. Nakano, M. Goto, and K. Sasaki, J. Phys. D: Appl. Phys. **50**, 234003 (2017).

[2] P. Cancio, et al., "*Saturated-Absorption Cavity Ring-Down (SCAR) for High-Sensitivity and High-Resolution Molecular Spectroscopy in the Mid IR*" (in *Cavity-Enhanced Spectroscopy and Sensing*, Ed., G. Gagliardi and H.-P. Loock, Springer, 2014, Chap. 4).

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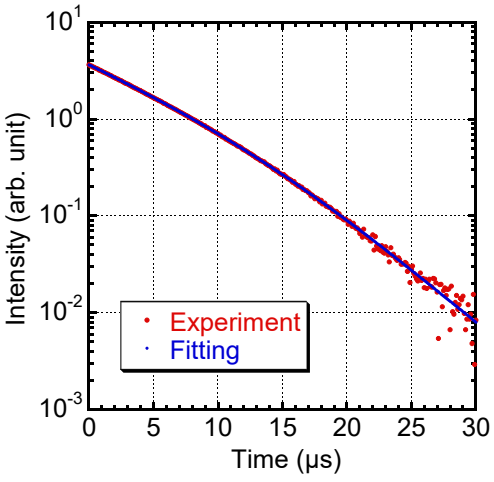

Fig. 1 An example of ringdown curve and its fitting with theory reported by Cancio et al.