Evaluation of Optical Thickness in He Cascade Arc Plasmas Using VUV Emission Spectroscopy

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Cascade arc discharge having some intermediate electrodes can generate high-density and high-temperature thermal plasmas in atmospheric pressures[1,2]. In general, an optical thickness becomes high for resonance lines, especially, Lyman α 1s-2p transition, because it has high spontaneous transition probability. A self-absorption (optically thick plasma), therefore, plays a critical role for population kinetics and radiation transport[3]. However, it is quite difficult to estimate the optical thickness quantitatively, because it depends upon the gas temperature and density of the emitter/absorber particles, their spatial distributions, line shape and so on. Thus, in this study we examined the influence of optical thickness by analyzing He I resonance line by changing the ambient pressure along line of sight. In particular, an aluminum (Al) foil which transmits He I Ly α line was used to separate the main vacuum chamber from differential pumping section, resulting in the change of the absorption length. As a result, it was quantitatively clarified that the absorption length-pressure product drastically influenced the optical thickness.

In order to investigate the optical thickness, we adopted a He cascade arc discharge source with a channel diameter of 8 mm,

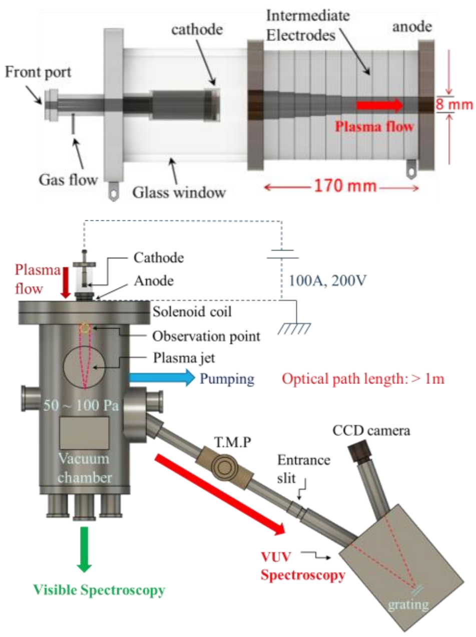

Figure 1. Schematic diagram of the cascade arc source and the VUV emission spectroscopy.

as shown in FIG. 1. The arc device consisted of an anode (W), intermediate electrodes (floating, 10-plates Mo) and a cathode (LaB_6 disk). The total length of intermediate electrodes was ~170 mm. The arc plasma generated between the anode and cathode was expanded through the anode exit into a large vacuum chamber evacuated below 50 Pa by mechanical booster and rotary pumps. He arc plasmas up to100-A discharge (<200 V) were generated under gas flow rates of 0.05 to 0.5 L/min. The emission from He I Lyman transition was observed by using a 1 m VUV spectrometer (800 grooves/mm, a back-illuminated CCD). In order to suppress the absorption between the plasma emission region and the entrance slit of the spectrometer, we installed a differential turbo molecular pump, by which the pressure was kept as low as possible (~5.5 Pa). Some vacuum tubes were prepared (190, 290, and 390 mm) where an aluminum thin foil (800 nm thickness) was glued to the tube tip, by which the ambient gas was isolated from that in the main chamber. As a result, the tube pressures was lowered less than 0.04 Pa, by which the self-absorption in the tube was suppressed substantially. Furthermore, by changing the gas flow rate and tube length, we scrutinized the radiation trapping effect by comparing the measured resonance intensity with the value obtained by solving the rate equation and radiation transport equation.

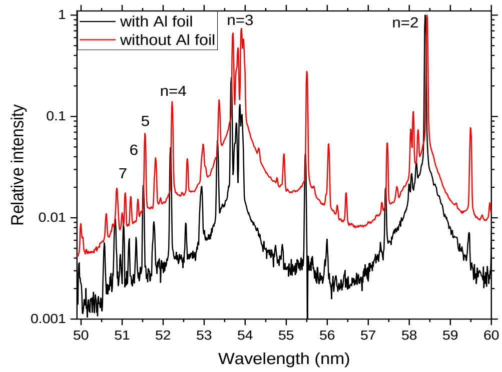

Figure 2. He I Lyman α line spectrum with and without Al foil.

Figure 2 shows the normalized intensity of He I Lyman α line spectrum at a discharge current of 100A and gas flow rate of 0.2 L/min with/without the Al foil. Gas pressure was measured 13.12 Pa and 37.67 Pa respectively. The He I Lyman α line intensity decreases (~ 3.05×10^4 CCD counts) with the Al foil even for high exposure time (5 min) with a vacuum tube of 290 mm. Al foil assist to reduce the He atom density inside the vacuum tube which lowering the self-absorption. Consequently, the He I Lyman α line intensity decreases sharply with the ambient gas pressures. On the other hand, the He I resonance line intensity decreases exponentially without the Al foil because of the influence of the self-absorption process. He I Lyman α line broadened without the Al thin foil (~ 0.039 nm) than that of with the Al foil (~ 0.037 nm) due to doppler effect.

References

[1] S. Namba *et al*, Rev. Sci. Instrum. **87**, 083503 (2016).
[2] S. Namba *et al*, Phys. Plasmas **25**, 113511 (2018).
[3] H. Kawazome *et al*, Plasma Fusion Res. **16**, 2401012 (2021).
[4] Md. Anwarul Islam *et al*, IEEE Trans. Plasma Sci. **49**, 21 (2020).
[5] Md. Anwarul Islam *et al*, Plasma Fusion Res. **16**, 2406011 (2021).