A laser-electrostatic hybrid thruster

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Abstract: We experimentally estimated the ion energy distribution in a laser-electrostatic hybrid thruster using a retarding potential analyzer. From the ion energy distributions, the most probable velocities of ions were estimated. It was shown that the velocities of ions increased (from 31 to 51 km/s) with augmentation of acceleration voltages (from).

I. Introduction

Small-sized onboard laser plasma thrusters are under significant development with rapid evolutions of compact , high-power laser systems[1-3]. One advantage of such newly developed laser thrusters is the use of solid-state materials as propellants. Because these laser propulsion systems use solid propellants, they do not require tanks, or piping systems, which are necessary for thrusters with liquid or gaseous propellants. Therefore, such laser thruster systems can have simple and compact designs. In addition, the thrust can be significantly controlled by varying the input laser power. We had previously conducted a preliminary study on a laser-electric hybrid propulsion system[4-7] to further improve the thrust performances and simplify conventional laser propulsion systems.

Figure 1 shows the relation between the specific impulse and the thrust density of various propulsion systems. As for the laser-electric hybrid propulsion system, wide operation from the electrostatic acceleration mode to the electromagnetic acceleration mode is possible as shown in Figure 2. The specific impulse and the thrust density can be changed according to the mission compared with other propulsion systems.

A schematic of our laser-electric hybrid acceleration system is shown in Figure 2. The basic principle of laser ablation thrusters is that a laser ablation plasma, induced through laser irradiation on a solid target, is further accelerated using an accelerator grid. Because the laser ablation plasma of initial velocity of ~15 km/s[6,7], is further accelerated by through an electrostatic or electromagnetic method, the thrust and specific impulses can be significantly increased. When a long-term space mission is done, this new propulsion system becomes big help.

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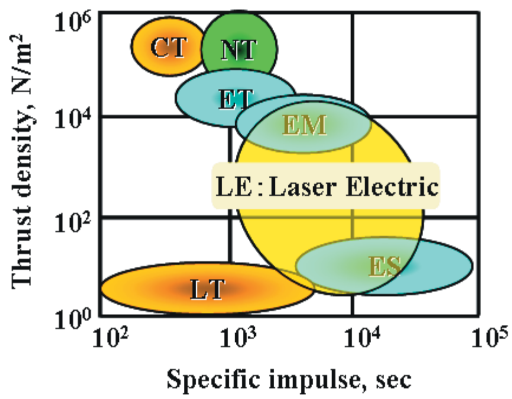
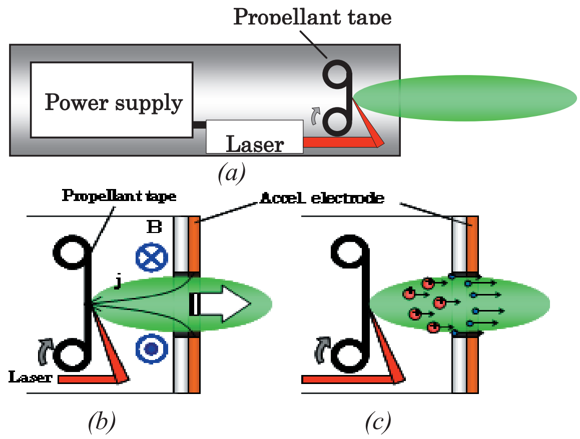


CT : Chemical Thermal , NT : Nuclear Thermal
ET : Electrothermal , EM : Electromagnetic
ES : Electrostatic , LT : Laser Thermal
Figure 1. Thrust density and specific impulse of various propulsion systems.



(a) pure laser thruster, (b) laser-electromagnetic hybrid thruster, (c) laser-electrostatic hybrid thruster.
Figure 2. Schematics of laser ablation thrusters.

II. Laser-Electric Hybrid Acceleration Thrusters

In laser-electric hybrid acceleration thrusters, the acceleration regimes of the laser ablation plasma can be classified into three types, according to the electrode configuration, plasma density, and electrical input power (voltage and current), i) electrostatic acceleration, ii) electro-magnetic acceleration, and iii) electro-thermal acceleration. Especially for the laser ablation plasma, depending on laser conditions such as pulse energy, fluence, etc., plasma density distribution can be widely controlled. Moreover, this can also be increased using additional electric discharges.

Therefore, by optimizing the electrode configuration to facilitate additional electric acceleration and by controlling the power source (voltage and current), a propulsion system that adapts to all the aforementioned acceleration regimes can be constructed using one thruster configuration. Such a system enables a robust conversion between high specific impulse operation and high thrust density operation according to mission requirements. The two types of acceleration schemes that are currently being investigated are described in the following subsections.

III. Experimental Apparatus

A schematic illustration of the laser-electrostatic hybrid thruster is shown in Figure 3. The hybrid thruster consists of a Cu target (propellant), acceleration electrode, and a laser oscillator. The Cu target was mounted on an X-Y stage to refresh the irradiated surfaces. For the laser oscillator, an Nd:YAG laser (LAMBDA PHYSIK, wavelength: 1064 nm, pulse energy: 340 mJ/pulse, pulse width: 5 ns, repetition rate: 10 Hz) was used (shown in Fig. 4 and Table 1). Laser ablation plasmas or ions were accelerated by the acceleration electrode consisting of 0.5 mm-thick Cu plates with a hole of 20 mm in diameter. The Kampton® tape of 100 µm in thickness was used as an insulator for the acceleration electrode.

Based on our previous measurements of electron temperatures and densities of a laser ablation plasma for the same configurations, a range of distances (Z: target and acceleration electrode gap) and a distance of 120 mm between the target and acceleration electrode were chosen for the effective electrostatic acceleration of ions. The target was biased from 0 to 150 V relative to an acceleration electrode potential, where applied acceleration voltages on the acceleration electrode varied from 0 to -150 V.

The ion energy distributions exhausted from the thruster were estimated using a retarding potential analyzer (RPA) consisting of 4 grids. The experimental apparatus is shown in Figure 5. The RPA was placed 200 mm away from the surface of the propellant target. The ion current was amplified using an amplifier (DC to 10 MHz) and was captured with an oscilloscope (Tektronix, TDS3034B; sampling rate: 2.5 GS/s; frequency bandwidth: 300 MHz).

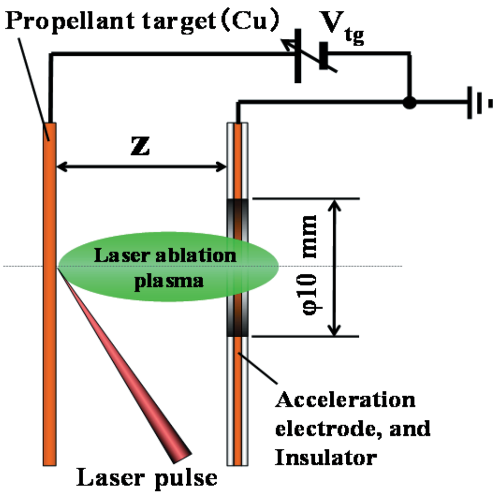


Figure 3. Laser-electrostatic hybrid thruster.


Figure 4. Nd:YAG laser.

Table 1. Specification of Nd:YAG laser.

wavelength	1064 nm
pulse energy	340 mJ
repetition rate	10 Hz
pulse width	5 ns
Peak power	0.17 GW
Beam diameter	7 mm

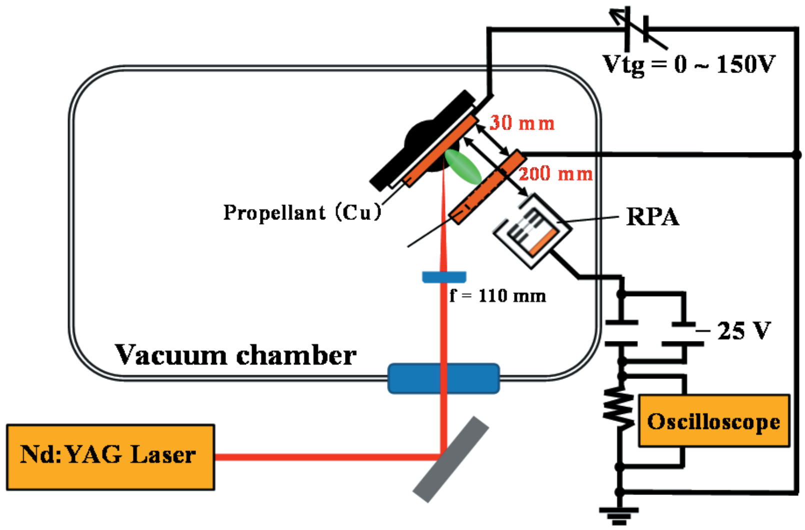


Figure 5. Experimental setup.

IV. Results and Discussion

Variations of peak ion currents with respect to changes of grid voltages of retarding potential analyzer (RPA) for various acceleration voltages (0 ~ -150 V) of the acceleration electrode are plotted in Figures 6 to 9. From the derivatives of these plots by grid voltages V, velocity distributions of ions, namely dIi/dV, were estimated and plotted against velocities of ions in Figures 10 to 13, in which ions were assumed as singly ionized cupper ions (Cu+).

From the ion energy distributions, the most probable velocities of ions were estimated and replotted in Figure 14 for various acceleration voltages. It can be seen that the velocities of ions increases (from 31 to 51 km/s) with augmentation of acceleration voltages (from 0 to -150 V).

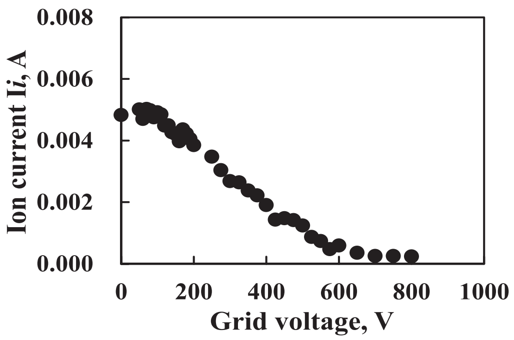


Figure 6. Variations in ion current with respect to grid voltage of RPA. (Acceleration voltage: 0V)

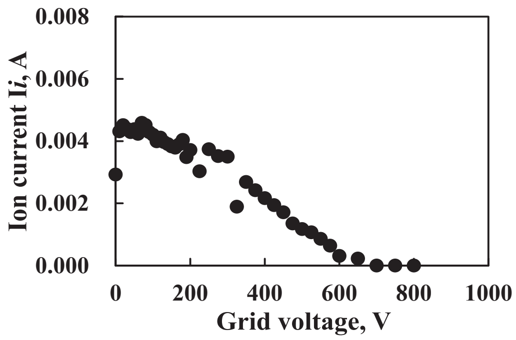


Figure 7. Variations in ion current with respect to grid voltage of RPA. (Acceleration voltage: -50V)

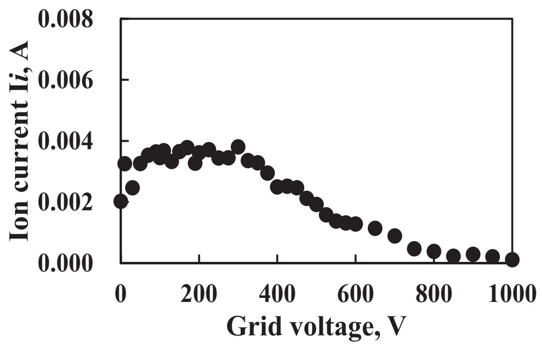


Figure 8. Variations in ion current with respect to the Grid voltage of RPA. (Acceleration voltage: -100V)

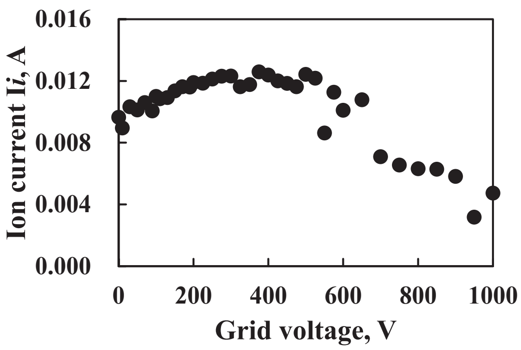


Figure 9. Variations in ion current with respect to the Grid voltage of RPA (Acceleration voltage: -150V)

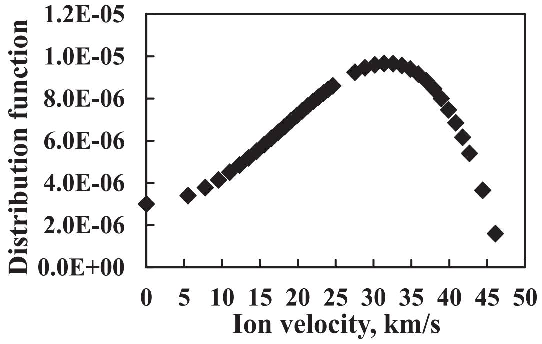


Figure 10. Ion velocity distribution (dI_i/dV) for acceleration voltage: 0V.

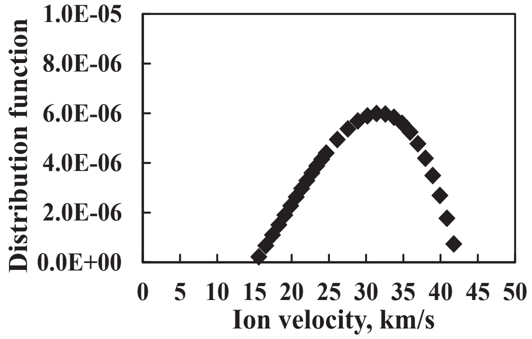


Figure 11. Ion velocity distribution (dI_i/dV) for acceleration voltage: -50V.

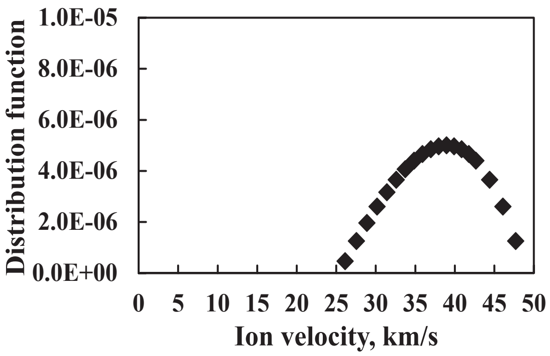


Figure 12. Ion velocity distribution (dI_i/dV) for acceleration voltage: -100V.

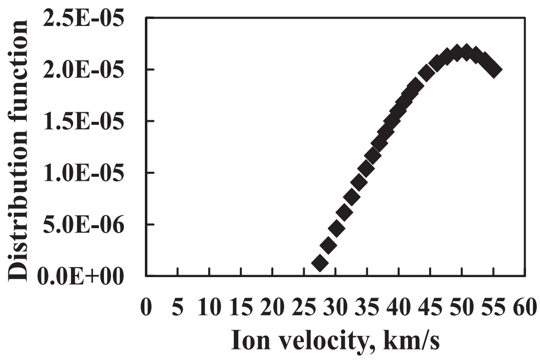


Figure 13. Ion velocity distribution (dI_i/dV) for acceleration voltage: -150V.

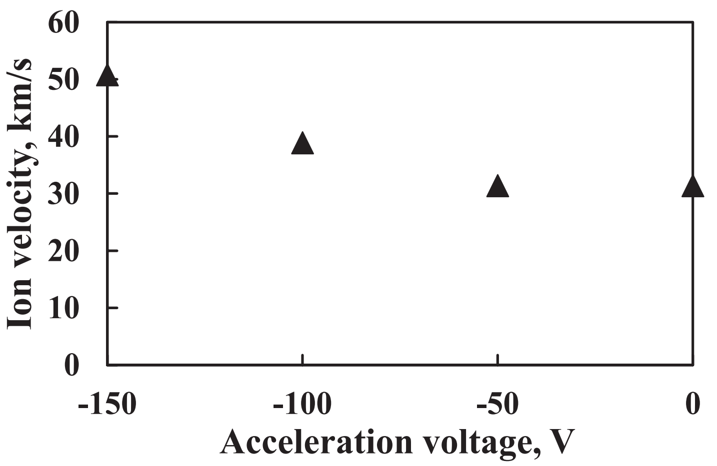


Figure 14. Most probable velocities of ions vs acceleration voltages.

V. Conclusion

We experimentally estimated the ion energy distribution in a laser-electrostatic hybrid thruster using a retarding potential analyzer. From the ion energy distributions, the most probable velocities of ions were estimated. It was shown that the velocities of ions increased (from 31 to 51 km/s) with augmentation of acceleration voltages (from 0 to -150 V).

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