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Observation of Stark Effect on Balmer-alpha line of Atomic Hydrogen with Wavelength Modulated Laser Absorption Spectroscopy

波長変調レーザー吸収法を用いた水素原子バルマーα線における シュタルク効果の観測

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We are developing a sensitive saturation spectroscopy system with the intention of applying it to Stark spectroscopy to measure electric field in plasmas. We applied wavelength modulated laser absorption spectroscopy to enhance the sensitivity for weak saturation signal of hydrogen Balmer-alpha line. The observed saturation spectra showed the fine-structure of Balmer-alpha line with sufficient frequency resolution. The observed spectra also showed peak shift and deforming by the Stark effect at the vicinity of a potential applied electrode.

1. Introduction

The role of electric field in the sheath and presheath regions of process plasma is essential to accelerate reactive ions. The measurement of these electric field is important to understand and to control the ion-surface interaction. In addition, The detail structure of the electric field in the sheath and presheath region is interested from the view point of basic plasma physics.

The Stark effect is used for the measurement of electric field by several researchers. For example, the measurement method based on laser-induced fluorescence-dip spectroscopy was developed by Czarnetzki et al. by using hydrogen atom as the probe particle[1], and Takizawa et al. applied this method using argon atom for various process plasmas[2]. This method has very high sensitivity for electric field, a few volt per centimeter by using of highly excited Rydberg states. However, for excitation to the field sensitive Rydberg states, pulsed tunable lasers are required as light sources, which requires high operation skill and high equipment costs. Adamov et al. applied two-photon absorption laser induced fluorescence (TALIF) method for non-Rydberg ($n = 3$) state of atomic hydrogen[3]. This method also used a pulsed tunable UV laser system for the two-photon absorption scheme.

To reduce the cost and technical difficulty of the light source for sensitive electric field measurement, we are developing an another Stark spectroscopy system to measure the electric field by saturation spectroscopy technique with an tunable diode laser. Saturation spectroscopy is a kind of laser absorption spectroscopy and achieves Doppler-free spectral resolution. It is theoretically expected that the Stark effect of the Balmer-alpha line of atomic hydrogen is larger than the natural line-width for electric field of a few tens volt per centimeter. One of difficulties of this method is the absorption of the hydrogen Balmer-alpha line is too small to detect directly for small experimental plasma source. In this work, we applied the wavelength modulation laser absorption spectroscopy to enhance the sensitivity for absorption with saturation spectroscopy to detect the Stark spectrum of Balmer-alpha line.

2. Experiment

The experimental apparatus is shown in Fig. 1. The plasma source was a inductively coupled plasma source with an internal antenna, which was connected to an RF power supply (13.56 MHz, 1 kW) via a matching circuit. The vacuum chamber was a 26 cm inner diameter and 26 cm height cylinder with con-

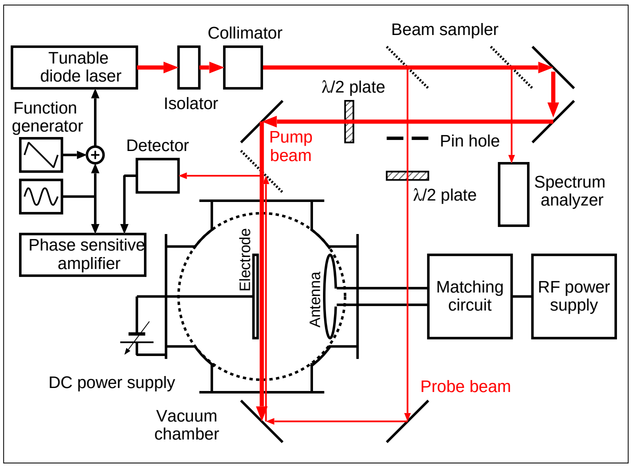

Figure 1: Experimental apparatus.

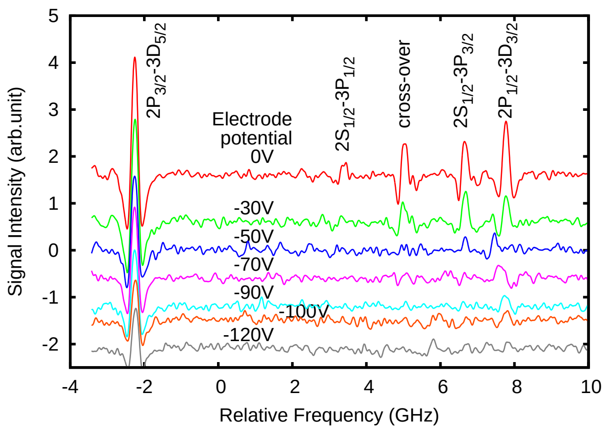

Figure 2: Observed Stark spectra of Balmer-alpha line with various electrode potential.

fronting optical windows. Hydrogen gas was fed into the chamber through a mass-flow controller. The hydrogen gas flow rate was 30 ccm and the pressure was 6.7 Pa (50 mTorr). A planner disc electrode with 150 mm diameter was placed near the center of the chamber and connected to a dc power supply.

The light source for saturation spectroscopy was a tunable cw diode laser, NewFocus TLB-9600. The frequency of the laser was scanned in 1 second over the range of 22 GHz, which covered the Doppler-broadened Balmer-alpha line. The frequency modulation was also applied to the laser. The modulation was 5 kHz sinusoidal waveform and the modulation width was 350 MHz. A part of the laser beam was picked up to a Fabry-Pérot spectrum analyzer to measure the scanning relative frequency.

A small fraction of the laser beam was picked up for a weak probe beam, and the remain intense beam was used as a pump beam. The intensity of the pump beam and the probe beam were 6.4 mW and 0.33 mW, respectively. The probe beam and the pump beam were injected into the chamber on the chord parallel to the electrode surface with counter direction each other. The half-wavelength plates were used to align the polarization of the pump and the probe beams to the direction of the electric field adjacent to the electrode surface. The distance between the surface of the electrode and the optical path was 1 mm, which was almost same the radius of laser beam.

The probe laser beam was picked up by a beam sampler and detected by a photo diode. The signal was amplified by a phase sensitive amplifier, which extracted the 2nd harmonic components related to the referenced modulation signal.

3. Results and discussion

Figure 2 shows the observed spectra with various applied electrode potential. In the case of the electrode potential was 0 V, clear saturation peaks corresponding to the major fine-structure of the Balmer-alpha line of atomic hydrogen were observed. Increasing the applied negative potential, decreasing hight of saturation peaks, and shifting or splitting the peaks except the $2P_{3/2} - 3D_{5/2}$ transition. Theoretically calculated Stark spectra show similar phenomena in the electric field of 0-100 V/cm. However, the structure of the experimental spectrum may be complicated because the saturation spectrum contains some cross-over peaks and the wavelength modulation spectroscopy makes bipolar shape peaks. Detail analysis is required to determine the electric field intensity by the observed spectra.

Acknowledgment

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