Deflagration-to-Detonation Control by Nanosecond Gas Discharge

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Introduction

The ultimate goal of this work is a obtaining of a small length of a deflagration to detonation transition under a minimum energy of an initiation. At the present work we studied deflagration-to-detonation control non-equilibrium plasma of nanosecond gas discharge. The ignition of fuel mixture and flame propagation was observed after ignition by nanosecond gas discharge. The nanosecond discharge as a source of ignition has a set of advantages [1, 2]: high spatial uniformity, high efficiency of formation of reactive species and coherence. The coherence is a simultaneous excitation of a mixture in a bulk volume here. The released chemical energy in chemical reactions is enough for a direct initiation of a detonation at appropriate conditions. In a work [3] it was shown that the critical energy of initiation depends strongly on a power of the initiation source. In terms of the work [3] the short nanosecond discharge is very prominent as an initiator of a gas detonation. The theoretical study of an application of nanosecond discharge was performed in [4]. The formation of strong shock (detonation) wave from compression waves arises if under the selected initial conditions and mixture composition the typical time of chemical energy release is shorter than time of gas-dynamic processes. It was shown that the length and time of DDT decreases at fast energy release and low temperature.

Experimental

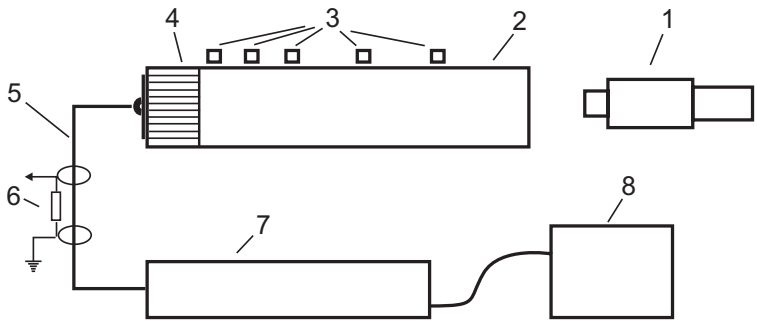

Figure 1: Scheme of experimental setup. 1 – ICCD camera, 2 – detonation tube, 3 – IR detectors, 4 – discharge chamber, 5 – high-voltage coaxial line, 6 – back-current shunt, 7 – high-voltage pulse generator (Marx), 8 – power supply.

The used experimental setup is shown in Fig. 1. The experiments were performed in a detonation tube with a diameter of 140 mm. The discharge device was attached to the end-plate of the detonation tube. The discharge chamber consists from a system of distributed electrodes, which provides uniform excitation at length of 80 mm. The discharge chamber

and the detonation tube are separated by an orificed plate. The orifices are arranged opposite to the each electrode. In the experiments the high voltage electrodes were supplied with a positive pulse with amplitude of 4–70 kV and duration at the half-width of 50 ns. Calculated reduced electric field ranges from 300 Td to 7000 Td near the high-voltage electrode. Given values of the reduced field lies in a range, which is optimal for ignition by discharge [1]. Five IR detectors are placed along detonation tube's axis. The flame speed was calculated from profiles of a voltage on the IR detectors, see fig. 2. Initial gas parameters: composition, pressure and temperature were measured in the experiments. Besides, current and voltage of the discharge gap were measured. The experiments were performed at initial pressures of 0.15-0.6 atm in fuel mixtures: $2H_2+O_2$, $C_3H_8+5O_2$, $C_3H_8/C_4H_{10}+5O_2+xN_2$ ($0\leq x\leq 10$), where C_3H_8/C_4H_{10} is liquified petroleum gas (LPG).

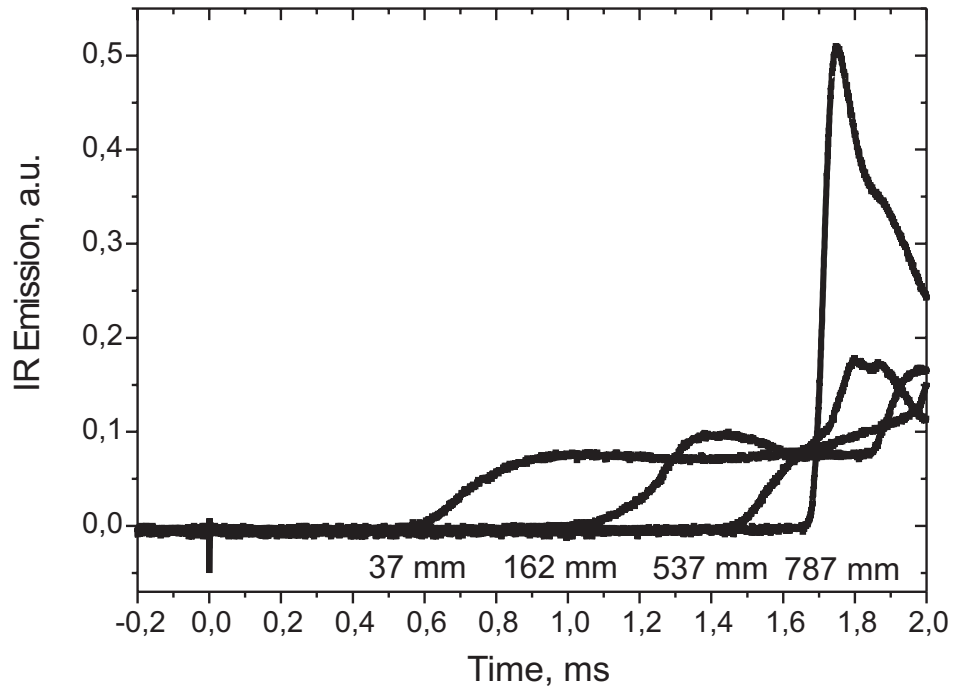

Figure 2: Response of IR detectors. Mixture: $C_3H_8/C_4H_{10}+5O_2+N_2$, pressure: 0.3 atm, transient detonation.

Fundamental Issues

The fig. 3 is a summary plot of the experiments in the mixtures $C_3H_8/C_4H_{10}+5O_2+xN_2$ ($0\leq x\leq 10$). The fig. 3 depicts the speed of the flame front measured at 412 mm apart from the discharge chamber. At relatively low pressures we observed the deflagration with a weak acceleration. At relatively high pressures we observed the C–J detonation. At intermediate conditions we observed the transient detonation fig. 2. In this mode the flame front accelerates strongly on motion in the tube. At conditions relative to the fig. 2 the speed of the flame front increases from 500 m/s at position of 150 mm to 2000 m/s at position of 650 mm.

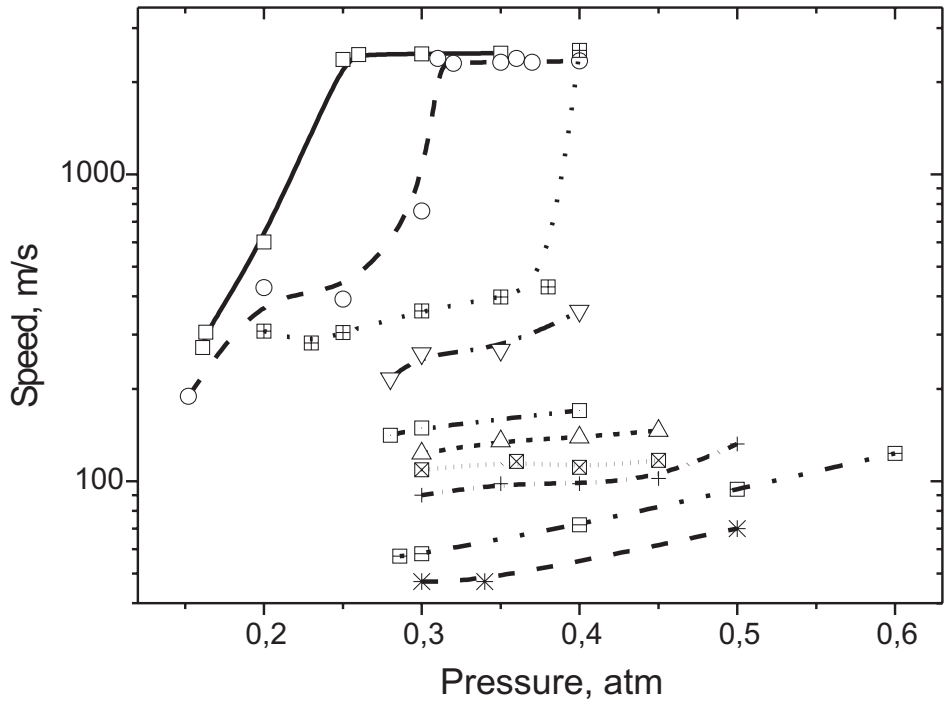

Figure 3: Speed of the flame front at 412 mm apart from discharge chamber in mixtures $C_3H_8/C_4H_{10}+5O_2+xN_2$. □ – x=0 (0%), ∘ – x=1 (14%), ⊞ – x=2 (25%), ▽ – x=3 (33%), ⊡ – x=4 (40%), △ – x=5 (45%), ⊠ – x=6 (50%), + – x=7 (54%), ⊟ – x=8 (57%), ∗ – x=10 (63%).

Through the end-plate of the detonation tube we carried out the observation of the discharge development and the formation of flame front (fig. 4). The observation were performed using ICCD camera "La Vision Picostar 12 HR". The initial stage of the discharge (up to 10 ns) is spatially quasi-homogeneous, while in the subsequent stages the discharge localized over the few sections of the high-voltage electrode. After 0.5–10 mc (in relation to the initial conditions) from discharge the mixture ignites in discharge chamber. The flame is stronger in some sections than in other sections of the discharge chamber. Nevertheless on the end-plate the mixture inflames simultaneously and the flame front covers the whole cross-section of the tube. A position of the flame front was determined by simultaneous measurements through the side-wall with help of the IR sensors . When the flame front passes from the end-plate the length of the diameter of the detonation tube, the front is spatially homogeneous over the cross-section of the tube.

It were carried out special experiments to determine the conditions of detonation initiation. The experiments were performed in $C_3H_8+5O_2$ mixture at initial pressure of 0.3 atm. The length and time of DDT amount to L_{DDT}=90 mm and t_{DDT}=0.6 ms at initiation energy of the discharge of 70 mJ.

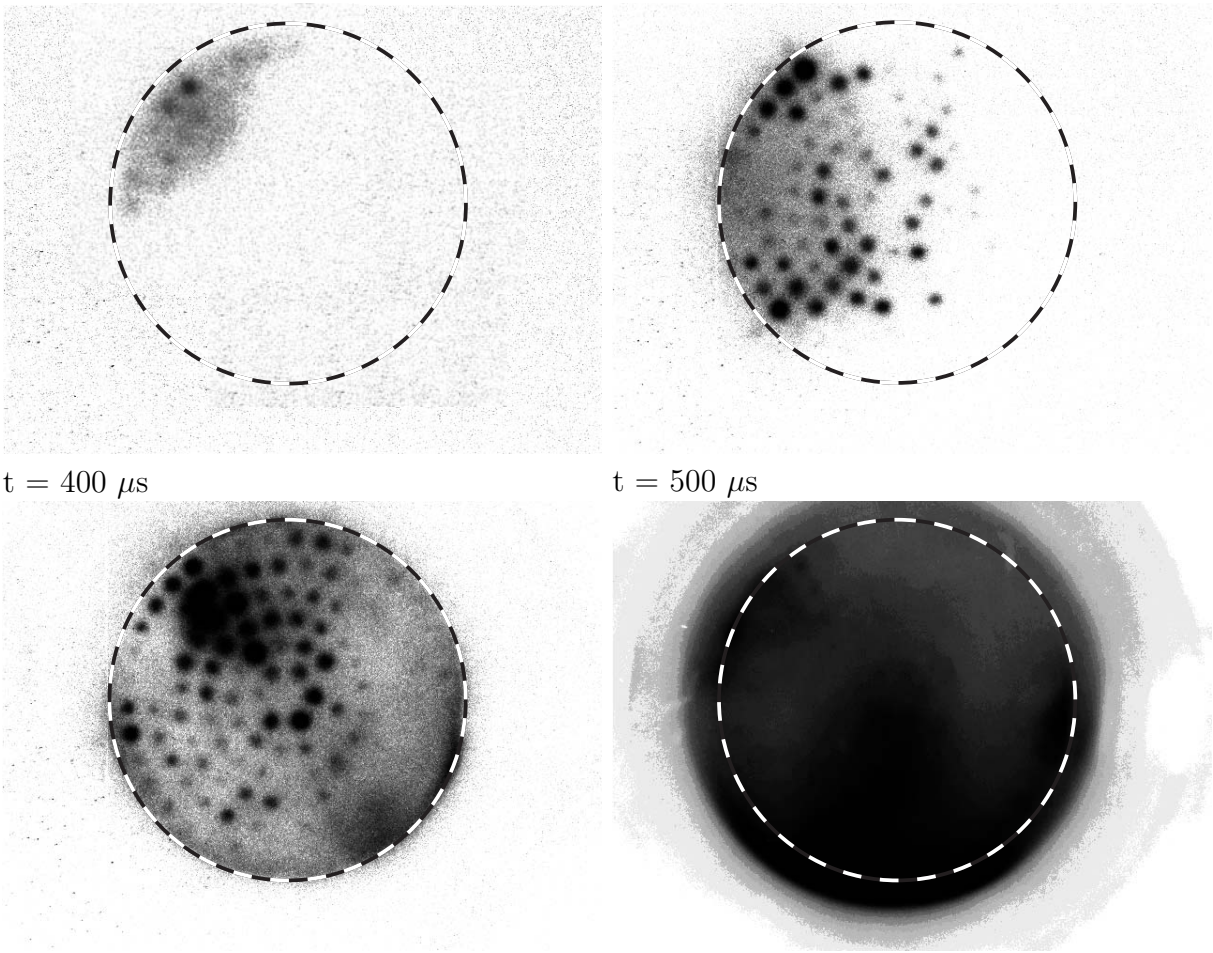

Figure 4: Negative image of flame front. The dashed line designates the contour of the discharge chamber.

References

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