論文内容の要旨

論文題目　　Laser Detonation Propulsion with Solid-state Laser

（固体レーザーを用いたレーザー爆轟推進の研究）

氏名　　王 彬

Studies have been done on the laser detonation propulsion with solid-state laser, especially on its beam energy absorption process and the energy conversion process. This thesis is divided to five chapters. In chapter 1, the background of this research was introduced including some closely related developments and important concepts. In laser detonation propulsion, the launch power is supplied remotely from ground based high power laser system. When the incident beam is focused by the thruster reflector, breakdown happens in the atmosphere air. The high speed expansion of the laser induced plasma results in the generation of a strong blast wave. Impulse is applied to the thruster when the blast wave reaches its inner wall. Since on-board fuel is not necessary when the flight is in the atmosphere, much higher payload ratio is expected compares with the traditional chemical launching system. Therefore, laser detonation propulsion is a promising alternative launch concept which can dramatically reduce the current launch cost.

Laser source selection is one most important issue which should be seriously considered. Previous works have concentrated on the using of CO_2 laser. There is still no systematic research on the using of solid-state laser as laser power source in performing this mission. This is majorly because due to its shorter wavelength, one tenth of that of the CO_2 laser, the energy conversion efficiency using this near-infrared laser is thought to be low. However, recent developments on high power solid-state laser system are gradually making it a potential candidate for fulfilling the requirements of laser propulsion launching mission. This is the reason we conducted this study, to clarify this feasibility from the views of energy absorption and conversion.

The chapters are arranged following this sequence: (1) the most important regime in the energy absorption is laser supported detonation regime. Its supporting and termination condition are clarified, in terms like LSD termination time and the laser power density on the blast wave front. (2) After that, the whole energy conversion process is studied. An analytic method is proposed to estimate this solid-state laser induced blast wave energy. Thus the energy conversion efficiency from laser beam to the blast wave is obtained. (3) The thrust performance with using of solid-state laser is firstly investigated with an impact pendulum system. The gotten momentum coupling coefficient verifies the calculated energy conversion efficiency. In addition, the influence of thruster geometer on thrust performance were tested and compared with the CO_2 laser result.

In chapter 2, research is concentrated on the supporting and termination conditions of solid-state laser generated LSD wave. The laser supported detonation regime is very important because it is the regime that absorbed laser energy could be efficiently converted to that of the blast wave. In this chapter, it is found that because of the wavelength difference, in LSD regime, it is actually a volume absorption in solid-state laser case than the thin layer laser absorption that happens in CO_2 laser case. In another words, strengthen of blast wave by ionization front in solid state laser case happens in two directions, both forward and backward in the laser channel. We named it as two directional LSD, to distinguish the backward propagation LSD in CO_2 laser case. To clearly identify its LSD termination condition, an innovative Half Shadowgraph Half Self-emission experiment is designed in which we can easily figure out the positions of the blast wave front and the ionization front. Result shows that, the termination happens at late time of the laser irradiation duration, for a 900 ns pulse laser, the LSD termination time is as long as 750 ns for 2.0 J pulse energy. It means that most of the laser energy could be absorbed in the LSD regime, which basically assures the high energy conversion efficiency from laser to the blast wave.

In chapter 3, the energy conversion process is studied. Firstly, with the help of pairs of a photodetectors and energy meters, the temporal laser absorption and transmission are obtained, which show that laser transmission is always happening during the laser irradiation, due to its low laser absorption efficiency in solid-state laser case. For estimating the laser induced blast wave energy, a three directional expansion model is proposed to describe the irregular blast wave evolution. With this model and the result gotten in shadowgraph experiments, blast wave energy under various conditions, like pulse energy, focusing number and ambient pressure, were calculated. The highest efficiency obtained is 59%. This result indicates that the energy conversion efficiency η_{bw} in using solid-state laser can achieve the same level as that using CO_2 laser. It brings a promising future of using solid-state laser to conduct laser launching mission.

In chapter 4, laser beam is focused in cone nozzle thrusters to measure the laser propulsion impulse use solid-state laser. Momentum coupling coefficient, C_{m}, as high as 220 N/MW was obtained. As compares with the corresponding result in CO_2 laser case, this result verifies the calculated η_{bw} well. Besides, to learn the thruster geometry influence on this propulsion performance, thrusters with different non-dimensional nozzle lengths are tested which is valuable for future thruster design.

Chapter 5 summarized the results obtained in our study. In our research, the supporting condition of LSD is clarified, as well as the energy absorption process. After optimization, the energy conversion efficiency could achieve as high as 59%, together with the C_{m} result, verifies the feasibility of using solid-state laser as power source in laser detonation mission.