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Impact of Electrodes Material on the Properties of Atmospheric DBD Plasma

Intesar H. Hashim[1]*, Abdel Karim L. Oudah[1], Bushra J. Hussein[2]

[1]*Department of Physics, College of Education, Mustansiriyah University, Baghdad, Iraq*

[2]*Department of Physics, College of Education for Pure Science (Ibn Al-Haitham), University of Baghdad, Baghdad, Iraq*

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Abstract

In this research, the effect of electrode material on the parameters of the produced DBD plasma was investigated. First, a non-thermal plasma was created by applying a 15 kV AC voltage between two electrodes and using a glass plate as a dielectric barrier in the design Dielectric Barrier Discharge (DBD) plasma system. The obtained plasma spectrum was analyzed using optical emission spectroscopy to calculate plasma parameters by the Boltzmann plot method. Electrodes made of copper, aluminium, and stainless steel were employed in this research. Electron temperature (T_e) for copper, aluminium, and stainless steel was found to be (1.398 eV), (1.093 eV) and (1.009 eV), respectively.

Keywords: DBD Plasma, Non-thermal plasma, Plasma parameters, Optical Emission Spectroscopy, Boltzmann plot.

تأثير مادة القطب على خصائص بلازما تفريغ حاجز العزل الكهربائي

انتصار هاتو هاشم[1]*, عبد الكريم لفته عودة[1], بشرى جودة حسين[2]

[1]قسم الفيزياء, كلية التربية, الجامعة المستنصرية, بغداد, العراق

[2]قسم الفيزياء, كلية التربية للعلوم الصرفة (أبن الهيثم) , جامعة بغداد, بغداد, العراق

الخلاصة

تمت دراسة تأثير مادة القطب على خواص بلازما DBD المنتجة في هذا البحث. تم إنتاج بلازما غير حرارية عن طريق نظام بلازما تصريف الحاجز العازل (DBD) من خلال تطبيق فولتية متناوبة 15 كيلو فولت بين قطبين وباستخدام لوح زجاجي كحاجز عازل. معلمات البلازما تم حسابها عن طريق تحليل طيف البلازما المقاس باستخدام التحليل الطيفي للانبعاثات الضوئية وباستخدام طريقة بولتزمان. تم استخدام أقطاب النحاس والألمنيوم والفولاذ المقاوم للصدأ لهذا الغرض. وجد أن درجة حرارة الإلكترون (T_e) تكون (1.398 eV) و (1.093 eV) و (1.009 eV) للنحاس والألمنيوم والفولاذ المقاوم للصدأ على التوالي.

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*Email: dr.intesarhato@uomustansiriyah.edu.iq

1. Introduction

Non-thermal plasma, such as dielectric barrier discharge plasma (DBD), has been extensively studied in many researches for different applications due to its high potential in technology applications [1] [2]. Non-thermal plasma, including the production of high-density plasma at room temperature, is very popular due to its low cost and no need for expensive and specialized laboratories [3] [4]. In atmospheric non-thermal plasma discharge, a sinusoidal single excitation source of kHz to MHz frequency is usually used. When the applied voltage reaches a high value, charge breakdown on the surface and current leakage to the insulating surface occur [5]. The DBD plasma properties can be enhanced by controlling the external parameters affecting these properties, such as the power supply voltage, which affects the value of the electric field, thus affecting the value of the plasma particles' energy. However, the practical aspects of the application are still under study. Even so, there is still a shortage of theoretical understanding of this discharge, which will allow researchers to tweak the system's operational parameters to get more precise results on plasma parameters. This is due to the fact that the chemical and physical properties are dependent on the electron heating process and power dissipation dynamics. As a result, plasma properties are extremely sensitive to instability, process transitions, and variations in plasma electron heating. Thus, it is essential to comprehend electron heating instruments that work by DBD systems surroundings parameters to support the theoretical part of the investigations utilized in these applications [6].

2. Dielectric Barrier Discharge (DBD)

The dielectric layer material that covers the electrodes is a critical component of DBD plasma (also, known as the quiet discharge). For industrial applications, DBD plasma utilizes a dielectric substance such as glass, quartz, ceramics, or polymers as a plasma stabilizer. Ceramics or glass are commonly used because they have a high insulation constant and a high breakdown voltage [7]. The dielectric materials must withstand the stress created by the discharge to avoid damage. The distance between the electrodes, the material of the electrodes, and the diameters of the electrodes are all parameters that can affect the discharge properties and contribute to the DBD device's efficiency and stability [8], [9].

3. Plasma Parameters

Optical methods employing spectral line emission intensity are widely used to measure internal plasma parameters T_e and n_e in the atmospheric pressure range. The Boltzmann plot method is employed to calculate the electron temperature in the plasma. It is a simple, widely used method for Optical Emission Spectroscopy (OES) measurement. OES measure the relative intensities of two lines from the same element. To implement the Boltzmann plot method practically, the excitation level must be reached under a local thermal equilibrium (LTE) condition [10]. With the help of OES, T_e can be determined using the Boltzmann relationship expression [11]:

$$\ln\left(\frac{\lambda_{ji} I_{ji}}{hcA_{ji} g_{ji}}\right) = \frac{-1}{kT_e}\left(E_j\right) + \ln\left(\frac{N}{U(T)}\right) \tag{1}$$

Where:

λ_{ji} : Wavelength.

I_{ji} : Relative intensity of the emission line between i and j energy levels.

k : Boltzmann constant.

A_{ji} : Transition probability for spontaneous radiative emission from upper level (i) to the lower level (j).

g_i : Statistical weight of emitting upper level (i) of the studied transition.

N : State number of densities

E_j : Energy of excitation at level(i).

An important parameter is the electron number density, which describes the environment of plasma and establishes its equilibrium status that is usually measured from the Stark broadening. It can be determined from the line width as follows [12]:

$$n_e = \left(\frac{\Delta\lambda}{2\omega_s\,(\lambda Te)}\right) N_r \tag{2}$$

Where:

$\Delta\lambda$: Full Width at Half Maximum (FWHM) of the line.

ω_s : Stark broadening parameter, which can be found in standard tables.

N_r : Reference electron density that is equal to 10^{16}cm^{-3} for neutral atoms while for single charged ions, it is 10^{17}cm^{-3}.

Plasma frequency of electron f_p can be computed from [13]:

$$f_p = \left(\frac{n_e e^2}{\varepsilon_0 m_e}\right)^{1/2} \tag{3}$$

Where:

f_p : Plasma frequency of electron.

ε_o : Permittivity of free space.

n_e: Electron density.

e : Electron charge.

m_e : Electron mass.

Another important parameter is Debye length or Debye shielding, that gives the quasi neutrality characteristic of the plasma. Where, the charged particles in plasma interact with each other to reduce the effect of the electric field created.

The Debye length can be defined as [13]:

$$\lambda_D = \left(\frac{k\,T_e\,\varepsilon_o}{n_e\,e^2}\right)^{1/2} \tag{4}$$

4. Experimental Part

In this paper, non-thermal plasma was generated under atmospheric pressure and room temperature using the DBD Plasma system. This system was designed with two circular electrodes. The details of the used system, as illustrated in Figure 1, are: the radius of each used electrode is 2.5 cm surrounded by Teflon (constant isolation of 2.1) with a thickness of 2.5 cm. The distance between the electrodes was 3 mm, and each electrode was connected to an AC high-voltage power supply of 15 kV and a frequency of 1 kHz. Also, a 2 mm thick glass as dielectric material was used. Different materials (copper, aluminium and stainless steel) were used for the electrodes, as shown in Figure 2.

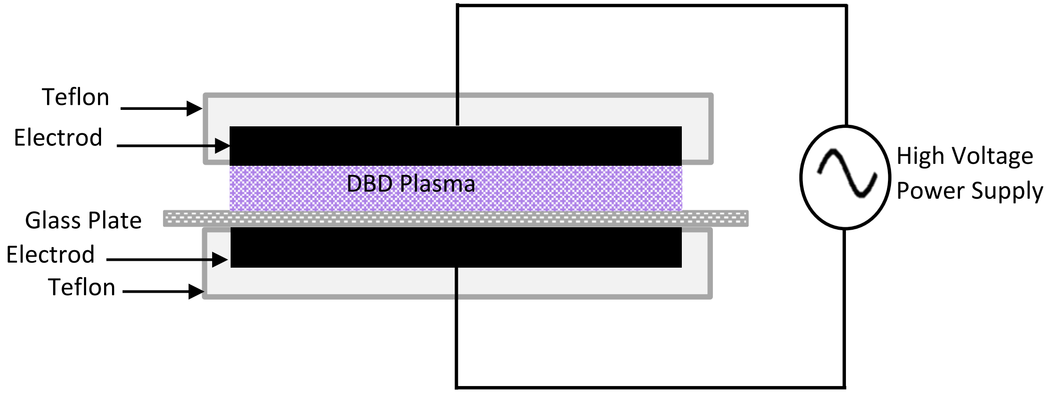

Figure -1: The locally designed DBD Plasma system.

Cupper **Aluminium** **Stainless Steel**

Figure 2: The used electrodes materials

5. Results and Discussion

Plasma spectra employing electrodes made of different materials (copper, aluminium and stainless steel) were recorded by the OES, as shown in Figure 3. The spectra are composed of many peaks: most of which are in the visible region and due to nitrogen ions with three types, according to NSIT data. So the generated plasma is due to nitrogen gas in the atmosphere. The peaks intensity in the plasma spectrum of the copper electrodes has higher values than that of aluminium and stainless steel electrodes for the same wavelength. While the stainless steel electrode had the lowest peaks intensity of the plasma spectrum

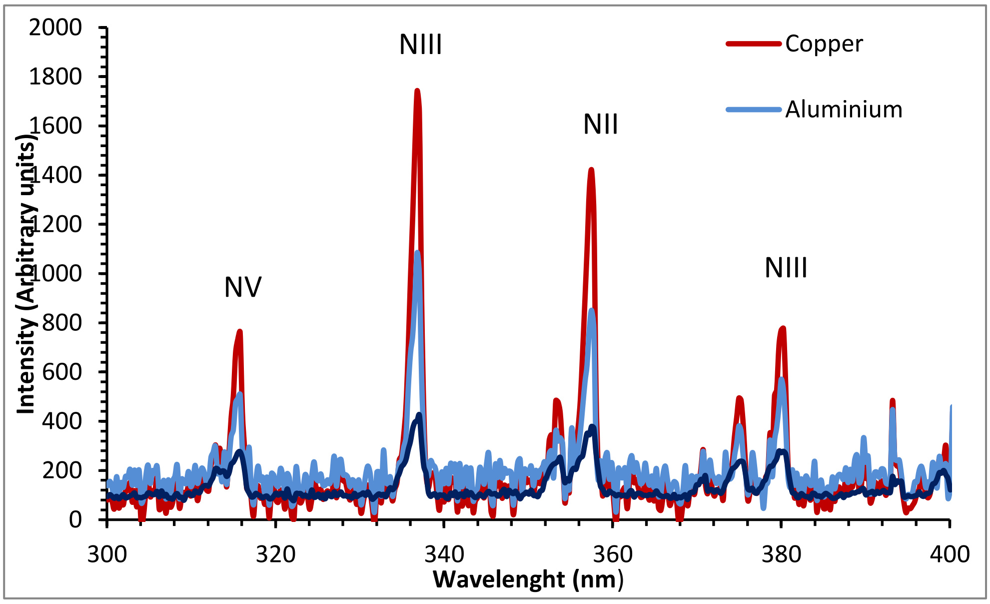

Figure 3: Plasma spectra for electrodes of different materials

The electron temperature of the generated plasma was calculated using the Boltzmann plot method, which was obtained from the inverse of the slope, as illustrated in Figure 4. It is obvious that electron temperature was affected by the electrode material. It was large for copper and smaller for stainless steel. Copper electrodes worked better as DBD electrode material due to the higher electrical conductivity facilitating the generation of high-energy electrons by the high voltage between the electrodes [14].

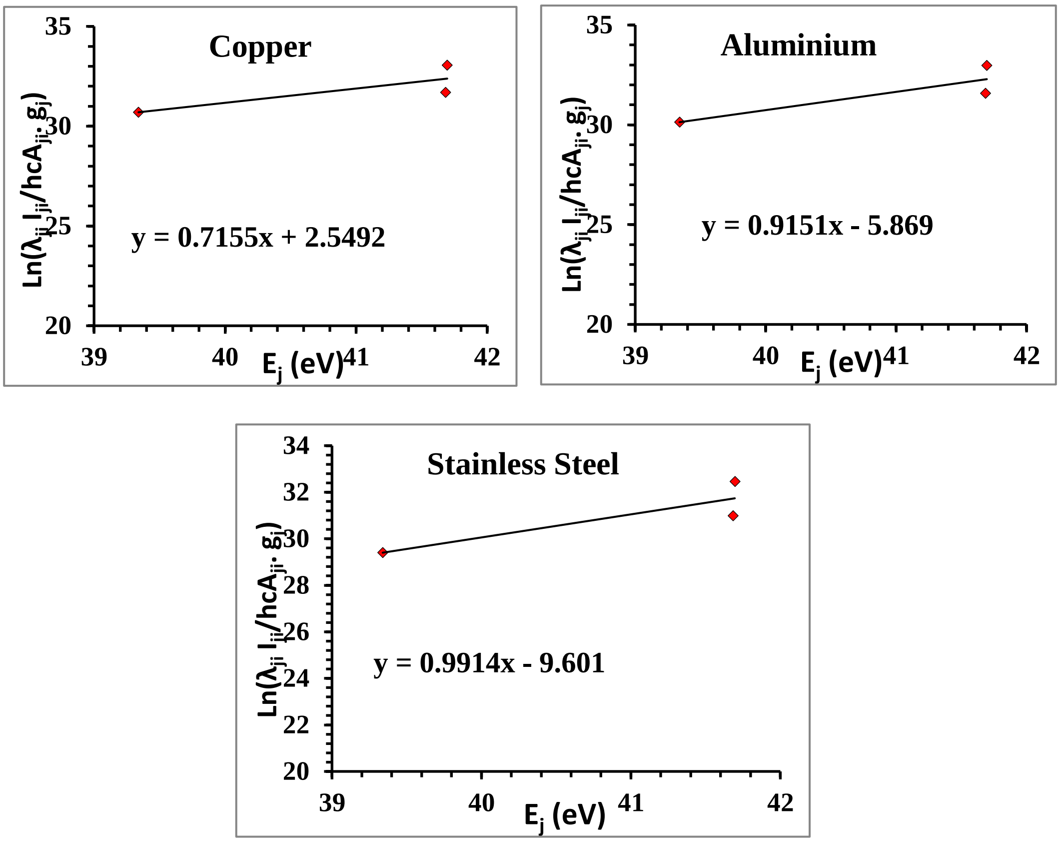

Figure 4: Calculation of electron temperature for the different electrodes.

The electron density for the different electrodes was calculated using Stark broadening as a result of the collision of species and the shift of the peak wavelength. Figure 5 shows the electron temperature and density variation for the different electrodes. The highest value of these parameters was obtained for the copper electrode.

Evaluations tests were performed on the variation of plasma frequency and Debye length calculated from Eq. 3 and Eq. 4, respectively for the different electrodes. Referring to Figure 6, the highest value of these parameters was for the copper electrode.

The results presented in Figure 7 illustrate the variation of the plasma parameter which indicates the number of particles in Debye sphere. Copper was superior to the other electrode materials due to its high conductivity, which causes high discharge and produces high-energy electrons.

The overall performance of the different electrodes and their effect on the plasma parameters is summarized in Table 1. It is noteworthy that all parameters of plasma calculated (f_p, λ_D and, N_D) met the plasma criteria.

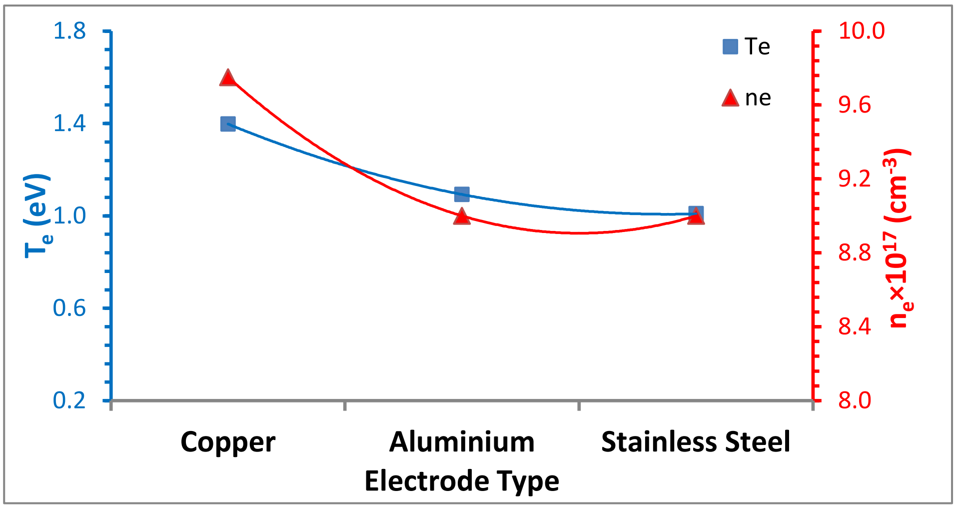

Figure -5: Electron temperature and density of plasma for the different electrodes.

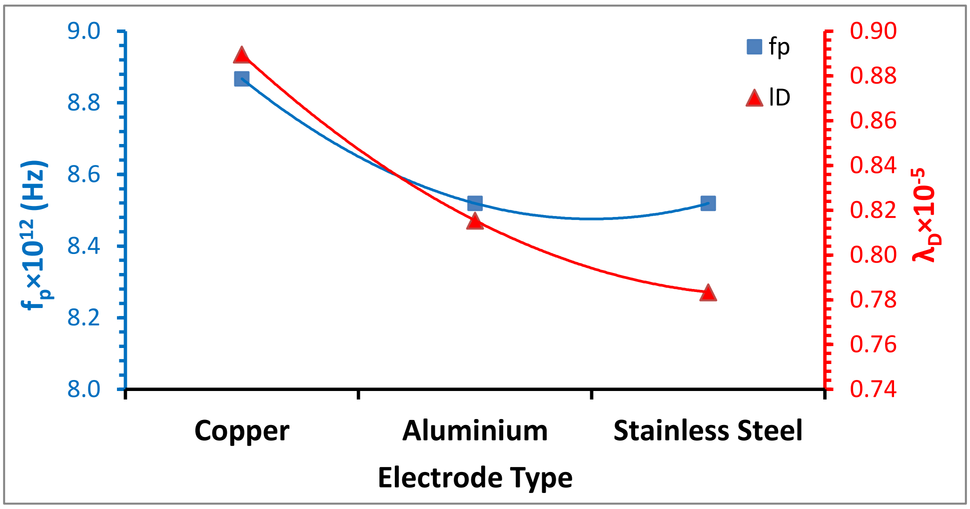

Figure 6: Plasma frequency and Debye length for the different electrodes.

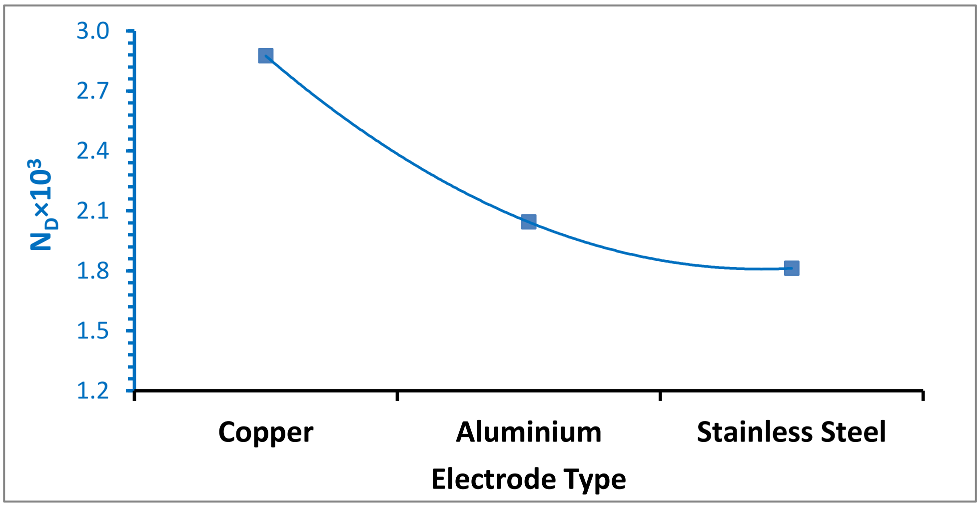

Figure 7: Plasma parameter for the different electrodes.

Table 1: Plasma parameters for the different electrodes

Electrode Type	T_e (eV)	$n_e \times 10^{17}$ (cm^{-3})	$f_p \times 10^{12}$ (Hz)	$\lambda_D \times 10^{-5}$ (cm)	$N_D \times 10^{3}$
Copper	1.398	9.75	8.867	0.890	2.875
Aluminium	1.093	9.00	8.519	0.815	2.044
Stainless Steel	1.009	9.00	8.519	0.783	1.813

6. Conclusions

DBD plasma operating at atmospheric pressure was produced using three electrodes made of different materials (copper, aluminium and stainless steel). Analysing the spectrum of the produced plasma, it was found that the resulting plasma was a non-thermal nitrogen plasma with highest intensity at 336.81nm wavelength. Three types of nitrogen gas appeared, and the predominant was NIII. Upon examining the results, it was observed that the highest electron temperature and density were achieved using copper electrodes. In contrast, the lowest electron temperature and density were achieved using stainless steel electrodes. That proved that the copper electrode is the best material in the DBD plasma system for applications with high electron temperature and electron density, such as industrial applications [15].

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