Radiation Trapping of He I Resonance Line in Helium Arc Jet Plasmas

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For plasma diagnostics, the line intensity ratio method is one of the useful methods to determine plasma parameters, such as electron temperature and density [1]. In general, a self-absorption process (radiation-trapping), especially, for He I resonance lines, plays an important role in population kinetics and radiation transport. Therefore, for dense plasma, the radiation trapping effect has to be taken into account for precise estimation of plasma parameters.

In our previous study, to evaluate the self-absorption effect, we measured the He I resonance line ($1s^1$S - np^1P) in an arc jet plasma. Interestingly, the forbidden line (1^1S -2^3P: 59.1 nm, intercombination line) as well as He I (1^1S -2^1P: 58.4 nm) was clearly observed by using a vacuum UV (VUV) spectrometer, even though the Einstein A coefficients for He I Ly α is 1.8×10^9 s^{-1}, whereas that of the forbidden line is ~18 s^{-1}. Therefore, we concluded the strong self-absorption process occurred and substantially changed the population distributions in our arc jet device [2,3].

Figure 1 shows a schematic diagram of the experimental setup for the cascade arc plasma source (TPD modified arc discharge) and the VUV emission spectrometer. The discharge channel was 8 mmϕ. The cascade arc apparatus consisted of 11 water cooled intermediate electrodes (molybdenum) between a cathode and an anode (Mo). The cathode was LaB_6 disk with a diameter 28 mm and a hole of 10 mmϕ. The volume of the expansion chamber was 0.2 m^3, and the pressure in the expansion chamber was adjusted by varying the pump operation. The discharge current and voltage were up to 100 A and ≤ 200 V, respectively. The He gas flow was introduced from the cathode side, and its flow rate was 0.42 L/min. The solenoid coil was applied 96 mT at the intermediate electrodes. The weakly ionized plasma was classified into a viscous gas, because the Knudsen number was 0.06 for the experimental conditions. The VUV spectrometer had a focal length of 1.0 m and a diffraction grating of 800 mm/grooves (Acton research corporation, VM-521). The detector was a back-illuminated type CCD camera. The spectrometer measured the plasma emission in 45 degrees with respect to the anode exit. The width of the entrance slit was 50 μm, resulting in the plasma observation area was 2.4 mm in width and 9.9 mm in height around the anode electrode. In this study, the pressures in the expansion chamber were 0.58 Pa, 16.2 Pa, and 44.6 Pa. The exposure time of the CCD camera was 60 s to improve signal noise ratio.

Figure 2 shows the intensity of the He I Ly α (The line profile was integrated against the wavelength). The intensity of the Ly line decreased drastically with increasing the ambient gas pressure. Assuming that the plasma is homogeneous, and the temperature/density variation along line-of-sight and a stimulated emission can be neglected, radiative transfer equation gives the intensity at the position x, $I(x)=I_0\exp(-\kappa x)$ [4]. Here, I_0 is the emission intensity at a position of x =0, κ is the optical thickness, the length of x is set to be 460 mm in this study. The relative values of the optical thickness normalized at 0.58 Pa are calculated to be κ=279 (16.2 Pa) and 769 (44.6 Pa). Consequently, it is found that the plasma is quite optically thick and Ly α intensity decreases by several order times compared with that in an optically thin case.

In this presentation, we will talk about the actual experimental setup and discuss how to evaluate the optical thickness in detail.

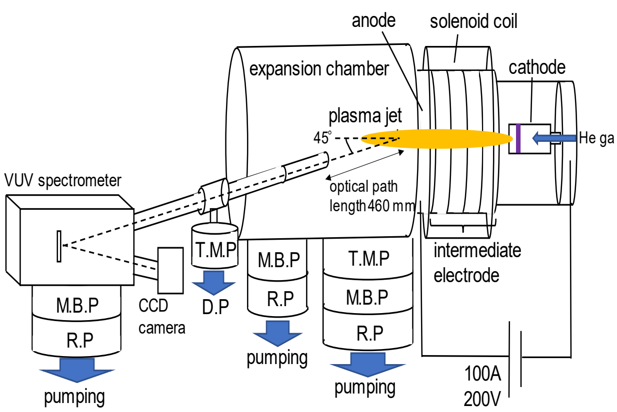

Fig. 1. A schematic view of the experimental setup. Differential pump (DP) was equipped between the expansion chamber and VUV spectrometer to reduce the self-absorption along the line of sight.

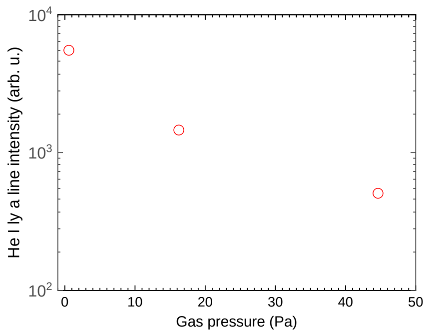

Fig. 2 He I Lyman α line intensity against the ambient gas pressure measured by 1 m VUV spectrometer.

References

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