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

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Arc discharge is one of the most important plasmas in the industrial fields. We developed an arcjet plasma device having a converging and diverging supersonic conical nozzle, by which the hydrodynamics and atomic/molecular processes in plasmas were examined by means of emission spectroscopy [1]. Recently, it was found that bright and dark emission structures were formed in the arc expansion section. Figure 1 shows a photograph of the phenomenon observed for the He arcjet plasma. The variation of the bright emission position in the residual gas pressure implied that the structure was caused by the collision of plasma and neutral particles in the expansion region [3]. 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. In order to understand the mechanism for generation of this emission structure in the arcjet, the spatial distribution of plasma parameters (electron temperature and density) along the jet axis was measured by electric probes and spectroscopic measurements.

Arcjet He 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 a 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 spectrum. Since the jet axis is perpendicular to the entrance slit of the spectrometer, the optical system composed of a lens and two mirrors is used to rotate the plasma image by 90 degrees. A two-dimensional (2D) spatial image of the plasma emission is observed by fully opening the entrance slit. 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.

Figure 1 shows the experimental results on spatial changes of plasma emission intensity, electron density and electron temperature. As clearly seen, around the bright emission regions the density also increases. However, no temperature variation is observed within the error bar. The reason for this could be interpreted that the temperature is too low to be determined accurately.

There is extremely strong correlation between the emission intensity and plasma density. This indicates that the compression wave formed in the expansion region causes higher plasma density, resulting in the bright recombining plasma emission. Conversely, the expansion wave lowers the density.

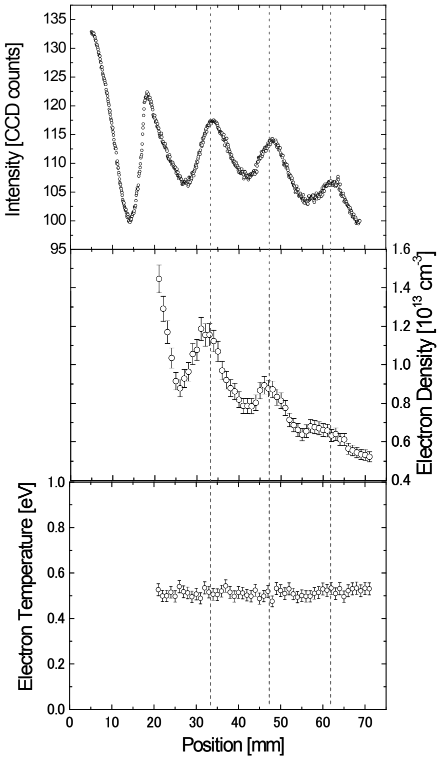

Fig. 1. Plasma parameters around the shock waves. From the top panel, spatial variation of the plasma emission intensity, electron density and electron temperature. The density shows the strong correlation with the plasma emission, implying the shock formation.

On the other hand, the wavelength (λ) of shock cell (separation length between the shocks) calculated from the Prandtl formula was in good agreement with the experimental value (λ~ 17 mm) [2, 3]. Hence, the formation mechanism of the bright and dark emission structure could be explained from the conventional compressible fluid dynamics.

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[2] Zel'dovich, Ya. B. and Raizer, Yu. P., *Physics of Shock Waves and High-Temperature Hydrodynamic Phenomena* (Academic Press, 1966).

[3] Kumagawa, G., Kozue, K., Fujino, S., Matsuoka, L., Endo, T., Namba, S., Ezumi, N., and Tamura, N., J. Korean Phys. Soc. (submitted).