IGNITION AND DETONATION CHARACTERISTICS OF MICRO EXPLOSIVES

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abstract: We successfully visualized ignition and propagation of micro detonation in a silver azide (AgN_3) pellet using a ultra high speed camera. Detonation speed in 1.5 mm diameter pellets ranges from 4 to 8 km/s. Ignition delay varies from 100 ns to 500 ns depending on ignition method.

Key words: Micro Explosives, Micro Detonation, Micro Combustor

1 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. Miniaturiaing these sysmtems 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 preceeding research [2], a small explosive charge (AgN_3 pellet) was used in medical applications as a shock wave generator. However, in this research, a explosion of 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 sence 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, AgN_3 will be sumarized.

2 EXPERIMENT

We chose AgN_3 for its relatively higher sensitivity. The pellet was 1.5 mm diameter and 1.4 to 1.8 mm length. 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. 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, and the laser was directly irradiated to the pellet.

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

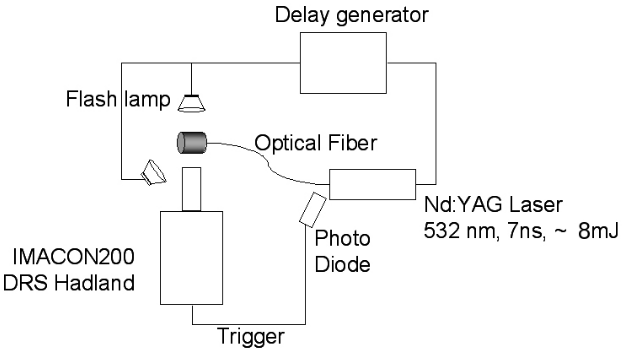

Fig. 1: Schematics of experimental setup

3 RESULTS

3.1 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 occured in between the 5th and the 6th frame, which means there are 400∼600 ns of ignition delay.

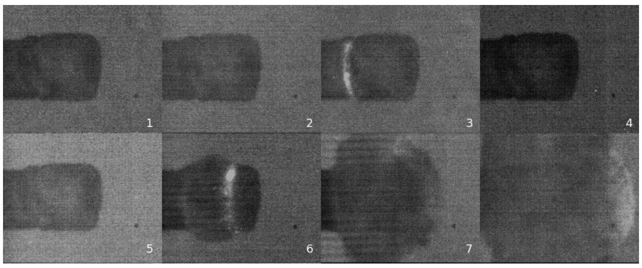

Fig. 2: From laser irradiation to explosion of a AgN_3 *pellet. 200 ns inter-frame, 50 ns exposure per frame.*

Figure 3 shows another shot with higher temporal resolution, 50 ns inter-frame and 25 ns exposure per frame. While this figure shows entire process of detonation propagation in a pellet, laser irradiation was not captured. Figure 4 shows photodiode signal detecting laser irradiation and framing monitor signal of the high speed camera. Instance of the laser irradiation is set to time 0. It can be seen from Fig. 3 that ignition occured between the first and the second frame, which corresponds to 475∼500 ns from laser irradiation. Thus, in this experimental condition, the ignition delay is about 500 ns.

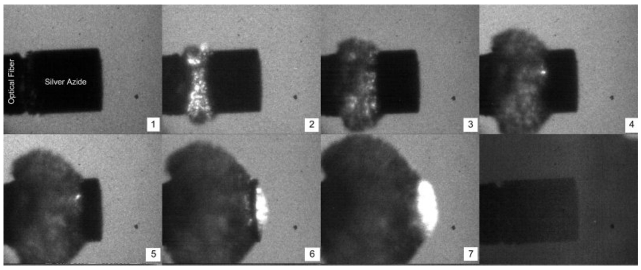

Fig. 3: Detonation progating in a AgN_3 *pellet of 1.5 mm diameter. 50ns interframe, 25ns exposure.*

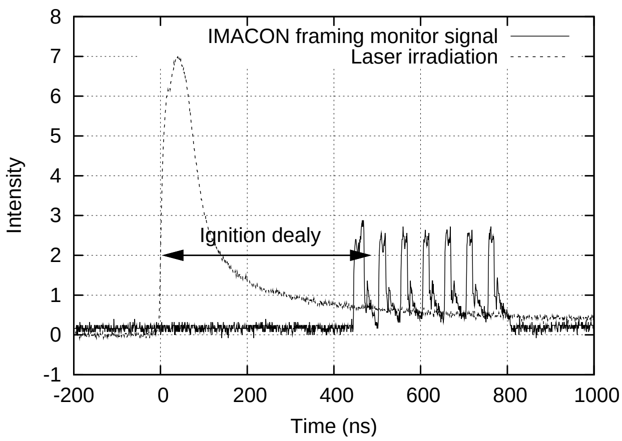

Fig. 4: Framing monitor signal of IMACON200 and photodiode output detecting laser irradiation.

The other series of experiments with different condition was conducted, where laser was directly irradiated without using optical fiber. In Fig. 5, laser was irradiated from right hand side of the pellet. The fisrt frame was only 121 ns after the laser irradiation, and already showed expansion of product gas. In this case, the ignition delay was less than 100 ns.

One of the reasons for the difference in ignition delay is difference in energy fluence of the laser. Since it is not straightforward to measure laser irradiation energy simultaneously, single shot energy was roughly estimated by duplicating similar experimental conditions and replacing the pellet with laser energy meter. Estimated values are about 1 mJ for direct irradiation case and about 70 μJ for fiber case. Thus, it is likely that the difference in ignition delay can be attributed to the difference in laser energy.

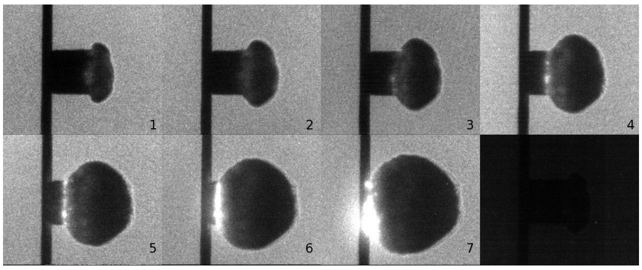

Fig. 5: Direct laser irradiation results in shorter ignition delay. 50ns inter-frame, 10 ns exposure.

3.2 Detonation Propagation

In Fig. 3, a lot of bright spots were obsearved 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 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 optical fiber core diameter is smaller than the pellet diameter, which could results in delayed ignition for outer surface. The initial detonation front might have curved shape, though it cannot be visualized.

Using shadowgraph images shown in Fig. 6, detonation velocity was measured at top and bottom surface of a pellet, and plotted in Fig. 7. Although it has relatively larger error bars, trend can be seen that initially it accelerated up to about 8 km/s, and then approaches to around 4 km/s, which looked like a steady detonation speed in this diameter.

Figure 8 shows velocity profiles for the direct initiation case shown in Fig. 5. Plotted are velocities measured at top, bottom and along with axis toward right hand side. It clearly differs from

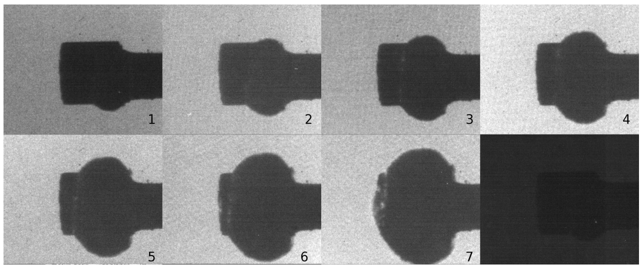

Fig. 6: Shadowgraph images of detonation propagation in a AgN_3 pellet. 25 ns inter-frame, 5 ns exposure.

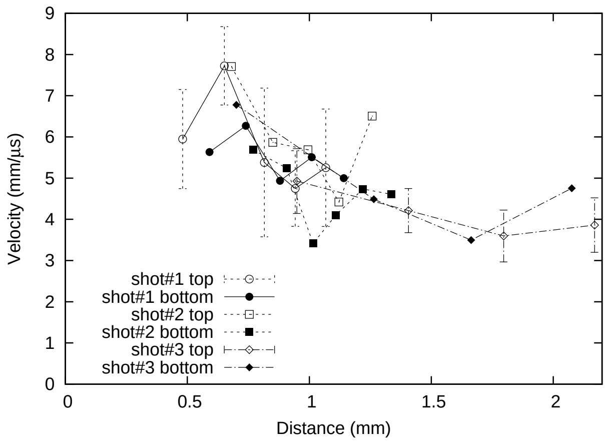

Fig. 7: Velocity profiles measured at top and bottom surface of a cylindrical pellet.

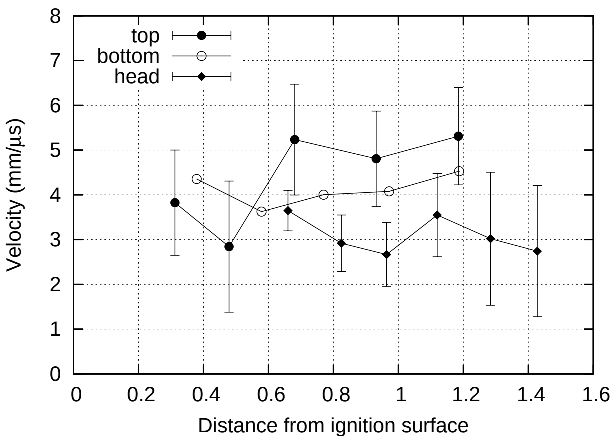

Fig. 8: Velocity profiles of detonation front by direct laser irradiation.

above mentioned fiber supported ignition case, i.e., there are no initial acceleration to 8 km/s range. It is unclear from currently available data, but one possible reason is that optical fiber acts as confinement and suppress expansion to backward axis direction, which in turn enhance acceleration in detonation front.

4 CONCLUSION

We successfully visualized initiation and detonation propagation in a 1.5 mm diameter AgN_3 pellet. In this scale, ignition and explosion are no longer instantaneous. There were 100 to 500 ns ignition delay depending on ignition laser energy. Detonation velocity can be as high as 8 km/s was obsearved, but steady state for 1.5 mm diamter was about 4 km/s.

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