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Applications of Saturation Spectroscopy to Plasma Diagnostics

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Saturation spectroscopy is a kind of laser absorption spectroscopy, and achieves a Doppler-free spectral resolution. This technique is widely used in the field of fundamental spectroscopy for the precise determination of the wavelengths of transitions. However, there are a few works of application of saturation spectroscopy to plasma diagnostics. Recently, we have applied this technique to plasma diagnostics in a few studies.

One is an application to Zeeman-splitting analysis of Balmer-alpha line of atomic hydrogen. This study intends to be applied to an analysis of spatial distribution of ionization in the Large Helical Device at the National Institute for Fusion Science. The Doppler-free spectral resolution is required for high temperature hydrogen plasma because the wider Doppler broadening masks the structure of the Zeeman-splitting spectrum. We developed a system of saturation spectroscopy to investigate the basic property of the saturation spectrum with a linear magnetized plasma device and a tunable diode laser. We obtained saturation spectra of Zeeman-splitting fine structures of Balmer-alpha line of atomic hydrogen in various magnetic field strength up to 1300 Gauss. In relatively low magnetic field strength, 60 Gauss, we also obtained simple saturation spectra of the fine structures without Zeeman-splitting. Most of the peaks were assigned to the fine-structure components of the Balmer-alpha line and its cross-over signals, which appeared at the midpoint of two transitions with a common lower level. However, irregular peaks also found at the midpoint of two transitions with different lower levels. These irregular peaks suggest that the population of $2s^2S_{1/2}$, $2p^2P^o_{1/2}$, and $2p^2P^o_{3/2}$ states are exchanged significantly.

The other application is measurement of electron density in low density argon containing plasmas. The peak height of the saturation spectrum is approximately proportional to the saturation parameter, which is reciprocally proportional to the effective relaxation probability of the upper and the lower levels. In the case of the lower level is a metastable state, the effective relaxation probability is sum of the reciprocal of the transit time through the laser beam and the electron impact quenching rate, which is proportional to the electron density. Thus, the peak height of the saturation spectrum has a linear relation with the electron density of argon plasma. We carried out to obtain the saturation spectra of argon $4s[3/2]^o_2$-$4p[3/2]_2$ transition line (763.511 nm) with argon-helium mixture plasmas in various electron density. The observed saturation spectra had wide base component which was caused by velocity changing collisions in the gas. The linear relation between the peak height of the saturation spectrum and the electron density was confirmed with compensation of the effect of the velocity changing collisions.

We also applied the saturation spectroscopy to a measurement of electric field strength in the sheath region of a hydrogen plasma. The electric field is deduced from the Stark spectrum of the Balmer-alpha line of atomic hydrogen. In many cases, a laser-aided Stark spectroscopy detects the perturbed energy levels of highly excited states (or Rydberg states) by electric field. Rydberg states show sufficient Stark effect to weak electric field for Doppler limited spectral resolution spectroscopy. However, it is difficult to detect the highly excited states because the transition probability decreases steeply with the principal quantum number. In this work, we employed the saturation spectroscopy at the Balmer-alpha line of atomic hydrogen to detect the Stark effects of lower-lying states. Since the Stark effect at Balmer-alpha line by weak electric field is much smaller than the Doppler broadening, Doppler-free spectral resolution is required for the Stark spectroscopy. The experiment was carried out in an inductively coupled hydrogen plasma. A grounded electrode was inserted to the plasma, and we measured the fine-structure spectrum of the Balmer-alpha line of atomic hydrogen in the vicinity of the electrode. The light source for saturation spectroscopy was a linearly-polarized single-mode diode laser. We obtained reasonable agreement between the theoretical Stark spectra and the observed saturation spectra. The frequencies of the $2p^2P^o_{3/2}$-$3d^2D_{3/2}$ and $2p^2P^o_{3/2}$-$3d^2D_{5/2}$ transitions shifted toward the low- and high-frequency sides, respectively, with the increase in the electric field strength. According to the experimental result, it is considered that the frequency distance between the above two peaks can work as a measure for determining the electric field strength. The electric field ranged between 15 and 120 V/cm within a distance of 1 mm from the electrode. The detection limit of the electric field was 10 V/cm since we could identify the change of 10 MHz of the distance of the above two peaks.

References

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