§7. Numerical Experiment for the Neutral Atom Density Measurement in Hydrogen-deuterium Mixed Plasmas

Fujii, K., Hasuo, M. (Kyoto Univ. Eng.),
Goto, M., Kato, D., Morita, S.

The neutral density distribution diagnostics we have previously reported [1,2] utilizes the emission from high temperature neutral hydrogen atoms in core plasma that appears in the far wings (more than 0.5 nm apart from the line center) of the Balmer-α line profile. However in deuterium-hydrogen mixed plasmas, the Balmer-α lines from deuterium and hydrogen atoms will be observed with only 0.2 nm wavelength separation. Therefore, the wing intensities of these lines will overlap each other. In this work, we studied the spectral properties in such mixed plasmas with numerical models, for the purpose of establishing neutral density measurement in mixed plasma.

We modeled a spectral profile from the deuterium-hydrogen mixed plasmas based on the model we have reported for pure hydrogen plasma [1,2] as follows;

$$I_{\mathrm{H}}(\lambda) + I_{\mathrm{D}}(\lambda) = \sum_{i=1}^{N} R_{\mathrm{CX}} P_\alpha (n_{\mathrm{H}} + n_{\mathrm{D}}) \{ n_{\mathrm{H}^+}\, g(\lambda | \lambda_{\mathrm{H}}, \sqrt{kT_i/m_{\mathrm{H}}}) + n_{\mathrm{D}^+} g(\lambda | \lambda_{\mathrm{D}}, \sqrt{kT_i/m_{\mathrm{D}}}) \} \Delta V_i \ ,$$

where R_{CX} and P_α are charge exchange rate coefficient and emission coefficient, respectively, the values of which are similar between deuterium and hydrogen atoms. ΔV_i is plasma volume discretized against the minor radius. T_i is the ion temperature at each minor radius position. $g(x \mid \mu, \sigma)$ is a Gaussian function with mean μ and standard deviation σ.

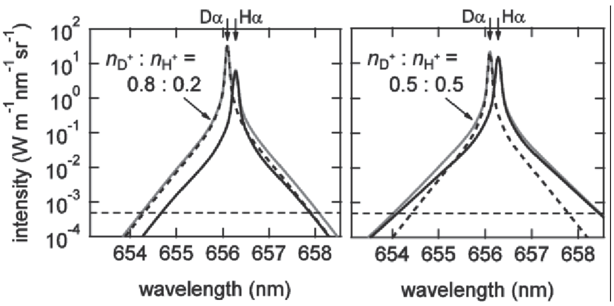

Fig.1 Simulated results of the Balmer-α spectral line profiles for deuterium-hydrogen mixed plasmas. (left) $n_{\mathrm{D}+} / n_{\mathrm{H}+}$ = 0.8/0.2 and (right) $n_{\mathrm{D}+} / n_{\mathrm{H}+}$ = 0.5/0.5 is assumed. The emissions from deuterium and hydrogen atoms are shown with black dashed and solid curves, respectively. The total intensities are shown by gray solid curves. The horizontal dashed line show the noise level by the readout noise of the photo-detector.

The profile depends not only on the ion temperature T_i but also on the deuterium and hydrogen ion densities ($n_{\mathrm{D}+}$, $n_{\mathrm{H}+}$) as well as the total of the neutral atom density ($n_{\mathrm{H}} + n_{\mathrm{D}}$).

We simulated a spectral profile for a deuterium-hydrogen mixed plasma based on a spectrum observed for a pure hydrogen plasma. Figure 1 shows simulated profiles with the deuterium/hydrogen ion density ratio $n_{\mathrm{D}+} / n_{\mathrm{H}+}$ = 0.8 / 0.2 and 0.5 / 0.5. Note that we assume the density ratio is constant along the minor radius. The horizontal dashed lines in the figures show the noise floor determined from the readout noise of the photo-detector.

In the case of $n_{\mathrm{D}+} / n_{\mathrm{H}+}$ = 0.8 / 0.2, the intensities from deuterium and hydrogen atoms in the long-wavelength-side wing (1.0 nm apart from the line center, corresponding to 1 keV ion temperature) are similar. On the other hand, in the case of $n_{\mathrm{D}+} / n_{\mathrm{H}+}$ = 0.5 / 0.5, the deuterium atom emission intensity is much smaller than that from hydrogen atom emission in both sides of the wings. Therefore, in the mixed plasma with hydrogen ion ratio of more than half, it will be difficult to extract the neutral atom density only from the experimental spectral profiles. For estimating the neutral atom density as well as the hydrogen and deuterium ion density ratio in such a case, certain prior knowledge (i.e., assumption) is necessary.

We also developed a transport model of deuterium and hydrogen atoms in the mixed plasma. Since the dynamics of neutral atoms are free from magnetic field and plasma turbulence, their density profiles can be estimated from electron temperature, ion temperature, electron density and hydrogen and deuterium ion densities. We assumed an axisymmetric plasma shape and developed a numerical code to simulate the atom densities with given ion temperature, electron density, and ion density ratio profiles.

The use of this model as a prior knowledge will make it possible to estimate the neutral density distribution from a spectral profile that is physically reasonable.

1) Fujii, K., et al., *Rev. Sci. Instrum.*, **85**, 023502(2014)

2) Fujii, K., et al., *Fusion Science and technology*, **69**, 514 (2016)