Directional Microplasma Thrusters Using Hollow-Core Optical Fiber Array

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Abstract: A newly proposed, directional microplasma thruster (FPT) has been reported as exhibiting greatly increased thrust force. Specifically, intense and energetic atmospheric plasma emissions were achieved by direct plasma jet-to-jet coupling using honeycomb-structured optical fiber arrays. Outer plasma plumes were coupled into the centered plasma plume at the ends of the fibers and merged with a centered plume. The intense plasma jet was made possible through jet-to-jet coupling in seven hollow-core optical fiber arrays. A pure plasma thrust, except for gas thrusts of about 15.7 mN with He and 23.2 mN with Ar gas, was obtained at optimization conditions. This approach to propulsion provides many advantages over present technologies including being flexible, self-addressable, directional, high thrust, low power consumption, small size, light, fast responder, long lifetime, and low cost.

Keywords: plasma thruster, jet-to-jet coupling, optical fiber, electric propulsion.

1. Introduction

Present electric propulsion systems, such as ion or hall thrusters, have lifetime limitations due to electrode erosion caused by ion bombardment [1]. Future missions such as interplanetary flight, and manned or unmanned flight to planets, require high power and high thrust. These needs make the limitation issues more severe. Recently, plasma thrusters have been receiving increased interest given their potential advantages over conventional systems such as lack of an explicit neutralizer, high power and thrust densities, and the absence of biased electrodes. However, these plasma thrusters are still very low thrust - about 11 mN in comparison with ion or hall thrusters [2, 3]. In addition, they also are difficult to change direction because of their limited flexibility. In order to solve the problem, we have been developing and studying advanced, flexible, microplasma thruster (FPT) systems that use hollow-core optical fibers with jet-to-jet coupling to increase thrust performance. Our previous experiments had suggested the usefulness of a multi-tube-array device comprised of seven or more glass tubes with a jet-to-jet coupling phenomenon between adjacent plasma jets. As a result, we achieved intense plasma emission through this direct jet-to-jet coupling [4]-[7].

2. Experiment

Experiments were performed using a simple plasma thruster, a schematic of which is shown in Fig. 1. The plasma thruster device is a honeycomb-shaped structure with a single hollow optical fiber in the center of the array; six remaining hollow optical fibers surround the centered optical fiber. Each optical fiber, within this array has an inner diameter length of 353 μm and an outer diameter length of 477 μm, with the center-to-center distance between the two adjacent optical fibers at 600 μm. The seven fibers were combined through a powered electrode with copper tape. A high-purity helium or argon gas (99.999%) was used as the discharge gas. In order to observe the input of electric energy, the voltage and current waveforms emanating from the powered electrode were measured using a high-voltage probe (Tektronix P6015A) and a current monitor (Pearson 4100). An inverter circuit was used to amplify a low primary voltage to a high secondary voltage. The driving circuit generated a sinusoidal voltage of several tens of kilovolts with a frequency of several tens of kilohertz. Direct-thrust measurements of a thruster were performed using a micro balance in ambient air conditions.

3. Results and discussion

Fig. 2 shows the microplasma thruster, jet array device comprised of seven hollow-core optical fibers. When a sinusoidal voltage waveform with peak voltage of 14 kV and frequency of 33 kHz (corresponding input power of 39 W) was applied to the powered electrode, the intense-glow plasma plume was produced. As shown in Fig. 2 (a), at the He gas velocity of 91.9 m·s-1, and a corresponding gas flow rate of 3.7 slm, the plasma plume was highly

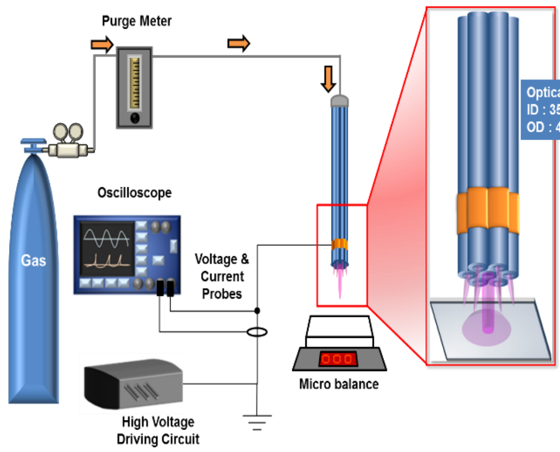
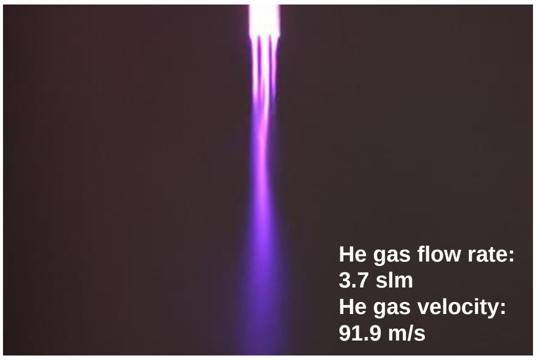
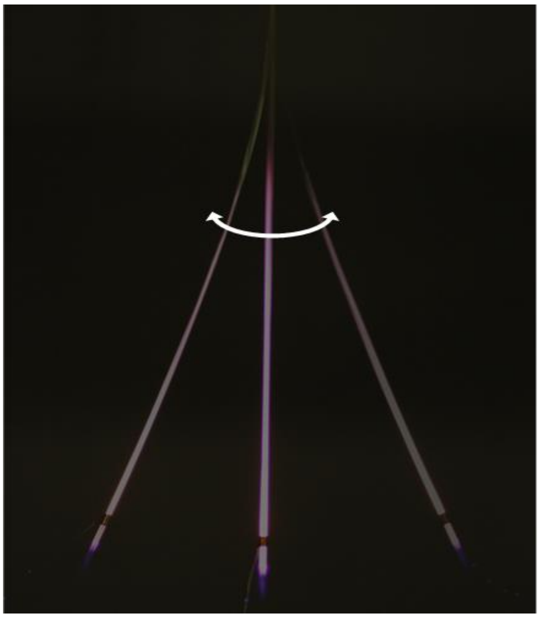


Fig. 1. Schematic diagram of experimental setup and new plasma thruster using hollow-core optical fiber.



(a)



(b)

Fig. 2. (a) Intense plasma plumes with glow discharge (b) flexibility from the new flexible plasma thruster using a single bundle with seven optical fibers.

concentrated at the center optical fiber. Here, outer plasma plumes, produced by this thruster device, were concentrated into the centered plasma plume at the ends of the fibers and merged with the centered plume. The intense plasma jet with stronger plasma emission became possible through a jet-to-jet coupling effect in the seven hollow-core optical fiber arrays. As shown in Fig. 2 (b), this microplasma thruster can easily change its direction because the fibers are inherently flexible yet robust. Fig. 3 shows changes in the maximum thrust under various different structures and discharge conditions such as a single tube with glow discharge, and a single bundle with seven optical fibers with glow and arc discharges. As shown in Fig. 3, using a single optical fiber with glow discharge, thrust was very low. However, using seven optical fibers with jet-to-jet coupling, thrust was considerably increased. In the case of seven optical fibers with arc discharge, maximum thrust of about 15.7 mN with He and 23.2 mN with Ar gas were obtained at optimization

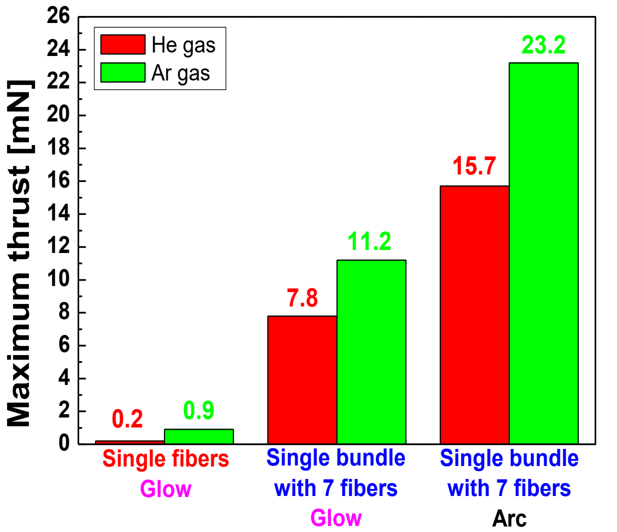


Fig. 3. Comparison of maximum thrust under different structures and discharge conditions such as a single tube with glow discharge, and a single bundle with seven optical fibers with glow and arc discharges.

condition. Discharge and thrust characteristics, effective electron temperatures, and a more detailed mechanism relative to the newly proposed flexible microplasma thruster with jet-to-jet coupling are under study and will be discussed in detail at a later time.

4. Conclusion

Described in this study is initial development of a microplasma thruster system using hollow-core optical fibers with jet-to-jet coupling. With this thruster, a maximum thrust of about 15.7 mN with He and 23.2 mN with Ar gas was obtained at optimization conditions. This microplasma thruster can also easily change its direction because the fibers are inherently flexible yet robust. In addition, such a flexible microplasma thruster system has no lifetime limitations. Thus, it is expected these experimental results will help enhance thrust characteristics in microplasma thrusters used for interplanetary flight, and manned or unmanned flight to the planets.

5. References

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