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Gas Temperature of Atmospheric Pressure Needle to Plane Dielectric Barrier Discharge Open Air Plasma

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Abstract: *Atmospheric pressure single dielectric barrier open air plasma discharges in the 'needle electrode-airgap-glass barrier-plane electrode' configuration are generated by a high voltage (5 kV) AC source operating at a frequency of 20 kHz and investigated by means of optical emission spectroscopy (OES). The produced plasmas are non-equilibrium, diffused shape and stable. The air gap and dielectric thickness between the electrodes appreciably influence the discharge plasma. The emission intensity increases with increasing air gap within the range of gap 0.5–1.0 mm at fixed dielectric thickness. By fitting the simulated spectra with experimental spectra using LIFASE software, the gas temperature is estimated. The gas temperatures (rotational temperature) are 330–305 K and vibrational temperatures 2400–1500 K by best fitting the optical emission spectra of the molecular band of* N_2^+ *(*$B^2\sum_u^+ \rightarrow X^2\sum_g^+$*, 1-0) for 0.5–1.0 mm electrode gaps and 0.15–0.75 mm dielectric thicknesses in open air.*

Keywords: *Air plasma, gas temperature, optical emission spectroscopy, needle to plane etc.*

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I. Introduction

Generation and uses of non-thermal atmospheric pressure DBD plasmas are investigated with growing interest because of its cost effectiveness and more convenient alternative to low pressure plasma technology [1]. Many configurations and properties for DBD and their applications have been studied in this regards. Capacitive coupled radio-frequency (RF) discharges are investigated for material processing and surface treatment [1]. At present, scientists are searching uniform and appropriate 'Bio-compatible' room temperature plasma source in atmospheric pressure which can be suitable for material processing and at the same time for the treatment of biological materials.

In most common configurations DBD's have dielectric cover on both electrodes but the DBD geometry with single dielectric barrier does not allow the charges to accumulate the electrode surface and all the charges to move into the electrical system [2]. The typical materials like glass, quartz, ceramics, alumina and polymers with low dielectric loss and relatively high breakdown strength can serve this purpose [2]. Electrode configuration plays an important role in this case. Needle to plane single dielectric barrier plasma source has been invented, characterized by means of various plasma diagnostic methods [3–5] and tested e vivo on cultured cells [6–7] and isolated tissues. The needle to plane DBD showed lower power consumption and higher discharge current than the conventional DBD type at a given voltage. Therefore, the needle to plane appeared to be more efficient than the conventional DBD [8]. When operated properly, the plasma remains at room temperature with stable diffuse discharge.

The gas temperature is one of the fundamental parameters in atmospheric pressure plasma discharges to understand physics of plasmas. To determine the gas temperature different methods can be used. Langmuir probe diagnostics could be a useful method at atmospheric pressure [9]. The above method is difficult because of small plasma dimension, electrode configuration and the non-thermal behavior and strong collision processes of plasma. The plasma temperature can determine properly by using Optical emission spectroscopic (OES) technique. De-Zheng Yang *et al* [10] studied the effects of pulse peak voltage, pulse repetition rate and the gap distance between electrodes on gas temperature and the emission intensities of NO, OH and N_2 in the needle-plate atmospheric pressure nanosecond barrier discharge plasma using OES. A diffuse bi-directional pulsed dielectric barrier discharge (BNPDBD) is investigated in air using the single needle-plate electrode configuration at atmospheric pressure [11].

The gas temperature (T_g) in non-equilibrium plasmas is often obtained from the plasma-induced emission by measuring the rotational temperature of a diatomic molecule in its excited state by fitting molecular spectra using LIFBASE software [12]. The physical mechanism of needle to plane discharge is yet to understand clearly and many factors like the influence of source voltage, electrode geometry, discharge gap and dielectric thickness need further investigation. Mangolini et al [13] investigated the influence of dielectric thickness on density profiles of Helium under an AC power supply. The reports about the influence of dielectric thickness and discharge gap on air plasma discharge by OES are relatively few in number. Therefore, the study of the effect of air gap and dielectric thickness on the performance of the needle to plane atmospheric pressure DBD by OES is essential.

In this article, characteristics of AC pulsed needle to plane single dielectric barrier air plasma at atmospheric pressure with different air gap and dielectric thicknesses are presented. The optical diagnosis of the produced needle to plane open air sustainable plasma is carried out for better understanding of its gas temperature. The aim of the present research work is to get control over plasma parameters for the optimum condition of plasmas discharge to be used for material processing and biomedical applications. In this investigation we used the LIFBASE software fitting process to estimate gas temperature (rotational temperature) and vibrational temperature using molecular N_2 spectra. Detail experimental setup, analytical results and discussions are given in the following sections.

Experimental setup

Figure 1 shows the schematic diagram of the experimental arrangement (needle-airgap-glass-plane) of the atmospheric pressure needle to plane dielectric barrier discharge (NPDBD) in open air.

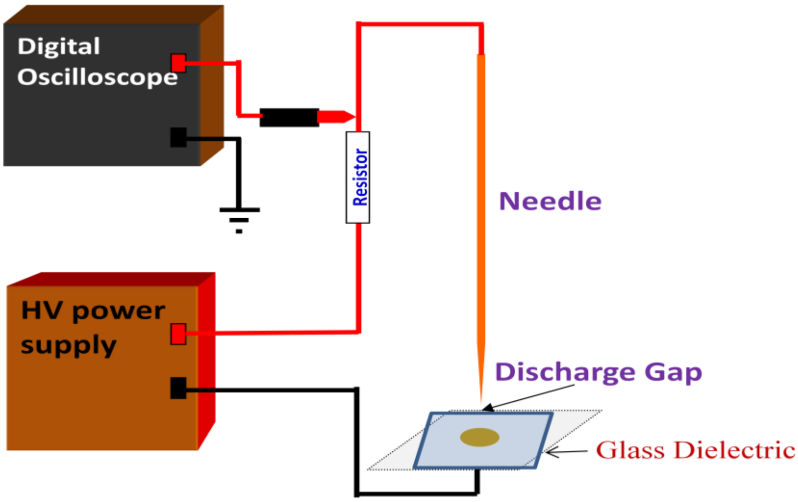

Figure 1: Schematic diagram of atmospheric pressure needle to plane dielectric barrier discharge.

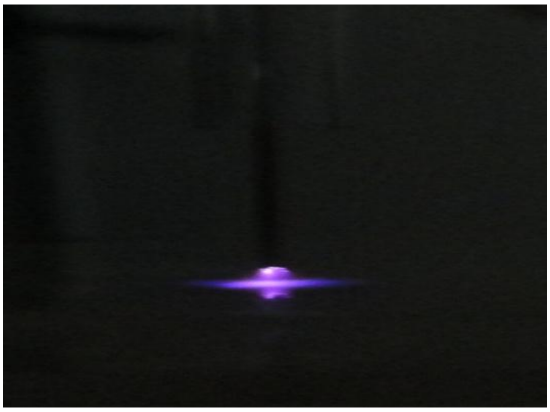

Figure 2: Camera view of atmospheric pressure NPDBD plasma.

The discharge is made between a floating needle electrode of diameter 0.2 mm and a silver plate electrode of diameter 3 mm with a gap distance 0.5–1.0 mm. The electrodes were connected to a high voltage 5 kV power supply operating at a frequency 20 kHz. The plate electrode is covered with a single dielectric barrier (glass) of 0.15–0.75 mm thickness. The produced air plasma is diffuse type and stable in nature as shown in Figure 2.

Emitted spectrum from the produced plasma is fed to the spectrometer (USB2000+XR1) through a 200 cm long optical fiber cable. The spectrometer is associated with a computer for spectral data acquisition. The discharge voltages, currents and emitted spectra are recorded for different air gap and different dielectric thicknesses in order to investigate the properties of the produced air plasma. The recorded emission spectra along with the identified major peaks of the species are depicted in Figure 3. The analytical results are discussed in the following sections.

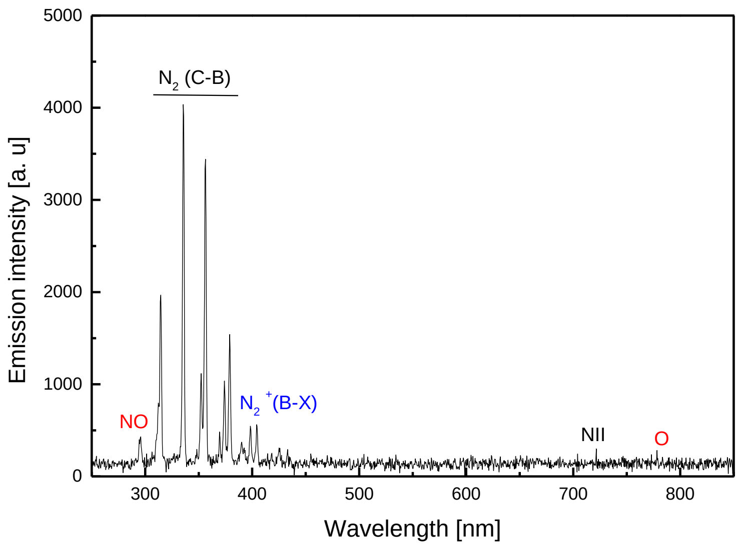

Figure 3: Emission spectra of 1.0 mm air gap and 0.45 mm dielectric thickness plasma with 5 kV source voltage and 20 kHz frequency.

Gas temperature measurement

The kinetics of reactions of molecular and atomic transitions in atmospheric pressure air plasmas is a very complex topic which has been studied by a number of researchers [14, 15]. In atmospheric pressure plasmas, the energetic free electrons, once created by applied electric field collide with heavy particles including neutrals and ions with a very high collision frequency (10^{11} H_z as diagnosed by millimeter wave interferometry), lose their kinetic energy, and subsequently recombine with ions or attach to neutral species on a much faster time scale than in low pressure (<1 Torr) plasmas [16]. Electron-neutral collisions are the dominant collision process in our low fractional ionized atmospheric pressure plasmas. In high pressure air plasmas, the excited metastable states, especially the vibrational states, are closely coupled with the free electron energies. Therefore, the electric field energy transferred to the free electrons will also excite molecular vibrational states on a very fast time scale [17–19]. Additionally, the two-body and three-body electronic recombination and attachment rates of air plasma species including N_2^+ are also very high [20]. The resonant rotational and vibrational states of air molecules store kinetic energy from electron collisions and dissipate a significant amount of the energy through radiative transitions. To estimate plasma gas temperature optical emission spectra of the first negative band of N_2^+ ($B^2\sum_u^+ \rightarrow X^2\sum_g^+$, 1-0) is used. Due to small energy gap between rotational levels, N_2^+ is readily achieved by translational motion and frequent collisions of heavy particles like N_2 and O_2 at atmospheric pressure air. Therefore, the rotational temperature of N_2^+ is approximately equal to the gas temperature of the plasma [16]. The software LIFBASE developed by Lugue and Crosley [21] is used to model OES and to determine the rotational temperature (gas temperature) of N_2^+ by fitting the simulated spectra with experimental spectra [15–22].

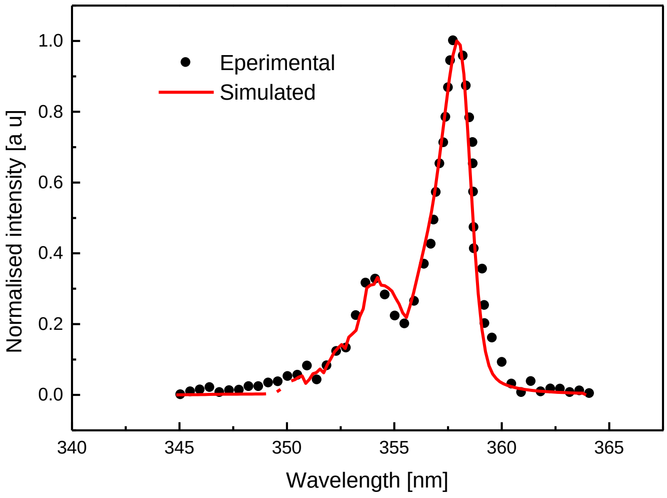

Figure 4: LIFBASE fitted nitrogen band for 1.0 mm air gap with 0.15 mm dielectric (glass) thickness.

Figure 4 shows the experimental spectra emitted from needle to plane electrode configuration diffuse DBD and the corresponding best fitted spectra of N_2^+ ($B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$, 1-0) under the condition of 4.8 kV pulse peak voltage, 20 kHz frequency, 1.0 mm discharge gap distance and 0.15 mm thick glass dielectric layer. It is found that the simulated spectrum fits the experimental spectra with good agreement when the rotational temperature of N_2^+ is equal to 325 K, so the gas temperature of the plasma is about 325 K. The low gas temperature indicates that the discharge has promising application potentials in many industrial and biological fields.

Figures 5 and Figure 6 show the effect of gas temperature and vibrational temperature with a variation of dielectric thickness, respectively. It can be seen that the rotational temperature reduce with increasing dielectric thickness. With the dielectric thickness increases, the electric resistance of the dielectric layer increases, hence the electric field across the discharge gap becomes weak. As a result, the high energy electron density and electron mean energy decay gradually which leads to the decreasing of the number of collisions between electron and heavy particles and the energy efficient transfer from electrons to heavy particles decreases. So the plasma rotational temperature and vibrational temperature reduce with the increasing dielectric thickness. Similar characteristics are found for 0.5 mm and 1.5 mm air gap. Therefore, it is clear that the discharge can be operated in a wide range of needle-plane electrode gap and dielectric thickness.

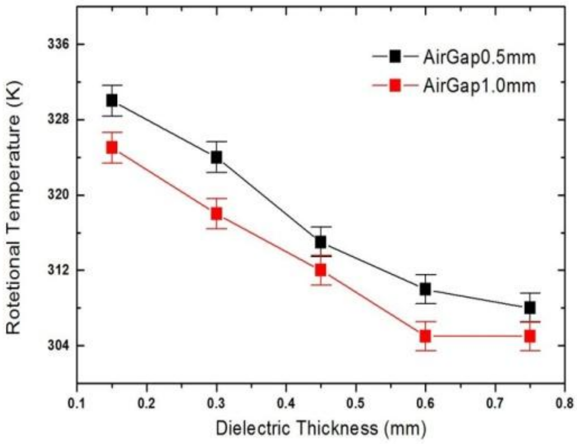

Figure 5: Variation of rotational temperature with dielectric thickness.

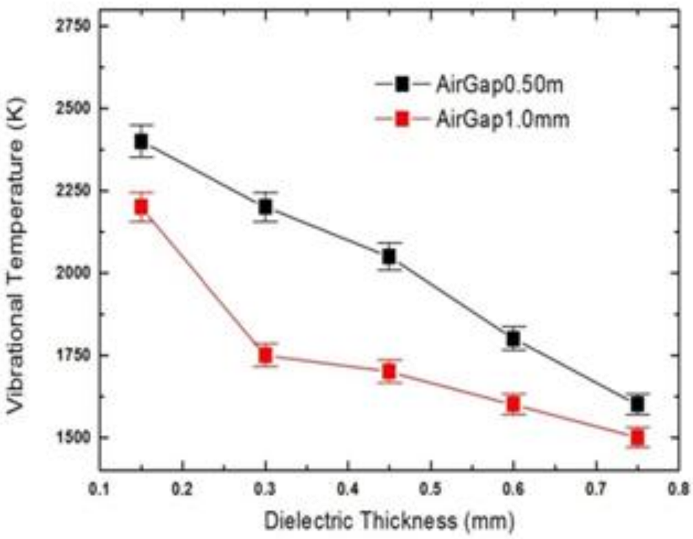

Figure 6: Variation of vibrational temperature with dielectric thickness.

The measured gas temperature is compared with different literatures as shown in Table 1.

Table 1: Comparison of gas temperature of the present work with other works

Type of discharge	Applied Voltage	Operating Frequency	Type of gas used	Gas temperature K	Reference
Atmospheric pressure NPDBD open air plasma.	5 kV	20 kHz	Air	332–305	Present work
Atmospheric pressure open air plasma needle.	200–400 V	13.56 MHz	Air	325–310	[23]
Atmospheric pressure gliding arc H_2O/O_2 plasma in open air.	4 kV	60 kHz	Air	2000–3400	[24]
Atmospheric pressure plasma jet utilizing Ar and Ar/H2O mixtures.	22 kV	10–42 kHz	Ar/H_2O	330–306	[25]
Air plasma under a double hexagon needle-array electrode at atmospheric pressure.	22–34 kV	150 Hz	Air	365 ± 5	[26]
Atmospheric pressure LESAR induced air plasma.	25 kV	13.56 MHz	Air	4400±50	[16]

From the above table, it is observed that the obtained result in this work of gas temperature from NPDBD open air plasma is better to other works [16, 23–26] on the basis of applied voltage or operating frequency. Therefore, it can be concluded that the plasma device of NPDBD is cost effective.

II. Conclusions

Atmospheric pressure single dielectric barrier discharges in the ‘needle electrode-airgap-glass barrier-plane electrode’ configuration are generated by a high voltage (5 kV) AC source operating at a frequency of 20 kHz and investigated by means of optical emission spectroscopy (OES). The electrode gaps in open air are 0.5–1.0 mm and the dielectric thicknesses are 0.15–0.75 mm. The produced plasma was non-equilibrium, diffused shape and stable. The air gap and dielectric thickness between the electrodes appreciably influence the discharge plasma. The emission intensity increases with increasing air gap within the range of gap 0.5–1.0 mm at fixed dielectric thickness. The gas temperature (rotational temperature) is estimated 330–305 K and vibrational temperature is 2400–1500 K by best fitting the optical emission spectra of the molecular band of N_2^+ ($B^2\sum_u^+ \rightarrow X^2\sum_g^+$, 1-0).

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References

[1]. J Park , I Henins, H W Herrmann, G S Selwyn, and R F Hicks: *J. Appl. Phys*. **89**, 20, 2001
[2]. W I Wiese*: Plasma Diagnostic Techniques*, edited by R H Haddlestone and S I Leonar; pp-369-377 (Academic, New York, 1965).
[3]. E Stoffels, A J Flikweert , W W Stoffels, and G M W Kroesen, *Plasma Sources Sci. Technol*. **11**, 383, 2002
[4]. I E Kieft, E P Van der Laan, and E Stoffels*: New J. Phys.* **6**, 149, 2004
[5]. E Stoffels, R E J Sladek, I E Kieft, H Kesten, and H Wiese: *Plasma Phys. Control. Fusion*, **46**, B167, 2004
[6]. I E Kieft, J L V Broers , V Caubet-Hilloutou , F C S Ramaekers , D W Slaaf, and E Stoffels: *Bioelectromagnetics* **25,** 362, 2004
[7]. I E Kieft , D Darios, A J M Roks, and E Stoffels*: IEEE Trans. Plasma Sci*. **33**, 771–5, 2005
[8]. Se-Jin Kyung et al: *Surface & Coatings Technology*, **202**, 1204–1207, 2007
[9]. M R Talukder, D. Korzec, and M. Kando*: J. Appl. Phys.* **91**: 9529-9538, 2002
[10]. De-Zheng Yang, Yang Yang, Shou-Zhe Li, Dong-Xia Nie, Shuai Zhang, and Wen-ChunWang, *Plasma Sources Sci. Technol.* **21**, 035004 (9pp), 2012
[11]. De-zheng Yang, Wen-chun Wang, Li Jia, Dong-xia Nie, and Heng-chao Shi: *Journal of Applied Physics* **109**, 073308, 2011
[12]. P J Bruggeman, N Sadeghi, D C Schram, and V Lins: *Sci. Technol*. **23**, 023001 (32pp), 2014
[13]. L Mangolini, C. Anderson, and J. Heberlein: *J. Phys. D* **37**, 1021, 2004
[14]. R J Vidmar, and K. R. Stalder: *in Proceedings of the AIAA* (unpublished), pp. 1–8, 2003
[15]. C. O. Laux, T. G. Spencer, C. H. Kruger, and R. N. Zare*: Plasma Sources Sci. Technol.* **12**, 125, 2003
[16]. S Q Luo, C M Denning, and J E Scharer*: J. Appl. Phys.* **104**, 013301, 2008
[17]. I V Adamovich, A P C J W Rich, and S A Zhdanok*: in AIAA Plasma Dynamics and Lasers Conference,* 31st, Denver, CO, June 19-22, pp. 1–19, 2000
[18]. Y P Raizer*: Gas Discharge Physics,* Springer-Verlag, Berlin, 1991
[19]. D Staack, B Farouk, A F Gutsol, and A A Fridman: *Plasma Sources Sci. Technol.* **15**, 818, 2006
[20]. K Akhtar, J E Scharer, S Tysk, and C M Denning: *IEEE Trans. Plasma Sci*. **32**, 813, 2004
[21]. J Lugue, and D R Crosley*: Lifbase Database and Spectral Simulation Program (Version 1.6), SRI International Report* MP 99-009, 1999
[22]. L Yu, L Pierrot, C O Laux, and C H Kruger: *Plasma Chem. Plasma Process.* **21**, 483, 2001
[23]. Xiaozhi Shen et al: *The Astrophysical Journal,* **801**:129 (11pp), (2015 March 10)
[24]. Z J Liu et al: *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy* **121**, 698–703, 2014
[25]. T Shao, K Long, C Zhang, P Yan, S Zhang, and R Pan: *J. Phys. D: Appl. Phys.* **41**, 215203, 2008
[26]. K Takaki, M Hosokawa, T Sasaki, S Mukaigawa, and T Fujiwara: *Appl. Phys. Lett.* **151,** 2005

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