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Optical measurements of unsteady phenomena on coaxial pulsed plasma thrusters

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A R T I C L E I N F O

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A B S T R A C T

At Gifu University, to understand unsteady operation phenomena including plasma generation and exhaust processes on a coaxial pulsed plasma thruster (PPT), the luminescence behavior has been studied. In this study, spatial velocity distributions were compared with the results of electrostatic measurement and high-speed photography, and the applicability of a photosensor system to the plume measurements in the region slightly downstream of the nozzle was confirmed. Using the results of the measurements using the photosensor system, the dependence of the impulse bit of the PPT on the cavity geometry was investigated. In addition, direct observations of the ablation process in the cavity of a propellant with slits were carried out. The duration of late-time ablation measured for the propellant with slits is longer than that for the propellant without slits. The results of the observations reveal that the direct observation method is effective for investigating late-time ablation phenomena.

1. Introduction

A pulsed plasma thruster (PPT) is a promising space propulsion system because of its easily controllable properties. Previously, experimental and numerical studies of PPTs were performed labor-intensively [1–14]. At Gifu University, the research and development of coaxial PPTs have also been carried out [10–13]. Fig. 1 shows the schematic of a coaxial PPT. In a previous study, the luminescence behavior was investigated by high-speed photography [11,12]. However, owing to the low spatial resolution, it is difficult to quantitatively evaluate the spatial distributions of a plume by high-speed photography. Thus, we carried out measurements of the plume using a photosensor system consisting of an avalanche photodiode (APD) module and optical fibers, and we compared the plume velocities with those obtained by high-speed photography [13]. The photosensor system enabled measurements with less noise and high sensitivity.

In the present study, to investigate the applicability of the photosensor system to the measurements of the spatial distributions of the plume properties in the region slightly downstream of the nozzle, the axial distributions of the velocities of the first and second peaks of the luminescence from the plume obtained by measurements using the photosensor system were compared with the distributions in a region far from the nozzle by electrostatic measurements using a double probe and the velocities estimated by high-speed photography. The velocities estimated by high-speed photography were analyzed using the time difference between the ablated plasma peaks in the cavity and the plume peaks. On the basis of the velocities obtained by the measurements using the photosensor system, the dependence of the impulse bit of the PPT on the cavity geometry was evaluated.

Thrust performance of the PPT including the impulse bit is strongly affected by the ablation process in the cavity. Thus, using the high-speed camera used for plume velocity estimation, direct observations of the ablation process in the cavity were performed. In these observations, slits were set in the propellant. To confirm the effectiveness of such observations, late-time phenomena were investigated.

2. Experimental procedure

2.1. Coaxial PPT and discharge conditions

A coaxial PPT named GOS-II was used in this study. Teflon tubes were employed as propellants. GOS-II was mounted inside a glass chamber suitable for high-speed photography. The igniter was setup in the cathode nozzle. The capacitance was fixed at 4 μF and the capacitor voltage was fixed at 2 kV in the present study.

2.2. Direct high-speed photography using propellant with slit

Direct high-speed photography of the ablation process in the cavity and the plume was carried out using a propellant with two slits along the line of sight, as shown in Figs. 2 and 3. The slits were covered with glass to avoid the leakage of the ablated gas. A

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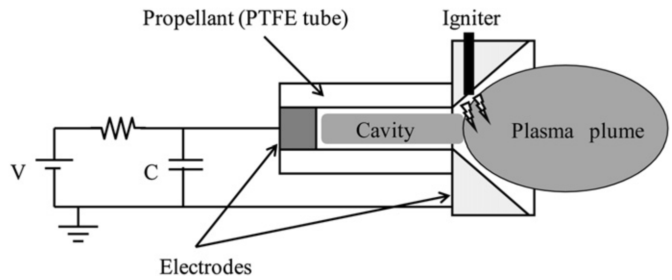

Fig. 1. Schematic of coaxial PPT.

SHIMAZU HPV-2A high-speed camera was used for the photography. This camera can take successive photographs at 30–1,000,000 fps, meaning that it can be used to observe the unsteady phenomena of a PPT operation with a duration of less than 100 μs.

2.3. Plume velocity measurements

To investigate performance of PPT, measurements of plume velocity distributions in the region slightly downstream of the nozzle are required. However, because of existence of high electric potential in the region, electrostatic measurements are unsuitable. Therefore, we performed measurements of plume velocity using a photosensor system. The contactless measurement system enables us to obtain velocity distributions without influences by high electric potential and without disturbing the plume. A schematic of our plume measurement setup using the photosensor system is shown in Fig. 4. To eliminate magnetic noise from a PPT operation with a high discharge current, we used two optical fibers and kept the photodiode away from the PPT system. To obtain a sufficient amount of light for the analysis of the spatial distributions of the plume, a C5331-04 APD module (Hamamatsu Photonics), was used. The APD module enables high-sensitivity optical detection. In addition, the temperature-compensated bias voltage and high-speed current-to-voltage amplifier circuits of the module can keep the gain constant and enable a high time resolution. The active area of the optical fibers is 1 mm. The luminescence from the plume was transported through the optical fibers and detected using the respective APD module. In addition, the APD module was mounted well away from the chamber to eliminate magnetic noise. The axial distributions of axial plume velocity in the region slightly downstream from the nozzle were estimated by a time-of-flight (TOF) method using the peak times of the luminescence observed at two different axial points placed 20 mm apart. To investigate the applicability of the photosensor system to plume measurement, electrostatic measurements using a double probe were carried out in a region away from the nozzle end (see Fig. 4).

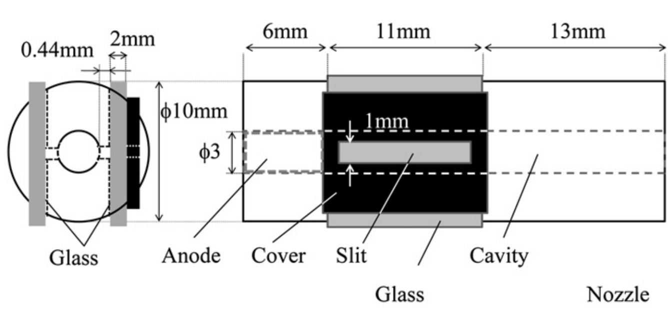

Fig. 2. Schematic of propellant with slits.

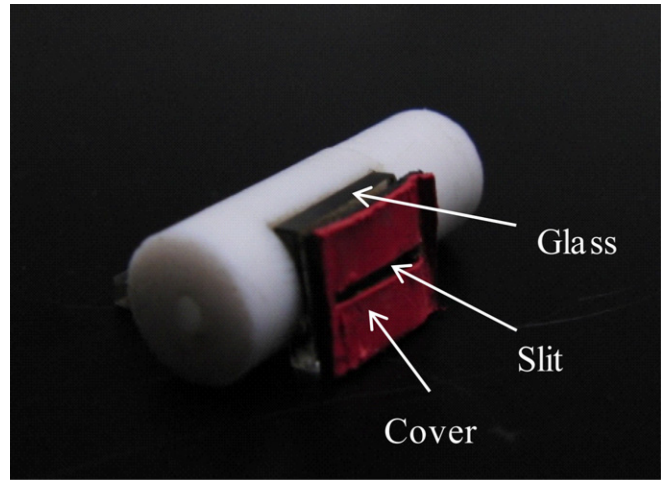

Fig. 3. Photograph of propellant with slits.

3. Results and discussion

3.1. Direct observation of ablation process and plume

The direct observations of the ablation process were carried out using a propellant with slits. First, to investigate the effects of the

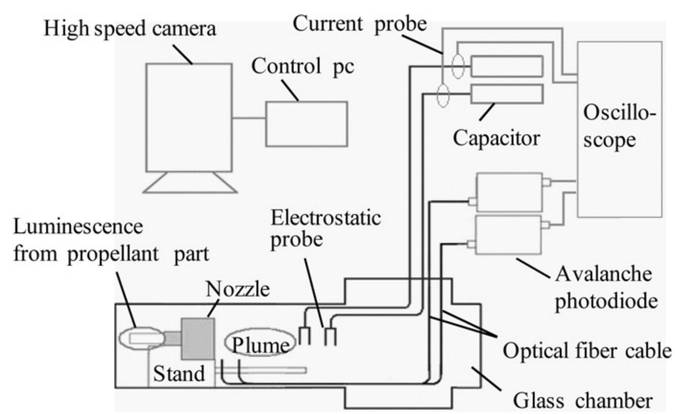

Fig. 4. Schematic of measurement setup.

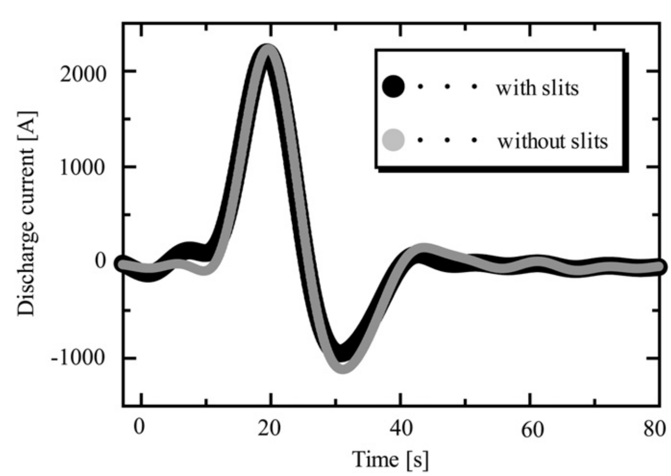

Fig. 5. Discharge current profiles for propellants with cavity diameter of 3 mm and cavity length of 25 mm with and without slits.