

# CHARACTERISTICS OF LASER-IGNITED MINIATURE EXPLOSIVES

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**Abstract:** We successfully visualized ignition and propagation of micro detonation in a silver azide ( $\text{AgN}_3$ ) pellet using a ultra high speed camera. We found that the detonation velocity varies with different pellet diameters, and ignition delays depending on incident laser pulse energy.

**Keywords:** Micro Explosives, Micro Detonation, Micro Combustor

## INTRODUCTION

Micro power generation systems utilizing hydrocarbon chemical reaction has been widely investigated for its relatively higher energy density. Some examples are ultra micro gas turbine, micro fuel cells, and micro thruster, which is often called as PowerMEMS. Miniaturizing these systems raises its own problems, such as increasing heat loss due to increasing surface to volume ratio.

Detonation is a self-sustaining combustion wave propagating in a supersonic speed. Recently, pulse detonation engine (PDE) has been extensively investigated because of its potentially higher efficiency. [1] Pulse detonation combustor (PDC) is just a tube which is filled with pre-mixed mixture. Detonation is driven from one end of the tube and exits at the other end, where nozzle or turbine system is attached to produce thrust or electrical power, respectively.

As micro combustor faces problem of extinction limit, detonation cannot propagate in a tube smaller than a certain diameter, which is called detonation limit or critical diameter in case of condensed matter explosives. Wu *et.al.* [3] reports Ethylene-Oxygen detonation in a tube with a diameter as small as 1 mm. However, it takes about 50 mm from the ignition point to establish detonation, which is not preferable for MEMS applications. In gaseous detonation, this relatively longer transition time/length might be major obstacle to miniaturize detonation combustor.

Some explosives has smaller critical diameter, and shorter transition length. In preceding research [2], a small explosive charge ( $\text{AgN}_3$  pellet) was used in medical applications as a shock wave generator. However, in this research, a explosion of  $\text{AgN}_3$  pellet was considered as a point energy source, that is, ignition and explosion occurs in a point both spatially and temporally. Thus, no details about how ignition occurs “*in*” a pellet were investigated. Other researches [4, 5] also

approximated small pellet explosion as a point source, and which makes sense at least at macro level applications. It can safely say that this approximation does not apply to few-mm or smaller scale applications.

We are aiming at utilizing detonation in PowerMEMS applications, it is important to investigate detonation characteristics near detonation limit. In this paper, using ultra high speed photography, ignition and detonation characteristics of small explosives,  $\text{AgN}_3$  will be summarized.

## EXPERIMENT

We chose  $\text{AgN}_3$  for its relatively higher sensitivity. Four different dimensions of  $\text{AgN}_3$  pellet were used in experiments, whose diameter and length were,  $\phi 1.0 \times 1.5$  mm,  $\phi 1.5 \times 1.5$  mm,  $\phi 1.5 \times 3.0$  mm, and  $\phi 2.0 \times 3.0$  mm. Density of the pellet is about  $1.0 \text{ g/cm}^3$ . Nd:YAG pulse laser (532nm, 7ns, 8mJ/pulse) was used to ignite the pellet. Two types of ignition methods were tested. The first one used an optical fiber, where the pellet was attached to a tip of the fiber, and the laser was irradiated through the fiber. The second method was direct irradiation, where the pellet was hanged in the air by metal wire or thread, or attached to metal jig having  $\phi 1.5\text{mm}$  hole through which the laser was introduced, and the laser was directly irradiated to the pellet. In the latter case, input laser was irradiated through a beam splitter, and its input energy was controlled by changing incident beam angle to the splitter. The laser energy was measured by an energy meter (Gentec QE12-LP-S-MB).

Figure 1 shows schematics of experimental setup. Ignition and detonation propagation were observed with a ultra high speed camera (DRS IMACON200). Both direct imaging and shadowgraph were used. Internal delay of the laser was about  $48 \mu\text{s}$  with  $1 \mu\text{s}$  error, which is quite large compared to micro-detonation time scale of few hundreds ns. Thus, the high speed camera was

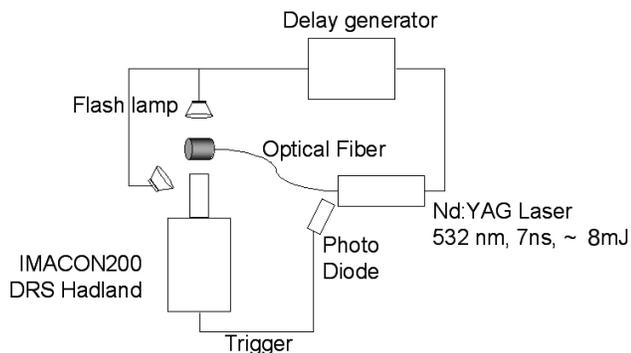


Fig. 1: Schematics of experimental setup.

triggered by the laser irradiation detected by a photo-diode.

## RESULTS

### Ignition Characteristics

In Fig. 2, whole process from laser irradiation to explosion was visualized with direct imaging. Laser was irradiated through an optical fiber. Inter-frame was 200 ns and exposure per frame was 50 ns. While the laser irradiation was captured in the 3rd frame, ignition of the pellet occurred in between the 5th and the 6th frame, which means there are at least 400 ns of ignition delay.

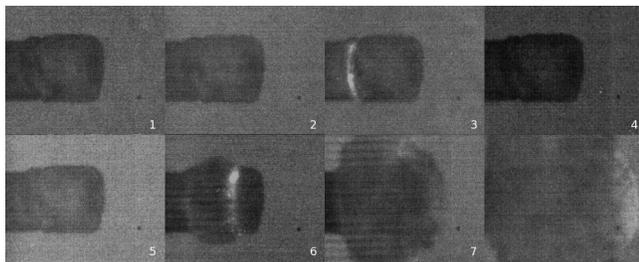


Fig. 2: From laser irradiation to explosion of a  $\text{AgN}_3$  pellet. 200 ns inter-frame, 50 ns exposure per frame.

In order to investigate effects of input laser energy on the ignition characteristics, we used laser beam splitter to control input energy. The  $\text{AgN}_3$  pellet was fixed on a tip of a metal jig, which has 1.5 mm hole through which the laser was irradiated. In this series of experiments, pellets of 2.0 mm diameter and 3.0 mm length were used. Laser energy was varied from a few tens of  $\mu\text{J}$  to over 1.0 mJ, by changing beam splitter angle. Figure 3 shows high speed photography of an experiment with laser energy of 0.39 mJ. Inter-frame of 80 ns was fixed through the series of the experiments, and the internal delay of the camera was adjusted to capture whole detonating process. Detonation front propaga-

tion was measured at top and bottom edge of the pellet image. Figure 4 shows  $x-t$  diagram for different input energy experiments. It clearly shows that ignition delays with decreasing laser input energy. Although propagation velocity is not steady throughout the process, ignition delay was determined, for the sake of convenience, by linearly extrapolating  $x-t$  plot to  $x=0$  axis. Resulted delay-energy relation was plotted in Fig. 5. Ignition delay was rapidly increasing with decreasing input laser energy. We may need more data points to quantitative analysis, especially in weaker energy region, since there must be energy threshold where ignition does not occur, as indicated in Ref. [5].

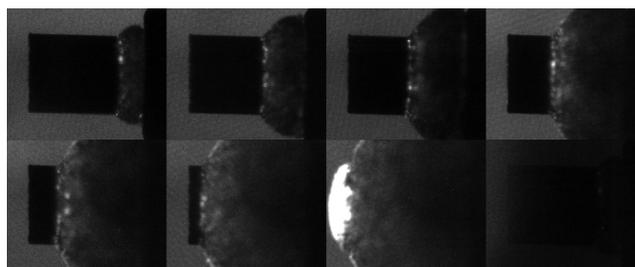


Fig. 3: Direct initiation with 0.39 mJ input energy. 80 ns inter-frame, 10 ns exposure per frame.

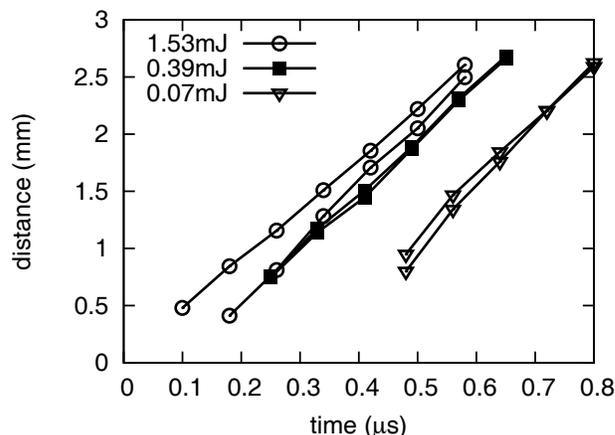


Fig. 4:  $x-t$  diagram for different input energies.

### Detonation Propagation Characteristics

Figure 6 shows another high speed photography of detonation propagation in a 1.5 mm  $\text{AgN}_3$  pellet. A lot of bright spots were observed in detonation front notably in the 2nd frame and the 6th frame. This could be so-called “hot-spot”, where ignition starts in a scattered regions which reflects initial heterogeneity inherent to solid explosives. The 6th frame clearly showed curved detonation front, where unburned portion remained in

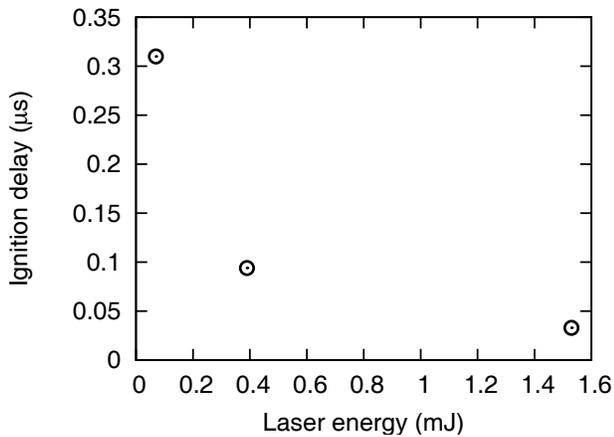


Fig. 5: Increasing ignition delay with decreasing input laser energy

ring-shaped while axis part already detonated. The reasons for this curvature are twofold. One is effects of rarefaction wave from outer surface, which decelerate detonation speed. The other is that the irradiation fluence of the incident laser may not have uniform intensity.

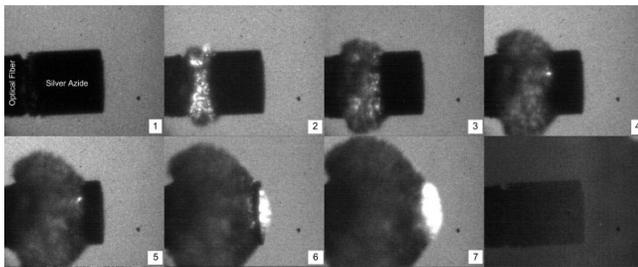


Fig. 6: Detonation propagating in a  $\text{AgN}_3$  pellet of 1.5 mm diameter. 50ns inter-frame, 25 ns exposure.

### Effects of confinement

Two different types of configurations for laser irradiation were tested, one through the fiber, and the other with direct irradiation. Figure 7 shows detonation propagation speeds for different configurations. Traveling distance is normalized by the pellet diameter. When the pellet is ignited on the tip of the fiber, initial detonation speed reaches up to 8 km/s, while the detonation driven by direct irradiation does not have such initial overshoot. This is caused by confinement by the fiber at initiating process. Nevertheless, there is no significant difference in detonation speed in a distance larger than 1.0.

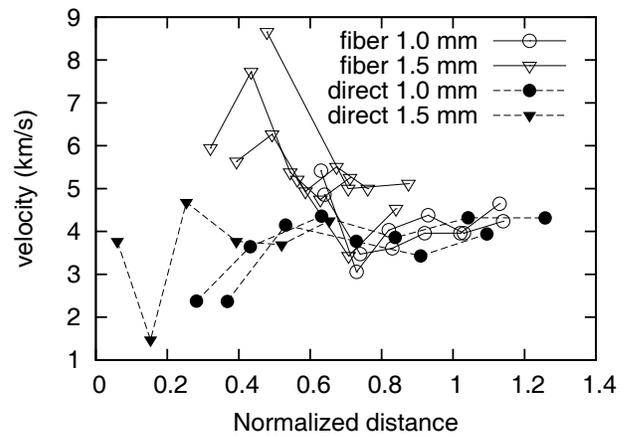


Fig. 7: Different ignition configuration only affects initial stage.

### Diameter effects

The effects of rarefaction wave can be investigated by changing explosive diameter, i.e., pellets with smaller diameter may have stronger effects by rarefaction wave. Figure 8 summarized detonation speed profiles for different diameter pellets. Steady state detonation speed was determined by linear fitting of  $x-t$  plots in region of normalized distance larger than 0.8, to exclude initiating process described in previous section. As the obtained detonation speeds have relatively large errors, averaged values were plotted in Fig. 9, along with minimum and maximum values. In this figure, horizontal axis is inverse of the pellet diameter, where vertical axis ( $1/d=0$ ) represents two dimensional limit in which detonation front would not be affected by the rarefaction wave, and would have no curvature.

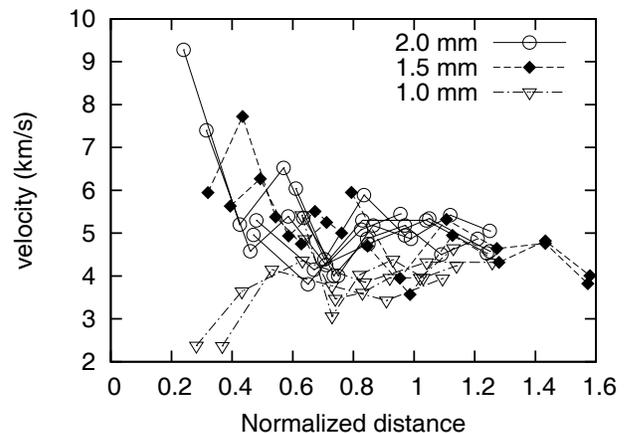


Fig. 8: Detonation propagation velocity profiles for different diameter pellets.

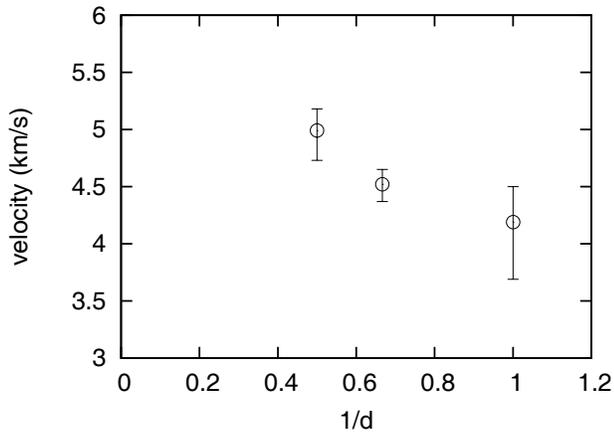


Fig. 9: Detonation speed decreases with decreasing diameter.

## CONCLUSION

We successfully visualized initiation and detonation propagation in small  $\text{AgN}_3$  pellets. Depending on the input laser energy, ignition delay up to few hundreds ns was observed, which would not be negligible in miniaturized applications. Although initial stage of detonation propagation strongly depends on initiation methods, whether initiation point is confined or not, final state detonation velocity is independent of the initiation. Steady state velocity depends on the pellets diameter, i.e., smaller pellets has slower detonation velocity.

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