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The power density limit of the Laser Supported Detonation Wave in the low pressure air atmosphere

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1. INTRODUCTION

Laser Supported Detonation (LSD) wave is known as one of the detonation waves that are supported by the external heat addition. When intense laser pulse is focused into the gas, the breakdown is initiated in the vicinity of the focus, and plasma is formed. The development stage of the breakdown is accompanied by propagation of the laser-absorption region along the laser light channel. It is well known that the absorption mechanism has two regimes analogous to those in combustion. At laser power densities greater than the order of 10^7 W/cm², absorption occurs in the Laser Supported Detonation (LSD) regime. On the other hand, at power densities lower than 10^6 W/cm², it occurs in the Laser Supported Combustion (LSC) regime.

In the LSD regime, incident laser energy is absorbed at a shock front, which is called an LSD

wave. The LSD wave travels at a supersonic velocity along the laser light channel in the direction opposite to beam incidence. In the LSC regime, laser absorption occurs in plasma mostly at uniform pressure. The absorption wave has a structure similar to a deflagration wave; it is called an LSC wave.

When the LSD wave is formed by focusing a laser pulse, the absorption wave regime changes from the LSD to LSC. The fractional absorption of the incident laser energy is influenced by the transition timing. In addition, the investigations on the regime transition of the laser absorption wave are very useful to understand the general characteristics of the DDT phenomena.

After the absorption by the LSD wave is terminated, the formed plasma expands quickly to drive a blast wave in the surrounding gas, and then, the absorbed energy is converted into the blast wave energy. In our previous study, the blast wave energy conversion efficiency that is defined as the fraction of the input laser energy that is converted into the blast wave energy was deduced using the shadowgraph method. As a result, the efficiency was found 0.5 in the standard air, and it decreased with the decrease in the ambient air density.

In this study, the influence of the ambient pressure on the laser power density limit of the LSD wave has been investigated.

2. EXPERIMENTAL APPARATUS

Plasma was produced by TEA CO_2 pulse lasers whose energy *E* was 4 J/pulse and 10 J/pulse. Pulse energy was measured before and after experiments using a joule-meter; consequent shot-to-shot pulse-energy fluctuations were maintained below 5% throughout experimentation. The laser beam was focused using an off-axial parabola mirror that was free from aberration. Experiments were performed in a cell whose air pressure is controlled using a vacuum pump.

3. RESULTS

Figure 1 shows shadowgraphs taken in the standard air atmosphere in the case of the input laser pulse energy E = 10 J/pulse. The laser beam was focused from the top in each picture. At $t \approx 0$, breakdown occurred at the focus and luminous plasma appeared. At $0 < t \le 2 \mu s$, the LSD wave was observed. Luminous plasma and the shock front traveled together along the laser light channel in the opposite direction to beam incidence.

At $2\mu s < t < 3\mu s$, the heating regime transition occurred, and the LSD regime terminated. After transition, plasma was left behind the shock. The shock wave expanded elliptically, further degrading plasma luminosity. This trend was observed also in the case of the E = 4 J/pulse.

Laser power density on an LSD wave was estimated to introduce a laser power density threshold for regime transition. Laser power density irradiated on an LSD wave; *S* in the decaying tail is expressed as

$$S = \frac{P_0 \exp\left(-t/\tau\right)}{\pi r^2},$$
(1)

where P_0 and τ are initial power and decay-constant of the tail, respectively. From pulse shape measurement, P_0 was estimated at 2.8 MW for the 4 J pulse, and at 8.1 MW for the 10 J pulse. The *r* expresses the LSD wave-surface radius; this is defined as

$$r = \frac{z}{2f} \tag{2}$$

wherein breakdown occurs at the focus. Here, z expresses LSD wave displacement along the laser light channel from the focus.

The measured threshold for the regime transition S_{tr} is summarized in Table 1. S_{tr} was found to decrease with *E*. The threshold has been measured under the low-density atmosphere, and it will be summarized later.



Fig. 1 Shadowgraphs

TABLE I. LSD-LSC transition threshold	
E (J/pulse)	Threshold (MW/cm ²)
4	7.4 ±0.1
10	3.7 ±0.4