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## A Comparative Study on the Electrical Characteristics of Generating Plasma by Using Different Target Sources

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### Abstract:

In this research, the electrical characteristics of glow discharge plasma were studied. Glow discharge plasma generated in a home-made DC magnetron sputtering system, and a DC-power supply of high voltage as input to the discharge electrodes were both utilized. The distance between two electrodes is 4cm. The gas used to produce plasma is argon gas which flows inside the chamber at a rate of 40 sccm. The influence of work function for different target materials (gold, copper, and silver), - 5cm in diameter and around 1mm thickness - different working pressures, and different applied voltages on electrical characteristics (discharge current, discharge potential, and Paschen's curve) were studied. The results showed that the discharge current and potential increase by increasing the applied voltage ranging between 300-700 V. Discharge current increased as working pressure increased in the beginning, and then semi-stabilized (slight increase) starting from  $1 \times 10^0$  mbar, while discharge potential decreased at the beginning as working pressure increased and then semi-stabilized at the same point at which discharge current stabilized. The Paschen's curves were compared with each other. It was concluded that the lower breakdown voltage was associated with lower work function of the (Au, Cu, and Ag) cathode material. Breakdown voltages were (395, 398, and 420) for Ag, Cu and Au respectively.

**Keywords:** DC sputtering, Glow discharge, Paschen's law, Plasma discharges.

### Introduction:

The plasma state of matter can be defined as the mixture of ions, electrons and neutral atoms which constitute a macroscopic electrically neutral medium that responds to the electric and magnetic fields in a collective manner. A particular characteristic of plasmas is the collective response to external perturbations. The long range electromagnetic forces in plasmas also spread the perturbations affecting the motion of large number of charged particles. The response to the perturbations of electromagnetic fields are collective; which include massive numbers of charged particles. The multi-component plasmas constitute of a mixture of different kinds of charged particles. Additionally, the dusty plasmas also include charged solid Micro particles. The large mass and electric charge obtained by these dust grains introduce new properties in these physical systems (1-3). The plasma glow discharge is usually obtained using DC or high frequency AC excitation inside a low-pressure gas chamber (4,5).

Of the many electrical regimes of DC discharges, three forms have been found to have analytical merit: the arc, glow, and corona discharges. Among these three types of discharges, the fundamental distinction is the operating current and voltage. The arc occurs at very high currents (hundreds of amperes) with a low voltage drop between electrodes (tens of volts). It also exhibits negative resistance; that is, the sustaining voltage drops as the current rises. The glow discharge (GD), which has conventionally been operated between 0.1 to 10Torr, exists at much lower currents (tens of milliamperes) and a higher voltage drop (hundreds of volts). Lastly, the corona discharge operates with very low currents (a few microamperes) and a much higher voltage drop (several kilovolts) (6). The mechanism of the gas breakdown can be explained as follows: a few electrons are emitted from the electrodes due to the omnipresent cosmic radiation. Without applying a potential difference, the electrons emitted from the cathode are not able to sustain the discharge. However, when a potential difference is applied, the electrons are accelerated by the electric field in front of the cathode and collide with the gas atoms. The most important collisions are the inelastic collisions in Non-LTE

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plasmas. The heavy particle temperature is low, but the electrons are at much higher temperatures, because they are light and easily accelerated by the applied electromagnetic fields. The high electron temperature gives rise to inelastic electron collisions, leading to excitation and ionization (7). The excitation collisions, followed by de-excitations with the emission of radiation, are responsible for the characteristic name of the 'glow' discharge. The ionization collisions create new electrons and ions. The ions are accelerated by the electric field toward the cathode, where they release new electrons through ion induced secondary electron emission (7- 10).

The breakdown voltage of the plasma generated by gaseous discharge can be found using the following equation (11, 12):

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

where:

$$pd = e^{1-b}$$

$V_p$ : Breakdown voltage,  $p$ : Gas pressure,

$d$ : The distance between the anode and cathode

$a, b$ : Constants

By differentiating equation 1 with respect to  $pd$ , and setting the derivative to zero, the minimum voltage can be calculated with the expression  $pd = e^{1-b}$ . It has been shown that for air at a standard atmospheric pressure of 760 Torr,  $a = 43.6 \cdot 10^6$  V/atm-m and  $b = 12.8$ . This yields and predicts the minimum arc voltage of 137 Volts for argon at larger than 12 micrometers.

From equation (1), it is clear that the breakdown voltage depends on the multiplication of the gas pressure and the distance between the poles, as well as on the nature of the cathode material when both the pressure and the distance are constant (13).

### Materials and Methods:

The DC glow discharge system includes two electrodes located in a cylindrical chamber. The cathode faces the anode, which provides an electric field for the gas discharge. Three targets were used in this work: gold, silver and copper, while the diameter of each target is 2cm. Discharge occurs by using argon gas with a flow rate of 40sccm when the distance between two electrodes is 4cm. The chamber was evacuated using a rotary pump (Edward of 12 m<sup>3</sup>/h). The amount of gas inside the chamber was limited using a flow meter and the pressure inside the chamber was observed using a Pirani gauge with Edward's controller 1105 (See Fig. (1)). A DC-power supply was used to supply variable applied voltage. A limiting resistor was used in the circuit to ensure that the discharge was beneath the abnormal glow discharge region.

Discharge potential and discharge current measured by digital multi-meter.

In this work the influence of different working pressures and different applied voltages on breakdown voltage, the behavior of potential, and current discharges were studied.

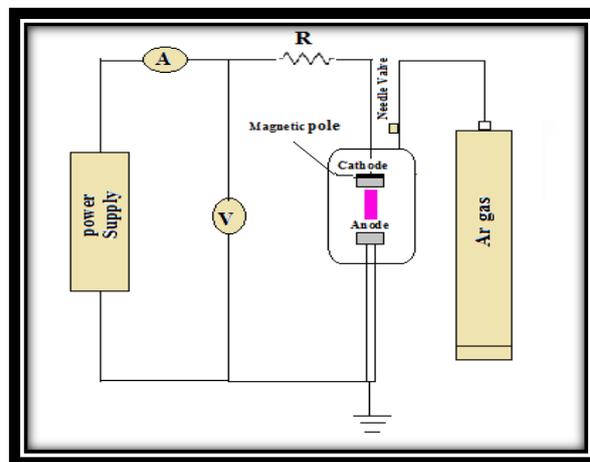


Figure 1. Experimental setup of the magnetron sputtering system

### Result and Discussion:

The electrical characteristics of discharge plasma, such as dependencies of discharge current on the applied voltage and gas working pressure inside the vacuum chamber as well as Paschen's curve, are of importance to introduce the homogeneity of the generated plasma.

In Figs. (2, 3), the discharge current and the discharge potential were calculated as a function of applied voltage for constant inter-electrode spacing  $d=4$  cm. The results demonstrate the increase of applied voltage leads to an increase in discharge current and discharge potential. This is because the electric field accelerates the ion and the electron, and as a result they collide with the atom of working gas. This generates new free electrons and positive ions (14). Since the visible glow already covers the entire work surface with increasing applied voltage (an increase in the cathode fall), an increase in current density will now be accompanied by an increase in voltage drop through the resistance of the glow discharge (i.e increases discharge current and discharge potential with increasing in applied voltage) (7).

With an increasing working pressure discharge, current increases while cathode potential decreases as shown in Figs. (4, 5), this may be related to the acceleration of electrons and positive ions which collide with the atoms and/or molecules, generating a discharge current which increases with an increase in gas pressure because more frequent collisions occur, which generates secondary

electrons and ions, reducing the electron mean free path and leading to more negative bias (15).

Figure (6) shows the breakdown voltage as a function of different targets, gold being the highest, silver being the lowest, and copper has a breakdown voltage in between both, which related to the work function. Gold is high (5.1ev), silver

(4.26ev), and copper in between (4.65 ev), as indicated in the periodic table (16-18).

Due to the ion impact, secondary electron emission increases accompanied by a decreasing work function that in turn increases the secondary electron numbers, which causes the ionization of neutral gas atoms of molecules that stifle the metal surface (19,20).

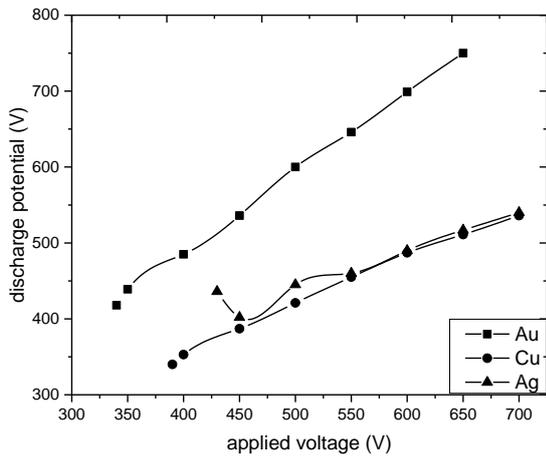


Figure2. The discharge current as a function of applied voltage

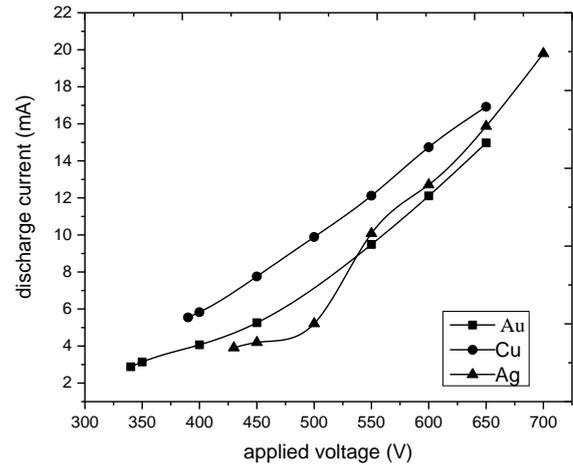


Figure3. The discharge potential as a function applied voltage in argon gas discharge plasma

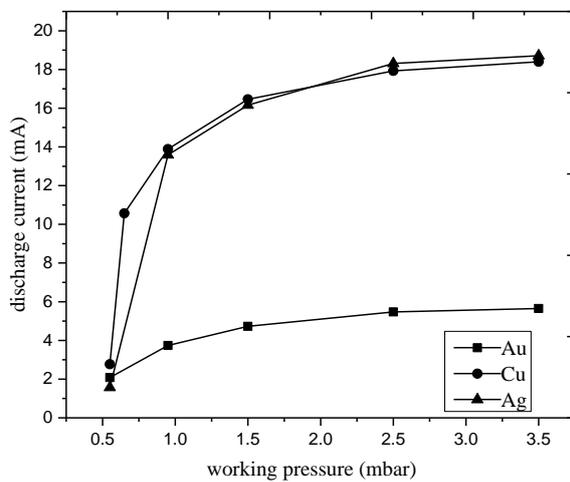


Figure4. The discharge current as a function of working pressure in argon gas discharge plasma

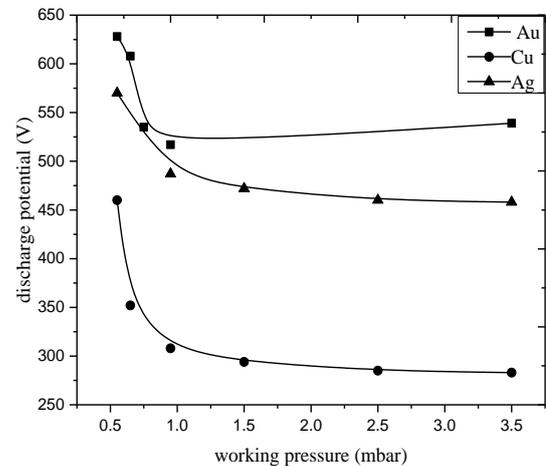


Figure5. The discharge potential as a function of working pressure in argon gas discharge plasma

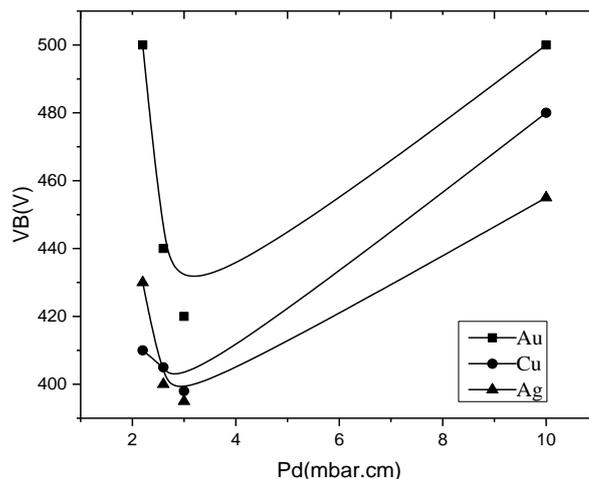


Figure 6. influence of target materials on the Panchen's curve

### Conclusion:

From I-V characteristics we conclude that the produced plasma – by using a DC-magnetron sputtering system – is operating in an abnormal glow discharge region because the voltage increases significantly with the increasing total current to force the cathode current density above its natural value and provide the desired current. We also investigated the effect of changing the working pressure and applied voltage on electrical characteristics (discharge current, discharge voltage and breakdown voltage). The results showed that the discharge current and discharge voltage increase with increasing applied voltage, and increasing working pressure while discharge voltage decreases with increasing working pressure. The breakdown voltage takes an ascending order starting with silver, copper and gold.

### Conflicts of Interest: None.

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## دراسة مقارنة للخصائص الكهربائية للبلازما المتولدة من أهداف مختلفة

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### الخلاصة :

تم في هذا البحث دراسة الخصائص الكهربائية لبلازما التفريغ التوهجي باستخدام منظومة التريذ الماكنتروني ذات التيار المستمر المحلية الصنع لتوليد بلازما التفريغ. كذلك استخدم غاز الاركون لانتاج البلازما بمعدل تدفق 40 Sccm وبمسافة فاصلة بين الاقطاب بمقدار 4cm وباستخدام مجهز قدرة عالي الفولتية. تم دراسة تأثير كل من دالة الشغل لاهداف مختلفة (ذهب، فضة، نحاس) - بقطر 5 سم وسمك 1 ملم- على الفولتية المسلطة وضغط التشغيل على الخصائص الكهربائية (تيار التفريغ، جهد الكاثود ومنحنى باشن). أظهرت النتائج ان كلا من تيار التفريغ وجهد الكاثود يزداد بزيادة الفولتية المسلطة والذي يتراوح بين 300-700. ان تيار التفريغ يزداد مع زيادة الضغط المسلط في البداية ثم يستقر نسبياً عند ضغط (زيادة ضئيلة ) ابتدأ من Imbar . بينما يقل جهد الكاثود مع زيادة الضغط المسلط ثم يستقر في نفس النقطة التي استقر فيها تيار التفريغ. لقد قورنت منحنيات باشن مع بعضها بالاعتماد على نوع مادة الهدف. وتم الاستنتاج ان جهد الانهيار يرتبط بدالة الشغل لكل من الذهب والفضة والنحاس.

**الكلمات المفتاحية:** التفريغ الكهربائي، قانون باشن، التريذ الماكنتروني.