§13. Spatially Resolved Spectroscopic Study of Arcjet Helium Plasma Expanding through a Rectangular Converging and Diverging Nozzle

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Atmospheric thermal plasmas have been extensively studied for applications in various engineering and scientific fields such as welding, nanoparticle synthesis, and waste treatment. One of the thermal plasmas, an arc plasma expanding through a converging and diverging nozzle with Laval or conical shape is expected as a compact electrothermal engine and thruster. In this study, an arc discharge device with a rectangular-shaped anode nozzle has been developed, so that we can observe the 2D emission profile of thermal arc plasmas generated inside the nozzle. In order to examine the characteristics of arcjet He plasmas, spectroscopic observations were conducted with a visible spectrometer. From analysis of continuum and line emission, we successfully obtained the spatial variations of electron density and temperature.

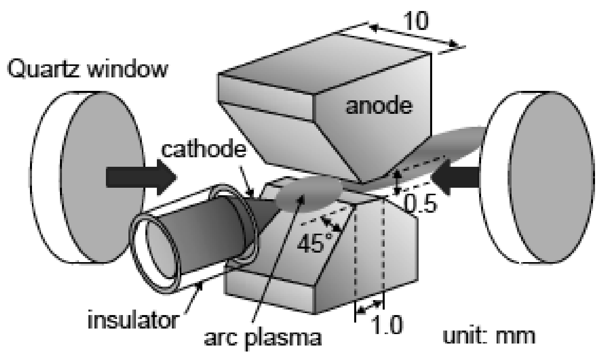

Fig. 1. Schematic diagram of the arcjet generator.

Figures 1 show a schematic diagram of the arcjet generator, which has been developed to directly observe the arc plasma generated in the nozzle. A pair of molybdenum anode was installed in the discharge assembly with a separation of 0.5 mm, which served as a converging-diverging slit type nozzle for the jet expansion. The throat width and length were 10.0 and 1.0 mm, respectively, and the diverging angle was 30°. Quartz windows were employed as the side walls to constrict the lateral gas expansion. The high density He arc plasmas were generated between the anode and a needle-shaped cathode (cerium tungsten (Ce/W) rod). The gap length between the anode and cathode was set to be 1.0 mm, and the discharge current and voltage were up to 50 A and ~20 V, respectively. In order to determine the electron temperature and density, spectroscopic observations along the expansion axis were carried out using a visible spectrometer (G=1200 grooves/mm, f=50 cm) with a CCD camera. Figure 2 shows the 2D profile of He I 587 nm line emission observed using CCD camera and an interference filter.

Intense continuum emission arising from the bremsstrahlung was observed around the nozzle throat.

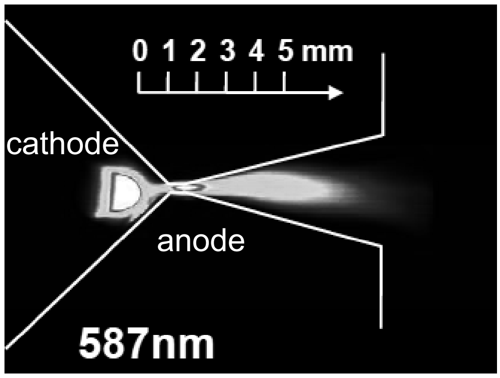

Fig. 2. 2D image of He I 587 nm line emission around the nozzle throat.

Comparison of the experimental spectra with the theoretical bremsstrahlung curve yielded the temperature of ~0.18 eV at the position of x=3.0 mm from the cathode and the current of 50 A. Moreover, in UV region another continuum spectra associated with the radiative recombination process also appeared. This recombination continuum showed that the thermal arc plasma could undergo the rapid cooling due to the adiabatic expansion. The temperature of ~0.15 eV was also determined by the recombination continuum, which was in good agreement with that derived from the bremsstrahlung. The spatial distribution of the plasma temperatures obtained by these methods is shown in FIG. 3 [1].

As for the determination of electron density, we measured the Stark broadening spectrum relevant to He atom (667.8 nm). The density evaluated from the line width was as high as 4.0×10^{15} cm^{-3} for x=0.5 mm and 50 A. In addition, it was found that the spatial distribution of the plasma density decreased linearly, which follows the hydrodynamic expansion from the slit nozzle.

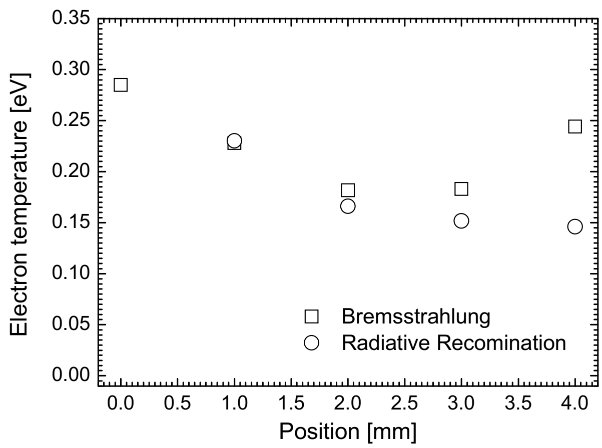

Fig. 3. Spatial variations of the plasma temperature.

[1] Namba, S., *et al.*, Jpn. J. Appl. Phys. **48**, 116005 (2009).