Measurement of Radicals in Plasma for Pollution Control and Its Future Prospects
環境応用プラズマのラジカル計測と今後の展望

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Measurement of radicals in a pulsed streamer discharge is introduced in this paper. Radicals (O_3, OH, O, N, $N_2(A^3\Sigma_u^+)$, NO, $O_2(v)$, and $N_2(v)$) were measured using laser spectroscopy. The pulsed streamer discharge is one of discharges used for pollution control. The laser diagnoses show densities, reaction rates, and spatial distributions of radicals. Streamer simulation that can reproduce the measurement results is also introduced, and future prospects is described.

1. Introduction

In gaseous pollution control using a plasma, the pollutants are removed by reaction with radicals. The radicals have been measured in the plasma and their densities, reaction rates, and spatial distributions have been investigated. This paper describes the radical measurements in a pulsed streamer discharge, which is often used for the pollution control, using laser spectroscopy. Then, a streamer simulation that can reproduce the measurement results is introduced, and future prospects is described.

2. Measurements of Radicals

The author's group has measured various radicals in pulsed streamer discharge. Table I shows the list of our measurements. Laser-induced fluorescence (LIF), Two-photon absorption LIF (TALIF), and coherent anti-Stokes Raman scattering (CARS) have been used for the measurements. Temperature is also measured from rotational temperature of radicals [4, 5, 15]. Shock waves and density of ambient gas in streamer channels were also measured using schlieren and shadowgraph [16, 17]. Figure 1 shows an example of the measurements. It shows one-dimensional distributions of OH density and gas temperature between the needle-plate electrodes of 13 mm distance. The streamer discharge occurs in a humid air with 100 ns, 32 kV pulse operated at 1 pps [4]. The reaction rate of OH radicals can be estimated from the decay rate of OH density shown in Fig. 1. The rise in temperature after discharge pulse is caused by vitration-to-translation energy transfer from N_2(v). The higher OH density near the needle electrode than near the plate electrode indicates that OH radicals are mainly produced in the secondary streamer, not in the primary streamer. In this way, the radical production process can be estimated from the LIF results. It was found that the N atom density is proportional to the square of discharge energy, while other radical densities are proportional to the discharge energy [9]. It indicates that N atoms are produced via two-step process with intermediate N_2(v) [18].

Table I. Radical measurements in pulsed streamer discharge by the author's group.

Radicals	Measurement method	Refs.
O_3	Laser absorption	1, 2
OH	LIF	3-5
O	TALIF	6, 7
N	TALIF	8, 9
$N_2(A^3\Sigma_u^+)$	LIF	10, 11
NO	LIF	12
$O_2(v)$	LIF	13
$N_2(v)$	CARS	14
Temperature		4, 5, 15
Schlieren and shadowgraph		16, 17

3. Simulations

The author's group has developed a simulation of pulsed streamer discharge [18, 19]. It can reproduce some of the measurement results: e.g. O, N, and OH production in the secondary streamer, two-step production of N atoms, saturation of OH production against ambient humidity, and streak photograph of streamer propagation. It can analyze major production and reaction paths of radicals [18, 19].

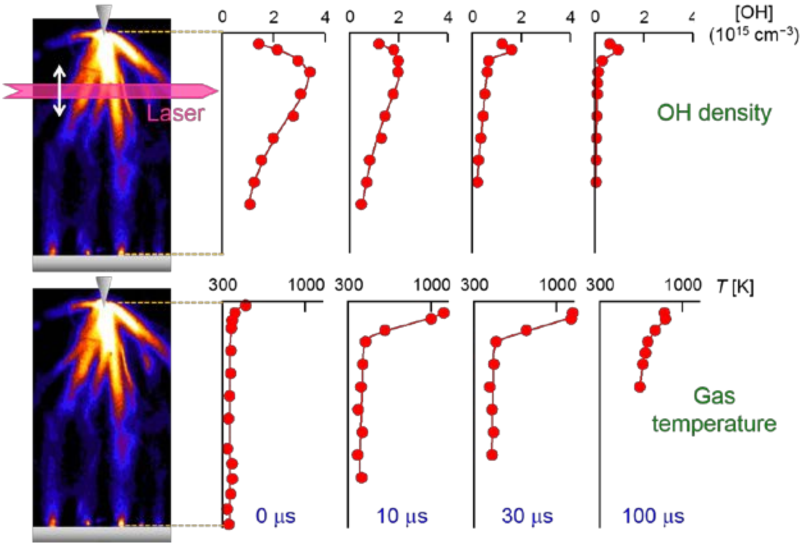

Fig.1. One-dimensional distributions of OH density and gas temperature between needle-plate electrodes [4].

4. Future Prospects

There are some measurements that should be conducted in future work. Measurement and simulation should be conducted under conditions similar to actual plasma reactors: the shape of reactor (coaxial reactor, not a point-to-plane electrodes), repetitive high-voltage pulses (not a single-pulse), and use of decomposition target gas in the ambient gas such as volatile organic compounds. Measurements in surface discharge [2] is also important because it occurs in dielectric barrier discharge and packed-bed type reactor. Clusters and tens of other species than those listed in table I should be measured. The radial distribution of radicals in the streamer channels is also important. Since the electron energy is not radially uniform in the streamer, the radial distribution of radicals depends on species [20].

5. Conclusions

Radical densities in a pulsed streamer discharge have been measured using laser spectroscopy. A lot of data have been accumulated and a streamer simulation has been developed that can reproduce some of the measured results. The behavior of radicals has been clarified gradually, but it is not sufficient. The pollution control technology needs more measurement data on radicals and a precise simulation that can reproduce the measurement results.

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