Acceleration Charactarisitc of Laser Ablation Plasma by Alternating Electrostatic Field

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A fundamental study of a laser-electrostatic hybrid propulsion system with alternating electric field applied to an acceleration electrode was conducted. Plasma was induced by laser beam irradiation onto a solid target and accelerated by electrical means. In this study, a nanosecond laser pulses exceeding an ablation fluence, it was shown that electrons, primarily absorbing the laser energy, were emitted earlier and faster from the target and then ions follow(-than ions). To accelerate the temporally shifted particles, an alternating electric field accelerator was developed, which can firstly accelerate electrons with a positive electric field pulse and then secondly accelerate ions with another negative electric field pulse. The acceleration characteristics of electrons and ions using alternating fields were evaluated by a retarding potential analyzer(RPA).

Key Words: Space Engineering, Electric propulsion, Double layer, Laser ablation plasma

1. Introduction

Small-sized onboard laser plasma thrusters are under significant development with rapid evolutions of compact but high power laser systems[1) 2) 3)]. One of the advantages of such laser thrusters is the use of solid-state materials for the propellant. Since any solid material can be used for the propellant, tanks, valves, or piping systems, which are necessary for thrusters with liquid or gaseous propellant, are not required for the laser propulsion system. Therefore, the laser thruster system can be very simple and compact. Also, significant controllability of thrust is possible by changing the input laser power[4) 5) 6)]. In order to further improve the thrust performances and system simplicities of conventional laser propulsion systems, a preliminary study on a laser-electric hybrid propulsion system was conducted.

1.1 Laser-electrostatic hybrid acceleration thrusters

The basic idea of this systems is that laser-ablation plasmas, induced through laser irradiation on a solid target, are additionally accelerated by electrical means. As the laser-ablation plasma has the directed initial velocity, which is further accelerated by electrical means, significantly high specific impulses can be expected.

A preliminary investigation on a laser-electrostatic hybrid acceleration thruster is being conducted, in which a laser-ablation plasma is accelerated by an electrostatic field. A focused laser pulse is irradiated on to a solid target, or propellant. Then, a laser-induced plasma, or laser-ablation, occurs at an irradiating spot of the propellant surface. In the laser-ablation process, first of all, electrons are emitted from the surface, and, then, ions are accelerated through ambipolar diffusion. In this study, those ions are further accelerated with an additional acceleration electrode. Since the laser-induced plasma is further accelerated by an electrostatic field, high specific-impulse can be expected.

1.2 Laser ablation plasma

Generation of a laser ablation plasma induced through an interaction of an intense focused pulsed laser and a solid target is a short-duration event. Plasma temperature and density dramatically change with time and in space. Figure. 1 shows a typical output signal measured by a Faraday cup (FC) fixed at 100 mm from a Cu target, showing temporal changes of electron current (negative signals, or below zero ampere) and ion current (positive signals, or over zero ampere) measured in a laser ablation plasma. This Fig. 1 shows that negative signals of electrons, primarily absorbing the laser energy inside and outside of the target, are reaching to FC earlier than positive signals of ions, since electrons are emitted earlier than ions from the target surface.

Then, ions follow foregoing electrons. Namely, a wavefront of a laser ablation plasma consists of two layers of electrons and ions, or a double laye[7)]. From the Fig. 1,a difference of arrival times of electrons and ion can be assumed as a gap between negative and positive peaks, which is about 10μs.

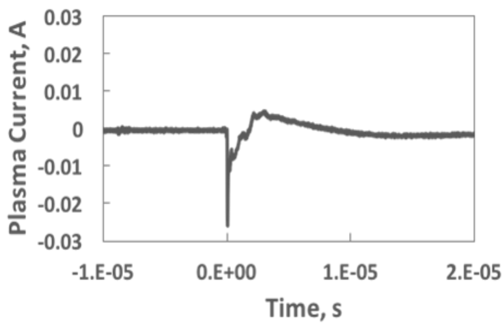

Fig. 1 Temporal changes of electron and ion currents measured in a laser ablation plasma

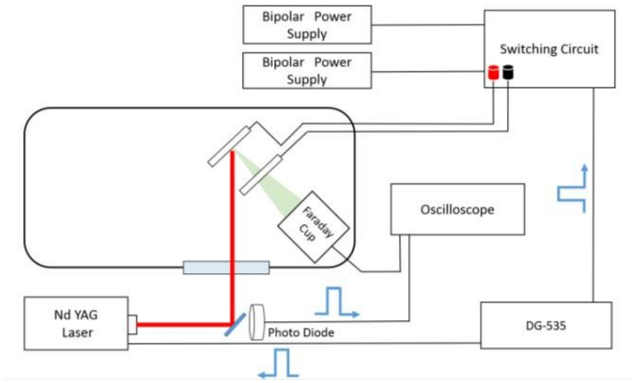

Fig. 2 Experimental setup

2. Expermental Appatratus

Temporal evolutions of the plasma current were measured by a Faraday Cup, as shown in Figure. 2. The Faraday Cup consists of three electrostatic grid and one collector grid. It was placed at 100 mm away from the thruster (target plate position) along the centerline. Temporal changes of the plasma currents were acquired by an oscilloscope (Tektronix, spectral width 300 MHz, maximum sampling rate 2.5GS/s). Since the transient probe data were highly reproducible, it was possible to obtain the current-voltage. The plasma current was estimated from the time of signal arrival to the Faraday cup. Pulse generator (DG-535) was used to transmit a signal to the IGBT and the Nd:YAG laser. It synchronize the switching circuit with the Nd:YAG laser.

2.1. Accelerator electrodes

A schematic illustration of a laser-electrostatic hybrid thruster is shown in Figure. 3. The hybrid thruster consists of a Cu target (propellant), an acceleration electrode, and a laser oscillator. The propellant target and accelerator electrode are connected to a switching circuit. This circuit provides alternating voltages (positive and negative voltages) between the target and the acceleration electrode. The Cu target was mounted on an X-Y stage to refresh irradiating spots of the target surface. For the laser oscillator, an Nd:YAG laser (wavelength: 1064nm, pulse energy: 340mJ/pulse, peak power: 0.17GW, pulse width: 5ns, repetition rate: 10Hz) was used. Laser ablation plasmas or ions were accelerated by the acceleration electrode made of a 0.3 mm-thick Cu plate with a hole of 10 mm in diameter. To evaluate the effects of the electrostatic field, effects of arbitrary delays and durations for the application of applied voltages to the target and acceleration electrode on ion emission characteristics were investigated.

2.2. Switching circuit

To induce alternating pulse voltages to the electrodes, we have developed a switching circuit, shown in Figure. 4. In this Fig, V1 and V2 are bipolar power sources. V1 provides a negative pulse voltage. On the other hands, V2 provides a steady positive bias voltage. By combing these negative pulse voltage and steady positive bias, alternating voltages to the electrodes can be generated. In this circuit, IGBT and capacitor (1μF) were used to generate a pulsed voltage wave. This pulsed voltage wave was transmitted to a secondary circuit through transformer (1:1) and applied to the electrodes. A typical output signal of alternating pulse voltages applied to the electrodes synchronized with a laser pulse is shown in Figure. 5. The voltages and durations can be controlled to optimize acceleration conditions.

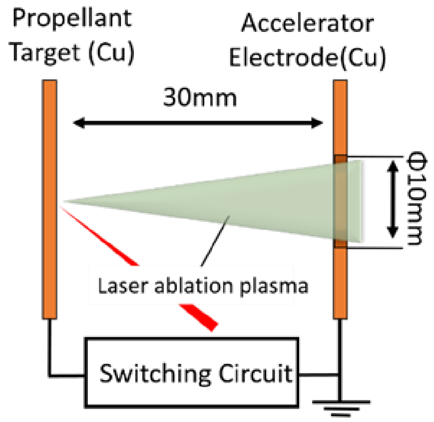

Fig. 3 A schematic illustration of a laser-electrostatic hybrid thruster

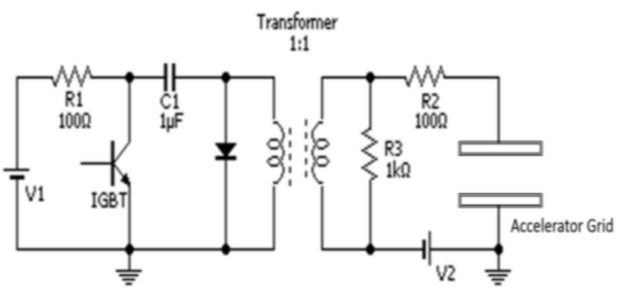

Fig. 4 Diagram of switching circuit

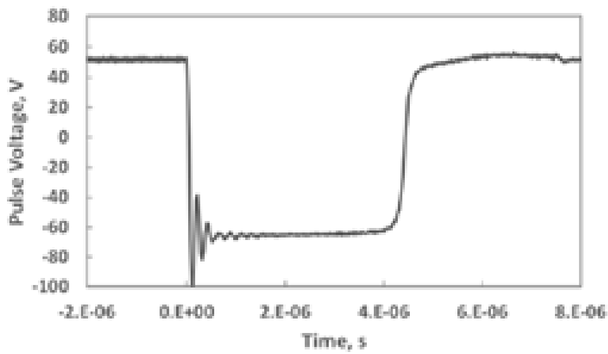

Fig. 5 Output voltage of switching circuit

2.3. RPA

To obtain ion energy (or velocity) distribution, a retarding potential analyzer (RPA) was employed. Values of ion currents for constant retarding potentials (or ion energies) are recorded, and then relations of potential (grid voltage, or ion energies) versus ion currents are plotted, as shown in Figure. 6. Taking first derivatives of the plot, or namely *dI/dV*, energy, or velocity, distribution of ions can be obtained.

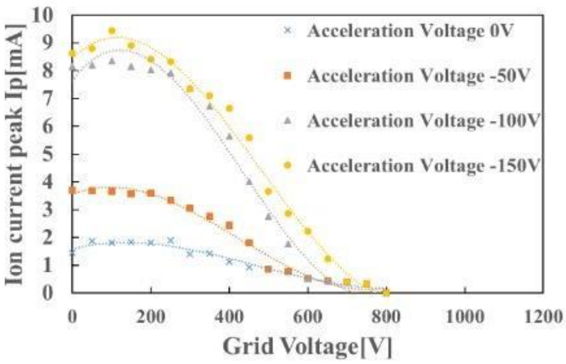

Fig. 6 Ion current vs grid voltage

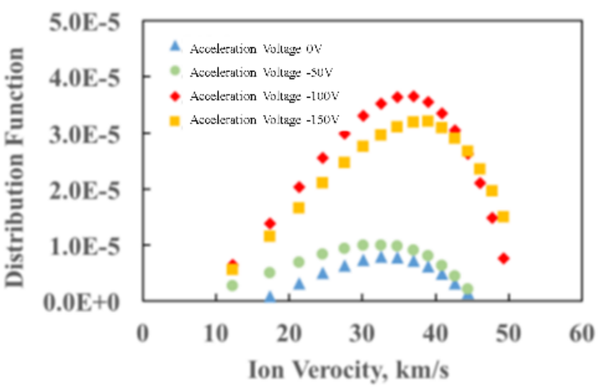

Fig. 7 ion velocity distribution of each pulse voltage for acceleration

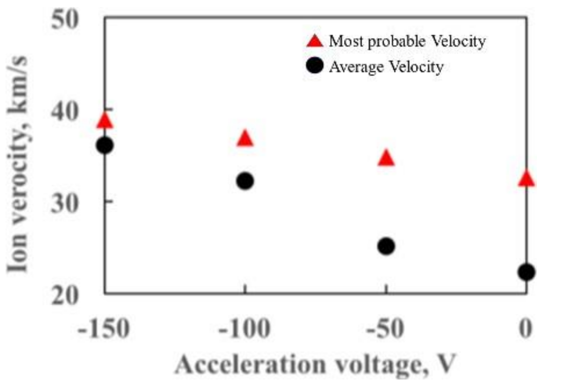

Fig. 8 Most probable and average velocity in case of pulse voltage acceleration

3. Results and Discussion

Figure. 7 shows ion velocity distributions when applying acceleration voltage of 0~-150V by the switching circuit. The vertical axis is the number of ions, and the horizontal axis is the ion velocity. From the Fig, as the acceleration voltage is increased, the most probable velocities gradually increased. The most probable velocities at each acceleration voltage and the average velocity can be obtained, as Figure. 8, from velocity distributions of Fig. 7 From Fig. 8, the ion velocity increased by the potential difference between acceleration electrode and propellant target. The most velocity of the ions increased from 32.5km/s (acceleration voltage is 0V) to 38.9km/s (acceleration voltage is -150V). The average velocity of the ions increased from 22.3km/s (acceleration voltage is 0V) to 36.1km/s (acceleration voltage is -150V).

4. Conclusion

A preliminary investigation of an alternating electric field accelerator for a laser-electrostatic hybrid thruster was conducted, in which a laser ablation plasma was accelerated by an alternating electrostatic field. A newly developed pulse generating circuit successfully generated alternating pulse voltages between electrodes. From the ion energy distribution measurement with RPA, it was confirmed that ions were accelerated by alternating electrostatic field.

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