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Ignition of Premixed Fuel by Streamer Discharges
ストリーマ放電による予混合気の着火

Eiichi Takahashi[1], Susumu Kato[1], Takehiko Segawa[1] Hirohide Furutani[1],
Michisuke Iga[2], Takafumi Honzawa[2], Shouichi Inami[3], Jyunya Miyata[3]
高橋栄一[1]，加藤進[1]，瀬川武彦[1]，古谷博秀[1]，
伊賀達介[2]，本澤尚史[2]，稲見昭一[3]，宮田淳也[3]

[1]*National Institute of Advanced Science and Technology (AIST)*
1-2-1 Namiki, Tsukuba Ibaraki 305-8564, Japan
[1]産業技術総合研究所　〒305-8564 つくば市並木1-2-1
[2]*University of Tsukuba, Graduate School of Systems and Information Engineering, 1-1-1, Tenoudai, Tsukuba, Ibaraki, 305-8573, Japan*
[2]筑波大学 大学院システム情報工学研究科　〒305-8573 茨城県つくば市天王台1-1-1
[3]*Mitsui Engineering & Shipbuilding Co., LTD., 3-16-1 Tamahara, Tamano, Okayama, 706-0014, Japan*
[3]三井造船株式会社　玉野技術開発センター　〒706-0014 岡山県玉野市玉原3-16-1

The ignition of premixed fuels by non-equilibrium plasmas was investigated. Pulsed streamer discharges were generated in the combustion chamber containing hydrogen/air mixture. A small increase of the initial temperature greatly increased the ignition probability. The role of radicals is discussed.

1. Introduction

Recently, from the view point of preventing global warming and effective utilization of fossil fuels, lean combustion is required to reduce nitrogen oxide emission and fuel consumption. Spark ignition, which has been used for many ignition applications, is using an arc discharge. The spark ignition is a type of equilibrium plasma in which the plasma electron and ion temperatures are equal and usually ignite pre-mixed fuels as point ignition. So, it is not suitable for the lean fuels because the velocity of flame propagation is usually slow in the fuels.

Non-equilibrium plasmas are plasmas in which electron and ion temperatures are different, result in generating radicals and ions efficiently. Streamer and glow discharges are type of the non-equilibrium plasmas. Additional characteristic of the plasma is the formation of a spatially spreading structure. Therefore, it is expected to realize a volumetric ignition.

There have been a lot of studies related to ignition by non-equilibrium plasmas [1-5]. The plasma physics and chemistry from the generation of non-equilibrium plasmas to ignition are not well understood. Hydrogen and/or oxygen radicals which are generated by the discharge are expected to play an important role for ignition. Streamer discharges does not always lead to ignition.

Recently, we observed the ignition of hydrogen and air mixture by streamer discharges and we found that the influence of initial temperature of several tens of Kelvin in the mixed fuel around room temperature. However, such a small difference is unlikely to affect both plasma generation and successive chemical reactions.

In this paper, the details of the experiment are reported and the results are discussed.

2. Experiment

The experimental setup is shown in Fig.1.

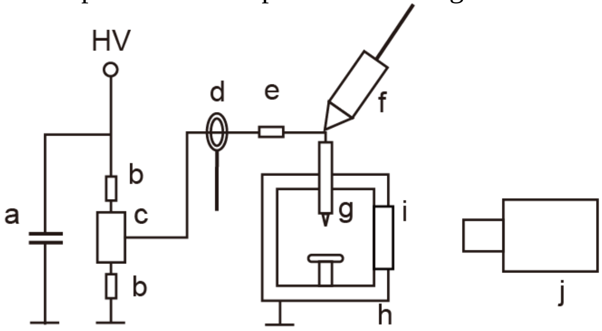

Fig. 1. Experimental setup. a: capacitor, b: resisters of 33 Ω, c: MOSFET, d: current probe, e: resister of 1 k Ω, f: HV probe, g: needle electrode, h: chamber, i: quartz window, j: ICCD camera

The charged capacitor of 1 nF was discharged through the MOSFET high-voltage-switch controlled by a TTL signal. The switch can supply a rectangular wave which has minimum pulse width of 200 ns. The minimum pulse width was used to avoid arc discharge formation.

High voltage pulses with positive polarity were applied to a needle electrode in the combustion chamber. The distance between the needle and plane electrodes was 5 mm. The images of discharge and OH self-emission were observed through a quartz window with an ICCD camera. The temperature of the combustion chamber was controlled by a heater and measured with a thermocouple supplied with the unit. Teflon was used as the sealing material to tolerate the high temperature experiment up to 200 ° C.

3. Results and discussion

Typical waveform of the high voltage pulse and image of streamer are shown in Fig.2. It has a rise and fall time of 40 ns and pulse width of 200 ns (FWHM). The image of the streamer was observed by ICCD camera without using optical filters. Spreading branches of streamers are clearly seen.

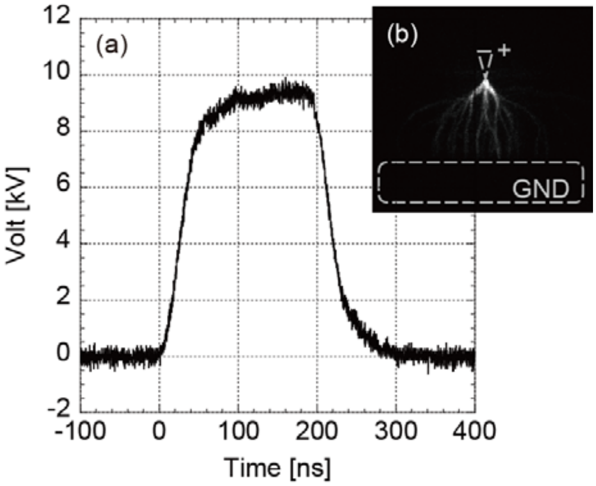

Fig.2 Typical waveform of the high voltage pulse (a) and image of streamer image (b).

When the streamer discharge turns into arc mode, the voltage of the waveform goes down to zero abruptly. By increasing the pressure and decreasing the width of high voltage pulse, the probability of the arc formation decreased.

The temporal evolution of OH* emission ignited by streamer is shown in Fig.3 (a)-(c). Initial OH* emission in Fig.3 (a) started along the streamer branches and expand as the flame propagation ((b) and (c)) .

The influence of initial temperatures is shown in Fig.3 (d). In spite of the streamer discharge, the fuel would not ignite at room temperature (~25 ° C), but the ignition probability increased to 100 % by only increasing the temperature of ~50 ° C.

The effect of oxygen radical for the ignition of hydrogen/oxygen mixture was investigated by ArF laser [5]. The ArF laser (λ = 193nm) radiation dissociate oxygen molecules and create oxygen radicals in ^{3}P state. This radical is expected to initiate branched chain reactions of hydrogen/oxygen mixture. Significant reduction of minimum laser energy for ignition was observed for the initial temperature above 250 °C. This reduction, however, can be explained by increasing the laser absorption by oxygen molecules. This suggests that higher temperature is required for the ignition by the radicals itself.

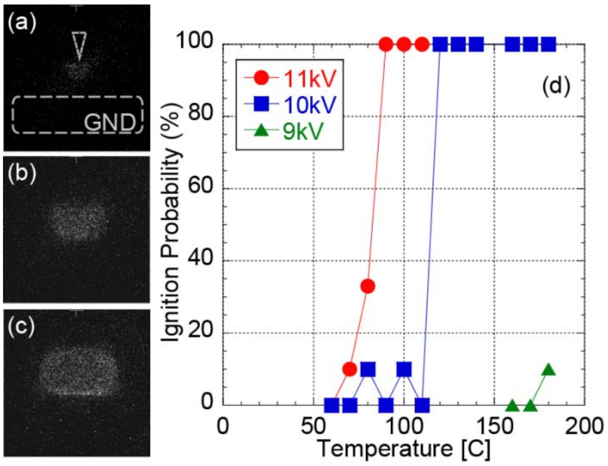

Fig. 3. (a)-(c): The temporal evolution of OH* emission by the streamer ignition. Optical filter for 310 nm inserted in front of the ICCD camera. Gate periods are (a) 50-300μs, (b) 300-550μs, (c) 550-800μs from the discharge. (d) The probability of ignition dependent on the initial temperature. Equivalence ratio ϕ=0.5.

The streamer discharges create not only radicals but ions and electrons. Further study is necessary to understand the phenomena.

6. Conclusions

Streamer ignition in the mixture of hydrogen and air was investigated. The slight increase of initial temperature greatly increased the ignition probability. Detailed plasma chemistry for the ignition needs to be investigated.

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