Effect of Electrodes types on the Properties of the Dielectric Barrier Discharge Plasma

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Abstract

In this research, the dielectric barrier discharge (DBD) plasma system was designed. This design consists of two electrodes with a diameter (5 cm) surrounding by Teflon with the top thickness (2 cm) and the bottom thickness is (2.9 cm). The glass as a dielectric barrier with (2 mm) in thickness was used.

Non-thermal DBD Plasma was produced by applying (16 kV) AC voltage source between the two electrodes and a glass plate as a dielectric barrier. The effect of electrodes type on the properties of produced DBD Plasma was studied; Copper and Aluminum electrode was used for this purpose. Plasma parameters were calculated by analysis Plasma spectrum measured using optical emission spectroscopy and using Boltzmann plot method. Electron temperature (T_e) found to be (4.46 eV) and (4.18 eV) for Copper and Aluminum respectively.

Keywords: DBD Plasma, Non-thermal plasma, Boltzmann plot.

دراسة تأثير نوع الأقطاب الكهربائية على خصائص بلازما تفريغ حاجز العزل الكهربائي

الخلاصة

في هذا البحث تم تصميم نظام بلازما تفريغ حاجز العازل حيث يتكون هذا التصميم من قطبين بقطر (5 cm) كل منهما محاط بمادة التيفلون بسمك علوي (2 cm) وسمك سفلي (2.9 cm) كما تم استخدام الزجاج كعازل وبسمك (2 mm).

تم إنتاج بلازما (DBD) الغير حرارية من خلال تطبيق مصدر فولتية متناوبة (16 kV) بين القطبين الكهربائيين والصفيحة الزجاجية كحاجز عازل. كما تم دراسة تأثير نوع مادة الأقطاب الكهربائية على خصائص البلازما (DBD) المنتجة، حيث استخدم نوعين من الاقطاب احدهما من النحاس والآخر من الألومنيوم لهذا الغرض. تم حساب معلمات البلازما بواسطة قياس تحليل طيف البلازما باستخدام التحليل الطيفي للانبعاثات الضوئية وباستخدام طريقة بولتزمان للرسم. اظهرت النتائج ان درجة حرارة الالكترون (T_e) تساوي (4.4642 eV) و (4.1841 eV) للنحاس والألومنيوم على التوالي.

1. Introduction

Atmospheric Non-thermal Plasma (ANTP) used widely investigated in many research and applied in several various industries due to their effect potentially on technology applications [1]. (ANTP) include generation high-density plasma at room temperature, which makes it desirable because of the low cost and doesn't need expensive laboratories [2]. There are many studies executed in related fields for (ANTP) to develop the practical applications and essential theoretical working [3]. In ANTP discharge, often, a sinusoid mono-excitement source is used with a frequency range from the kHz to MHz. However, it is difficult to fulfill the independent control and improvement of plasma parameters by considering the efficiency of a singular excitation source [4]. Many researchers have begun studying the possible applications of discharge plasma to reduce the aforementioned problems [5]. Among which, as an efficient method to improve generation (ANTP), radio-frequency (RF) paying dielectric barrier discharge (DBD) with two sources of the independent power excitation. (ANTP) has achieved rising attentiveness by enabling independent control of the parameters of plasma and improvement the discharge for different applications [6].

However, studies are still passed on the practical aspect of applications and lack theoretical understanding of such discharges which would enable researchers to change operation parameters in the system to determine results detailed of plasma parameters. This is due to the chemical and physical properties which depend on the dynamics of the power dissipation and the mechanisms of the electron heating, whereby the plasma parameters are highly sensitive and affected by instabilities, process transitions and the variations associated electron heating for plasma. It is therefore necessary to understand electron heating mechanisms in (DBD) system that working by atmospheric pressure to compensate for the theoretical aspect of the studies that are used this applications.

2. Dielectric Barrier Discharge (DBD)

DBD Plasma or (silent discharge) used a dielectric material such as Polymers as a plasma stabilizer to uses in the industrial applications. The important part of DBD Plasma is the dielectric layer material, which covers the electrodes. Usually, the materials which have high insulation constant and high breakdown voltage such as ceramics or glass are used. The dielectric material must be able to avoid the damage caused by the stress due to the discharge. There are some factors can affect the discharge properties and contributes to the efficiency and stability of the DBD device such as the distance between the electrodes, the diameter of electrodes, and the electrode material [7]. To improve the discharge parameters can be used to adjust various external parameters, for example:

1. The discharge voltage applied affects the quantity of the electric field, hence on the energy of the charged particles.
2. The power controls the ionization density, hence is an approximate variable for the plasma density. Also, it is a probable variable to control for the energy of plasma.
3. The pressure of the gas controls the collisions of electron frequency that means a free path of plasma constituents.
4. The gas sort controls the ionization, thus the energy of necessary to produce an ion-electron pair in the plasma was controlled.
5. The electrodes form can affect the energy input by changing the electric field and change the shape of the electrodes.
6. Cathode properties can affect the discharge properties, such as the emission coefficient, or the able to the emission of thermal ions.

The types of electrodes configurations of DBD Plasma can be shown in Figure 1.

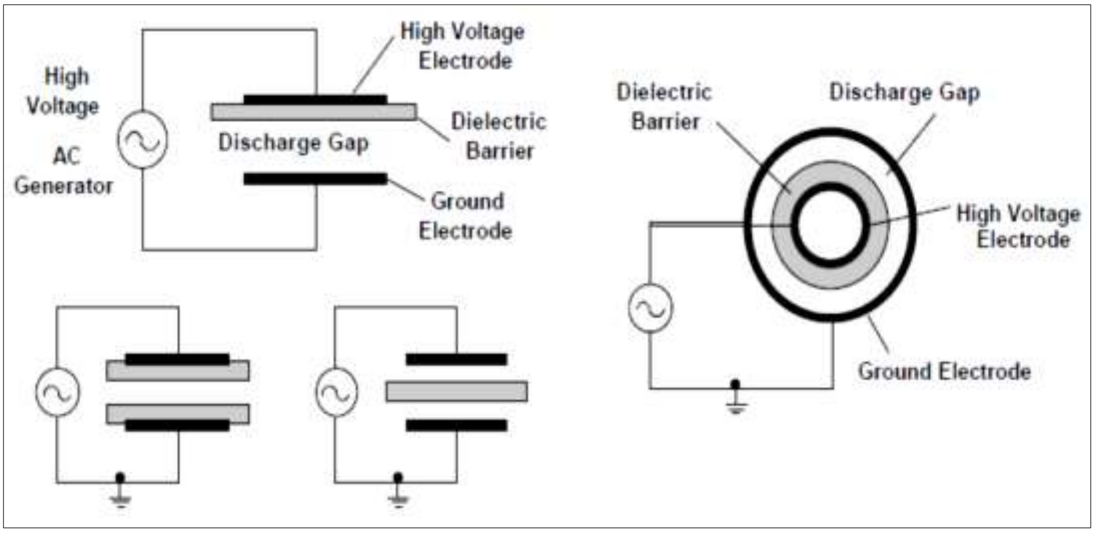

Figure (1): the electrode configurations of DBD Plasma [7].

3. Experimental Work

In this research, the dielectric barrier discharge (DBD) Plasma system was designed to generate plasma normal atmospheric pressure. This system consists of two electrodes made of Copper and Aluminum, respectively. The diameter of each electrode is (5 cm) surrounding by Teflon with thickness (2.9 cm) for the bottom electrode and (2 cm) for the top electrode. The electrodes are fixed on a holder at one end, moving up and down to control the distance between the electrodes, and each of them is connected to alternating voltage power.

In this work, a dielectric material of glass with thickness (2 mm) was used, and the dielectric constant was (3.7 – 10) [8]. Glass is placed between the two electrodes to form a discharge process. Figure 2 shows the locally designed DBD Plasma system.

Figure (2): The locally designed DBD Plasma system.

The power supply for the alternating voltage and the locally designed produces high voltage up to (20 kV) and a frequency of up to (35 kHz) and current in mA. The electrodes are surrounded by a dielectric material of Teflon with constant isolation (2.1) at room temperature and frequency (1 kHz) [8].

4. Results and Discussion

In this research, two types of electrodes (copper electrode and aluminum electrode) were applied using high voltage (16 kV), alternating current (352 mA), frequency (22.507 kHz) and distance between the electrodes (d=3 mm). Glass dielectric between the electrodes with thickness (2 mm) was used. Plasma parameters were calculated by measurement of plasma spectrum analysis using optical emission spectroscopy and using the Boltzmann plot method.

4.1 Copper Electrodes

The spectral analysis of the plasma produced by the spectroscopy device was studied. Spectrum lines of plasma for the Copper electrodes indicate in Figure 3.

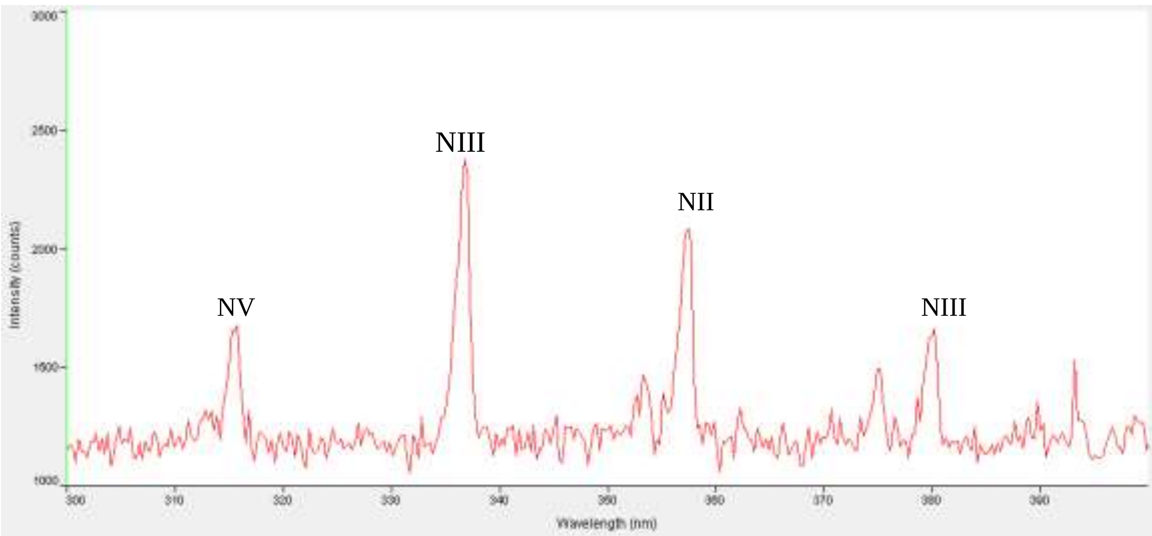

Figure (3): Spectrum lines of plasma of the Copper electrodes.

The spectrum emission data of Nitrogen lines for Copper electrode at (2 mm) thickness of glass dielectric shown in the **Table (1)**.

Table (1): Spectrum emission data of Nitrogen lines for the Copper electrodes.

Species	Intensity	λ (nm)	$g_j\ A_{ji}\ (s^{-1})$	E_j (eV)
NV	1862	315.8	3.09×10^{8}	88.02204
NIII	2843	336.81	8.89×10^{8}	39.35235
NII	2521	357.5	7.26×10^{7}	24.38934
NIII	1877	380	7.21×10^{7}	41.68434

The temperature of the electron was calculated from:

$$\ln\left(\frac{I_{ji}\ \lambda_{ji}}{g_j\ A_{ji}}\right) = -\frac{E_j}{k_B\ T_e} + C \qquad \text{...(1)}$$

where, I_{ji} : intensity of the emitted light from (j) to (i) levels, λ_{ji} : wave length, g_j : statistical weight of the upper level, A_{ji} : the Einstein transition probability of spontaneous emission, E_j/k_B : the normalized energy of the upper electronic level, C can be calculated by the relation:

$$C = \ln(hcN_j/4\pi Q(T)) \qquad \text{...(2)}$$

Q(T) : the partition function.

$$Slope = -\frac{1}{k_B\ T_e} \qquad \text{.. (3)}$$

hence $k_B = 8.617 \times 10^{-5}\ \text{eVK}^{-1}$

The Boltzmann plot for spectral analysis foe Copper electrodes as in Figure 4.

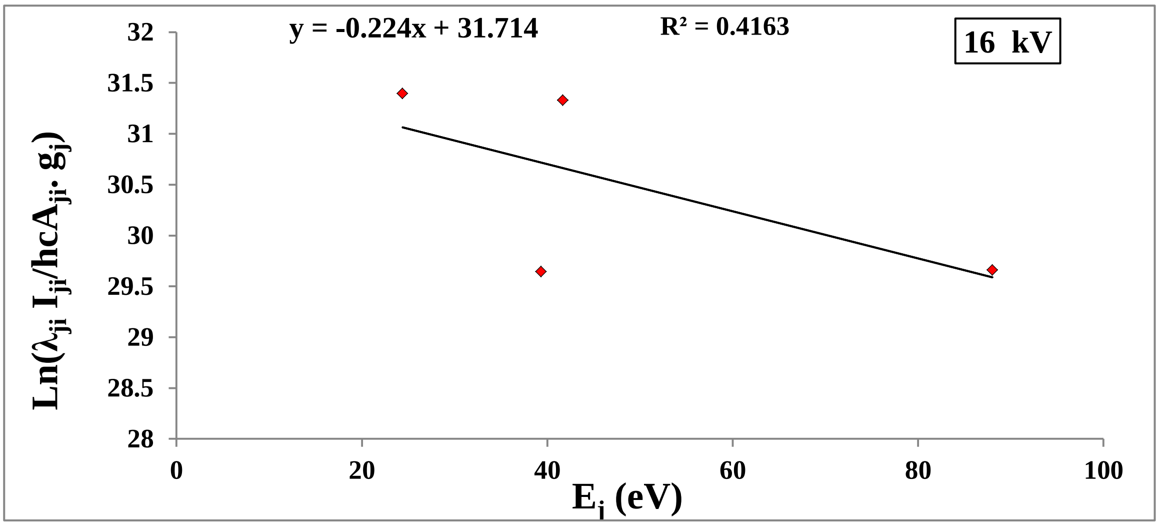

Figure (4): The Boltzmann Plot for spectrum line for Copper electrode.

The temperature and density of electrons were calculated, it is about (4.46 eV) and (9.90×10^{17} cm^{-3}) respectively, as in **Table (2)**.

Table (2): Plasma parameters for Copper electrodes.

T_e (eV)	T_e (K)	FWHM	n_e (cm^{-3})	F_p (Hz)	λ_D (cm)	N_d
4.464285	**51785.71**	**1.32**	**9.90×10^{17}**	**8.935×10^{12}**	**1.578×10^{-5}**	**16.288×10^{3}**

4.2 Aluminum electrodes

The spectral analysis of the plasma produced by the spectroscopy device was studied. Spectrum lines of plasma for the Aluminum electrodes indicate in Figure 5.

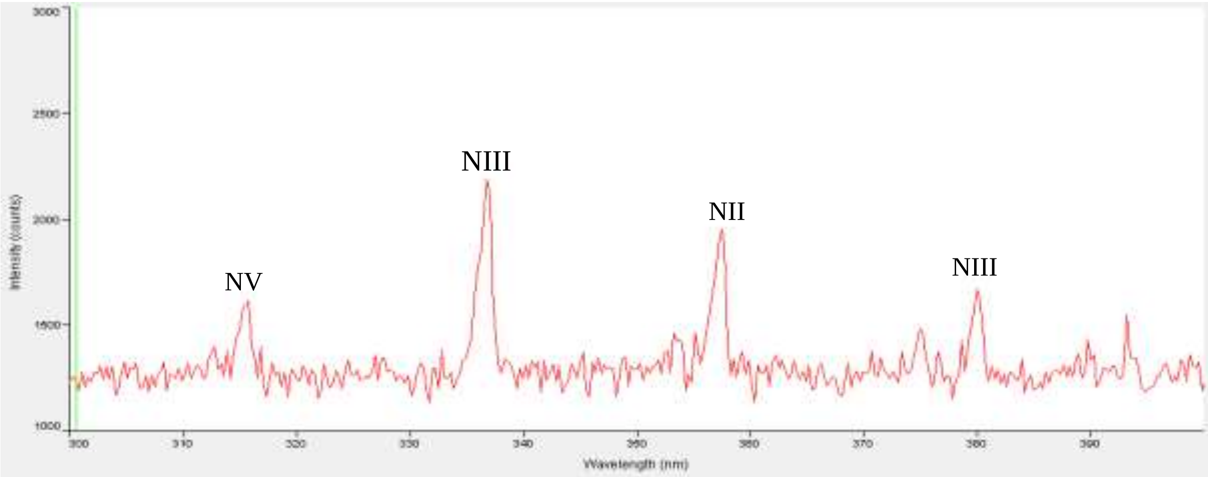

Figure (5): Spectrum lines of plasma of the of the Aluminum electrodes.

The spectrum emission data of Nitrogen lines for Aluminum electrode at (2 mm) thickness of glass dielectric shown in **Table (3)**.

Table (3): Spectrum emission data of Nitrogen lines for the Aluminum electrodes.

Species	Intensity	λ (nm)	$g_j A_{ji}$ (s^{-1})	E_j (eV)
NV	**1609**	**315.8**	**3.09×10^{8}**	**88.02204**
NIII	**2185**	**336.81**	**4.06×10^{8}**	**39.34503**
NII	**1951**	**357.5**	**7.26×10^{7}**	**24.38934**
NIII	**1670**	**380**	**7.21×10^{7}**	**41.68434**

The Boltzmann plot for spectral analysis for Aluminum electrodes shows as in Figure 6.

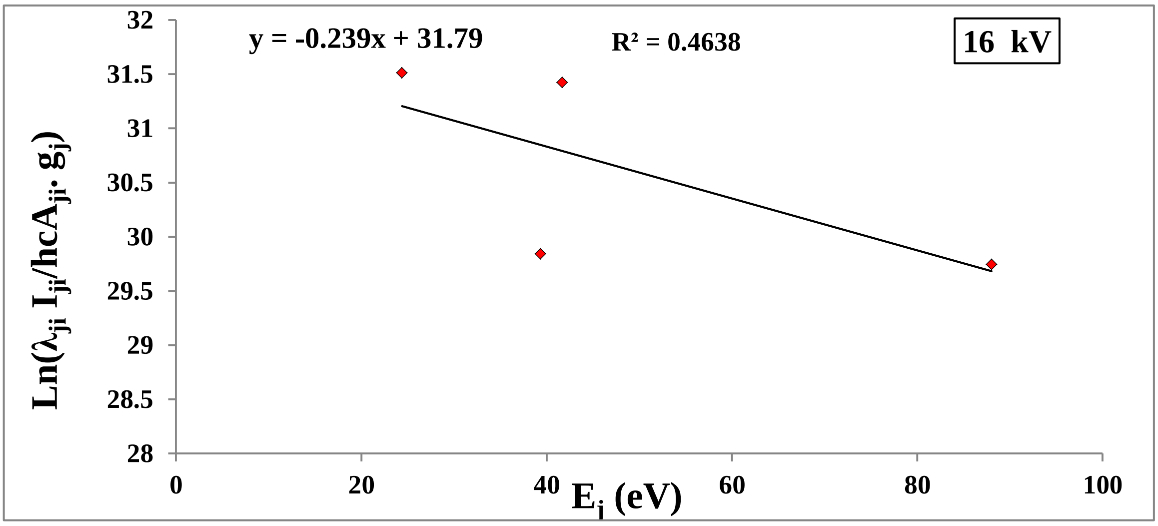

Figure (6): The Boltzmann Plot for spectrum line for Aluminum electrodes.

The temperature and density of electrons of plasma for Aluminum electrodes were calculated, it is about (4.18 eV) and (9.90×10^{17} cm^{-3}) respectively. The plasma properties for Aluminum electrodes summarized in **Table 4**.

Table (4): Plasma properties for the Aluminum electrodes.

T_e (eV)	T_e (K)	FWHM	n_e (cm^{-3})	F_p (Hz)	λ_D (cm)	N_d
4.18410042	48535.56	1.32	9.90×10^{17}	8.935×10^{12}	1.527×10^{-5}	14.779×10^{3}

5. Conclusions

The results obtained by using two electrodes Copper and Aluminum by DBD Plasma system at (16 kV) voltage and Spectrum lines measuring by Optical Emission Spectroscopy (OES) were analyzed to calculate the plasma properties using the Boltzmann plot method, can be summarized in:

- The produced plasma is Nitrogen plasma.
- The intensity in the plasma spectrum for Copper electrode is higher than that for Aluminum electrode for the same wavelength (λ = 336.81 nm)
- The electron temperature for plasma found to be (4.46 eV) and (4.18 eV) for Copper and Aluminum respectively.
- There is no change in electron density of plasma found for both electrodes Copper and Aluminum.

- Copper electrode is better than Aluminum to produced non thermal DBD plasma.

References

[1] J. R. Roth, J. Rahel, X. Dai, and D. M. Sherman, J. Phys. D: Appl. Phys. **38**, 555, (2005).

[2] T. Shao, C. Zhang, K. Long, D. Zhang, J. Wang, P. Yan, and Y. Zhou, Appl. Surf. Sci. **256**, 3888, (2010).

[3] F. Iza, J. K. Lee, and M. G. Kong, Phys. Rev. Lett. **99**, 075004, (2007).

[4] D. Z. Yang, W. C. Wang, S. Zhang, K. Tang, Z. J. Liu, and S. Wang, Appl. Phys. Lett. **102**, 194-102, (2013).

[5] J. Waskoenig and T. Gans, Appl. Phys. Lett. **96**, 181501, (2010).

[6] D. X. Liu, A. J. Yang, X. H. Wang, C. Chen, M. Z. Rong, and M. G. Kong, J. Phys. D: Appl. Phys. **49**, (2016).

[7] M. Okubo, T. Kuroki, H. Kametaka, T. Yamamoto, Odor Control Using the AC Barrier-Type Plasma Reactors IEEE Transactions on Industry Applications, **37**, 5, (2001).

[8] H. H. Murbat, A. H. Ali, I. A. Alhmeedi, N. K. Alameer, " Design and Fabrication of Non-thermal DBD Plasma and Study the Electrical Properties ", **12**, No. 4, (2016).