Flowfield Observation Using a Two-Dimension-Like Low-Power DC Arcjet

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Abstract

By using the DC arcjet for internal observation, the inner flow and the arc behavior is observed with various operation conditions under the high voltage mode, and it is found that a local increase of the electron density and ionization characteristic is formed just before the transition.

Introduction

In researches of DC arcjet, there are some important trends, such as the stabilization of its operation and the improvement of its durability. In order to investigate them, it is necessary to observe that happens in the flowfield and how it effects to the internal conditions. However, there is little observation in detail about the internal flowfield because of the difficulty to observe it without influences by instrumentation, for example, an electric probe. On the other hand, spectroscopic method is suitable for the observation in view of no influences to the internal circumstances. But in the co-axial arcjet thruster, it is surrounded by metal body. To solve this difficulty, a two-dimension-like DC arcjet for flowfield visualization was designed in the Institute of Space and Astronautical Science(ISAS) and dedicated to the observations even under similar operation conditions of SAGAMI-III which is a 300W-class DC arcjet developed by ISAS. In this paper, it is introduced the ISAS-VAJ, and observation results using it are presented.

ISAS-VAJ

ISAS-VAJ has an anode plate in the shape of nozzle that is sandwiched between two quartz plates so as to enable the inner observations. The alignment of the electrodes has two type, one is slit-type, the other is hole-type. In the case of the slit-type, an example of observation taken by a CCD camera is shown in Fig.1.

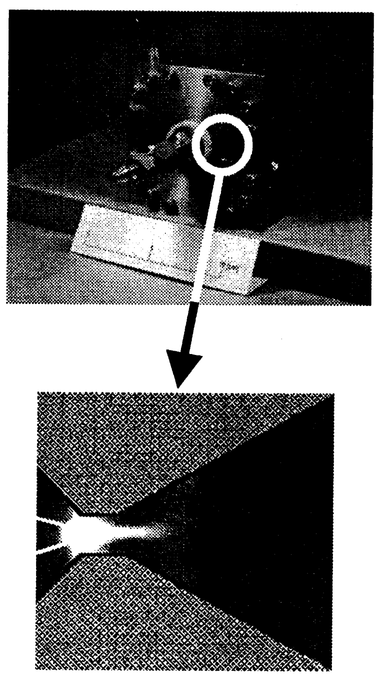

Fig.1: Appearance of ISAS-VAJ and an example of observation.

As the anode nozzle of VAJ is 2-dimension-like, the performance of thruster may be different from

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a real-mode DC arcjet. In Fig.2, the discharge characteristic of ISAS-VAJ is compared with that of SAGAMI-III, and the two is not so different each other. While, the specific power and the plenum pressure of ISAS-VAJ are compared with those of SAGAMI-III in Fig.3, and the both of VAJ with slit-type anode are not similar to those of SAGAMI-III but it is given near the operation of SAGAMI-III in case of the VAJ with hole-type anode. Therefore, it is useful in view of properties to observe using ISAS-VAJ.

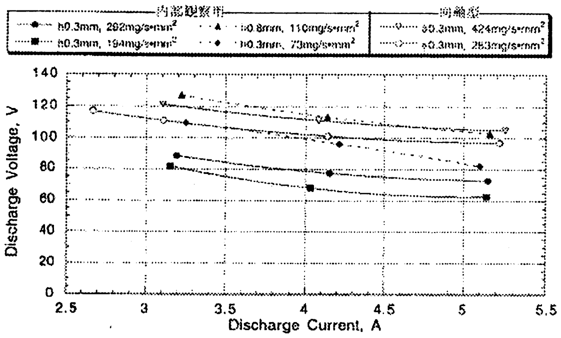

Fig.2: Discharge characteristic

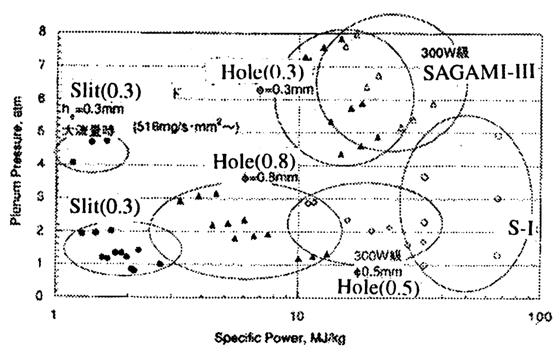

Fig.3: Specific power and plenum pressure

In this paper, the observation is carried out by the CCD camera to take pictures of the arc column, and by a spectroscopic system to investigate the inner plasma. In the operational conditions, the discharge current is set up within 3-7A, and mass flow rate of propellant is set up within 98-343mg/sec which results in the plenum pressure up to 0.75-3atm.

2-D Observation under High Voltage Mode

Electron temperature is deduced from H_β and H_γ lines by Boltzmann plot, it is effective only when the multiplier of population density ratio has -1 ~ 0 value which represents that the population distribution of excited levels obey Boltzmann or Saha-Boltzmann relation. Concerning the VAJ, such region just exists in the constrictor, and the maximum temperature is 10000-16000K as shown Fig.4. Focusing into the high temperature area, the area tends to expand broader as the mass flow rate or the discharge current increases. While it is expanded in two-dimensional directions of the flowfield and the diameter when the discharge current increases because of the flow Joule heating, it expands only in direction of the flowfield with increasing mass flow rate. Near the nozzle wall in the upstream region, there is a local distribution that reveals higher temperature than surrounded area, because the arc column attachment to the wall there takes place.

Electron density is deduced from Stark broadening of H_β line, and its distribution is shown in Fig.5. There is the highest density on the cathode tip, that is, the entrance of constrictor, and decreases as going downstream. The density increases with increase of the mass flow rate, and the gradient is relaxed with increase of the discharge current

Ionization and Recombination is determined the multiplier of population density ratio and the previous two parameters, and the boundary is represented by Byron's boundary temperature and Griem's boundary density. For example, if the electron temperature is lower than the Byron's boundary and the electron density is smaller than the Griem's boundary, then, if the multiplier of population density ratio is positive, the plasma is under the CRC(Caputure-radiative-cascade) phase which represents that recombination is much dominant according to the phase characteristic[1]. The multiplier distribution is shown in Fig.6.

From these results, there is strong ionization characteristic at the cathode tip and near the centerline in constrictor as shown in Fig.7. And around it, there is both characteristics of ionization and recombination. As going downstream, ionization becomes weaker and little ionization characteristic exists in the nozzle. But even in the nozzle upstream region, there is relatively strong ionization characteristic near the wall because of the attachment of arc column, mentioned previously in the electron temperature distribution.

Time-development of 1-D Distribution

The results of the time-development of 1-D distribution on the centerline are shown in Fig.8.

The electron temperature is improper because the multiplier of population density ratio has an invalid value for Boltzmann plot except in constrictor under the high voltage mode, then, detailed explanation is omitted here.

The electron density has a local increase in the nozzle upstream region under the low voltage mode, and the discharge mode transfers to the high voltage mode just after the complete relaxation of the above local electron density hump.

The ionization and recombination behavior coincides with that of the electron density, namely, a local ionization characteristic appears in the nozzle upstream region under the low voltage mode, and disappears just before the transition to the high voltage mode. The plenum pressure is constant in spite of the perturbation of the discharge voltage or the transition. Therefore, the local behaviors mentioned above can give information concerned with the transition.

Understanding of Discharge Mode

From the above, the discharge mode is understood as shown in Fig.9. In the low voltage mode, an edge of the arc column is attached to the wall with in the constrictor. The flow is heated by crossing the arc, but in the opposite, the cold flow gets into the constrictor, and the heated flow is cooled rapidly by the cold flow. On the other hand, the arc column gets into the nozzle upstream region, and is attached to the wall under the high voltage mode. In the constrictor, the arc column exists on the centerline and surrounded by the cold flow. In the nozzle, the flow is heated by crossing the arc. It is suspected that the amount of heating by the arc is greater under the high voltage mode than under the low voltage mode because the cross section of the heating is wide under the high voltage mode. In fact, it is not contradictory to the results by the measurement of thrust performances, for example, specific impulse.

Conclusion

By using the ISAS-VAJ, external observations are enabled with no influences to the inner circumstances. It is thrown light on understanding of the discharge mode by means of spectroscopic method. The flow is heated partially and the arc column is attached to the wall in the constrictor under the low voltage mode, and the arc gets into the nozzle and heats the flow as a whole. It is not contradictory to the results by the measurement of thrust performances. Concerned with the transition, it is found that the electron density and ionization characteristic increase and form a hump in the nozzle upstream region under the low voltage mode, and it disappears just before the transition. It is suspected that the formation and disappearance may be a factor of the transition. The details are related in IEPC-99-031 by author.

References

[1] T. Fujimoto, *BUNKO-KENKYU*, **34**, 6, pp.347 (1985).

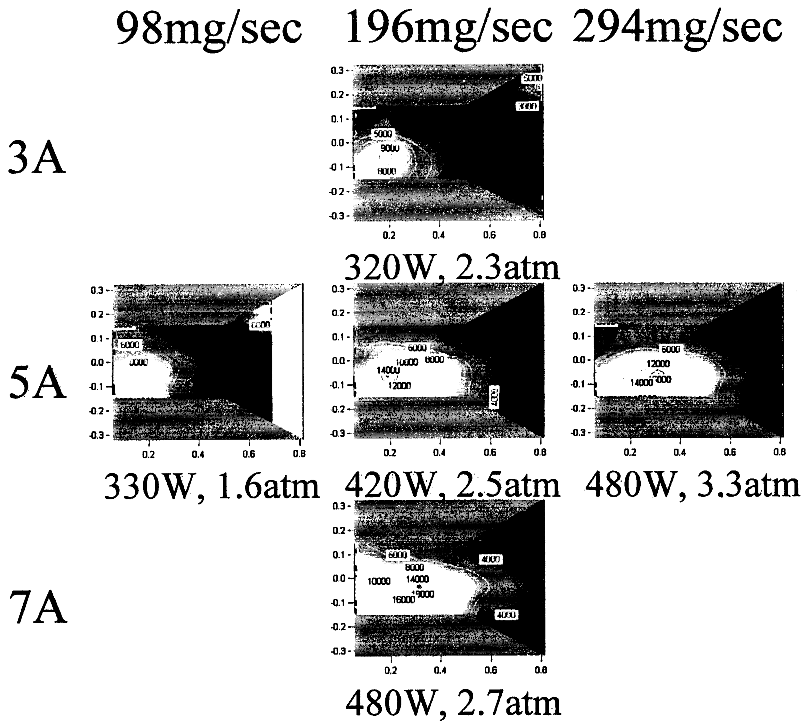

Fig.4: Electron temperature distribution

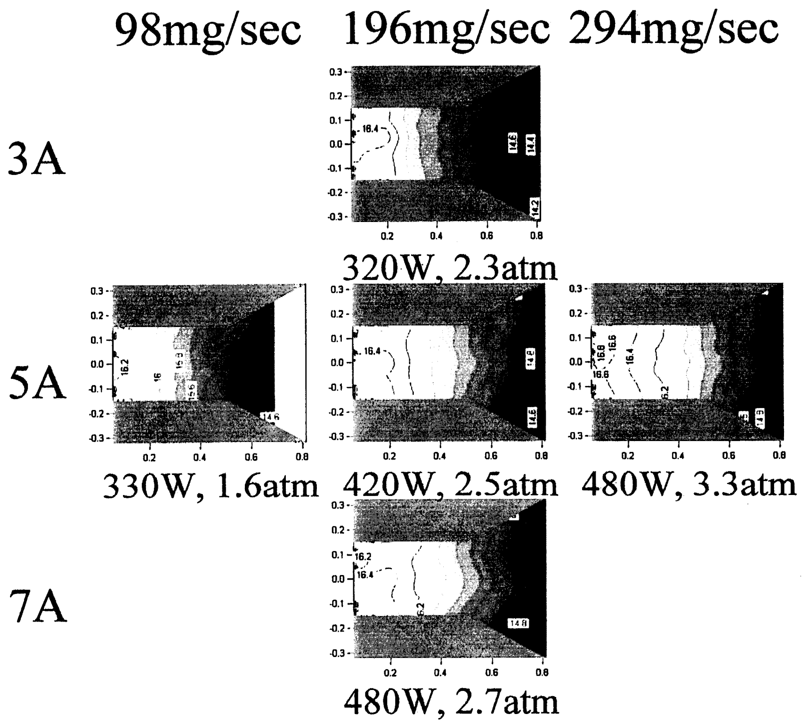

Fig.5: Electron density distribution

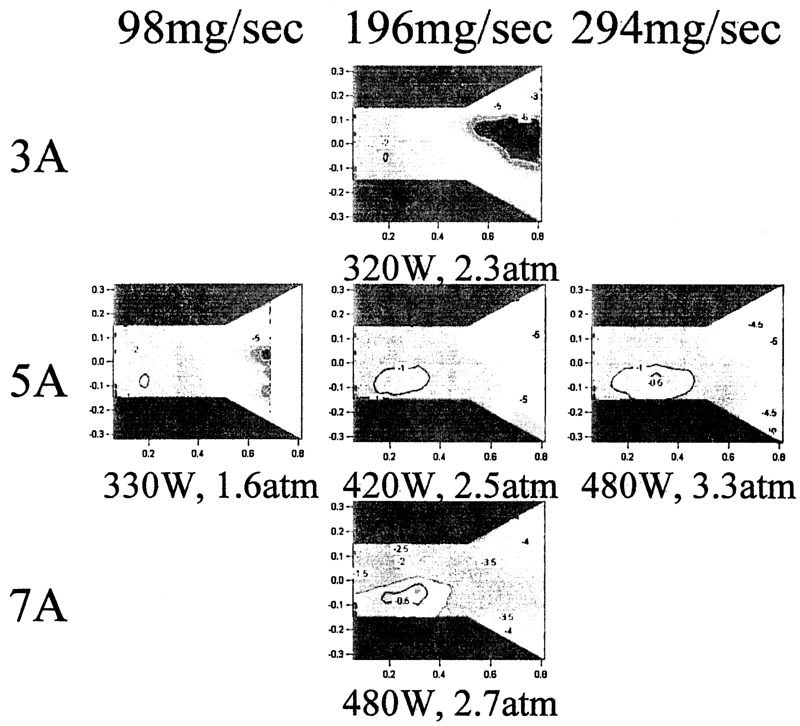

Fig.6: Multiplier of population density ratio distribution

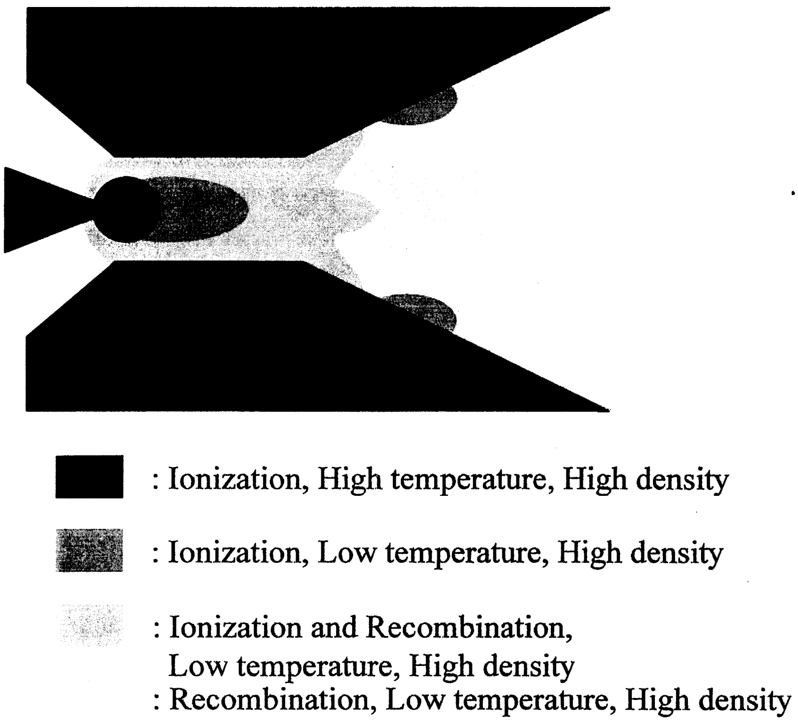

Fig.7: Electron density distribution

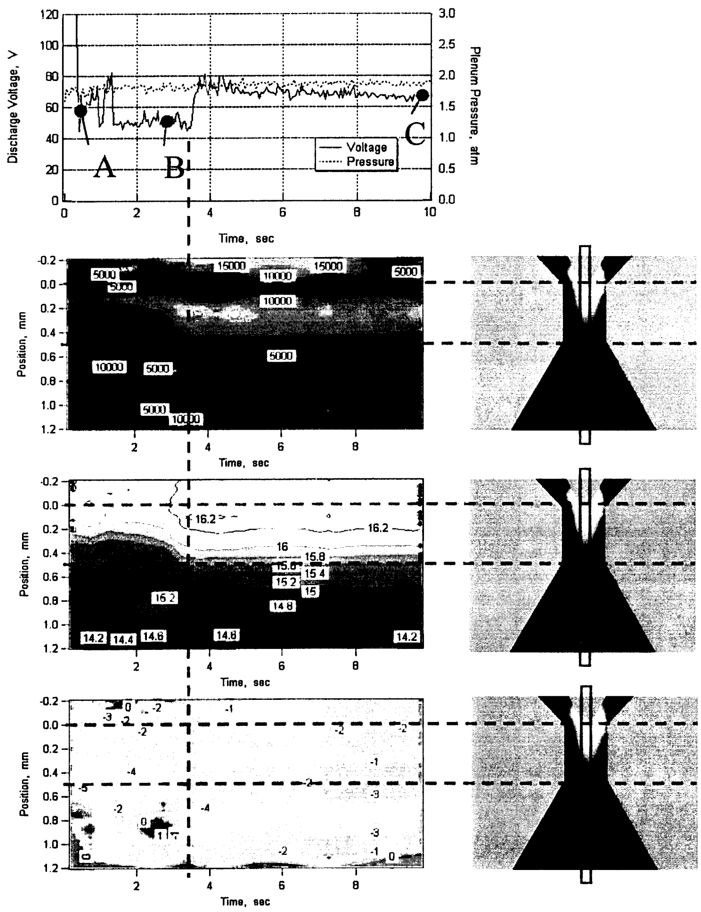

Fig.8: Plasma parameters time-development before and after the transition. From avove, discharge voltage and plenum pressure, electron temperature, electron density and multiplier of population density ratio. Corresponding position is shown by the pictures next to the ones.

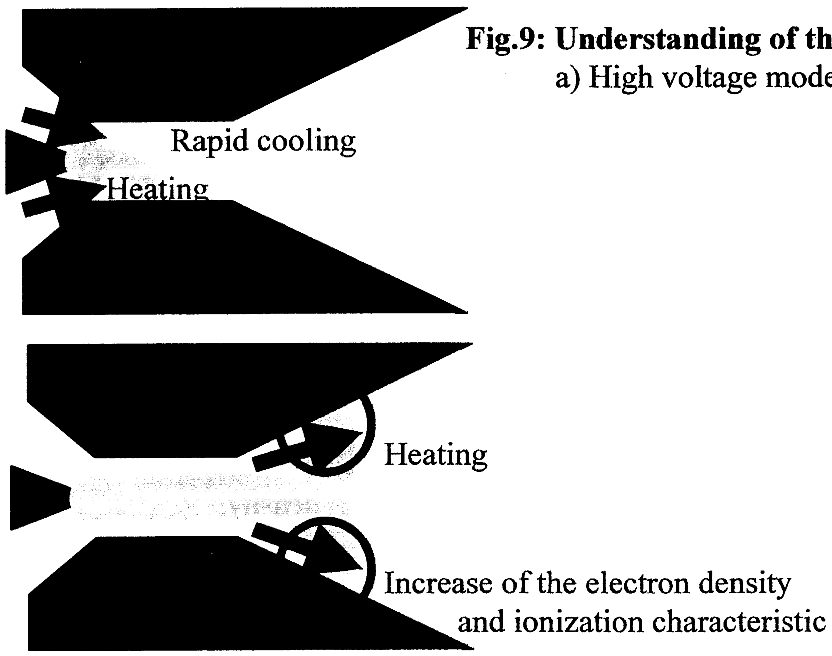

Fig.9: Understanding of the discharge mode
a) High voltage mode, b) Low voltage mode