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Spectroscopic Study of Plasma Parameters Produced by Pin-Plate DC Discharge Technique

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Abstract
In this work, plasma parameters such as electron density (n_e), electron temperature (T_e), Debye length (λ_D), plasma frequency (f_{Plasma}), and Debye number (N_D) for Cu plasma produced by Pin-Plate DC discharge were studied. Spectroscopic technique was used to analyze and determine spectral emission lines. The value of the electron density for Cu was in the range $(1.5–3.5)\times10^{18}cm^{-3}$ and for the electron temperature was in the range (1.31 – 1.61)eV. Finally, plasma parameters of Cu were caculated through plasma produced by Pin-Plate DC discharge using different voltages (600-900) V.

Keywords: Cu plasma; Pin-Plate; Plasma Parameters; D.C. discharge

دراسة طيفية لمعلمات البلازما المتولدة بواسطة دبوس وصفيحة بتقنية التفريغ التيار المستمر

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الخلاصة
في هذا البحث ،تم دراسة معلمات البلازما مثل كثافة الالكترون(n_e) ودرجة حرارة الالكترون(T_e) وطول ديباي (λ_D) وترددالبلازما (f_{Plasma}) وعددالجسيمات في كرة ديباي (N_D) لعنصر النحاس الناتج بأستخدام دبوس وصفيحة بتقنية بلازما تفريغ التيارالمستمر بواسطة تحليل وتحديد خطوط الانبعاثات الطيفية باستخدام تقنية التحليل الطيفي. حيث كانت النتائج التي حصلنا عليها هي قيمة كثافة الإلكترون للنحاس (1.5 – 3.5)$\times10^{18}$(cm^{-3}) ودرجة حرارة الإلكترونeV (1.61 – 1.31). وأخيرًا تم مناقشة معلمات البلازما للنحاس من خلال البلازما الناتجة عن دبوس وصفيحة بتقنية بلازما تفريغ التيار المستمرباستخدام فولتيات مختلفة ذات مدى V(900−600).

Introduction

In the radiation sources for atomic spectrometry, plasma is produced by electrical discharge. Here electrically charged particles (ions, electrons) are moved between two electrodes (in a gas-filled discharge tube) under the influence of an electric field where they can also recombine and lose their charge. The electrons gain energy from the applied electric field enabling them to induce ionizations during the collisions; electrons are expelled from the electrode (cathode) by colliding with energy-rich ions As a consequence of all these steps, the gas is somewhat ionized, and plasma is formed [1]
The different types of discharges can be obtained depending on the applied voltage and the discharge current[2, 3]. Plasma is detected using the spectral analysis technique of optical

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emissions. Some data, like the initial formation of the material, can be obtained from the plasma spectrum generated. Emission line characteristics can supply data about plasma temperature (Te) and electron density (n_e) [4]. The method utilized in this work is the Boltzmann plot , it is a widely utilized method for spectral measurements. It depends on measuring the relative density for one line from the same elemental , to apply the Boltzmann method to the gauge of electron temperature, to applied the Boltzmann method the gauge of electron temperature, the level of excitement must be done arrive under local thermal equilibrium (LTE) stipulation. The last allows us to use the traditional Boltzmann plot technicality to calculate (T_e) using the following equation [5].

$\ln(\lambda_{ji}I_{ji}/hcA_{ji}g_{ji})=-1/kT(E_i)+In(N/U(T)$ (1)

where Iji is the intensity, λji its wavelength, gi is statistical weight, Aji is the transformation probability for spontaneous irradiative emission from the level i to the lower level j, Ei is the excitation energy (in electron volts), k is Boltzmann constant, N state culture densities [6]. The density of the electron can be determined by the Stark broadening of an emission line or using the linear density ratio of different emissions for the same element [7].

This work used the Stark broadening method to calculate the electron density in(cm^{-3}) using the following equation [8].

$$n_e=(\Delta\lambda/2\omega_s)N_r \quad (2)$$

Wher ω_s is the theoretical line full-width Stark broadening parameter, calculated at the same reference electron density

$N_{r\approx10}{}^{17}cm^{-3}$

The responses of charged particles (ions and electrons) to decrease the impact of electric fields applied to it is called Debye shielding. This shielding, a special property for plasma, granted quasi-neutrality . A distance (λ_D), which is called the Debye length, can be calculated from the following equation [9].

$$\lambda_D=(\varepsilon_0KT/n_ee^2)^{1/2} \quad (3)$$

where ε_0 is the permittivity of free space, e the electron charge,T_e, the electron temperature . Also, the number of particles (N_D) in a Debye sphere can be calculated using the given equation [10]:

$$N_D=4/3\pi\lambda^3{}_Dn_e=1.38\times10^6T^{3/2}/n_e{}^{1/2}(T \text{ in K }) \quad (4)$$

Experimental setup

The system consists of a 10 cm long copper cathode electrode with a tapered tip and a circular shaped aluminium anode. The distance between the electrodes is 5mm. The system is under a pressure of 0.003 mbar. Different voltages ranging between (600-900) volts were applied between the electrodes. A spectrometer was used to determine the emission wavelengths of the generated plasma. The spectrometer used must be fast, have the same response time in every shot, and reacts to a wavelength between 200-900,so Surwit (S3000-UV-NIR) spectrometer was chosen. Each spectrum was obtained over a wavelength range of 300-700 nm. Figure 1 shows a schematic diagram of the experimental setup.

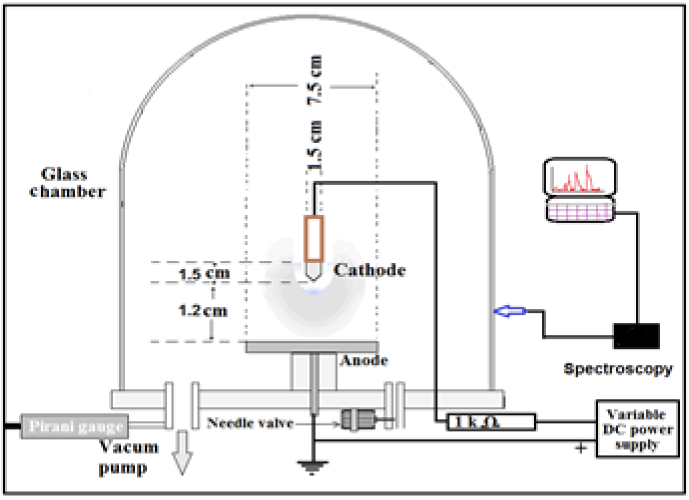

Figure 1- Schematic diagram for the experimental setup[2].

The spectra emitted from copper plasma were within a spectral range of (300 – 800) nm. The data were discussed and compared with data from the (NIST) [11], as shown in Table 1**.**

Table 1-Spectroscopic parameters of the Cu plasma corresponding NIST database

Elements	**λ (nm)**	$g_k A_{ki}\ (s^{-1})$	$E_k(eV)$
Cu II	**337.4**	**4.1×10^{8}**	**18.36**
	388.4	8.20×10^{8}	18.15
	390.3	8×10^{8}	18.41
	468.1	3.3×10^{8}	16.84
	537.5	5.7×10^{7}	19.44

Results and discussion

Figure 2 shows the emission spectra for copper plasma produced in vacuum at different applied voltages (600,700,800 ,900)V using the Optical Emission Spectroscopy (OES) technique. Emission spectra were recorded in the spectral range (300 to 800)nm. From the figure, it is clear that the intensity of the spectral lines increases with the rise of the applied voltage.

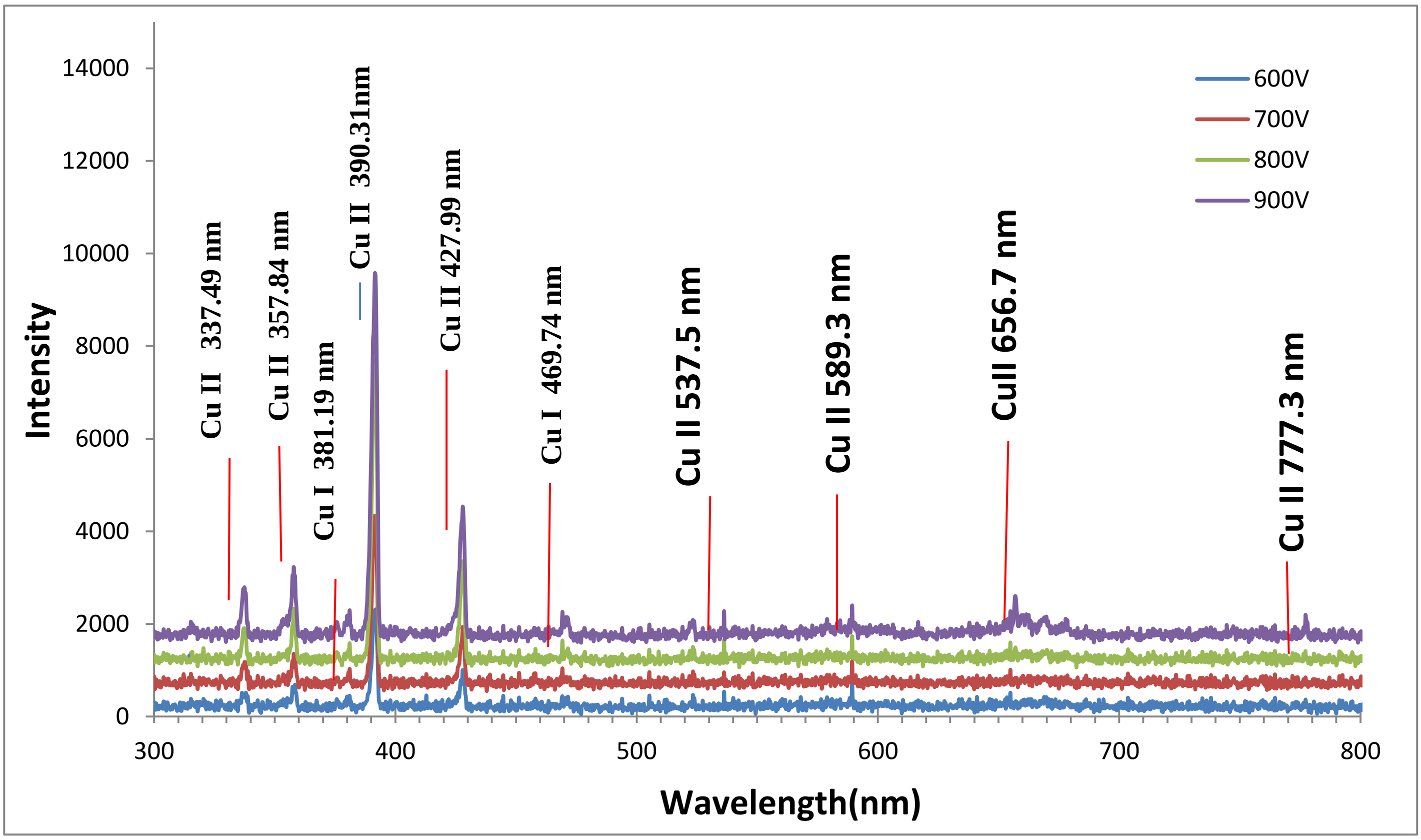

Figure 2-Emission spectra of Cu plasma at different applied voltages.

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The Boltzmann way requires tops that originate from the same atomic species and the same ionization stage. R^2 is a statistical coefficient indicate the goodness of the linear fit which takes a value between (0 and1).

Boltzman plots were drawn for Cu spectral lines , as shown in Figure 3. The fitting equations and R^2 values are shown in the figure for all fitting lines. The best one has an R^2 value closer 1.

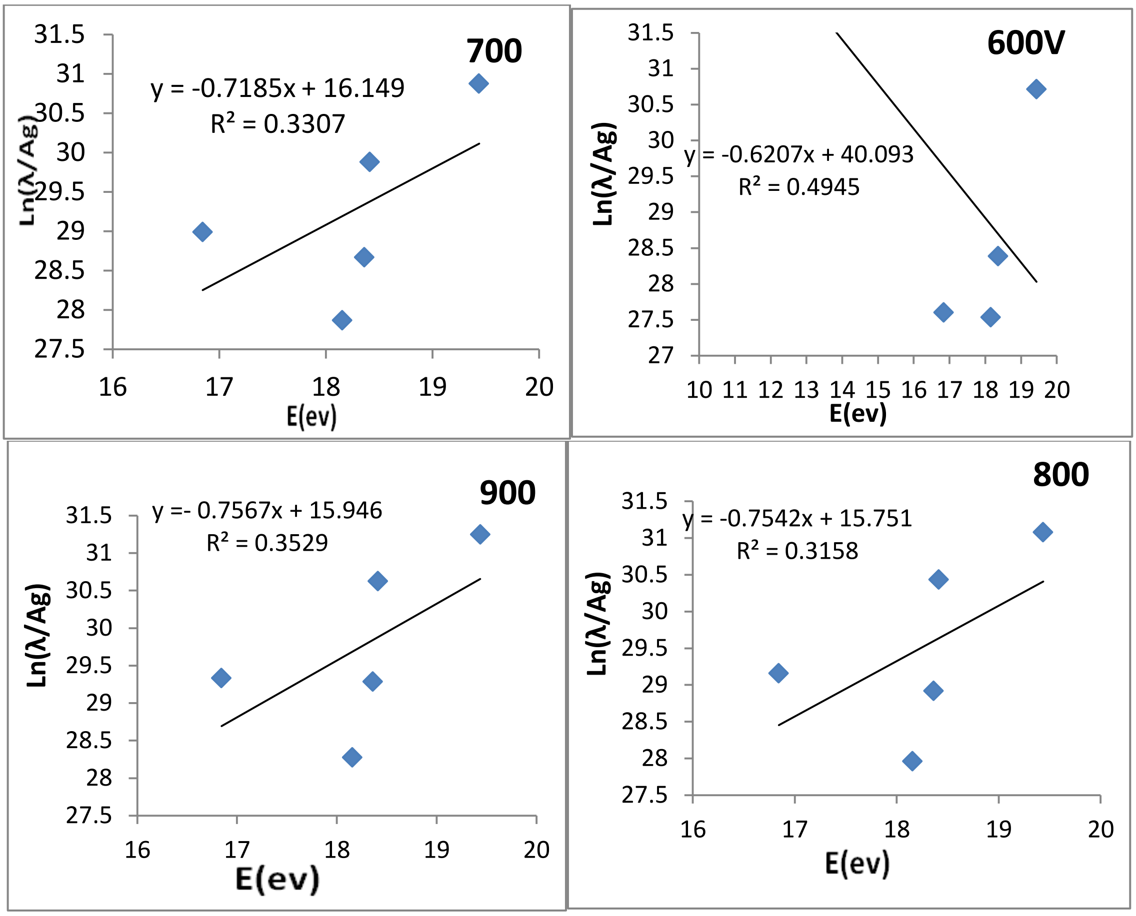
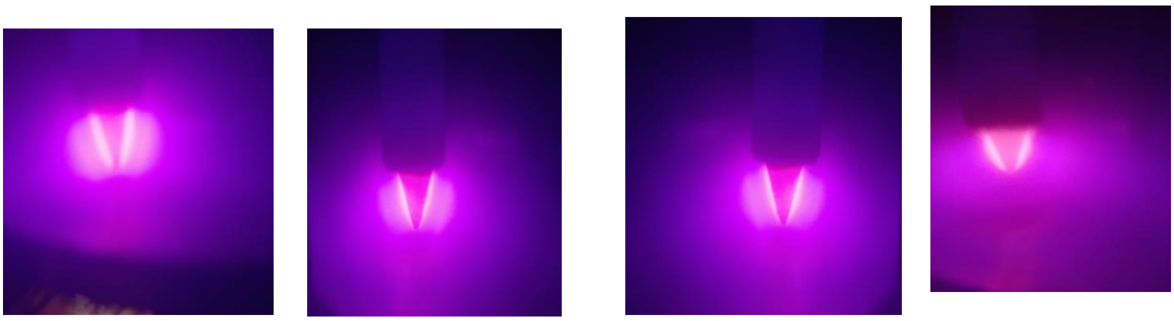


Figure 3-Boltzmann plots of Cu lines with different voltage in the vacuum



V=600 Volt **V=700Volt** **V=800Volt** **V=900Volt**

Figure 4- represents some images of the plasma generated between the two poles of the system, and each image represents a certain voltage, through which we notice the increase in the glow of the plasma with the increase of the voltage applied

Table 2-Plasma parameters for Cu in Vacuum with different voltage

V (volt)	$T\ (eV)$	$n_e \times 10^{17}$ (cm^{-3})	$\lambda_D \times 10^{-5}$ (cm)	$N_D \times 10^{3}$	$w_p \times 10^{12}$ (Hz)
600	1.61	15.00	0.770	2.866	10.998
700	1.40	18.00	0.650	2.073	12.048
800	1.33	30.00	0.493	1.503	15.554
900	1.31	34.50	0.456	1.370	16.680

Conclusions

A pin- plate system was used to produce copper plasma. The spectrum lines emitted from the plasma depend on the operating conditions. The spectrum was taken from the center point near the anode electrode with different voltages with a range of (600-900) volts and at constant pressure (0.1mbar). It was found that the emission intensity increases with the applied voltage. From Table 2, it can be noted that electron density (n_e) and plasma frequency (ωp) increased with increasing the applied voltage.While, the electron temperature (Te), the Debye length (λ_D) and the Debye frequency (N_D) decreased with the increase of the voltage applied to the electrodes

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