

§9. Laser-aided Spectroscopic Diagnostics in a Negative Hydrogen Ion Source

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The investigations on the production processes and extraction mechanisms of negative hydrogen ions are still insufficient in cesium-assisted negative hydrogen ion source for NBI heating. We started this research activity from this academic year with the intention of investigating the behaviors of atomic hydrogen and cesium vapor in a negative hydrogen ion source. In this academic year, we tried to detect the laser absorption signal in the Balmer- α line of atomic hydrogen in the large-scale, arc-discharge negative hydrogen ion source in NIFS.

The system for laser absorption spectroscopy is shown in Fig. 1. The light source was a diode laser (New Focus, Vortex II), which emitted tunable single-mode laser radiation in the wavelength range of the Balmer- α line of atomic hydrogen. The laser beam passed through the plasma in the region close to the grid electrode (the plasma grid) for extracting negative ions. The transmitted laser beam was detected using a photodiode. The wavelength and the scanning frequency of the laser beam were monitored using a wavemeter and a Fabry-Perot interferometer, respectively. The output power of the diode laser was approximately 15 mW, but the laser power injected into the plasma was attenuated to avoid the optical saturation.

We observed no absorption signals in the geometry of simple absorption spectroscopy even in a high arc-discharge power of ~ 80 kW. This indicates a low density of atomic hydrogen at the $n = 2$ state, which may be due to a low electron temperature in the extraction region of the negative ion source. Then, we employed frequency-modulated absorption spectroscopy. In this method, the frequency of the laser beam was modulated in two manners. One was the wide (~ 100 GHz), slow (1 s) scan with a triangle waveform to measure the absorption spectrum in the entire wavelength range of the Doppler-broadened Balmer- α line. The other frequency modulation had a sinusoidal waveform at a frequency of 600 Hz. The second frequency modulation was superposed on the first modulation. The signal from the photodiode was connected to a lock-in amplifier which amplified the signal component at the second harmonic of the sinusoidal frequency modulation (1.2 kHz). The amplitude of the second frequency modulation was optimized experimentally. This method (hereafter “the $2f$ method”) can yield a signal which is similar to the second-order derivative of the absorption line profile with a much higher sensitivity than the simple absorption spectroscopy. The $2f$ component in the amplitude modulation of the laser beam, which occurred simultaneously with the frequency modulation, was subtracted to obtain the correct $2f$ spectrum.

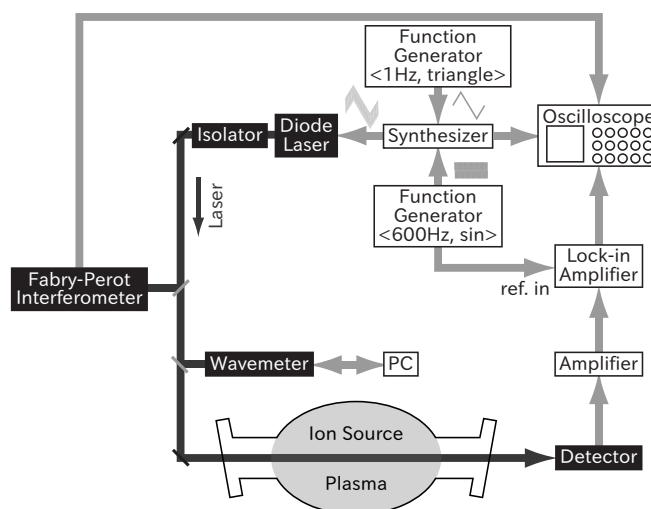


Fig. 1: System for laser absorption spectroscopy in the negative hydrogen ion source in NIFS.

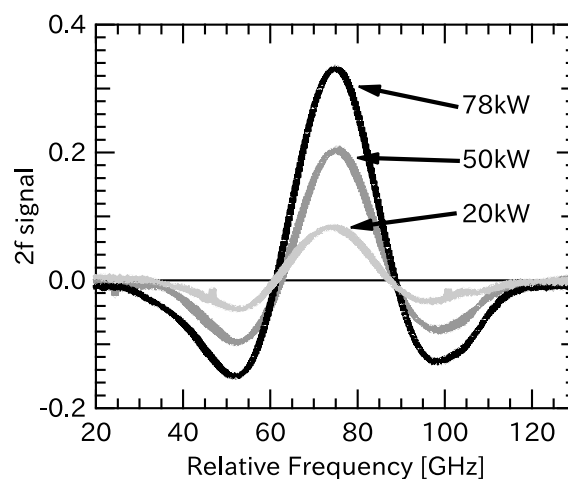


Fig. 2: Examples of $2f$ spectra at the Balmer- α line of atomic hydrogen.

Figure 2 shows typical spectra obtained by the $2f$ method. It is understood from the principle of the $2f$ method that the positive peak is observed at the peak position of the absorption line profile. The negative peaks are observed at the inflection points of the absorption line profile. Therefore, we can estimate the absorption line profile of the Balmer- α line from the $2f$ spectrum. The Doppler-broadening of the absorption line profile estimated from the $2f$ spectra gave us an estimation of ~ 3000 K as the translational temperature of atomic hydrogen in the negative ion source. A greater absorption was observed at a higher arc-discharge power, but the temperature of atomic hydrogen was insensitive to the arc-discharge power as shown in Fig. 2.