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Measurement of electron temperature and density of an arcjet plasma by an electric probe
静電プローブ法によるアークジェットプラズマの電子温度・密度計測

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It was found that bright-dark emission structure was formed in arcjet plasmas. This structure is quite similar to the shock wave that can often be observed in an under-expansion of compressible fluid. In order to measure plasma parameters with high spatial resolution, we fabricated a Langmuir probe. Preliminary experiments showed that the electron density and temperature at the nozzle exit were ~10^{13} cm^{-3} and ~1.5 eV, respectively. Comparison of these data with the parameters measured by spectroscopic observation implied a formation of collisional sheath, by which the temperature was like overestimated.

1. Introduction

Atmospheric thermal plasmas have been applied to a variety of engineering and scientific fields. We have developed arc plasma sources for compact and low-cost arcjets.

Recently, we found that bright-dark emission structures were formed in our arcjet plasma [1]. These structures are quite similar to the shock wave that can often be observed in an under-expansion of compressible fluid. Because the expanding plasma has a low degree of ionization, major particles can be regarded as neutral gas. Thus, gas flow is mainly described by using conventional compressible gas dynamic theory. We measured plasma parameters to investigate the mechanism for the formation of the bright-dark emission structures by using emission spectroscopy in UV/visible wavelength region. However, line-of-sight measurement hindered the determination of plasma density and density with high spatial resolution. In this study, therefore, we employed a Langmuir probe method. As a result, electron density was n_e ~ 1.1×10^{13} cm^{-3} and electron temperature was T_e ~ 1.5 eV at the nozzle exit. Electron density is estimated to be lower and electron temperature is slightly higher than the expected values. The reason for this is probably caused by the effect of a collisional sheath

2. Experimental setup
2.1 Arc discharge source

Figure 1 shows a schematic diagram of the arcjet source used in this study. He arc plasmas were generated between a cathode (2.4 mmϕ Ce/W rod) and a copper anode. The plasma expanded through a converging and diverging anode nozzles into a low-pressure expansion region. A throat diameter and a divergence angle of the supersonic nozzle were 1 mm and 40°, respectively. The discharge current and voltage were I = 20–50 A and V_d ~ 30 V, respectively. The electrode gap was less than 5 mm, and the arc discharge was operated at a pressure of P < 3000 mbar. The pressure in the expansion section was kept to be P_e~10 Torr by using rotary and mechanical booster pumps. The x-axis was taken to be in the direction parallel to the plasma expansion. The zero position along the x-axis was at the nozzle exit. Thermal plasma generated by the arc discharge with the temperature of a few eV and

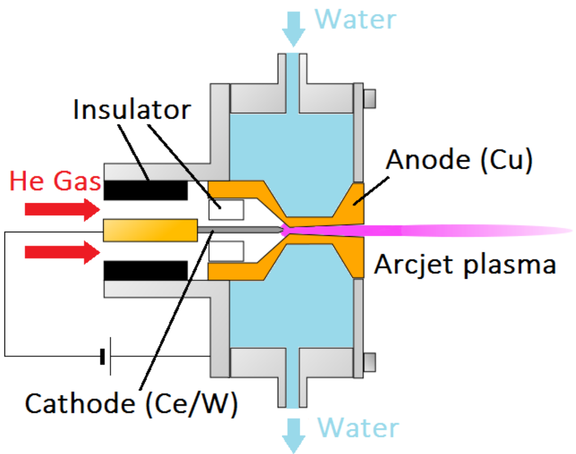

Fig.1 Schematic of the arcjet plasma source

the density of ~10^{17} cm^{-3} turned into a recombining plasma in the downstream from the nozzle due to an adiabatic expansion [2-4].

2.2 Langmuir probe

A Langmuir electric probe were used to characterize plasma parameters. For high spatial resolution measurements, we fabricated a probe with relatively small electrode. The probe tip was a tungsten rod with a diameter of 0.5 mm and a length of 1.0 mm, which was mounted on an *x*-stage to measure the plasma parameters on the jet axis without breaking vacuum. The probe current-voltage (I_p−V_p) characteristics were measured by applying 100 Hz, 50 $V_{p\text{-}p}$ sweep voltage to the probe chip. The electron temperature and density were evaluated by analyzing the I_p−V_p characteristic [5-6].

3. Results and Discussion

In this study, plasma parameters were measured under a condition of no bright-dark emission structures in order to confirm that the probe system worked well. The discharge pressure and current were set to P=1800 mbar and I=25 A, respectively. Figure 2 and 3 show spatial distributions of the electron density and the temperature. As clearly seen, the electron density decreases with plasmas expanding from the nozzle. We obtain the peak electron density of 1.3×10^{13} cm^{-3} and the temperature of 1.4 eV. However spectroscopic measurement showed n_e ~ 5×10^{13} cm^{-3} and T_e ~ 0.4 eV: the density derived by the probe method is lower while temperature is slightly higher than the values obtained by spectroscopic analysis, implying the appearance of a collisional sheath. [7-8]. The collisional sheath hinders the motion of the electrons, where frequent collisions with neutral atom take place. Thus, the electron density obtained by using probe measurements tends to be lower than actual values, because the probe current is decreased due to the collisional sheath. Moreover, the electron temperature is measured slightly higher because low-energy electrons cannot reach the probe electrode. Therefore, we need to employ collisional sheath theory.

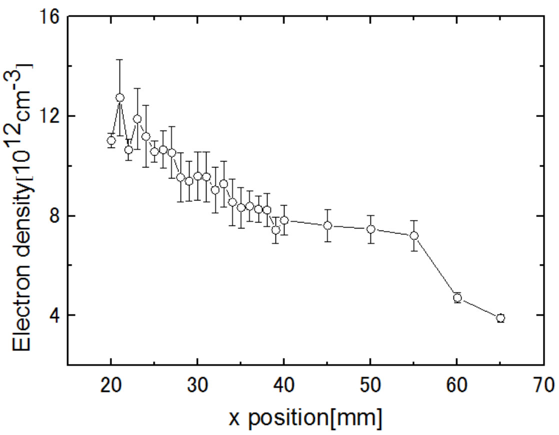

Fig.2 Spatial distribution of electron density

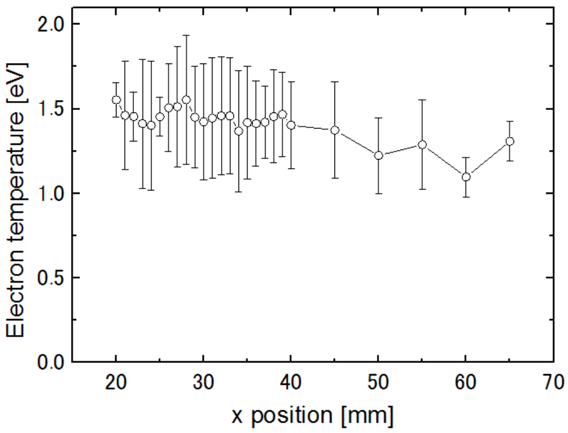

Fig.3 Spatial distribution of electron temperature

4. Conclusion

In order to measure plasma parameters of arcjets in the expansion section, we employed a Langmuir probe method, by which plasma parameters can be derived with higher spatial resolution. As a result, electron density was n_e~1.1×10^{13} cm^{-3} at 20 mm from the nozzle exit and decreased with expanding from the nozzle. Moreover electron density is lower and electron temperature is a little higher than the expected values. The reason for this is ascribed to the effect of the collisional sheath. We need to employ the collisional sheath theory to determine the plasma parameters accurately.

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