§6. Self-reversal in Hydrogen Lyman-α Line Profile

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The self-reversal in the hydrogen Lyman-α line profile has been measured for a high density discharge. The Lyman-α line may be emitted in a narrow layer located at the plasma boundary region. The occurrence of the self-reversal suggests a considerably large optical thickness in this emission layer.

Conventionally, the hydrogen atom density has been evaluated from the Balmer-α line intensity which is related to the $n = 3$ level population, where n stands for the principal quantum number. However, in order to deduce the ground state atom density from the $n = 3$ level population, an appropriate collisional-radiative model and accurate electron temperature T_e and density n_e at the emission location are necessary.

Meanwhile, the radiation trapping of Lyman-α line emission is caused by the ground state atoms, and therefore the absorption strength should be directly related to the ground state atom density. Here, the self-reversal in the Lyman-α line profile is quantitatively analyzed on the basis of the radiation transport equation, and a quantity which corresponds to the product of the ground state atom density and the atom layer thickness is determined.

The Lyman-α line profile is observed with a VUV spectrometer having the focal length of 3 m and a 1200 grooves/mm grating. The spectrometer is equipped with a spatial resolution slit and the spatially resolved spectra are recorded on a CCD (charge coupled device) detector. In the present study we focus our interest on a spectrum taken with a central viewing chord on a horizontally elongated poloidal cross section.

The observation is carried out for a discharge with the internal diffusion barrier (IDB). The radiation is accumulated for 1 s after terminating the pellet injection, during which the line-averaged n_e is decreased from $2.5 \times 10^{20}\,\mathrm{m}^{-3}$ to $1.1 \times 10^{20}\,\mathrm{m}^{-3}$. Figure 1 shows the observed Lyman-α line profile. A remarkable feature of the spectrum is that a dent shows up at the line center which is considered to be the self-reversal due to the strong reabsorption effect. We attempt to deduce quantities related to the ground state atom density from this spectral shape.

Here, a two levels model is employed and a slab geometry having the thickness of L is considered as the radiation and absorption medium. All of T_e, n_e, and the ground state density $n(1)$ are assumed to be constant in the medium. The radiation transport is expressed with an equation as

$$I_\lambda = \int_{-L/2}^{L/2} \eta_\lambda \exp\left[-\kappa_\lambda\left(\frac{L}{2} - x\right)\right] \mathrm{d}x, \tag{1}$$

where I_λ is the observable line intensity profile, and η_λ and κ_λ are the emission and absorption coefficients, respectively. These coefficients are generally the functions of the wavelength λ and the location x and are explicitly written as

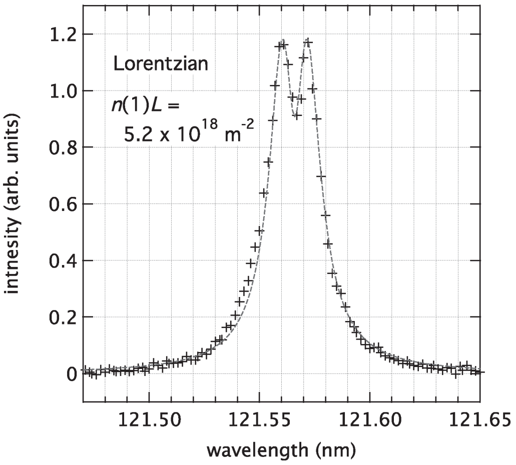

Fig. 1. Example of the observed Lyman-α line profile which exhibits the self-reversal. The dashed-line is the result of fitting in the radiation transport analysis.

$$\eta_\lambda = \frac{hc}{4\pi\lambda} n(2) A(2,1) P_\lambda, \tag{2}$$

$$\kappa_\lambda = \frac{\lambda^4}{2\pi c} n(1) B(1,2) P_\lambda. \tag{3}$$

Here, h and c are the Planck's constant and the light speed, respectively, $n(2)$ is the $n = 2$ level population, $A(2,1)$ and $B(1,2)$ are the spontaneous transition probability and the absorption coefficient for the Lyman-α line, respectively. The function P_λ is the normalized profile common for both of η_λ and κ_λ and is assumed to be constant in the medium.

Since $n(1)$ is constant, κ_λ only depends on P_λ. On the other hand, $n(2)$ or η_λ also depends on the location owing to the non-local absorption processes even under constant T_e and n_e. The spatial profile of $n(2)$, which is obtained as the solution of the Holstein equation[1)], has been evaluated by many workers for various P_λ, such as the Gaussian and Lorentzian profiles, and is expressed as a function of the optical thickness at the line center $\kappa_0 L$.

The fitting formula for the $n(2)$ profile by Molisch et al.[2)] is here employed and eq. (1) is evaluated. The measured line profile in Fig. 1 is found to be well fitted when a Lorentzian profile is considered as P_λ. As the result of fitting $n(1)L = 5.2 \times 10^{18}\,\mathrm{m}^{-3}$ is derived. The fitting result is shown with the dashed line in Fig. 1. This result indicates $n(1) = 5.2 \times 10^{19}\,\mathrm{m}^{-3}$ when the atom layer has 10 cm thickness.

1) Fujimoto, T.: Plasma Spectroscopy, Clarendon Press, Oxford, (2004).
2) Molisch, A. F. et al.: Radiation Trapping in Atomic Vapours, Clarendon Press, Oxford, (1998).