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浮遊金属液滴への低出力 CW レーザーアブレーション推力の測定

Measurement of low-power CW laser ablation thrust on levitated metallic droplets.

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1. Introduction

In recent years, the increase in space debris has become a major problem. Space debris orbiting the earth comes in all sizes. In this study, we consider the removal of debris smaller than 10 cm,1) which is difficult to observe and impossible to avoid debris collision by orbit control. In a research case study by Ebisuzaki et al.2) , using an ultra-wide angle telescope, a search laser , debris of about 1-10 cm in size is deactivated by repeated irradiation of nanosecond pulsed lasers with a time-averaged power of 500 kW. When such high-power laser beam is irradiated to such a small space debris as described above, most of the debris melts and turns into a molten droplet. Moreover, experiments in which a pulsed laser is irradiated on a droplet have been extensively studied in the field of fluid dynamics in recent years. By analogy with the results, if pulsed laser beam is applied to a droplet and a large thrust is applied, the droplet can be deformed greatly and cracked, leading to fragmentation and increase of space debris.3-4) Therefore, a method to avoid debris by using a low-power density laser to generate thrust is favorable. And, previous laser ablation thrust experiments about measurement of laser ablation thrust have used target materials that are sufficiently large for the thermal input and do not simulate thermomechanical isolation and high power density(10^8[W/cm^2]~ 10^{12}[W/cm^2]).5) But space debris in real space is thermo-mechanically isolated, and when CW lasers are irradiated for a long time, space debris smaller than 10 cm would dissolves and becomes droplets. So, in our laboratory, we used an electrostatic levitation furnace (ELF), which can simulate a thermomechanical isolated space debris in space by levitating a sample using electrostatic force. This device can be used to measure the laser ablation thrust by irradiating CW laser beam to a molten metal. Previous studies have measured laser ablation thrust using a ground-based ELF. However, there is an problems with levitation of aluminum and convection currents in the metallic droplets, which reduce the heat transfer characteristics. Therefore, in this study, we measured the laser ablation thrust generated in aluminum, the main material of debris, by using ELF installed in the ISS, and eliminate the above effects.

2. Experimental Methods

2.1. Experimental equipment

In this study, experiments were conducted using an ELF installed in the ISS. A schematic diagram of the ISS-ELF is shown in Figure 1. electrodes are installed in each of the three axial directions, and the voltage applied between the electrodes is controlled by PD control based on data from the position sensor called IVS to enable stable levitation. In addition, four semiconductor lasers are installed, each of which can independently determine its output. This experiment was performed under Ar , 2 atm atmosphere.

2.2. Experimental procedures

First, the sample was allowed to float stably in the chamber. After that, the voltage applied to the sample was OFF and the sample was allowed to free drift until it moved 2[mm] from the initial position. After the 2[mm] sample move, the application of voltage was restarted, and the sample was returned to the initial position again by PD control. This operation will be referred to as FD in the following text. Next, the output power of the four lasers was increased simultaneously to melt the sample. Once it was confirmed that the sample could be melted and was stably levitated, the output power of laser 4 was increased while the output power of lasers 1, 2, and 3 was decreased while maintaining the melted state. When the output of lasers 1, 2, and 3 reached 0 and only laser 4 was being irradiated, FD was performed. After that the output of all lasers was reduced to 0, and after cooling, FD was performed again, and the sample was collected.

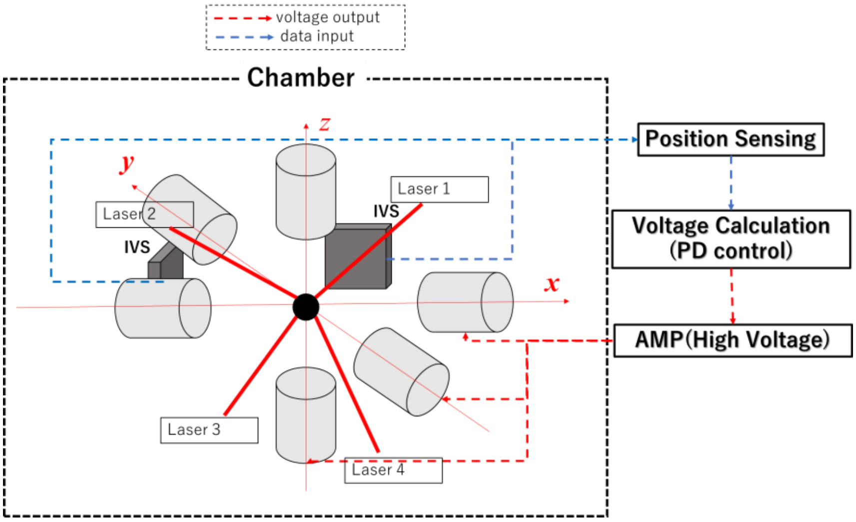


Figure 1. A schematic diagram of ISS-ELF

3. Result and Future vision

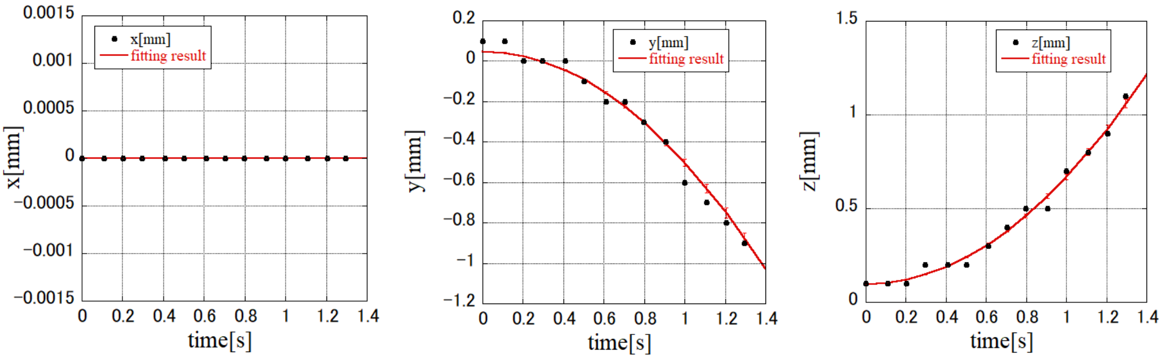
Figures 2. show the positions of the samples detected by the IVS and the results of fitting with a quadratic function when FD was performed under the experimental conditions shown in Table 1. The IVS data are rounded up to the first decimal place.6)

From these results, it was found that the motion of the sample during FD could be captured and fitted, making it possible to measure the force generated on the sample during laser irradiation. Each of the fitting results is $y = (0.0 \pm 0.0)x^2 + 0$, $y = (0.55 \pm 0.02)x^2 + 0.05$, $y = (0.57 \pm 0.05)x^2 + 0.09$, for x, y and z direction.

The measured forces are shown in Table 2. However, the ISS is in orbit at an altitude of about 400[km] and is slightly affected by the Earth's gravity. Furthermore, it is possible that offset voltage is applied when the control voltage is applied, so that even when the control voltage is turned off, the voltage is not completely zero. Therefore, we are planning to study an analysis method to remove these effects and to discuss the data after the analysis.

Acknowledgement

I would like to thank the researchers at JAXA's Ishikawa Laboratory for allowing us to use their electrostatic levitation furnace as an experimental device, for their advice and cooperation on experimental methods, and for giving us the opportunity to conduct on-orbit experiments on the ISS. I would like to take this opportunity to express our deepest gratitude.



(a) x-direction (b) y-direction (c) z-direction

Figure 2. Change in sample position during laser irradiation FD

Table 1. Experimental conditions

Material	Mass[mg]	Radius[mm]	Laser Power [W]	Power density [10^6W/cm^2]
Zirconium	23.070	0.945	30	2.5

Table 2. Measured thrust

x-direction[nN]	y-direction[nN]	z-direction[nN]
0.0±0.0	-25.4±0.8	-26.4±0.5

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