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周方向非一様性な推進剤によるホールスラスタの放電特性

Discharge characteristics of Hall thrusters by azimuthally non-uniform propellant

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Abstract（概要）

Discharge oscillation suppression by azimuthal non-uniform propellant supply was reproduced with another anode layer Hall thruster, and localized discharge oscillations were investigated with azimuthally located mini-Faraday probes. The local oscillations are analyzed in AC and DC components, and it is found that total discharge oscillation is suppressed mainly by mitigation of local oscillation itself and partially by desynchronization of them by different phase and frequency.

Nomenclature

$\dot{m}_{\mathrm{diff}}$: differential mass flow rate between high/low $\dot{m}$
$\dot{m}_{\mathrm{tot}}$: sum of mass flow rate in high/low $\dot{m}$
$\dot{m}_{\mathrm{high}}$: mass flow rate in high $\dot{m}$ region
$\dot{m}_{\mathrm{low}}$: mass flow rate in low $\dot{m}$ region
⊿: oscillation amplitude

1. Introduction

The term 'discharge current' corresponds to the current flowing to the whole anode region, which is usually used to discuss Hall thruster discharge characteristics. This total discharge oscillation can be thought to originate from all the localized oscillations in the discharge channel. Considering the superposition of local oscillations, it is postulated that total discharge oscillation can be suppressed by suppressing local oscillations. In this research, localized discharge oscillations were investigated in AC and DC components, and influence strength of possible total oscillation suppression mechanisms are discussed.

2. Experimental setup and procedure

2.1 R-58 operation system The anode layer thruster R58 is shown in Figure 1 (a). The thruster was tested in the 2 m diameter, 3 m long space chamber at the University of Tokyo, with a total pumping speed of 37,000 liters/s. A hollow cathode HCN-252 was used as an electron source. The hollow cathode was fed with xenon, and the flow rate was set to 0.29 mg/s for all anode mass flow rate. Xenon to the thruster was fed by two commercial mass flow controller to high $\dot{m}$ and low $\dot{m}$ region separately.

2.2 Azimuthal non-uniform propellant supply To supply non-uniform propellant flow, a plenum chamber and a hollow anode are divided into four sections with separators. The propellant was supplied by two pairs, and mass flow rate for each port was independently controlled by the two mass flow controllers.

As an index of non-uniformity of propellant supply, the normalized differential mass flow rate[1)]

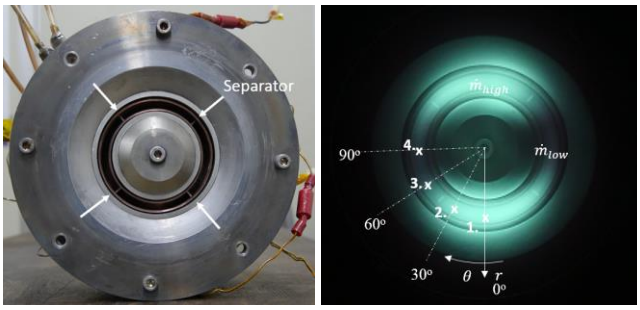
$$\dot{m}_{\mathrm{diff}}/\dot{m}_{\mathrm{tot}} = (\dot{m}_{\mathrm{high}} - \dot{m}_{\mathrm{low}})/(\dot{m}_{\mathrm{high}} + \dot{m}_{\mathrm{low}}) \quad (1)$$

is used, and the experiment was carried out for $\dot{m}_{\mathrm{diff}}/\dot{m}_{\mathrm{tot}}$ = 0.0 to 1.0, here $\dot{m}_{\mathrm{tot}}$ is kept at 2.72 mg/s. The sample photoshoot for $\dot{m}_{\mathrm{diff}}/\dot{m}_{\mathrm{tot}}$ = 1.0 is shown in Figure 1 (b).

2.3 Local ion beam current measurement It is shown by previous researches[2)] through light intensity analysis that discharge current oscillation is proportional to the plasma density fluctuation, which means this can represent local discharge behavior. The current density was acquired by mini-Faraday probes with ∅ 2 mm ion collector cupper rod with ∅ 6 mm guard-head at 3 cm downstream from the hollow anode tip. Signals were measured simultaneously by a 4-ch digital oscilloscope with the sampling rate 5 MS/s.

3. Results and Discussion

3.1 Reproduction check of discharge oscillation stabilization effect Effect of azimuthal non-uniformity on stabilizing discharge oscillation is well reproduced as shown in Figure 2. The two representative regimes, high/low ⊿ regimes, are



(a) Anode layer thruster R66 (b) local measuring positions

Figure 3 The thruster used is in (a) and non-uniform operation and azimuthal local positions of measurement is shown in (b).

checked. The effect of oscillation suppression by azimuthal non-uniform neutrals is confirmed even with a different thruster.

3.2 Investigation of local oscillations in DC and AC part

3.2.1 DC part of local oscillations Beam current non-uniformity resulting from the non-uniform propellant supply is observed. In both regime, as $\dot{m}_{diff}/\dot{m}_{tot}$ increase, azimuthal gradient is increased. Mean current density over all local locations has barely changed as 0.283±0.012 mA/mm^2 for high ⊿ regime and 0.274±0.008 mA/mm^2 for low ⊿ regime.

3.2.2 AC part of local oscillations AC signals of four local oscillations are shown in Figure 3 for high ⊿ regime for two different $\dot{m}_{diff}/\dot{m}_{tot}$ = 0.0 and 0.8, respectively. The plotted data are after digital low-pass filter with cutoff frequency 100 kHz. In case (a), it is observable that all local oscillations is synchronized, causing a high amplitude, so-called breathing oscillation. On the other hand, with non-uniformity, case (b), local oscillations no longer show synchronized behaviors, and the magnitude itself are reduced to about 10% compared to $\dot{m}_{diff}/\dot{m}_{tot}$ = 0.0.

3.2.3 Possible total oscillation suppression mechanisms The following oscillation suppression mechanisms can be considerable for suppressed total discharge oscillation: suppression of local oscillation itself, and de-synchronization of local oscillations by different phase and frequency. It seems that local oscillation suppression itself is the most influential mechanism because amplitude itself is reduced to about 10%.

4. Conclusion

It is confirmed that discharge oscillation suppression by azimuthally non-uniform propellant supply is reproducible in another anode layer Hall thruster. From the present research, the following points are concluded.

- DC components of local oscillations shows it is in proportional relation with the supplied non-uniform propellant while keeping average current density unchanged.

- Mitigation of local oscillation itself has most strong influence on suppressing total discharge oscillation by reducing the magnitude to about 10%. Desynchronization of local oscillations are observed, however influence is considered weak.

Investigation of reasons for local oscillation mitigation by azimuthal non-uniform propellant is reserved for future work.

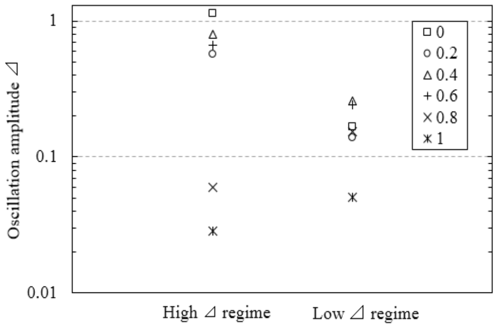
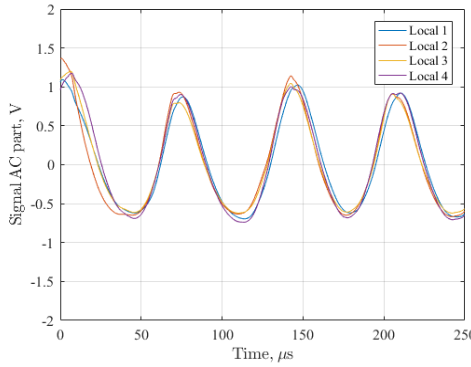
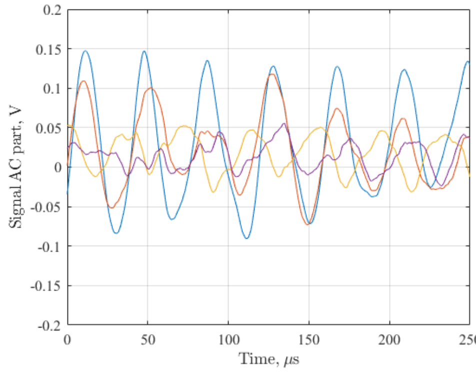


Figure 1 As the $\dot{m}_{diff}/\dot{m}_{tot}$ increases, discharge oscillation is being suppressed in both regimes.



(a) $\dot{m}_{diff}/\dot{m}_{tot}$ = 0.0



(b) $\dot{m}_{diff}/\dot{m}_{tot}$ = 0.8

Figure 2 Frequency behavior at local positions with respect to $\dot{m}_{diff}/\dot{m}_{tot}$. In (a), all local oscillations are synchronized. On the other hand, the discrepancy of phase and frequency is noticeable in (b) low ⊿ regime.

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