# Measurement of Gas Temperature of Nano-pulse Helium Dielectric Barrier Discharge Plasma by Identification of OH Spectrum

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**Abstract:** Decomposition of hazardous materials by atmospheric-pressure plasma is mainly affected by characteristics of electron and gas temperature. These characteristics could be analyzed by optical emission spectrum, and in particular, gas temperatures can be simulated from the measurement of OH spectrum. In this study, the OH spectrum from plasma generated by causing nano-pulse dielectric barrier discharge on the mixed gas of helium and air was observed, and the gas temperature was inferred from the synthetic spectrum.

**Keywords:** Atmospheric Plasma, Dielectric Barrier Discharge, Gas Temperature, Optical Emission Spectroscopy

## 1. Introduction

Application research on atmospheric pressure plasma is becoming more active. In particular, a technology for decomposing hazardous substances using atmospheric plasma from dielctric barrier discharge (DBD) is under study. The decomposition of hazardous substances by plasma is primarily affected by the characteristics of electron generation by discharge, and for this purpose, a method of analyzing the temperature and density of electrons in an analytical method based on modeling considering the major interactions between atoms and molecules in the gas used in discharge. In addition, in the practical application phase of the technology, not only the characteristics of plasma electrons but also the influence of the temperature of the gas itself should be considered. In general, the gas temperature may be measured through a thermocouple, but this method may affect the flow of plasma itself, and thus non-penetrating methods are utilized. The representing example of non-penetrating diagnostic methods is emission spectroscopy, which indirectly calculates temperature by observing spectrum, and for temperature measurement, molecules such as nitrogen ($N_2$, $N_2^+$) or hydroxide (OH) are mainly used [1]. This is because these molecules occupy a high composition ratio in the atmosphere, making it relatively easier to measure the spectrum.

Specifically, diagnosis techniques measuring the gas temperature using optical emission spectrum include observing the spectrum broadening due to the Doppler effect [2], and a method of using Boltzmann distribution of atomic or molecular spectra. In the case of diagnosis analyzing the Doppler broadening, the increase in the width of the molecular spectrum is relatively small, so a spectrometer with very high resolution is required to determine the broadening. In case of utilizing Boltzmann plot, the spectrum itself must be synthesized and compared with the experimentally obtained one for accuracy of simulataion. Therefore, in this study, a molecular spectrum suitable for the resolution of the spectroscope in possession is simulated through a theoretical model, and compared with the spectrum obtained in the experiment to analyze the measurement accuracy of the gas temperature. And using this method, the gas temperature in the DBD plasma according to the power characteristics was diagnosed and compared with the actual measurement results.

## 2. Experiment Setup

Figure 1 shows a schematic of a cylindrical DBD device constructed to generate helium plasma, which is the subject of temperature measurement. For the application of high voltage, an alternating current power and a nano-second pulsed power source was used, and in case of nano-pulsed power, electrical conditions were changed by changing the applied voltage, pulse width, and frequency using the functions embedded in the power source. The high-voltage electrode is a stainless screw with a length of 20 cm and a diameter of 1 cm. As the dielectric, cylindrical quartz was used, with an outer diameter of 26 mm and a thickness of 3 mm. In the case of the gas composition, helium gas with a flow rate of 4.7 L/min was injected into the device under atmospheric pressure. A spectrometer (HRS-500, Princeton Instruments) coupled with ICCD camera (PI-MAX4, Princeton Instruments) is used for optical measurement of plasma spectrum.

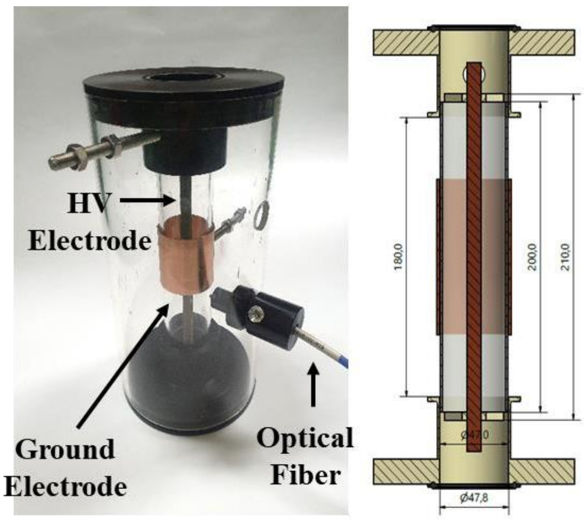


Fig. 1. A schematic of a cylindrical DBD device.

## 3. Data and Results

Fig. 2 show the grating emission spectrum of pulsed DBD plasma generated by nano-second pulsed power in a mixed gas of helium and air. In the pulsed discharge, a high-voltage pulse having a voltage of 14 kV and a pulse width of 140 ns was applied at a repetition rate of 1 kHz. The central wavelength of the spectrometer is set at 308 nm, and the grating of 1200 groove/mm is selected and blazed at 500 nm. The slit width was set to 28 μm. Under this condition, the spectrum is derived to have a range of 20 nm and a resolution of 0.0628 nm.

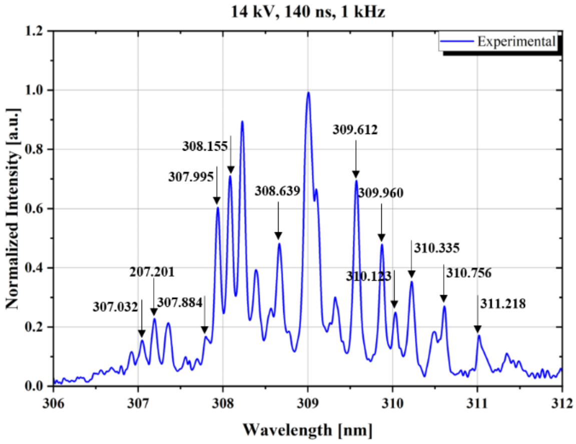


Fig. 2. Identification of the helium DBDs spectrum with OH radical.

In the atmospheric pressure, the approximation of the gas temperature of the plasma is achieved by analyzing its rotational temperature of OH molecule, through the peak curve analysis of its spectrum. This approximation could be justified from the assumption that the population distribution in the ground state obeys a Boltzmann distribution, where the ground state rotational temperature equals the gas temperature, and due to the low rotational levels of OH ( $A^2\Sigma^+(v'=0) \rightarrow X^2\Pi\,(v''=0)$ ). The transition wavelength can be expressed as [3]:

$$\lambda^{Av'J'}_{Xv''J''} = \left\{ n_a \sum_{p=0}^{5}\sum_{q=0}^{1} Y^{A}_{pq}\left(v'+\frac{1}{2}\right)^{p} [J'(J'+1)]^{q} - Y^{X}_{pq}\left(v''+\frac{1}{2}\right)^{p} [J''(J''+1)]^{q} \right\}^{-1} \quad (1)$$

as the refractive index of air and spectroscopic constants of vibrational and rotational transitions is given. The rotational transition can be expressed from the state of vibrational transition as [3]:

$$\mathrm{I}_{J'J''} = \frac{K}{\lambda^4} S_{J'J''} \exp\left(-\frac{E_{J'}}{k_B T_{rot}}\right) \quad (2)$$

Thus, it can be derived from the line spectrum obtained from the experiment as an equation for the rotation temperature. The Boltzmann plot can be extrapolated by applying data on wavelength and energy of the known OH spectrum to the equation along with the experimental results, and the rotational temperature can be inferred from the slope of the curve.

Fig. 3 shows a comparison of the synthetic spectrum of OH obtained from the simulation program Rotem2 [4] to the spectrum measured with an actual spectrometer to obtain the rotational temperature of the OH molecule. This program simulates a synthetic spectrum suitable for device conditions through the chi-square method. The spectral band of the 306-312 nm wavelength range corresponding to $A_2\Sigma^+ \rightarrow X^2\Pi$ transition was simulated, from which the gas temperature was obtained. The gas temperature inferred from the synthetic spectrum is 520 K.

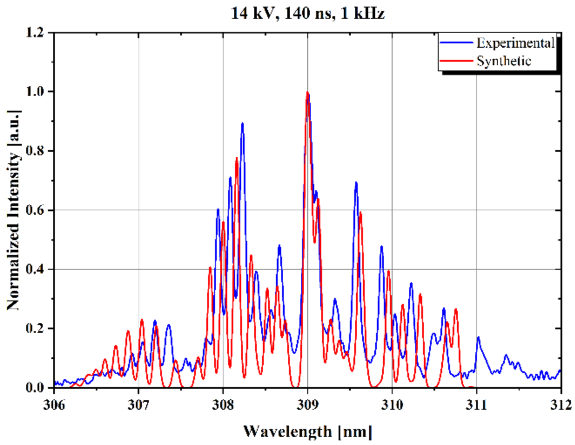


Fig. 3. Measured and simulated optical emission spec tra around the OH line (308 nm).

Since the emission of pulsed plasma generated form the device was not strong enough, it was inevitable to set the exposure time of the spectrometer to increase the amount of light. This may have led to a decrease in resolution in measuring the line spectrum, and future experiments would be conducted through improvements in the optical diagnostic system.

## 4. Acknowledgments

This work was supported by Samsung Advanced Institute of Technology (SAIT).

## 5. References


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