§12. Spatial Distribution of Plasma Parameters of Shock Wave in an Arcjet Plasma

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Recently, various kinds of the shock waves have been extensively studied in the fields, for example, conventional shock by using a shock tube, Bow shock and laser-induced shock wave. When a high pressure gas expands through a supersonic nozzle into vacuum, the shock waves such as barrel shock and Mach disk are frequently formed, where steep density and temperature gradients occur [1]. A diamond shaped shock wave, so called *shock diamond*, is also observed in a detonation of chemical combustion, in which the shock wave and combustion region propagate together.

On the other hand, arcjet plasmas have attracted a great deal of interest in the scientific and engineering fields, such as, fundamental hydrodyamics, atomic and molecular processes, disposal treatment and electric thruster in space. In an arcjet plasma expanding through a supersonic nozzle, we have found that the shock diamond having rotational structure was created. The formation of the shock strongly depended on the experimental conditions in both arc discharge and expansion regions. The detailed conditions for the generation of shocks, however, have been not understood so far. In order to investigate the spatial distribution of the plasma parameters in the shock region, an electric probe measurement was made.

The helium arc plasmas are generated between a copper anode and a cathode consisting of a 2.4-mm-diameter Ce/W rod [2, 3]. The discharge current and voltage are I = 10–30 A and V_d = 30 V, respectively. The electrode gap is around 3 mm, the discharge pressure is up to 1130 Torr, and the gas flow rate is 5.0 L/min. The plasma expands through converging and diverging anode nozzles (having a throat diameter of 1 mm and a divergence angle of 40°) into a low-pressure expansion region. On the other hand, we measure the plasma temperature and density by using an electric probe (single Langmuir probe). The probe electrode is cylindrical tungsten rods with a diameter of 0.5 mm and length of 1.0 mm, and the reference electrode is the anode. The probe assembly can be moved two-dimensionally in the horizontal direction without breaking vacuum. As for vertical direction, a fast scanning system is employed to drive the probe by using a compressed air cylinder. The scanning length and duration of the probe are 0.3 m and 0.8 s, respectively, resulting in the spatial resolution of as high as 2 mm. The probe current-voltage ($I_p - V_p$) characteristics are measured by applying 1-kHz sweep voltage on the probe chip.

Figure 1 shows a two dimensional emission image of the shock wave at a discharge current of 10 A and voltage of 30 V. As clearly seen, the bright emission regions also appear far from the nozzle exit. The relevant electron temperature and density along the jet axis are shown in Fig. 2. Around the bright emission, the density rises drastically, whereas the dark emission regions have lower density compared with the intense ones. The temperature slightly increased at a position of 25 mm, although the variation is within the error bar. This shows 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. For more accurate measurements of the plasma parameters, we employ a double probe method. Moreover, a Mach probe is also used to estimate the supersonic plasma flow.

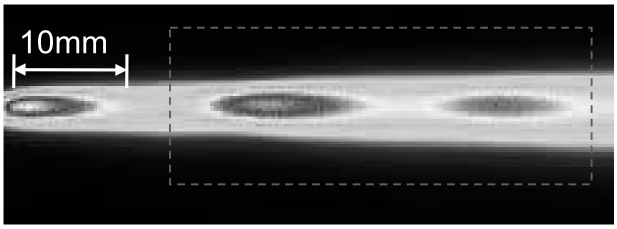

Fig. 1. Two dimensional emission image of the shock wave. The anode nozzle is located at the left (not shown) and the plasma expands from left side to right.

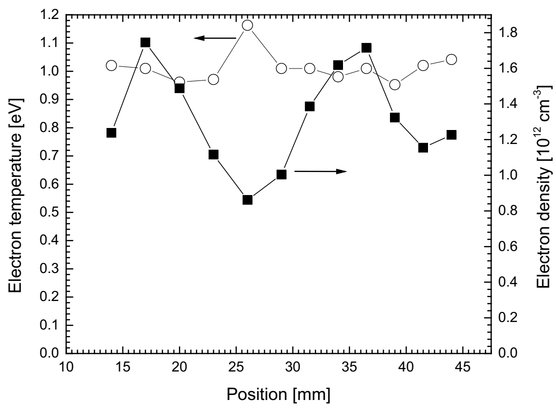

Fig. 2. Spatial distribution of the electron temperature and density along the jet axis (dotted area in Fig. 1).

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[2] K. Kozue, G. Kumakawa, S. Namba, T. Endo, K. Takiyama, K. Sato and N. Tamura, Plasma Sci. Technol. **15**, 89 (2013).

[3] Kozue, K., Nakamitsu, Namba, S., Endo, T., Takiyama, K., Sato, K., and Tamura, N., Plasma and Fusion Research, **6**, 2406054 (2010).