§10. Mechanism of Shock Wave Formation in an Arcjet Helium Plasma

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Atmospheric thermal arc is one of the most important plasmas in the industrial fields, such as weldings, treatment of harmful substances and plasma propulsions. We have studied the hydrodynamics and atomic/molecular processes in arcjets that are generated by adiabatic expansion of the thermal plasma through a supersonic nozzle. Recently, it was found that bright and dark emission structures were formed in the expanding plasmas [1]. The monochromatic emission image observed for the He arcjet plasma (wavelength: He I 382 nm) is shown in Fig. 1. According to the compressible fluid dynamics, this structure is considered to be a shock wave that occurs for an under-expansion in the supersonic free jet [2]. In order to understand the mechanism for generation of this emission structure, the plasma parameters (electron temperature and density) along the jet axis was measured by an electric probe and emission spectroscopic measurements [1, 3].

Arcjet He/Ar plasmas are generated between a cathode (2.4 mmϕ Ce/W) and copper anode. The plasma expands through a converging and diverging conical anode nozzle into the low-pressure expansion region. The discharge current and voltage are I = 30 A and V_d ~ 30 V, respectively. The arc discharge is operated at ~1200 Torr. The pressure in the expansion section is kept to be less than 10 Torr by pumps. A visible spectrometer with 1.0-m focal length and the diffraction grating of 2400 grooves/mm is used to measure high-resolution line spectra (resolution: ~9 pm@632 nm). A Langmuir electric probe is also used to characterize the plasmas. The electrode is cylindrical tungsten with a diameter of 0.5 mm and length of 1.0 mm, and the reference voltage is the anode electrode.

The spatial variations of electron density observed by the spectroscopy and probe method are shown in Fig. 1. For the density determination from the plasma emission, we analyzed the Stark broadening width of He I line spectrum. The reason why the probe measurement yields the lower plasma density than those obtained by the emission spectroscopy can be explained by the appearance of the collisional sheath in high-gas pressures [4]. At the bright emission positions (x=18 and 37 mm) the density increases, so that there is strong correlation between the emission and plasma density. This phenomenon implies that the compression wave created in the expanding jet causes higher plasma and gas densities, resulting in the bright recombining plasma emission, whereas the expansion wave lowers the densities.

According to the aerodynamics, the separation length between the shock cells is described by the Prandtl formula. In this study, the interval of the bright position (~ 17 mm) is in agreement with the theoretical value [2, 3]. As a result, the formation mechanism of the bright and dark emission structure could be well explained from a view point of the compressible fluid dynamics.

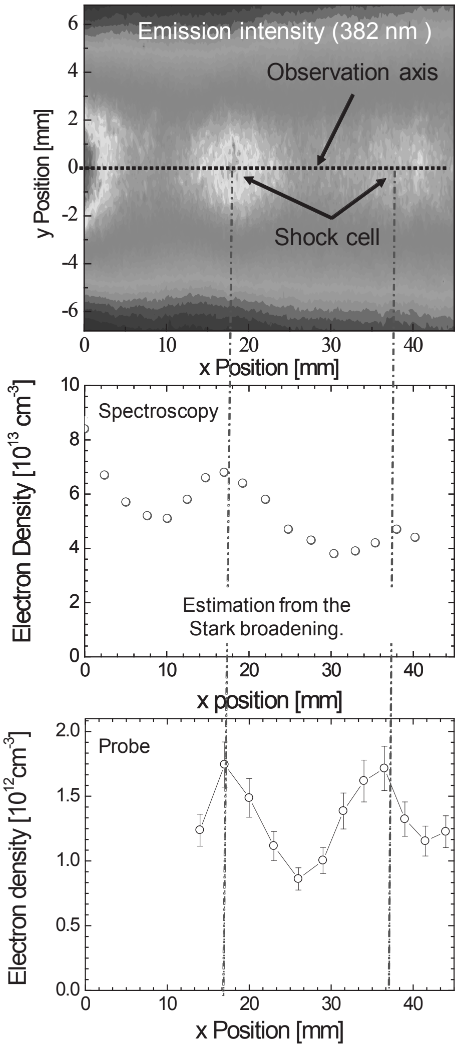

Fig. 1. Spatial variations of plasma parameters. From the top panel, the monochromatic emission image of He I 388 nm, electron densities determined by the Stark broadening spectra and probe measurements, respectively.

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