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A Comparative Study of the Electrical Characteristics of Generating Argon Plasma in Different Inter-Electrode Spacing Discharges

Younus K. Jabur1 Mohammed K. Khalaf[2], Mohammed Gh. Hammed[3]
1,3. Physics, Department, College of Science, University Of Anbar, Anbar, Iraq
2. Ministry of Sciences and Technology / Baghdad / Republic of Iraq

ABSTRACT

This work aims to study the effect of different inter-electrode spacing of the DC system on the generated plasma and the electrical characteristics (I-V discharge voltage). The study uses Paschen gas pressure (I-P) curves for glass samples by niobium. The plasma is produced when the argon gas flows into the chamber at 0.08 mbar and the injected voltage of 700 V. The Paschen curve is considered for distances (2, 4, 6, 8 cm) by measuring the collapse voltage and current-voltage (I-V). Of the curve flow, I-P increased due to the increment of discharge current. The best discharge current value is 40 mA and the distance is 4 cm. The results reveal that the inter-electrode spacing influences the values of the electrical characteristics of the generated plasma. The proportion of discharge voltage to discharge current is direct and nonlinear. In addition, the findings indicate that the best distance is 4 cm.

Keywords: Niobium, DC sputtering, Paschen's law, Plasma discharges.

1- INTRODUCTION

Mono- or multilayers of thin films with thicknesses in the range of 10 nm to 1 μm [1] are typically chosen for scientific observation. According to the thin film materials classification, there are three main divisions such as coatings, metallic and dielectric coating [2].

Recently, plasma physics have shown a wide range of applications in industry for special glasses or metal coating works. Interest in the reactive DC magnetic sputtering system has also increased too [3, 4]. A glow discharge (GD) plasma is a partially ionized gas consists of positive or negative ions and electrons [5]. This creates a potential difference in a chamber filled with argon gas (Ar) [6].

A needle valve controls the pressure (P) in a chamber while the voltage in this method is measured between the electrodes of anode and cathode. By changing this pressure, the breakdown voltage *VBR* can be obtained using different discharge voltages. In different gases, the *VBR* decreases with the increment of *pd* (pressure and distance between the electrodes). Therefore, plasma is formed between the plates and caused the flow of the current in the system. The voltage across the plates falls dramatically when the voltage breaks down. In order to study the electrical behaviours, the DC is first ignited by an exceeding breakdown voltage. The principle characteristics of plasma discharge from the I-V, I-P characteristics and Paschen law *VBR-pd* have been studied as functions of inter-electrode spacing and gas pressure in the chamber [7]. The usual Panchen's law [8]:

$$V = f(pd) \quad (1)$$

Its describes the breakdown voltage characteristic of *p* and *d*, written as [9, 10]:

$$VBR \frac{apd}{\{ln(pd) + b\}} \quad (1)$$

where VBR is the breakdown voltage, and a and b are constants.

In equation 1, it seems that the *VBR* depends on the multiplication of the *p* to *d*. It also, depends on the nature of the cathode material when both the *p* and the *d* are constant [11]. In this study, the influence of different working inter-electrode spacing, pressures, and applied voltages on the electrical characteristics is investigated.

2-EXPERIMENTAL SETUP

In this research, the DC sputtering system is equipped with anode and cathode in the chamber. These electrodes provide electricity for the argon discharge. Niobium (Nb) 99.9% with diameter 5 cm and thickness 3mm is used as the target material.

Argon gas discharge is supplied at a flow rate 45 sccm using different inter-electrode spacing of 2, 4, 6 and 8 cm. The chamber is firstly vacuumed by using the rotary pump as can be seen in Fig. 1, the flow meter regulates amount of gas inside the chamber. The working pressure is 8 x 10^{-2} mbar measured by Pirani gauge. The applied voltage is 700 volts and the discharge current is 40 mA. The influence of different inter-electrode, different working pressure and different applied voltage on *VBR* is recorded. Figure 2 shows the schematic diagram of the sputtering system.

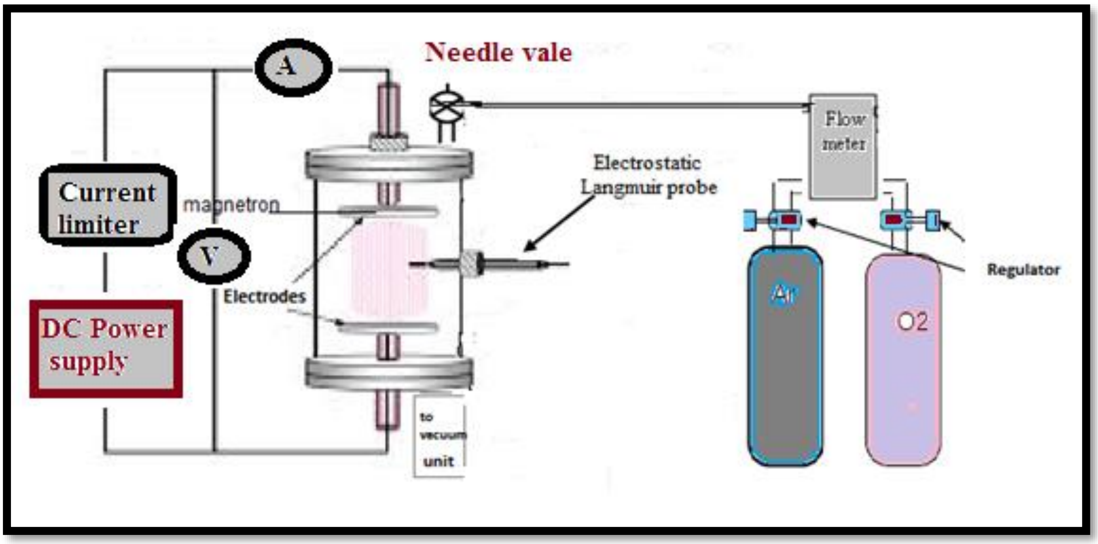

Figure 1. Schematic of the DC Magnetron Glow sputtering Discharge-sputtering set- up Schematically [12].

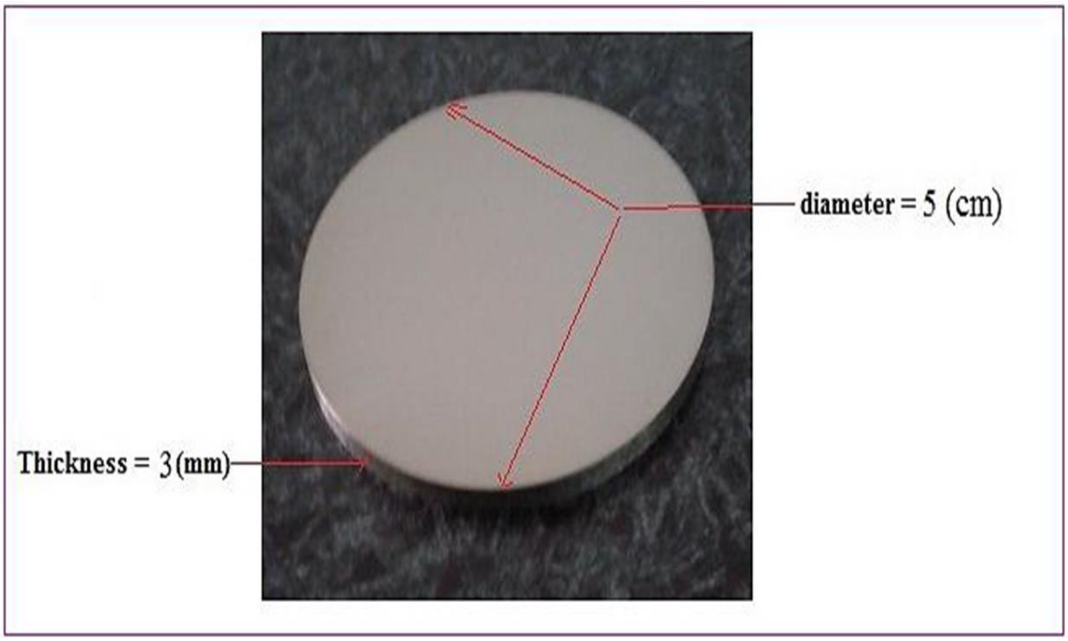

Figure 2. Target of Nb .

Alcohol, distilled water and air dryer are used for cleaning the substrates which are films coated on the glass substrates. This procedure pushes the base pressure to approximately 8.0 x10^{-2} mbar before starting of each deposition. Argon flow rate causes the sample preparation to be adjusted accordingly for suitable stoichiometry and thickness. Sputtering is conducted at a constant applied voltage. While exposing a substrate, the target is conditioned with the reacting gases at the selected deposition circumstances. The DC power supply affects the cathode voltage and the flow of Ar. Introducing the Ar into the chamber at an identified pressure needs the needle valve balance and the deposition time of 2 hours exposure in all experiments.

3-RESULTS AND DISCUSSION

Figure 3 depicts the DC glow discharge (I-V) characteristics of the inter-electrode spacing (d) for argon. It can be seen that the current values rise with the rise of DC power supply voltage and resistors. This means that the electric field accelerates the electrons and ions which then collide with gas atoms causing an increase in the current discharge and gas temperature. In terms of interaction energy, all ionization processes can be subdivided into the following five types: direct by the electron effect, collision with particles, photoionization, surface and electron emission. The ionization collisions create ions and electrons. When the ions are speeded up in the electric field across the cathode, the current density on the cathode surface goes up in a direct nonlinear proportion with the increase of the voltage. The plasma behaves electrically as a resistor [13]. Also, it becomes clear that, the discharge current at 4 cm inter-electrode spacing is higher than in other distances because the 4 cm is the best distance at a maximum value for discharging current.

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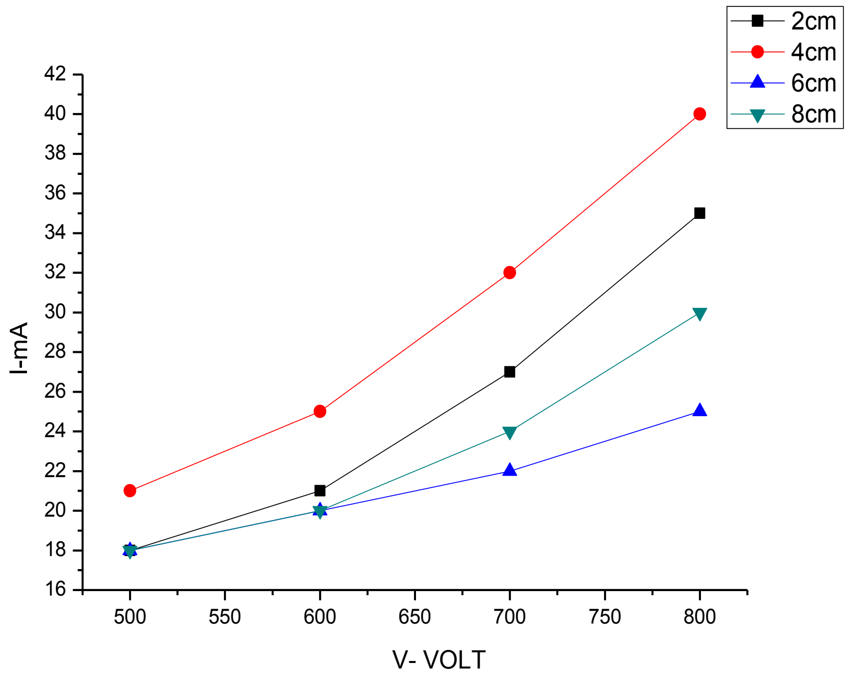

Figure 3 Discharge current –Volt characteristic curve at Different Inter-electrode Spacing at Working Pressure of 0.08 mbar.

discharge current and the cathode potential are calculated as a function of applied voltage for different inter-electrode spacing and constant pressure. The results indicate that the growth of applied voltage enhances the discharge current and cathode potential. The electric field accelerates electron and ion, and as a result, they collide with the gas atoms creating a positive ion and free electron [13]. A visible glow already covers the complete work surface with the increasing applied voltage (an increase in the cathode fall). This means that the discharge current and the discharge potential are in a positive correlation with in the applied voltage [15]. In Fig. 4, the I-P characteristics portray enhancement of the discharge of Ar gas rises in glow discharge current with a rise in the pressure at constant applied voltage. This is because chamber pressure growth generates more ions raising the secondary electron emission. [16].

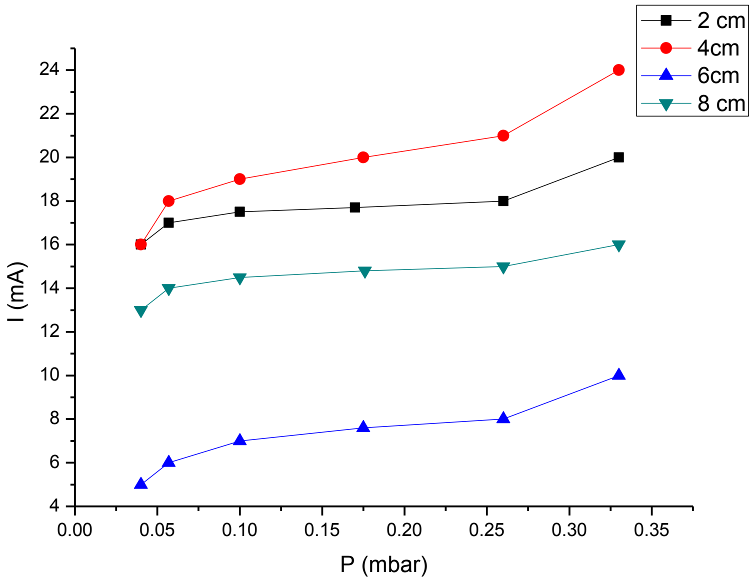

Figure 4 Discharge Current – Working pressure Curve at Different Inter-electrode Spacing at of 700 volt.

Current discharge increases correlate positively with the working pressure at constant applied voltage to different inter-electrode spacing (2, 4, 6, 8 cm) as shown in Fig.5. However, the discharge potential decreases with the same pressure as can be seen in Fig. 6. This is because the applied voltage accelerates electrons and positive ions which collide with the molecules or/and atoms generating a current discharge. Then the discharge surges with the gas pressure because more frequent collisions occur, which generates secondary electrons and ions reducing further the electron mean free path [17].

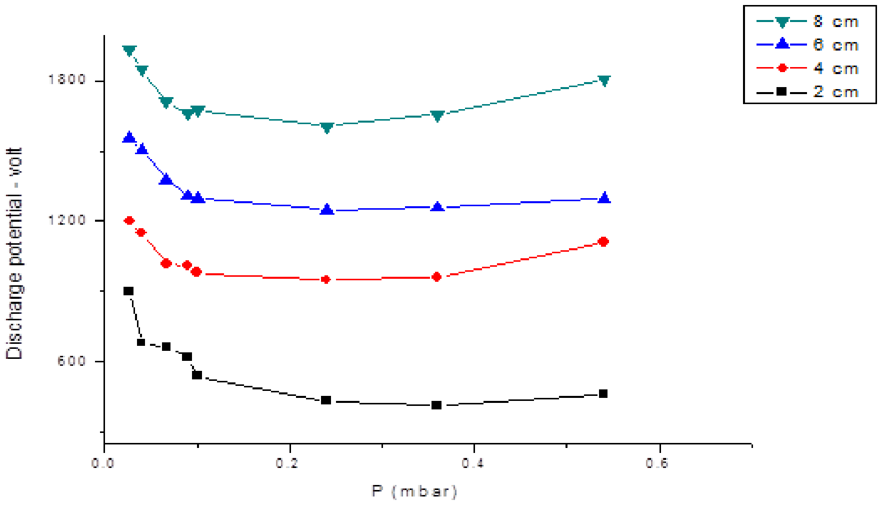

Figure 5 The discharge voltage – working pressure curve at of 700 volt.

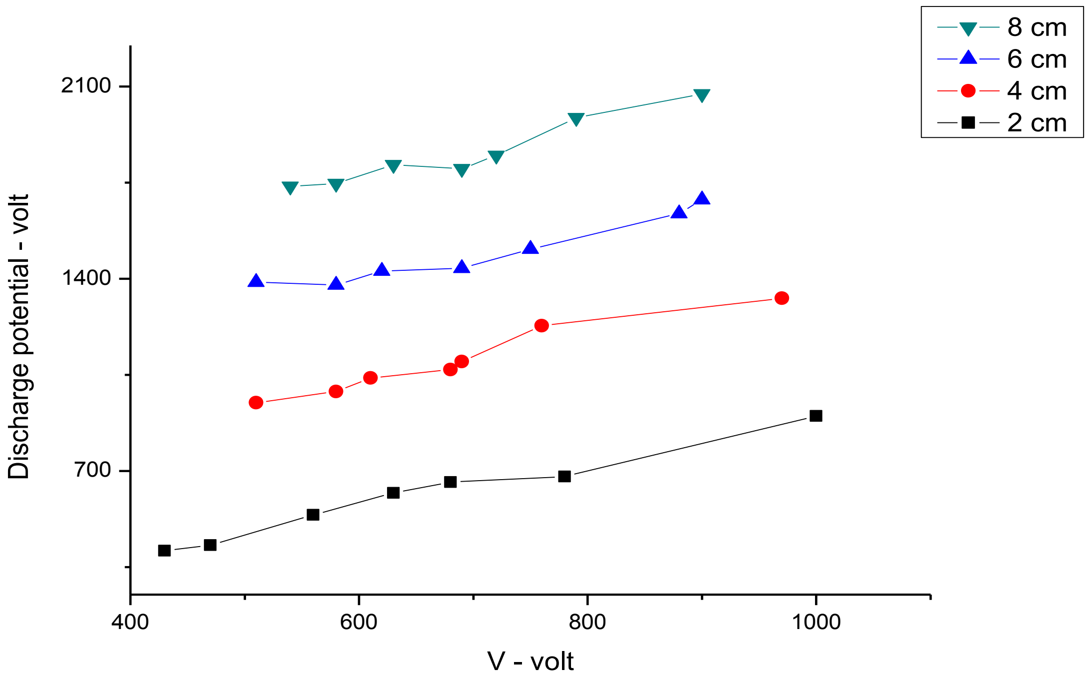

Figure 6The Discharge Voltage – Working Pressure Curve at of 700 Volt.

The low voltage is the minimum voltage at the transition of *VBR* [18]. The flux discharge breakdown curves are illustrated in Fig. 7 where it applies the Paschen's *VBR* = *f* (*pd*) law. From this relationship, we observe that the collapse voltage depends on *d*and *p*.

The pressure variability is mostly noticeable at *pd* where *VBR* change is the highest. When the applied voltage is not much lower than the breakdown voltage, a stray source of radiation could ionize sufficient neutrals to produce breakdown [19]. The breakdown voltage is not dependent on *pd* only, but on *d* as well. This figure also depicts the four Paschen curves of four different inter-electrode distances (2,4,6,8 cm) and dependence of the breakdown voltage on *d*. The Paschen minimum happens at the same value of *pd*. However, the breakdown voltage differs depending on *d*. Therefore, referring to Paschen law, the breakdown voltage relies on *pd* not on *p* and *d*, when *pd*=0, the breakdown voltage is infinite value(i.e $pd \neq 0$).

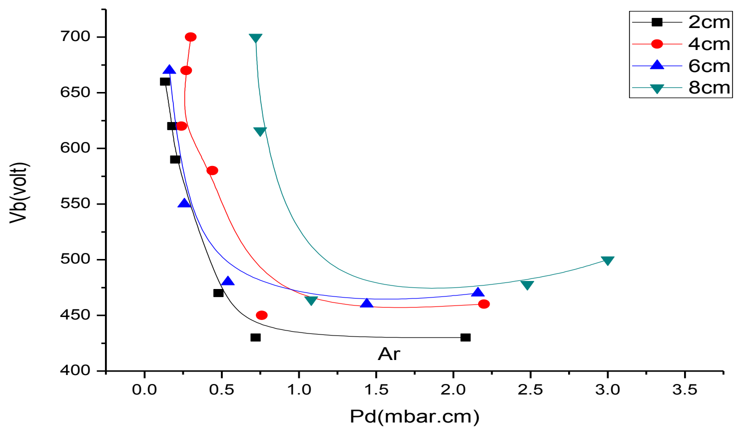

Figure 7 Paschen's curves at D different Inter-electrode Spacing

Figure 8 shows a positive correlation between *Te* and *p*. This may be attributed to the increase of the *p* inside the discharge chamber. Furthermore, when the electron frequently collides with the neutral argon atoms, the later also increases while the mean free path between two sequential collisions decreases. Therefore, the ionization process decreases. Besides, at a growing *p*, the number of atoms negatively correlates with the energy acquired by the electrons particle from the electric field because of the fast growing and increasing energy is transferred from the kinetic energy to the neutral species through inelastic collision.

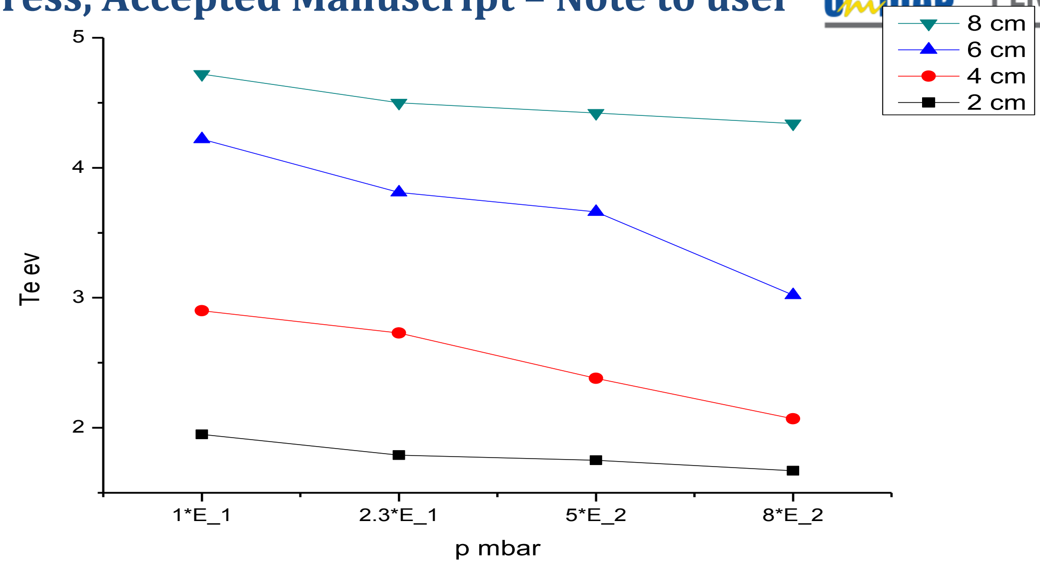

Figure 8 The Evolution of Electron Temperature with Working Pressure

Figure 9 shows *Te* which gradually rises with the rise of the applied voltage at a particular pressure. The increment of *Te* might be due to the increase in the kinetic energy of the electrons gained from the electric field. Similarly, *ne* increases when the applied voltage grows.

The supplied voltage of glow discharges plasma also influences *Te* and *ne* for Argon discharges plasma. The influence of applied voltage is straight forward: a positive correlation between the *Te* and *ne* is observed. The increase of *Te* with DC power may explain by noting that there are usually two modes of operation. This is because electron attachment consumes the low energy electrons and therefore it shifts the mean energy of the resulting electron distribution to higher energies. The electron temperature increases (i.e. electron density decreases) with the input applied voltage at a constant pressure because the increase of electron collision with the argon atoms and this collision causes a reduction in the electron energy. As a result, the density of negative particles will increase, since the probability of attachment process escalates with the cut of electron energy.

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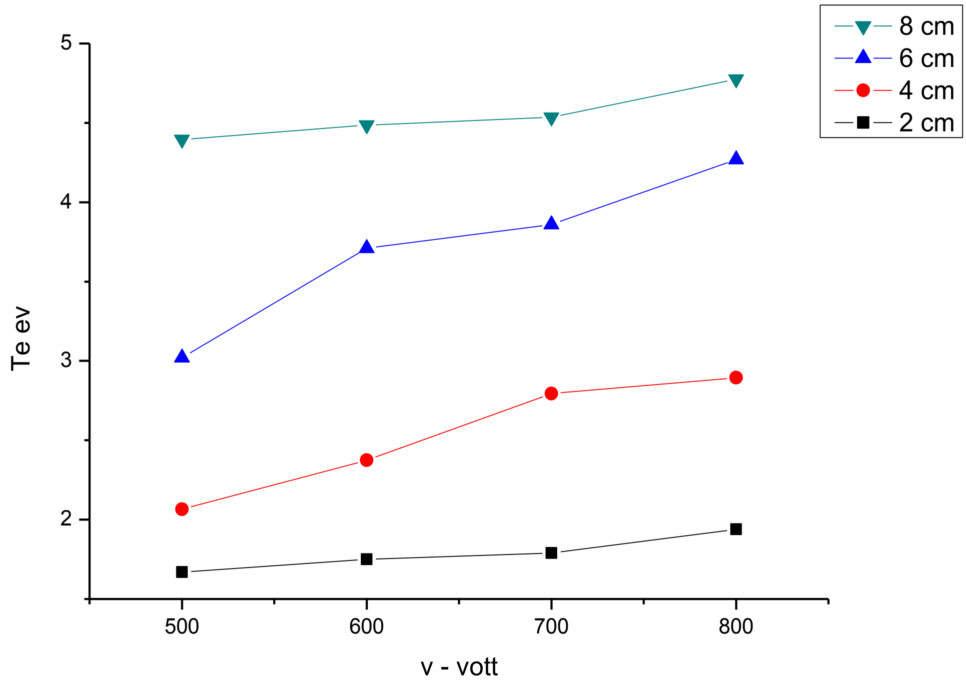

Figure 9 The Evolution of *ne* with Working Pressure

CONCLUSION

Plasma is successfully produced by using a DC-magnetron sputtering system. The I-V characteristics are operating in an abnormal glow discharge region. This is because the total current increases with the voltage. The results show that changing the different inter-electrode Spacing affects the electrical properties. The best distance is recorded at 4 cm.

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