High-sensitivity Lamb dip spectroscopy with frequency modulation technique

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The Balmer-alpha line of atomic hydrogen is useful for sheath electric field measurements because of its accessibility by diode lasers and its high-sensitivity to electric field due to the linear Stark effect. The Balmer-alpha line of atomic hydrogen has fine structure components and a large Doppler broadening. Therefore, the Doppler-free spectroscopy is required for highly sensitive electric field measurements. However, it is difficult to apply a simple Doppler-free absorption spectroscopy because the hydrogen plasma is optically thin for the Balmer-alpha line of atomic hydrogen. In our previous work, a high-power and pulse modulated hydrogen plasma was used to demonstrate sheath electric field measurement [1]. The modulation technique limits the applicability of electric field measurement for other plasmas.

In this work, we applied the frequency modulation (phase modulation) technique [2] to enhance the sensitivity of absorption spectroscopy for low-power cw plasmas. In the frequency modulation technique, the laser light frequency is modulated by a high-frequency sinusoidal wave. The laser light of frequency f_0 modulated by frequency f has sideband components at $f_0 + f$ and $f_0 - f$ with antiphase. The modulated laser light is transmitted through a plasma and detected by a photodiode. When the two sideband components have different intensity at the detector, a beat signal with a frequency of f is generated. For Lamb dip spectroscopy, the modulation frequency is chosen to be equal to the Lamb dip width, typically tens MHz, and the RF signal is detected with high sensitivity by an RF lock-in amplifier or narrow band RF rectifier. We confirmed this technique with the argon $4s[3/2]^o_2$-$4p[3/2]_2$ transition in a low-density plasma. The laser light oscillated by a tunable diode laser was phase modulated by an electro-optic modulator with a 50 MHz RF signal. The modulated laser light was split into two beams, an intense pump beam and a weak probe beam, and then injected into the plasma from counter directions. Two beams were crossed in the plasma at a small angle. The transmitted probe beam was led to an avalanche photodiode detector. The detected RF signal was amplified, rectified and the signal intensity was recorded on an oscilloscope. The Lamb dip of 2.5×10^{-3} depth was clearly detected. The results applied to the Balmer-alpha line of atomic hydrogen will be discussed at the conference.

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[2] G. C. Bjorklund, Opt. Lett. **5**, 15-17 (1980)

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