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DC Glow Discharge Plasma Characteristics in Ar/O_2 Gas Mixture

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Abstract

In this article, the effects of the O_2 ratio on the electrical characteristics, including the I-V characteristic curve, Panchen's curve, and I-P curve, were tested in a sample of O_2/Ar gaseous mixture . The sample was produced by plasma-based DC magnetron sputtering with niobium metal as a target material. The inter-electrode spacing value was 4 cm. Plasma diagnosis via the Optical Emission Spectroscopy (OES) method was used to achieve Te and Ne mixture values of 20 %, 30 %, 50%, and 70% in the Ar/O_2 system. The results showed that the discharge is operating in the abnormal glow region and the discharge current was decreased by increasing O_2 percentage. In addition, the experimental results showed that the discharge is optimal at 30% gas ratio. It was found that the electron temperature was decreased with increasing working pressure and increased with increasing the O_2 percentage, while electron density was increased with increasing both working gas pressure and O_2 percentage.

Keywords: DC sputtering, Panchen's law, Plasma discharges, Optical emission Spectroscopy

خصائص توهج تفريغ البلازما للتيار المستمر في خليط غازات الاركون والاوكسجين

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الخلاصة

في هذا البحث ، يتم دراسة تأثير نسبة O_2 في خليط الغاز (O_2 / Ar) على الخصائص الكهربائية [لمنحني I-V ، ومنحنى Panchen ومنحنى I-P] للعينة بواسطة بلازما الترذيذ الماكنتروني DC بواسطة معدن النيوبيو كمادة هدف .والمسافة بين الاقطاب هي 4 سم. تم استخدام تشخيص البلازما بطريقة الانبعاث الضوئي الطيفي (OES) للحصول على خليط Te و ne في (Ar / O_2) بنسبة (20٪ ، 30٪ ، 50٪ ، و 70٪). أظهرت النتائج أن التفريغ يعمل في منطقة التوهج غير الطبيعي. وانخفض تيار التصريف بزيادة نسبة O_2. بالإضافة إلى ذلك ، أظهرت النتائج التجريبية أن التفريغ هو الأمثل في نسبة الغاز 30 ٪. لقد وجد أن درجة حرارة الإلكترون انخفضت مع زيادة ضغط العمل وزيادة مع زيادة نسبة O_2 ، في حين زادت كثافة الإلكترون مع زيادة ضغط غاز العمل ونسبة O_2.

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1- Introduction

Plasmas have been employed in many important applications during the last years, such as those of glasses, magnetic media, thin film material, semiconductor fabrication, etc [1, 2]. Glow discharge (G D) is plasma with an ionized gas that contains negative or positive ions, in addition to more neutral species [3]. Such systems have been achieved by applying different potentials between two electrodes. The commonly utilized gas is argon [4]. The principle characteristics of plasma, for example the Paschen law (V_b-pd), the I-P, and I-V characteristics, were studied as functions of inter-electrode spacing and the gas pressure [5]. The Panchen's law is expressed as:

$$V_{br} = f(pd) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$Vbr = \frac{BPd}{Ln(APd) - Ln[Ln(1+\gamma^{-1})]} = f(pd)\ldots\ldots\ldots 2$$

It describes the breakdown voltage characteristic between P and d [6], and is also written as : where A and B are properties of the gas and γ (secondary electron coefficient) is a property of the electrode material . From equation (2), the breakdown voltage depends on the product pd and does not depend individually on p and d [7]. The voltage of breakdown also depends on factors such as type of gas, cathode material, and magnetic field strength in the chamber.

There are many plasma diagnostic techniques that were developed to determine the concentrations of different reactive species in plasmas; for example, optical spectroscopy, Langmuir probe, and mass spectroscopy are used to calculate parameters of plasma, e.g. electron temperature (Te), electron density (ne), etc. Plasma diagnostics does not have any influence on plasma due to obtaining important information without sensors or detectors [8-10].

T_e can be estimated by calculating the ratio of intensity of spectral lines for emission (1 and 2), as in equation (3) [11]:

$$\frac{I_1}{I_2} = \frac{A_1 g_1 \lambda_2}{A_2 g_2 \lambda_1}\ exp\left(-\frac{E_{1-}E_2}{K_B T_e}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where I_1 and I_2 represent the intensities of the two spectral lines, A_1 and A_2 represent transition probability of the two spectral lines, λ_1 and λ_2 represent wavelengths of the two emission lines, g_1 and g_2 are the statistical weights of the two spectral lines, E_1 and E_2 are the upper level energies of the two spectral lines, and *KB* is Boltzmann's constant. *Te* can be extracted from equation (4)

$$K_B T_e = \frac{E_{1-}E_2}{\ln\left(\frac{I_1}{I_2}\right) - \left(\frac{A_1 g_1 \lambda_2}{A_2 g_2 \lambda_1}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Using equation (4), electron temperature can be calculated. The values of E_1, E_2, A_1, A_2, g_1 and g_2 are obtained from the National Institute of Standards and Technology (NIST). The n_e can be determined from Boltzmann -Sasha equation [12], as follows:

$$n_e = \left(\frac{2\pi m_e K}{h^3}\right)^{3/2} \times \left(\frac{A_1 g_1 \lambda_2}{A_2 g_2 \lambda_1}\right) e^{\left(-\frac{E_{1-}E_2}{K_B T_e}\right)} \times (T_e)^{3/2} \ldots\ldots (5)$$

The values of E, A, and g for these lines were obtained from NIST [13].

2- Experimental part

This work was conducted by utilizing a DC plasma system. The diagram used to curry out the electrical discharge characteristics of the circuit is illustrated Figure-1.

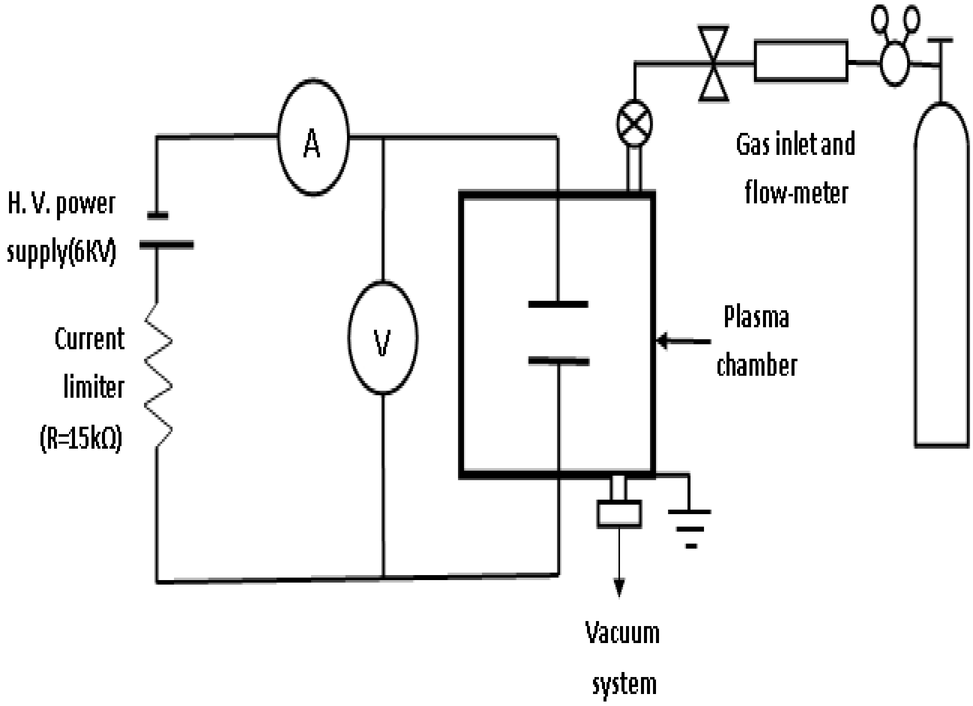

Figure 1-The DC Plasma circuit

The electrode was placed in a chamber, while the pressure was controlled by a special tool (needle valve). The voltage in this method was applied between anode and cathode, keeping the ground of anode. By varying the value of p, the breakdown voltage (Vbr) occurs at many discharge values. When different gases are used, the Vbr decreases with the increase in pd, whereas, after that, it increases with increasing pd. When the breakdown occurs, the plasma is formed between the plates and the current begins to flow through the system quickly. The voltage across the plates drops quickly once the breakdown occurs. To obtain electrical characterizations, the DC was first ignited by providing an over breakdown voltage with dc supply. The principle characteristics of plasma discharge, such as the I-V, I-P , and Paschen law (Vbr-pd) were studied as functions of inter-electrode spacing and gas pressure in the chamber. Niobium (Nb) with high purity (99.9%) was used as a sputtering target. The target was 5 cm in diameter and 3 mm in thickness, while the distance between the top electrode and the target was 4 cm. Ar/O2 mixture was introduced into the chamber at a specified pressure by using a needle valve.

3-Results and discussion

I-V characteristic curve was drawn and demonstrated in Figure-2, at several O_2 ratios (20%,30%,50%,and 70%) in Ar/O_2 gas mixtures . The gas pressure value was 0.075 mbar. The applied voltage increase at the discharge current increase, the potential V is further increased, the current rises rapidly. It is clearly evident from Figure-2 that all the devices were prepared in the abnormal regime, the plasma behaves electrically rather similar to a Resistor [14]. Shown that, increasing the O_2 percentage at the same gas pressure and applied voltage, the discharge current decreases with increased O2 percentage in (Ar/O_2) gas mixture. my be explained this state: the ionization cross section of O_2 is smaller than of Ar [15] The negative ions at discharges oxygen, lead to the decreases of the discharge current and electron density which due to increase of plasma resistance.

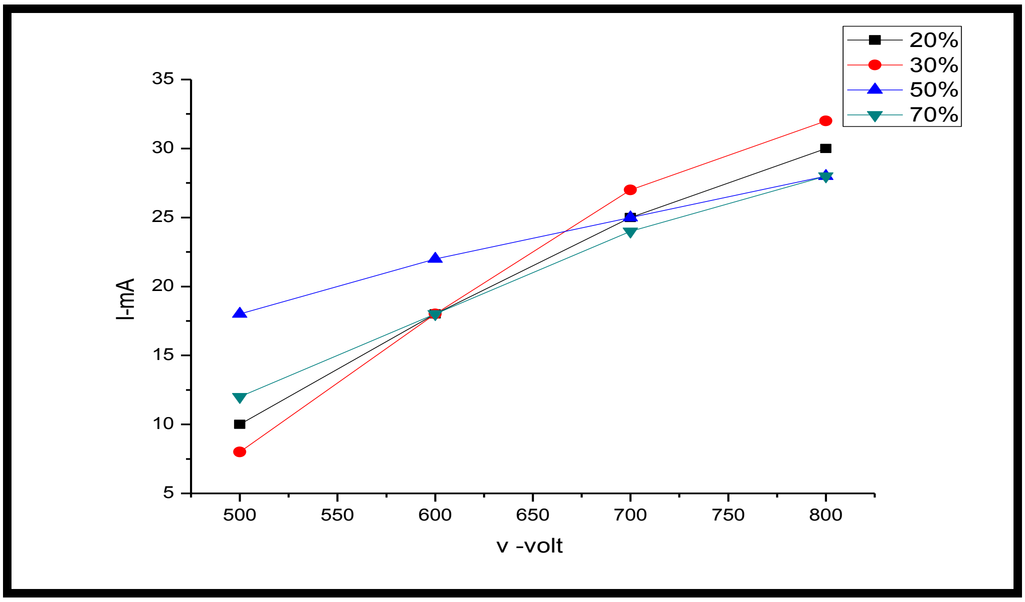

Figure 2-The discharge Volt – current curve at many O_2 percentage at 0.075mbar.

Changes of plasma characteristics can be worthy of attention when a small amount of oxygen was added, so we get adequate information about the properties of oxygen plasma such as Vibrational, molecular dissociation and rotational. VB were increased when the little amounts of O_2 was added and resistance of plasma was increased because of high increasing of chamber pressure leads to the increase of generation of ions and free species in glow electron affinity of O_2, and also discharge voltage was increased. The current-pressure characteristics of dc glow discharge for different ratio gas at constant inter-electrode spacing (d =4 cm) for argon gas are shown in Fig.ure-3. The current was varied by changing the working pressure with a fixed controller resistance. The I-P. Characteristics of Ar gas discharge shows increment in glow discharge current with increasing the produced pressure in reactor at constant applied voltage. This behavior result of the column, which leads to increasing the probability of secondary electron emission. The decreasing of discharge current with high value of working pressure attributed to reduce the mean- free path of gas discharge electrons resulted in the increase of electron-neutral collision [16].

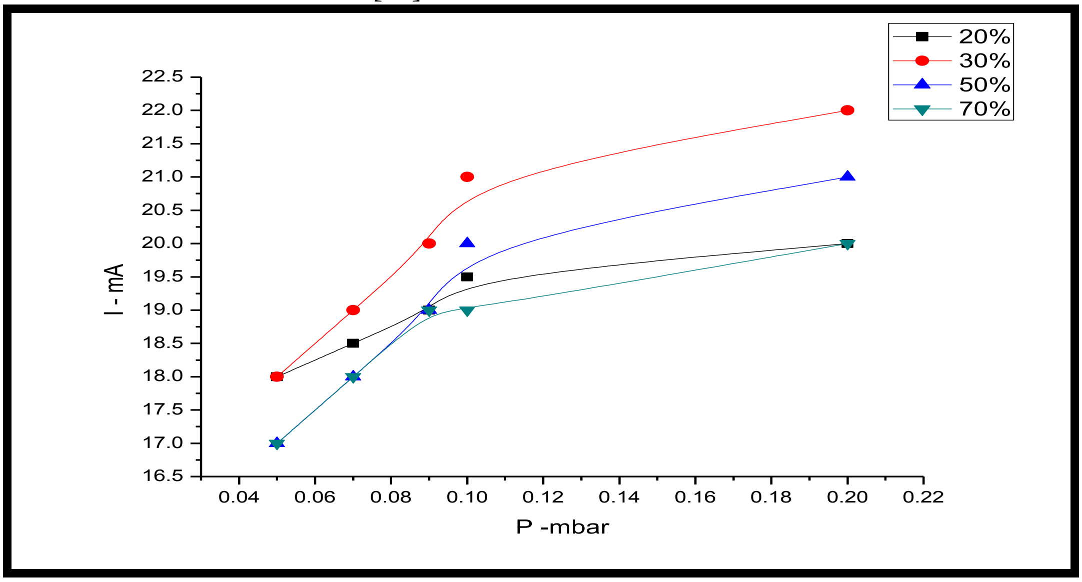

Figure 3-The discharge current – working pressure curve at different O_2 percentage at of 700 Volt

Figure-4 explain Paschen curves of different Ar/O_2 gas mixture at distance between the electrodes (4cm). The variation of the breakdown potential as a function of gas pressure, with V_b was increased as oxygen gas increase. Electrical breakdown the of gases is the in the transition from an insulator to a conducting level. And they minimum voltage at which this transition occurs is called breakdown voltage Vb [17].

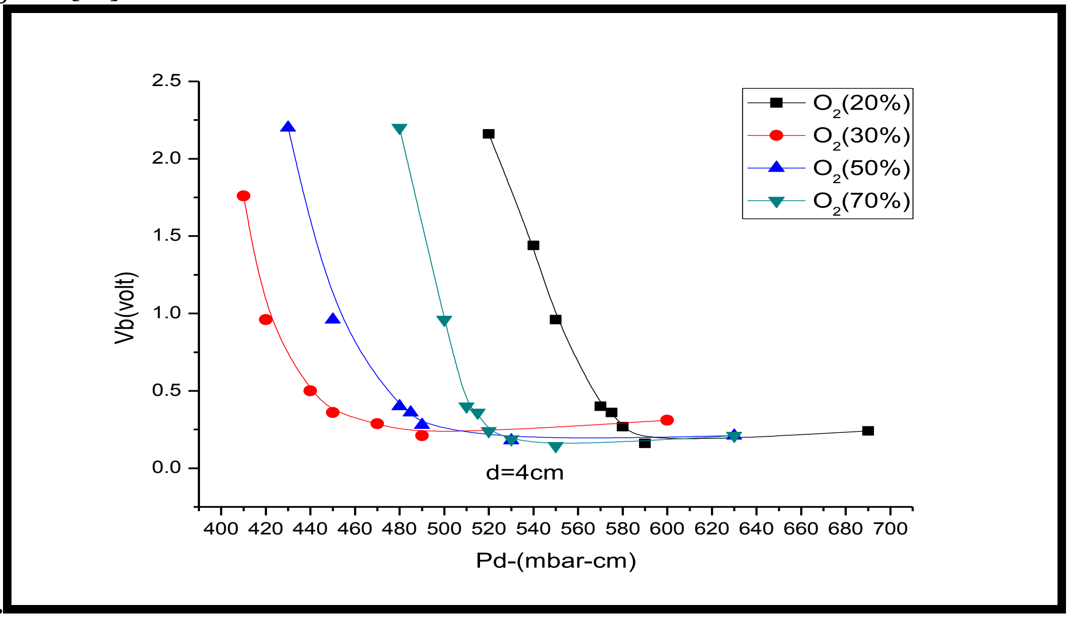

Figure 4-Paschen's curves at different O_2 percentage.

Spectra of glow discharge were recorded in the wavelength range 200- 900nm. Figure-5 shows the emission spectra in Ar plasma of glow discharge at working pressure 7.5x10-2 mbar, supplied voltage of 700Volt and 4 cm inter-electrode spacing, these three charts are an example to show the variation of line intensity as a function of gases ratio of mixture (Ar /O_2).Oxygen ratio depends on lines under study are shown in Fig. 5. The increase of these lines with O_2 increasing percentage was seen. From figure 434.8 nm and 750.38 nm atomic argon lines have the same shape. The slight decrease with the increasing of O_2 percentage or P was also seen.

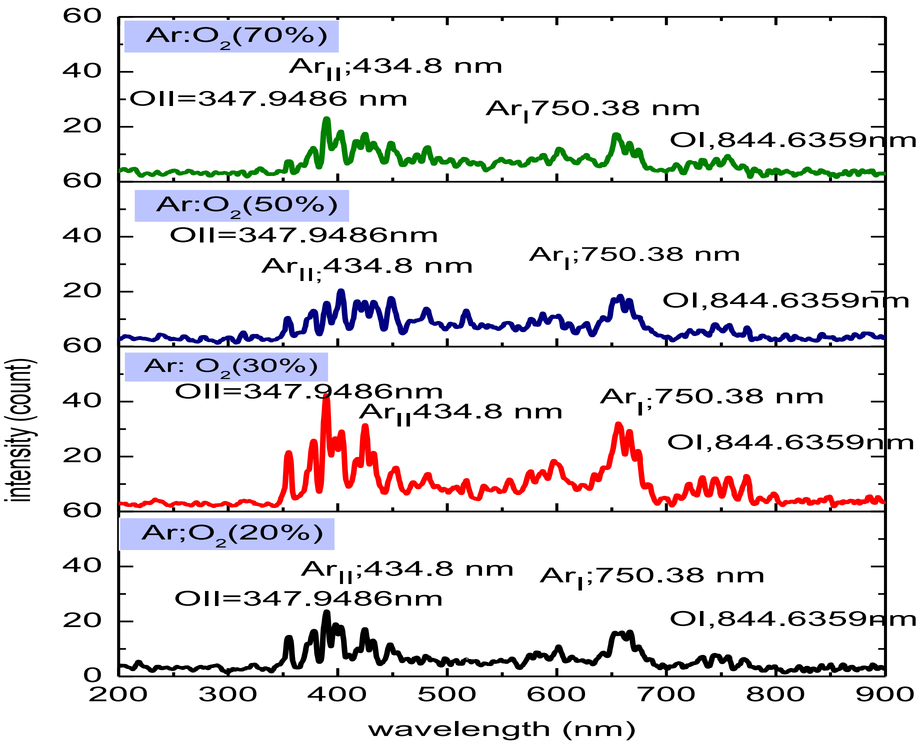

Figure 5-Emission intensity spectrum at different ratios of Ar/O_2 gases mixture

From Figure-6 it can be found that the higher electron temperatures be constant with the lower operating pressure. The decreasing of temperature with the increases in working P may be lead to increases the number of collisions between the electrons When the working pressure within the chamber, and the gas atoms increased. As a result of exchange the energy between the electrons and gas particles the gas temperature increases by reducing the electron temperature. Also Figure-7 shows that, the consequent the effect is that electron density becomes very high near the cathode due to enhanced ionization rate.

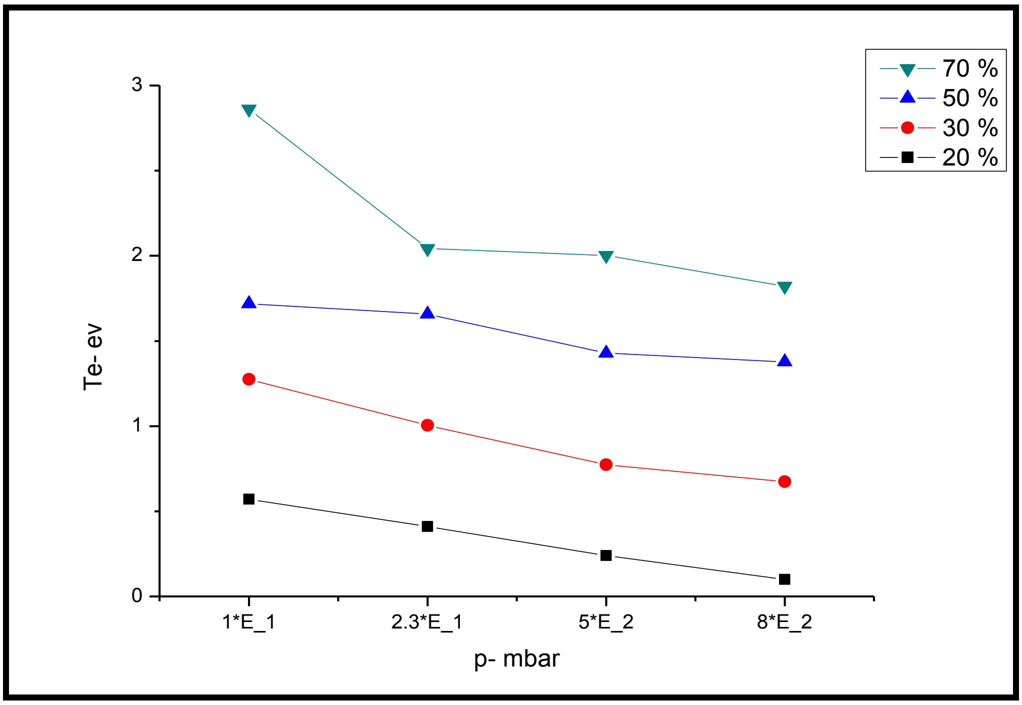

Figure 6-The evolution of electron temperature with working pressure.

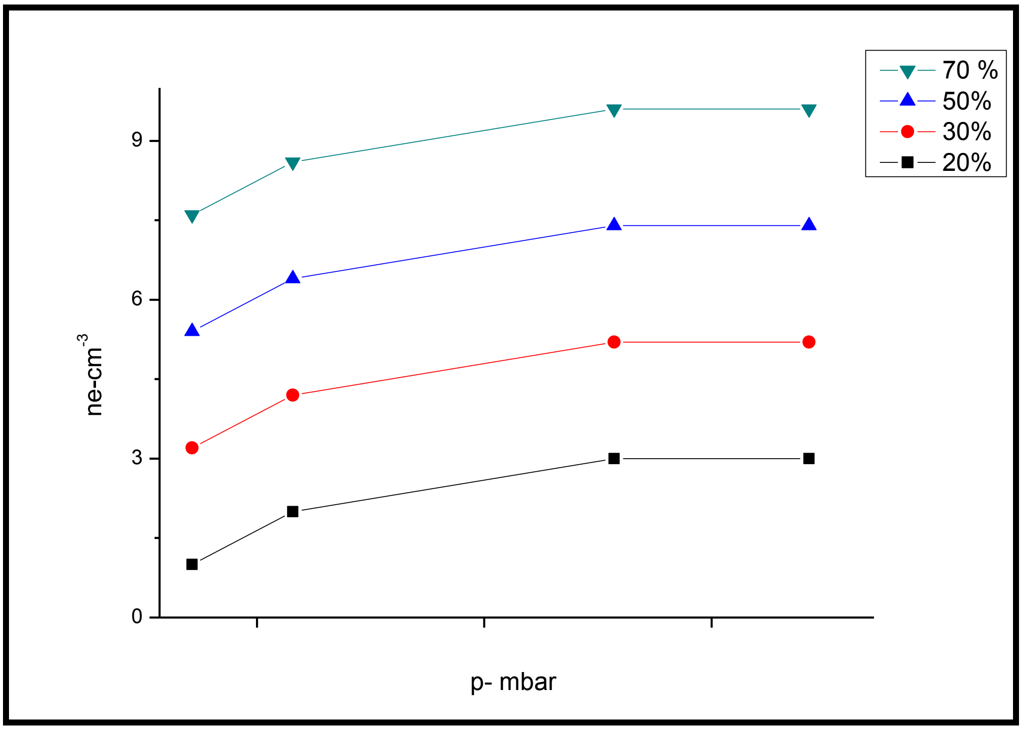

Figure 7-the evolution of electron density with pressure.

The supplied voltage of glow discharges plasma does also influence Te and ne. For Ar discharges plasma, as shown at Figures-(8,9) influence of applied voltage is straight forward: an increase of Te is seen as ne decreases of the free electrons The increase of Te with dc power may be explained by noting that there are usually two modes of operation. This is lead to electron attachment take the low energy electrons. From Figures- (8, 9), the electron temperature increases (i.e electron density decreases) with input applied voltage at constant pressure. The reason is the increasing input power leads to the increase of the energy of the secondary electron ejected from cathode by ion bombardment. The distribution of electron temperature is lower in 0.8mbar, which is because collisions increasing between other species and electrons. [18]

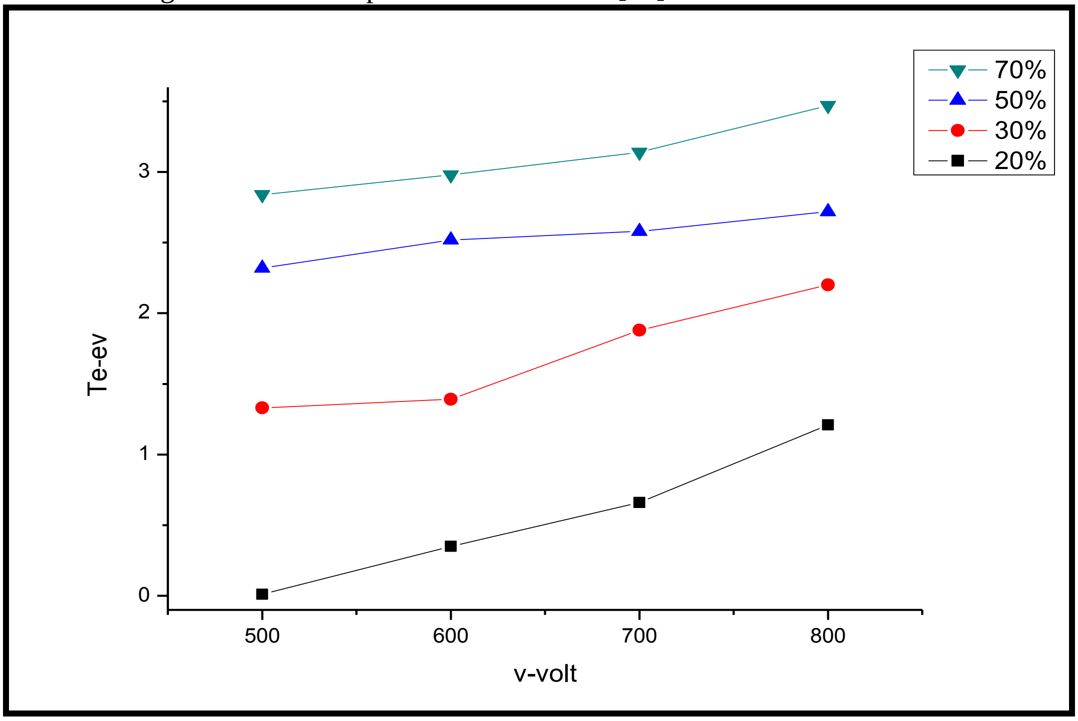

Figure 8-The evolution of electron temperature as a function of O_2 with applied voltage

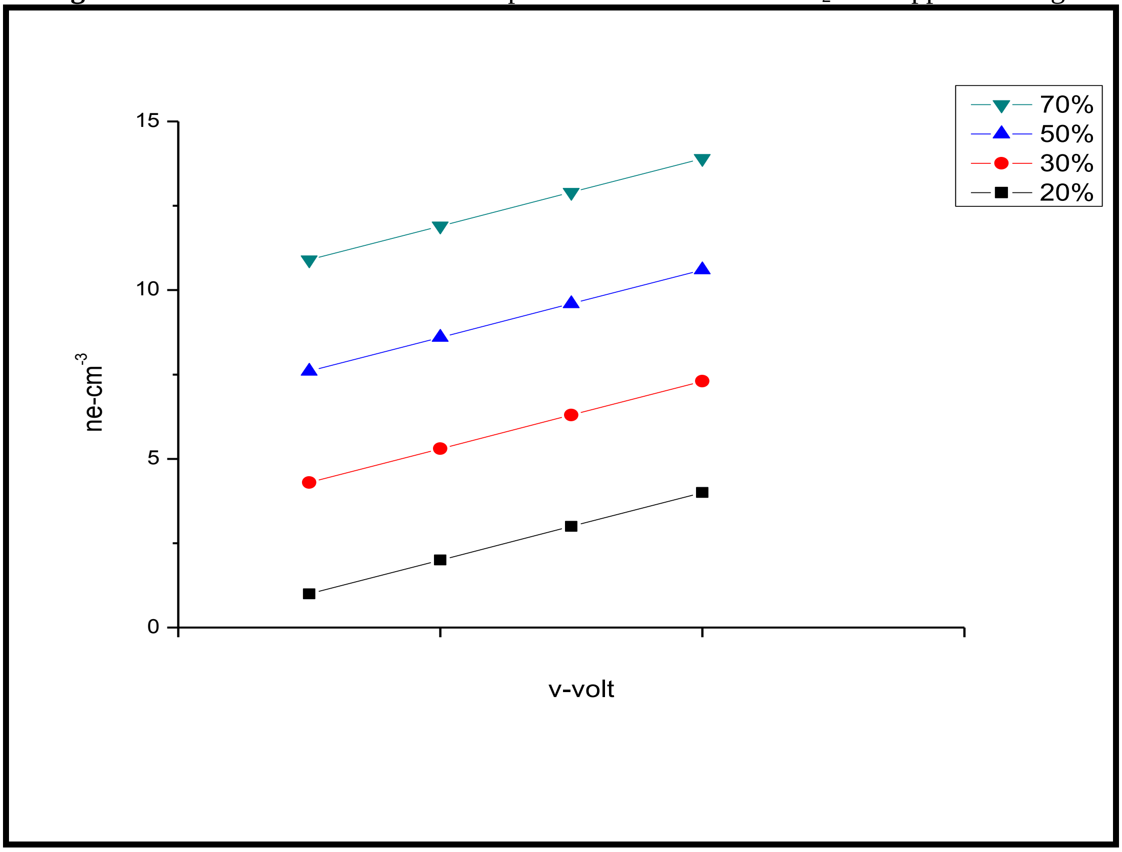

Figure 9-The evolution of electron density with applied voltage

Conclusion

In this article results showed that addition of O_2 to mixture of Ar/O_2 .At the value constant to V and P, the characteristics of current and voltage show a Decreasing in current and increasing in plasma density ,The best current value was at the ratio 30% .The Increase ratio of O_2 to Ar due to increase in the values of breakdown voltage. The addition of O_2 lead to the electron temperature decrease and the electron density increased with both increasing working gas pressure and O_2 percentage.

References

1. Samples, S.C. **2016** "Effect of Electrodes Separation in DC Plasma Sputtering on Morphology of," **19**(4): 78–85.
2. Kelly, P.J. and R. D. Arnell, R.D. **2000**. "Magnetron sputtering: a review of recent developments and applications," *Vacuum*, **56**(3): 159–172.
3. A. Bogaerts, E. Neyts, R. Gijbels, and J. Van der Mullen, **2002**. "Gas discharge plasmas and their applications", *Spectrochimica Acta - Part B Atomic spectroscopy*, **57**(4): 609–658.
4. Zigan, L. **2018**. "Overview of Electric Field Applications in Energy and Process Engineering," *Energies*, **11**(6).
5. Hassouba, M.A. and Mehanna, E.A. **2009**. "Electrical characteristics of (N2-H2) gas mixture DC glow discharge" *International Journal of Physical Sciences*, **4**(11): 713-721 .
6. Hamadi, O.A., Khalaf, M.K., Kadhim, F.J. and Chiad, B.T. **2014**. "Operation Characteristics of a Closed-Field Unbalanced Dual-Magnetrons Plasma Sputtering System," **41**(January): 24–33.
7. Farag, O., Mansour, M., El-sayed, N. and Elghazaly, M. **2013**. "Mixing and cathode material effects on breakdown voltage of DC Ar glow discharge," *Peagia Res. Libr. Appl. Sci. Res*., **4**(1): 146–150.
8. Sh. H. Abd Muslim, **2015**. "Electrical discharge characterizations of dc-planar magnetron (PM) Plasma device", PhD. Thesis,Mustansiriyah University .
9. Deeba, F., Qayyum, A. and Mahmood, N. **2014**. "Optical emission spectroscopy of 2.45 GHz microwave induced plasma," pp. 1–22.
10. Qayyum, A., Zeb, S., Ali, S., Waheed, A. and Zakaullah, M. **2005**. "Optical emission spectroscopy of the active species in nitrogen plasma," *Plasma Devices and Operations*., **14**(1): 61–70.
11. Hassouba, M.A. and Dawood, A. **2014**. "A Comparative Spectroscopic Study on Emission Characteristics of DC and RF Discharges Plasma using Different Gases", *Life Science Journal*, **11**(9): 656-666.
12. National Institute of Standards and Technology (NIST) 2014,Atomic Spectra Database, (version 5). Available at http://physics.nist.gov/asd3, last updated: September 16.
13. Kramida, A., Ralchenko, Y. and Reader, J. **2013**. "NIST atomic spectra database (ver. 5.1)," Natl. Inst. Stand. Technol. Gaithersburg, M.
14. Goldstein, J., Newbury, D.E., Joy, D.C., Lyman, C.E., Echlin, P., Lifshin, E., Sawyer, L.C. and Michael, J.R. **2003**. "*Scanning Electron Microscopy and X-ray Microanalysis*" (Third ed.), Springer, New York, USA.
15. Rudd., M.E., DuBois, R.D., Toburen, L.H. and Ratcliffe, C.A. and Goffe, T.V. **1983**. "Cross Sections for Ionizaton of Gasesby 5-4000-keV Protons and for Electron Capture by 5-150-keV Protons" *Phys.Rev*., A28 ,pp.3244-3257.
16. Boening, H.V. **1982**. "*Plasma Science and Technology* ".Cornell University London.
17. Shishoo, R. **2007**. "*Plasma Technologies For Textiles*" Cambridge England.
18. Lizhena, Y. and Yuefei, Z. **2011**. "Characterization of the discharge in array needle cathodes and applications", *Physics Procedia*, **18**: 2–8.