Electrical characteristics and plasma diagnostics of (Ar/O₂) gas mixture glow Discharge

Mohammed K. Khalaf [1], Ibrahim. R. Agool[2], Shaimaa H. Abd Muslim[3]

[1] Ministry of Sciences and Technology / Baghdad / Republic of Iraq
[2] Al-Mustansiriyah University / Baghdad/ Republic of Iraq
[3] Al-Mustansiriyah University / Baghdad/ Republic of Iraq

ABSTRACT

The oxygen plasma has many important applications in the semiconductor industry. When addition a small amount of oxygen gas can significantly change the plasma characteristics, In this paper, The current –volt, characteristic curve and breakdown potential have been measured at different O₂ percentage in (Ar/O₂) gas mixture, the measurements show that the addition of oxygen leads to decrease in the discharge current at the same discharge voltage and gas pressure. Contrary, the lower breakdown potential at lower O₂ percentage the minimum breakdown voltages were found (320 , , 347, 370, 400)volt at (10%, 50%, 75%, 100%)O₂ percentage respectively. The electron temperature and density calculated from I-V curve of single Langmuir probe at pressure (0.14) mbar for different O₂ percentage. We observed two different groups of electrons characterized by different temperature and density, the result showed that the electron temperature increase with the addition of O2. While, the electron density decreased with increase percentage O2.

Keywords: glow discharge, Paschen's law, plasma diagnosed, Langmuir probe.

1. INTRODUCTION

A glow discharge (GD) is a plasma; that is, a partially ionized gas consisting of electron and positive (and sometimes negative) ions, as well as a large number of neutral species[1] . It is created by applying a potential difference between two electrodes that are inserted in a cell filled with a gas [2]. At normal temperature and pressure, the gases are excellent insulators [3]. Various phenomena occur in gaseous dielectrics when a voltage is applied. As the applied voltage is low, small currents flow between the electrodes, and the insulation retains its electrical properties. On the other hand, if the applied voltages are large, the current flowing through the insulation increases very sharply, and an electrical breakdown occurs [4].The The physics of the electrical breakdown have a great significance because of its wide applications in electronics and technology [5]. The electrical discharges in gases are of two types, i.e. (i) non-sustaining discharges, and (ii) self-sustaining types. The breakdown in a gas, called spark breakdown is the transition of a non-sustaining discharge into a self-sustaining discharge. The build-up of high currents in a breakdown is due to the process known as ionization in which electrons and ions are created from neutral atoms or molecules, and their migration to the anode and cathode respectively leads to high currents [4]. As mentioned above a glow discharge is formed by application of a potential between two electrodes. Depending on the pressure p of the gas and the distance d between the electrodes a breakdown voltage of

$$V_B = \frac{Bpd}{\ln[\ Apd\ -\ln(1+1/\gamma)]} \qquad (1)$$

Is required for a self –sustaining discharge. This equation is known as Paschen's law, Where V_B is the breakdown voltage P is the pressure and d is the gap distance. The constants A, B and γ(secondary electron coefficient) are constants (depend upon the composition of the gas).depend Depend upon the composition of the gas[6]. This equation shows a relationship between V and pd, and implies that the breakdown voltage varies as the product pd varies.The relationship between V and pd is not linear and has a minimum value for any gas. The existence of a minimum sparking potential in **Paschen's curve may be explained as follows:**

At low pd values before the Paschen's minimum, the average length of the electron trajectory is longer and the ionizing collision frequency lower. A higher voltage is needed to maintain the number of ions with the required energy to regenerate a continuous flux of primary electrons. In short, a higher voltage is needed to start a self-sustained discharge.For higher pd values, the mean free path of electrons is shorter and collisions more frequent. However, the electron energy increment increase between collisions is lower. Excitation competes against ionization, and higher voltage is needed to produce more ions. Moreover, at higher pressures, the ionic mean free path is lower and ions lose energy in the gas by elastic and resonant charge exchange collisions. Higher voltage is required to maintain sufficient ion energies [7]- [9]. Oxygen plasma has an important application in the semiconductor industry due to their ability of charge

free, Unlike electropositive plasma with ions and electrons. An electronegative plasma is composed of three different charges, positive ions, electrons, and negative ions, which were formed the attachment reaction of electron to the neutral atoms or molecules[10]. In addition, the oxygen gas is one of the best sterilization agents [11]. Since only a small amount of oxygen gas can significantly change the plasma characteristics, obtaining the fundamental knowledge and the experimental results about the oxygen plasmas is important in determining the optimum operating conditions with certain plasma characteristics[12] In this study, The discharge was diagnosed using a Langmuir probe oriented parallel to the cathode. The Langmuir probe can be interpreted from an experimental point of view as a simple current collector surface immersed into the plasma environment. The electron temperature, Te, is determined in electron volt (eV) from the slope of the ln (I)–V curve of the probe in the transition region between floating potential and plasma potential by the following equation [13]:

$$T_e = \frac{e}{k \dfrac{d \ln I}{dV}} \qquad (2)$$

Where e is the electronic charge, k is the Boltzmann constant. I is the electron current and V is the probe voltage. The electron number density, obtained from the electron saturation current (I_{Se}) using the following. Equation [14]:

$$n_e = \frac{4 I_{se}}{eA} \left[\frac{m_e}{2kT_e} \right]^{\frac{1}{2}} \qquad (3)$$

Where A is the probe area, and m_e is the magnitude of electronic mass.

2. THE EXPERIMENTAL SETUP

A schematic diagram of the device used in this investigation shown in Figure (1). The discharge was operated in DC mode, the external resistance RL was used to limit the discharge current, to ensure that the discharge would be limited to the abnormal glow discharge region. And digital multi-meters was used measured the discharge current and the voltage. The plasma chamber itself is a cylindrical stainless steel vacuum chamber with length 40 cm and 30 cm diameter. Basically, the inside of the chamber consists of two electrodes between which the glow- discharge is formed One of them is movable (denoted Anode)and the fixed electrode (denoted cathode) . And each of them was 10 cm diameter, and the cathode to anode separation was fixed at 4.5 cm; the discharge chamber was evacuated using a two-stage rotary pump (Edward of 12 m^3/h), and diffusion pump (Alcatl of 380L/sec) The gas flows controlled with flow meter as a gas flow rate of the gas mixture and the gas pressure was monitored by perani gauge with Edward's controller 1105. The applied voltage was controlled by a DC power supply which can produce potential up to 1400 volt.Our measurements were carried out using a cylindrical shape probe with 0.5 mm base diameter and 2 mm length, made of tungsten wire. The wire must be will be insulated for preventing take –current collection. In the oxygen environment, a problem of oxide build-up on the probe was encountered, which caused alterations in the current-voltage curves under positive bias. The probe then required cleaning to eliminate the oxide. For the cleaning, the probe was kept at a negative bias in an argon plasma for several minutes; by allowing only an ion flux to bombard the probe surface, the contamination layer can be sputtered away. To minimize this contamination problem, the experimental data was collected quickly. Each run took under 5 minutes, and. In between runs, the probe was kept at a negative bias.
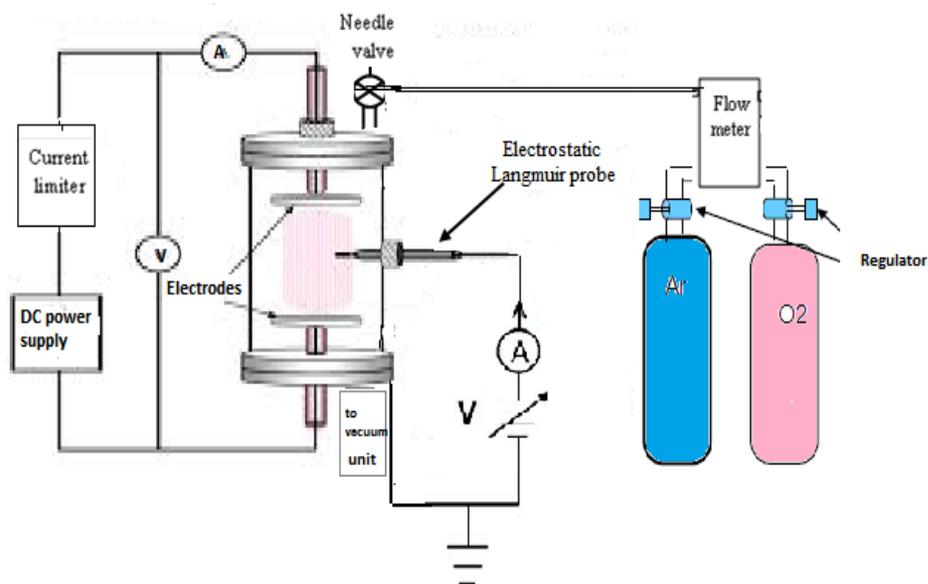
Figure 1. a schematic diagram of the experimental setup.

3. RESULT AND DISCUSSION

The current –volt characteristic, at different O_2 percentage in (Ar/O_2) gas mixture shown in figure 2. Where gas pressure is kept constant at 0.14 mbar. From this figure, We can show that the discharge current increase at the applied voltage increase that means the electrical discharge are operation in the abnormal glow discharge region. It is clearly seen that, at the same applied voltage and gas pressure, the discharge current decreases by increasing the O_2 percentage in(Ar/O_2) gas mixture. The decrease in the discharge current with increased O_2 percentage can be explained as follows: the ionization cross –section of O_2 is smaller than that of Ar[15]. In addition, Since the electron affinity of oxygen, discharges in oxygen contain negative ions, which result in the increase of plasma resistance due to reduction of electron density and thus the discharge current decreases.
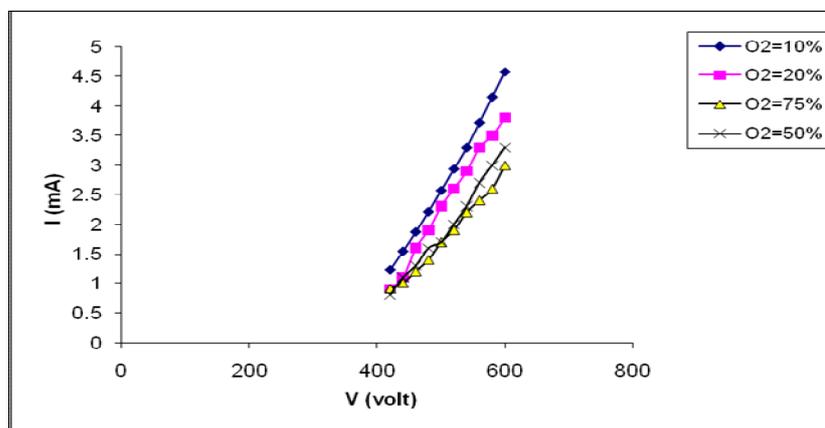

Figure 2. Thedischarge current –Volt characteristic curve at different O_2 percentage at working pressure of 0. 14mbar.

The values of the breakdown voltage for different O_2 percentage in (Ar/O_2) gas mixtures are shown in figure 3. The gas breakdown voltage V_B was determined as a function of the product of the gas pressure p and the inter electrode distance d. the minimum breakdown voltage as (320, 347, 370, 400)volt at (10%, 50%, 75%, 100%) of O_2 percentage respectively. From this figure, we can show that the breakdown voltage increase by an additional increase in O_2 percentage of the gas mixture this can be related to, the additional energy loss channel oxygen gas such as vibration, rotational and molecular dissociation, V_B abruptly was increased when the small amount of oxygen was added. In addition, since plasma resistance was increased due to high electron affinity of oxygen, discharge sustained voltage was also increased . Furthermore, the oxygen is electronegative gas and the loss of electrons due to diffusion and attachment to oxygen molecules in (O_2 /Ar) plasma requires the electric field strength in the plasma to be higher than in argon plasma so as to produce enough electrons to maintain the plasma discharge. As the number of additional oxygen molecules increases, a progressively higher electrical field is required. J.K. Rhee et al [12] shown the same results.
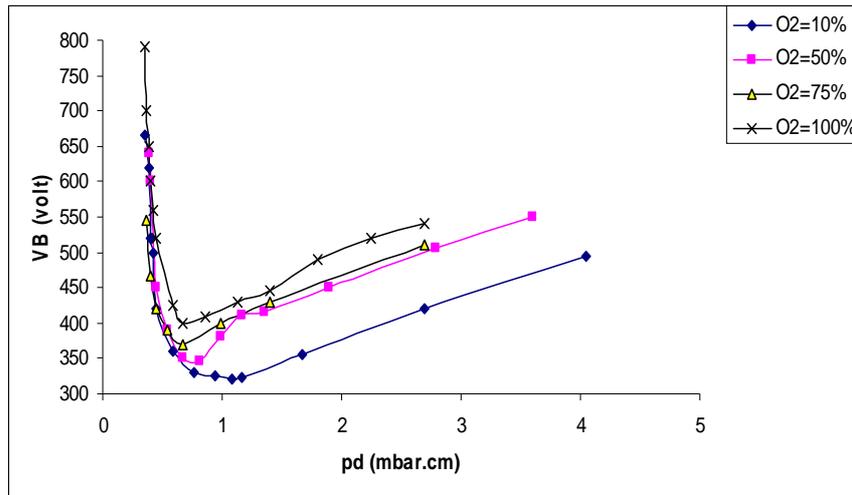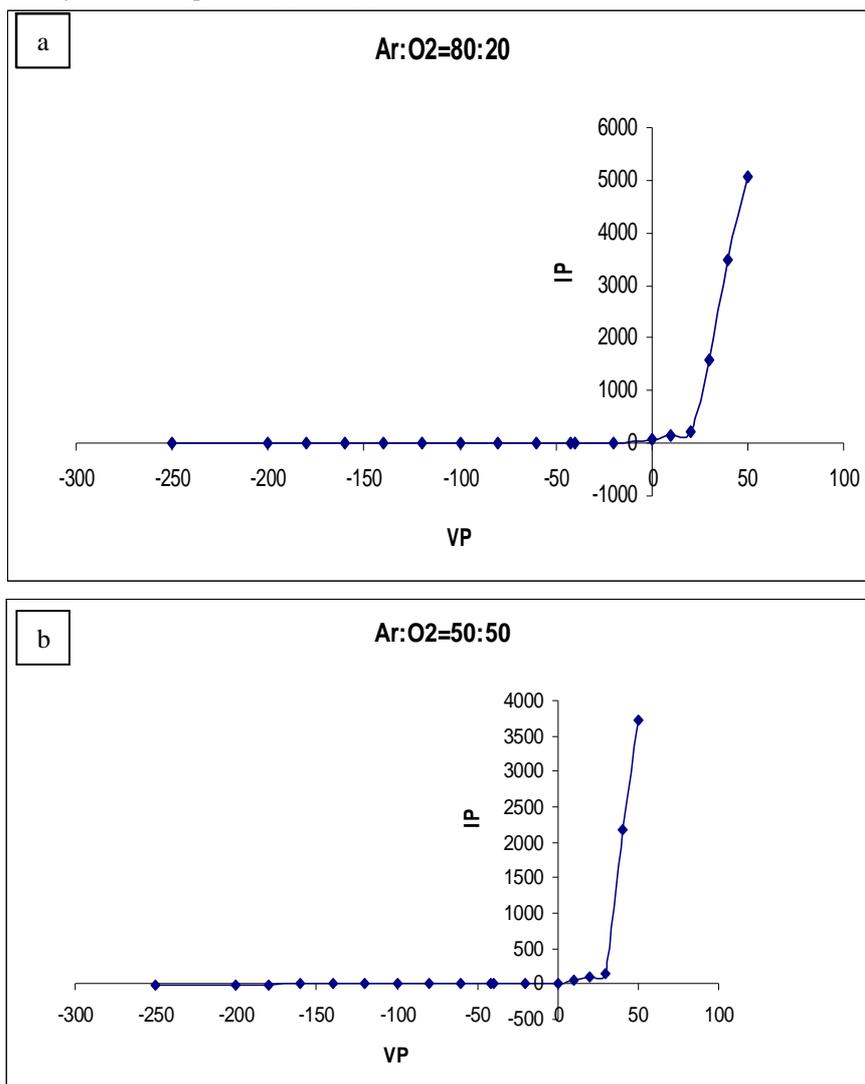
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Figure 3. Paschen's curves at different O_2 percentage.

The discharge was diagnosed using a cylindrical Langmuir probe, the electron temperature and density obtained from I-V curve data figure 4, probe characteristics with the signature of two groups of electron were observed. The two groups of electrons fast and slow electrons. Depending upon their origin. The fast electrons are created at the cathode surface in secondary processes, and are. Subsequently, accelerated in the sheath potential, and. Slow electrons are those created by ionization processes. These groups are characterized by different average.kinetic energies and temperature. Such a characteristic is shown plotted on semi logarithmic axes figure 5. From those shapes, it can calculate the electron temperature Te and density ne from equation(2)and (3).
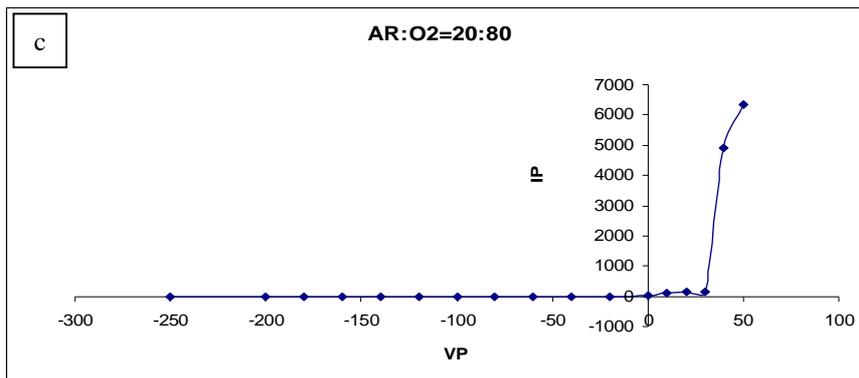
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Figur 4.(a,b,c) The Langmuir probe voltage-current characteristic for different O2 percentage.
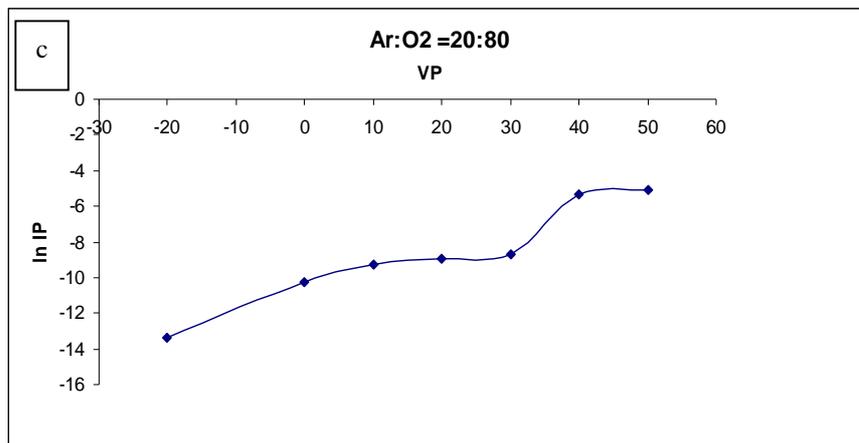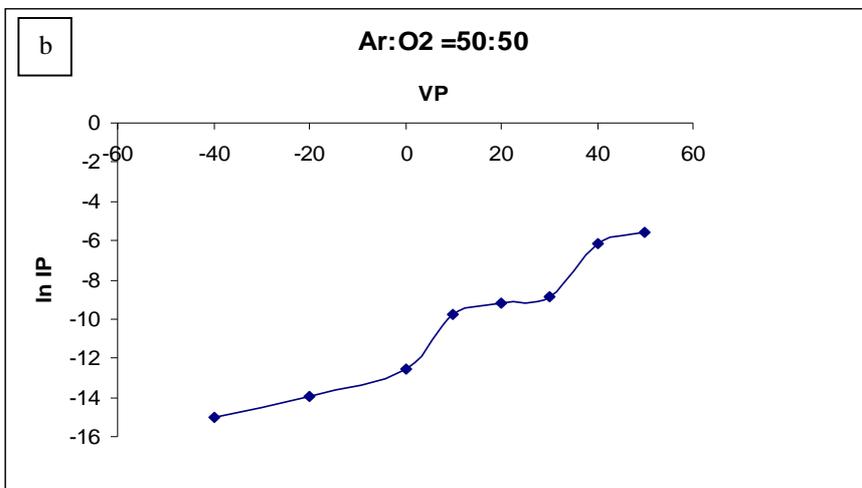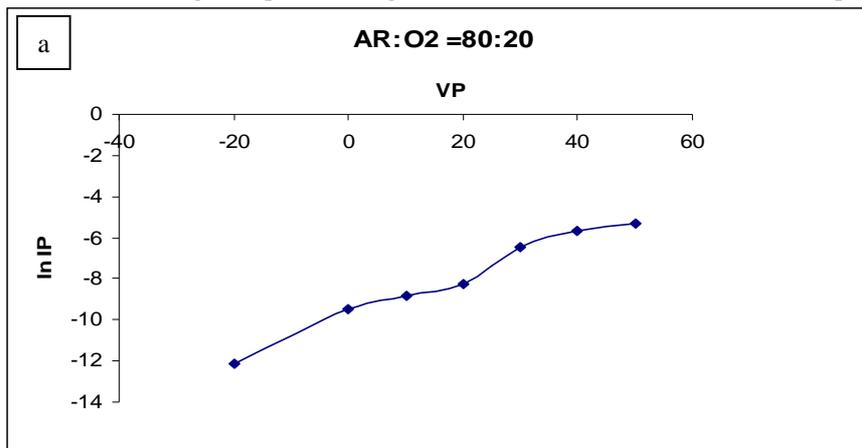

. **Figure .5**.(a,b,c) Ln probe current as a function Probe voltage for different O_2 percentage.

Figure 6. shows the evolution of n_e and T_e as a function of O_2 percentage from this figure one can see that both electron's temperature increases with increase O_2 percentage due to the decrease in the energy loss by the electrons during ionizing collision with O_2 molecules as the ionization cross-section for O_2 is smaller than that of Ar. while the electron density decrease with the addition of O2 in the ambient gas, The phenomenon is explained by the molecular gases O_2 reduce the electron density due to the high-energy losses in excitation of vibrational levels [16], Furthermore, the electronegativity of gas O_2decreases the electron density with increasing the oxygen percentage due to the electron's attachment. Moreover, the fast electron density lower than slow electron density this can be attributed to Fast electrons impart their energy through collisions of the first kind to cause ionization. And finally join to the group of slow electrons.
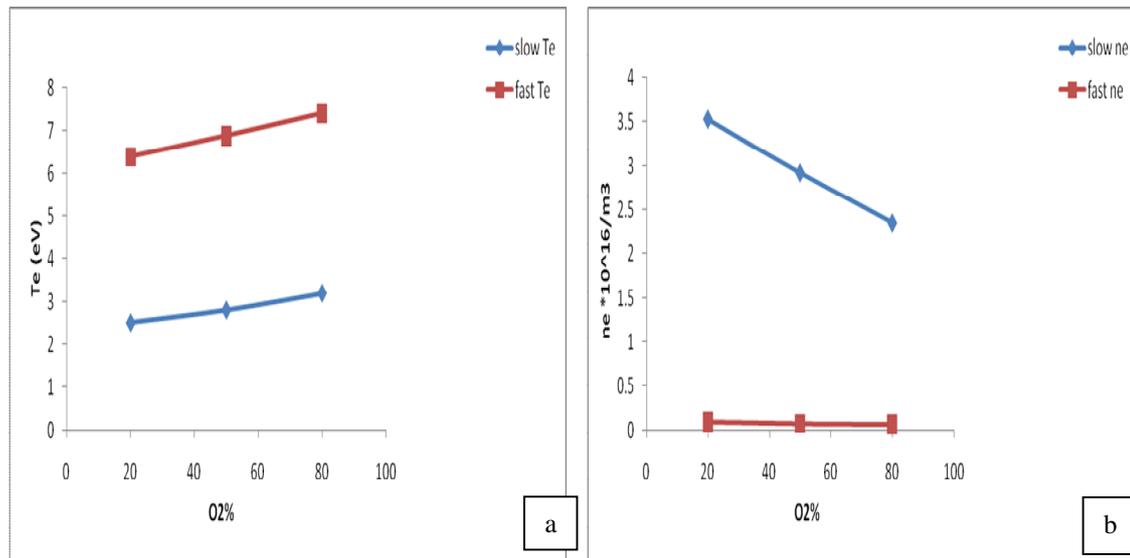

Figure6.: Ar/O_2 plasma (a)electron temperature , (b) density for different O_2 percentage.

4.CONCLUSION

The variation in the electrical parameters, and plasma properties of a glow discharge in the (Ar/O_2) gas mixture was the subject of this paper.
A main Results in this work can be summarized as follows:
1-the Current –volt characteristics for different O_2 percentage in a mixture of Ar/O_2 shows that the addition of O_2 to, He discharge causes and decrease in the values of the discharge current at the same discharge voltage and gas pressure.
2- increase of O_2 to Ar discharge causes an increase in the values of breakdown voltage.
3-from I-V curve of Langmuir probe we found there are two groups of electron temperature.
4- the electron temperature increase with the addition of O_2. Contrary, the electron density decreased with the addition of O_2.

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AUTHOR

Shaimaa H. Abd Muslim received the B.S. and M.S. degrees in Physical Science / Laser and Molecule from Al-Mustansiriyah University in 2004 and 2008 , respectively. She now PhD. Student .