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Self-absorption of He resonance line outside of the plasma

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The analysis of emission spectra is a widely used method for estimating electron temperature and density. Emission spectroscopy has the advantage of providing the properties of plasma through non-invasive methods. In particular, the line intensity ratio method using helium atoms is widely applied to measure electron temperature and density. It has been reported that, for accurate estimation of electron temperature and density, the effect of radiation trapping of helium resonance lines must be considered when using the line intensity ratio method[1].

On the other hand, recent simulation studies suggest that the radiation trapping of helium resonance lines is also significant in the region surrounding the plasma[2]. The simulation results suggest the importance of incorporating radiation trapping outside the plasma for plasma diagnostics using helium atom spectra, but little experimental verification has been done. We have developed the helium resonance line observation system to experimentally verify the effect of radiation trapping around the plasma.

We used VUV, Thomson, Stark, and Doppler measurements to observe the plasma parameters at the same position. The schematic diagram of the experimental apparatus is shown in Figure 1. We employed the cascade arc discharge device to produce high-density helium plasma. A 0.8-μm-thick aluminum filters are attached to the tip of the VUV spectrometer to transmit the VUV photons to the detector, while hampering the helium atoms to go into the spectrometer so that radiation trapping do not happen inside the VUV spectrometer. The position of the aluminum filter can be externally controlled, making it possible to obtain the distribution of the helium resonance line intensity along the optical axis. The effective absorption length due to radiation trapping can be quantitatively estimated from the obtained intensity profile. Furthermore, by using the simultaneously acquired measurement data based on Thomson scattering, Stark broadening, and Doppler broadening measurement, we can analyze the relationship between the radiation trapping intensity around the plasma and the plasma parameters and gas temperature.

Preliminary experimental results on the relationship between the absorption coefficient of the helium resonance line (58.4 nm, $1s^2$-1s2p) and helium atom temperature is shown in Figure 2. As the discharge current increased, both the electron density and the neutral helium atom temperature rose, whereas the electron temperature showed little variation. The effect of radiation trapping on the resonance line intensity became more pronounced at lower gas temperatures, and the absorption coefficient decreased with the increase in the gas temperature. These trends are consistent with the results of radiation transport simulations around the plasma. This behavior is likely attributed to the temperature difference of the helium neutral gas temperature between inside and outside of the plasma, which affects the process of radiation trapping. In this presentation, we will introduce these experimental findings in detail and discuss their implications.

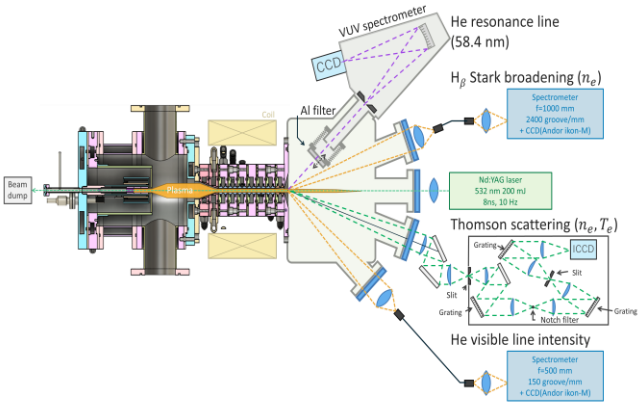

Figure 1 Schematic diagram of the helium resonance line observation system.

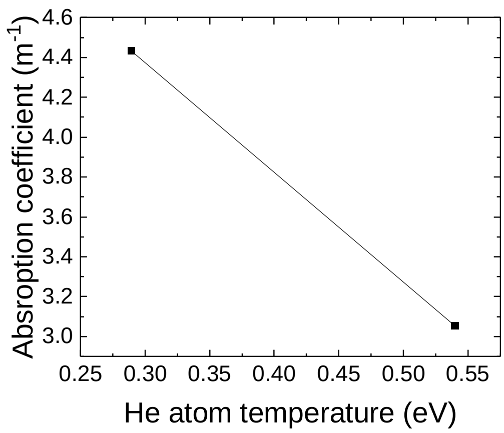

Figure 2 Dependence of the absorption coefficient of the helium resonance line around the plasma on the helium gas temperature.

[1] S. Kajita et al., Physics of Plasmas, **16**,(2009).
[2] R. Shigesada et al., Physics of Plasmas, **29**,(2022).