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Transient phenomena in a premixed burner flame superimposed with a dielectric barrier discharge

誘電体バリア放電重畳予混合バーナー火炎における過渡現象

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We are investigating control methods of combustion chemical reactions by superimposing nonequilibrium plasmas. In this work, we activated combustion chemical reactions by superposing a dielectric barrier discharge (DBD) onto a premixed burner flame with methane/oxygen/argon mixture. We observed transient phenomena in the flame using a CCD camera with a gated image intensifier when we excited DBD by pulsed high voltage.

1. Introduction

Development of new combustion technologies is necessary to reduce the consumption of fossil fuels and to avoid the global warming due to the emission of CO_2. Normal combustion is sustained by chemical reactions under thermodynamic equilibrium. Innovations in combustion technologies are considered to be difficult under the limitation of thermodynamic equilibrium. On the other hand, the activation of combustion chemical reactions would be possible with the help of plasma which could produce radicals such as oxidants and resolved fuels by electron impact processes. We are investigating mechanisms and control of combustion chemical reactions by superimposing a dielectric barrier discharge (DBD) onto a premixed burner flame. We have obtained experimental results which suggest enhanced burning velocity. The enhanced burning velocity may be attributed to new pathways of combustion reactions with the help of high-energy electrons in DBD.

In this work, we examined transient phenomena in the premixed burner flame by capturing the optical emission image using a CCD camera with a gated image intensifier.

2. Experimental setup

We superimposed coaxial-type DBD onto a premixed burner flame with methane/oxygen/argon mixture. Figure 1 shows a schematic illustration of the experimental apparatus. A burner was electrically grounded, and the nozzle was attached on a dielectric base plate. The burner nozzle played a role of the ground electrode. A slender flame was covered with a quartz tube. An aluminum electrode was attached on the outside of the quartz tube, and it was connected to a high-voltage, low-frequency power supply, resulting in DBD inside the quartz tube. The power supply consisted of a function generator (HP 8116A) and a high-voltage amplifier (Trek Japan 10/10B). In the following experiments, the flow rates of methane, oxygen, and argon were 0.38, 1.0 and 5.6 slm, respectively, corresponding to an equivalence ratio of 0.76. The discharge power evaluated from a V-Q Lissajous curve, which was approximately 3W, was 2% of the

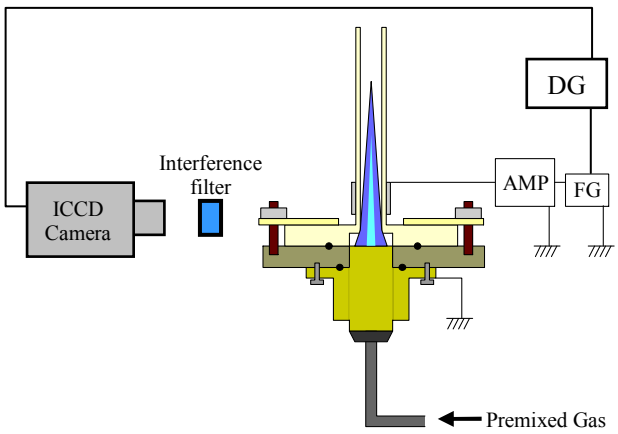

Fig. 1 Experimental apparatus.

chemical power yielded by combustion reactions.

3. Experimental results and discussion

In the first experiment, the pulse frequency and the voltage were set at 1 kHz and ±8 kV, respectively, and the distance between the electrodes was set at 80 mm. We synchronized the trigger to the gate of the ICCD camera with the pulsed voltage, and the origin of the time axis in the following results is the rise time of the pulsed voltage. The gate width was 25 μs. We attached interference filters in front of the ICCD camera to separate the optical emissions of OH and Ar from other emissions. The results shown in Fig. 2 were observed at delay times between 475 and 600 μs. From these pictures, we confirmed that the bright emission of Ar was synchronized with that of OH and the bright area of the Ar emission was the same as that of the OH emission. The optical emission image of Ar at 550 μs suggests that the pathway of the discharge current is the flame region, since the optical emission of represents the location of high-energy electrons. Hence the enhancement of the optical emission intensity of OH is considered to be mainly caused by electron impact excitation.

In the second experiment, the pulse frequency and the voltage were set at 2 kHz and +8 kV, respectively, and the distance between the electrodes was set at 15 mm. Figure 3 shows the optical emission image of OH at various delay times. According to these pictures, discharges occurred at delay times of 25-50 and 275-300 μs. On the other hand, it was observed that the length of the flame was shortened at any delay times. The shortened flame length indicates the enhancement of the burning velocity in the flame. Hence, it is suggested that the lifetimes of chemically active species, which are produced by electron impact processes, are much longer than the period of the pulsed voltage as well as the discharge duration, and the enhanced combustion state is sustained for a long time by DBD with a short duration. In addition, the experimental results indicate that the superposition of DBD onto the bottom part of the flame changes the entire shape of the flame, which also suggests the long lifetimes of chemically active species.

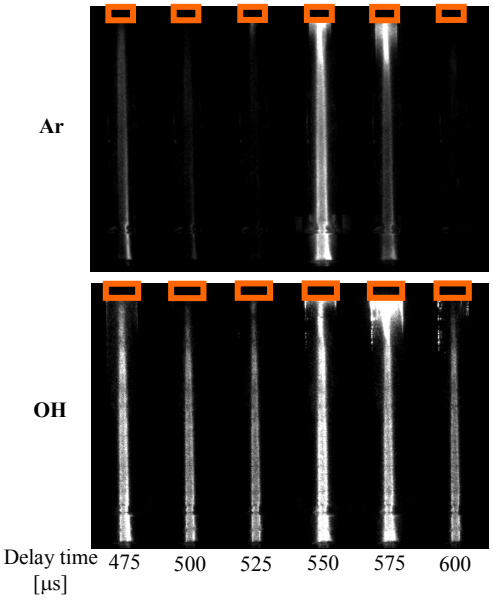

Fig. 2 The comparison of the emission from Ar and OH radicals

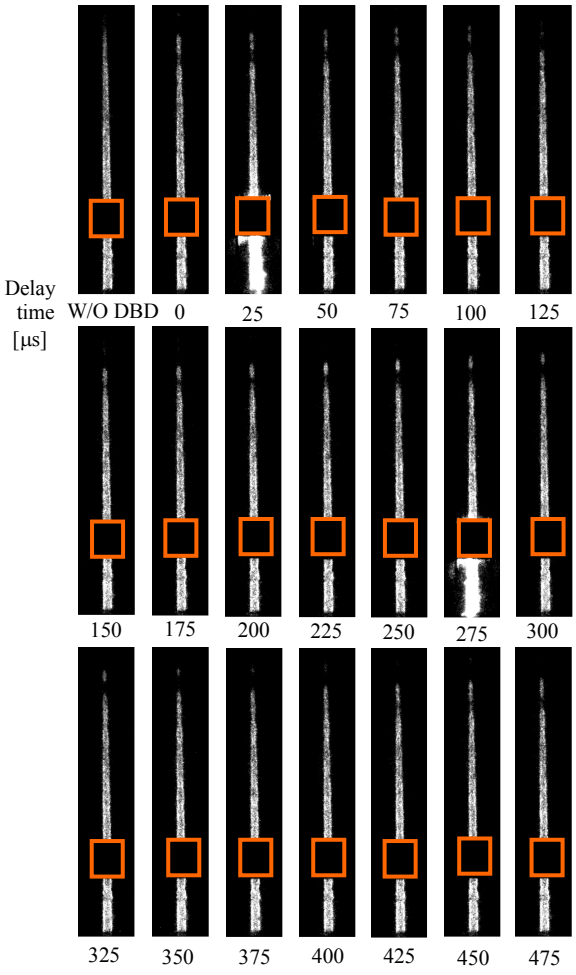

Fig. 3 The change in the flame shape and the emission intensity from OH