Measurement of ozone density distribution in a dielectric barrier discharge ozone generator using laser absorption method

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Measurement of the ozone density in a dielectric barrier discharge (DBD) ozone generator is investigated using a laser absorption method. A laser beam at 594 nm, which corresponds to the peak wavelength of the ozone absorption spectra, propagates through the DBD plasma and the transmittance of the laser beam is measured at different positions of the ozone reactor along its gas flow direction. Although the spatial distributions of the ozone density in the ozone reactor could be estimated tentatively, further investigations including the validity of the results are absolutely necessary.

Most of the industrial ozone generators employ a excitation of dielectric barrier discharge (DBD) plasma for the ozone synthesis since a large amount of ozone can be obtained with high concentration. However, ozone generation by the DBD has some problems to be resolved [1], [2]. For example, although plenty of experimental and theoretical studies related to the ozone generation have been reported, it seems to be difficult to reproduce the actual ozone generation characteristics by means of the computational simulations because of the complicated plasma chemistry in the ozone generator [2]. This means that the detailed mechanism for the ozone formation has remained unknown. From the viewpoint of the experiments for estimating the ozone generation characteristics, the ozone concentration is evaluated generally by the UV ozone monitor located at downstream of the ozone generator. However, the authors think that the measurement of the ozone concentration inside the plasma could be more reasonable approach to clarify the mechanism of the ozone formation and to resolve the above-mentioned problems. The present study investigates measurement of the ozone density in the DBD ozone generator using a laser absorption method.

Figure 1 shows a schematic diagram of the experimental setup for measuring ozone density. Although the ozone measurement based on the optical absorption has been commonly performed in the UV region, we have advocated the use of the visible region [3]. This allows us to use a laser as a light source, which emits a narrow beam capable of propagating through the small discharge gap. The diode-pumped solid-state (DPSS) laser (Cobolt AB., Mambo) that outputs a stabilized CW beam at 594 nm with a spectral line width less than 1 MHz is employed in this experiment, The simplified-dual beam method is also adopted to eliminate the effect of the laser output drift from the measurement [4]. The laser beam passes first through the beam splitter to split the beam in two ways as the main and reference beams. The main beam is chopped by an optical chopper to get the detectable square-wave signal for the two-phase lock-in amplifier (NF Corporation, LI5640). The modulated beam propagates then through the DBD plasma excited in the ozone reactor via a 400μm-pinhole. The intensity of the main and reference beams is detected by the photodiodes 1 and 2 which are then fed to the lock-in amplifier. The modulated main beam is measured based on the phase detection by the lock-in amplifier whereas the reference beam without modulation is just detected using an auxiliary DC voltmeter attached also to the same instrument.

In order to observe the spatial development of the ozone density along the gas flow direction of the ozone generator, the ozone reactor employs a rectangular plane electrode configuration. The area of the discharge electrode is 50$\times$30 mm. Two parallel dielectric electrodes made of soda glass are separated with 1 mm distance and have the aluminum back electrodes. The DBD is excited by applying a sinusoidal voltage between the electrodes using an inverter neon transformer (LECIP Corp., M-5). The enlarged and cross-sectional view of the DBD electrode is also shown in the same figure. The laser beam propagates through the DBD in the 50-mm side direction, which means that the light path length is 50 mm. The ozone reactor is movable along the gas flow direction by an x-stage to evaluate the spatial distribution of ozone density in the ozone reactor.

Figure 2(a) shows the temporal variation of the transmittance I/I_0 of laser beam propagated in the DBD. The ozone reactor is driven with the applied voltage of 84 V for the neon inverter and with 0.15 L/min in gas flow rate. The measurements were performed changing the position of the ozone reactor along the gas flow direction between the gas inlet ($x = 0$) and outlet ($x = 30$ mm). The ozone concentration is acquired simultaneously at the downstream of the ozone reactor by the UV ozone monitor and the results are represented in Fig. 2(b). In the case of the results at the gas inlet ($x = 0$ mm), the transmittance decreases from 1 to 0.99 during the ozone generation between $t = 50$ and 150 s. Interrupting the ozone generation at $t = 150$ s, the transmittance returns to almost initial value. Similar results are seen at the different positions. These results indicate that the optical absorption could be caused by the ozone molecules generated in the ozone reactor, depending upon the position of the ozone reactor. However, the transmittance observed during the ozone generation seems to be unstable. In particular, after stop the ozone generation, the transmittance becomes excessively larger than that before the ozone generation ($I/I_0 > 1$). This is obviously caused following the variation of the main beam intensity, but we have not yet understood the cause of such strange behavior, which still remains as unsolved issue.

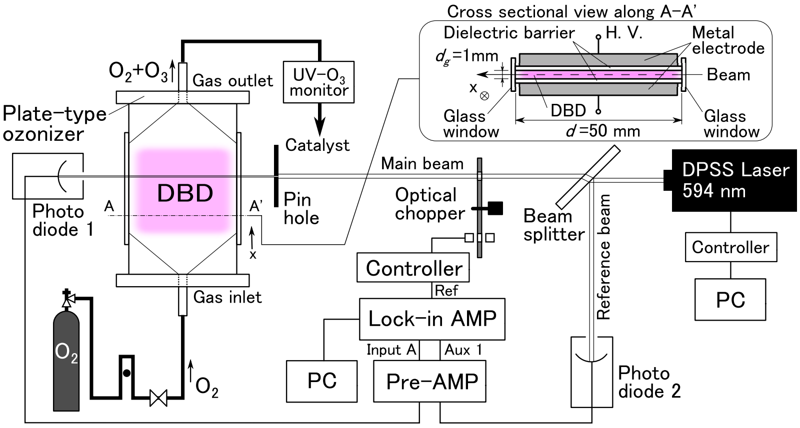

Fig. 1: Experimental setup for ozone density measuremnt.

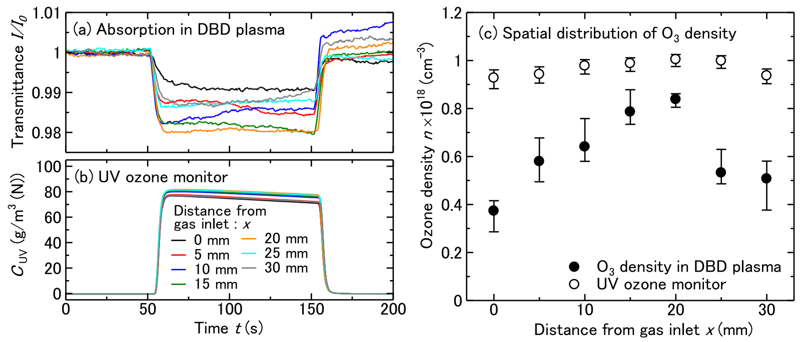

Fig. 2: Temporal variation of (a) transmittance and (b) ozone concentration by UV monitor. (c) Spatial distribution of ozone density in ozone reactor.

Although it is difficult to evaluate the ozone density in the ozone reactor from the present results due to the above-mentioned issue, we tentatively estimate the spatial distribution of the ozone density along the gas flow direction in the ozone reactor. The results are shown in Fig. 2(c). The solid circles are the ozone density in the ozone reactor determined from Fig. 2(a) and the open circles are the ozone concentration by the UV ozone monitor estimated from Fig. 2(b). These are determined as the average amount obtained during ozone generation between $t = 62$ and 150 s in Fig. 2(a) and (b) since the ozone concentration measured by the UV ozone monitor is almost stabilized. The ozone density in the ozone reactor increases towards the gas outlet and reaches its maximum at $x = 20$ mm. Further away from this position, the ozone density adversely decreases, and that obtained finally at the gas outlet is 0.54 times smaller than that measured externally by the UV ozone monitor. Further investigations including the validity of these results are absolutely necessary.

References

[1] M. Taguchi *et al*., *Euro. Phys. J. Appl. Phys.*, **55** (2011) 13805.
[2] M. Tanaka, *Proc. 18th Annual Conf. Ozone Sci. and Technol. Japan 2008* (2008) 153-156.
[3] K. Teranishi *et al*., to be published in *Ozone Sci. & Eng.*
[4] M. H. Proffitt and R. J. McLaughlin, *Rev. Sci. Instrum.* **54** (1983) 1719-1728.