Electron behaviors in methane and air pre-mixture gas flame under microwave electric field

マイクロ波照射による空気メタン予混合ガス火炎中の電子の挙動

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Recently, plasma-assisted combustion has been focused on for achieving more efficient combustion way of fossil fuels and so on. Shinohara et al has reported that the flame length of methane and air premixed burner shortened by irradiating microwave power without increase of gas temperature. This suggests that electrons heated by microwave electric field assist the combustion. To clarify this mechanism, electron Monte Carlo simulations and simple rate equations in methane and air mixture gas have been done. And it is found that the simulated emission from Second Positive Band System agrees with the experimental result.

1. Introduction

Recently, plasma-assisted combustion[1] has been focused on due to achieve more efficient way of fossil fuels combustion, reducing pollutants and so on. Shinohara et al[2] has reported that the flame length of methane and air premixed burner shortened by irradiating microwave power without increase of gas temperature. This result suggests the electron heating by microwave power affect on burning velocity in combustion system. To clarify this phenomena, electron behavior under microwave power should be examined. For the first step, in this paper, electron Monte Carlo simulation in methane and air mixture gas has been done.

2. Modeling

To simulate inside the flame under microwave electric field, zero dimensional model was used. The simulated area is inside the flame as shown in Figure 1(unburned gas area).

To determine the electron energy distribution function (eedf) and transport parameters, electron Monte Carlo simulation has been done in zero dimension. The simulated conditions are applied electric field ~300V/cm with frequency of 2.45GHz and the total gas pressure of 1atm. The gas temperature is assumed to be 2000K. The gas is mixture of nitrogen, oxygen and methane and the mixture ratio is 8:2:1. Figure 2 shows the eedfs obtained from e-MCS. As shown in the Figure, as the electric field decreases, high energy electrons decrease significantly. It is found that the electric field at more
than 300V/cm is suitable for this model. To solve inside the flame using simple rate equations, the parameters and reactions written below were used.

Electric field: 300V/cm, Freq. 2.45GHz
Excitation frequency for C\(^{3}\)Pu: 1.1x10\(^7\) (1/s)
Electron density 1.0 (cm\(^{-3}\))
Einstein’s A coefficient: 2.45x10\(^7\) (1/s)

Reactions considered
\[ \text{N}_2 + e \rightarrow \text{N}_2^*(C) + e \]
\[ \text{N}_2^*(C) \rightarrow \text{N}_2^*(B) + h\nu \]
\[ \text{N}_2^*(A) + e \rightarrow \text{N}_2^*(A) + e \]
\[ \text{N}_2^*(A) + \text{N}_2^*(A) \rightarrow \text{N}_2^*(C) + \text{N}_2 \]
\[ \text{N}_2^*(C) + \text{N}_2 \rightarrow \text{N}_2^*(a*) + \text{N}_2 \]
\[ \text{N}_2^*(C) + \text{O}_2 \rightarrow \text{N}_2 + \text{O} + \text{O} \]
\[ \text{O}_2^- + \text{N}_2^*(A) \rightarrow \text{O}_2^- + \text{N}_2 + e \]
\[ \text{O}_2^- + \text{N}_2^*(B) \rightarrow \text{O}_2^- + \text{N}_2 + e \]

At this condition, effective ionization freq. is almost zero. And gas flow is assumed and the value is 5 l/min.

The electron density was solved using eq. (1)
\[
\frac{dn}{dt} = C - \frac{n}{\tau} 
\]
\( C \) is assumed to be electron density which is diffused from the flame and \( \tau \) is assumed as electron loss coefficient by gas flow.

3. Results and discussions
Figures 3 and 4 show temporal evolution of electron density and Intensity from 2\(^{nd}\) positive band system in nitrogen gas. In Figure 3, electron density quickly increases as microwave electric field is applied. And the electron density reaches about 2x10\(^6\) cm\(^{-3}\). After the electric field is off, the electron density gradually decreases. As shown in Figure 4, The intensity from 2\(^{nd}\) positive band system in nitrogen gas agrees with the experimental results. It is found that the time constant \( \tau_{\text{ON}} \) is related to gas flow parameter. It is not shown in the paper, but the intensity is not so sensitive by the time constant \( \tau_{\text{ON}} \). And the initial electron density sensitivity is also examined. And it is found that the value of the initial electron density supposes to be low.

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References