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Electrical glow discharges and plasma parameter of planar sputtering system for silver target

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Abstract

DC planar sputtering system is characterized by varying discharge potential of (250-2000 volt) and Argon gas pressures of (3.5×10^{-2} – 1.5) mbar. The breakdown voltage for silver electrode was studied with a uniform electric field at different discharge distances, as well as plasma parameters. The breakdown voltage is a product of the Argon gas pressure inside the chamber and gab distance between the electrodes, represent as Paschen curve. The Current-voltage characteristics curves indicate that the electrical discharge plasma is working in the abnormal glow region. Plasma parameters were found from the current-voltage characteristics of a single probe positioned at the inter-cathode space. Typical values of the electron temperature and the electron density are in the range of (2.93 –5.3) eV and (10^{-16} - 10^{-17}) m^{-3} respectively.

Key words

Silver target, glow discharge, plasma parameter, dc sputtering.

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دراسة معلمات التفريغ الكهربائي لمنظومة الترذيذ المستمر لهدف مسطح من الفضة

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الخلاصة

لقد تم في هذا البحث دراسة الخصائص الكهربائية ومعلمات البلازما لمنظومة الترذيذ المستمر مصنعة محليا، من خلال تغير فرق الجهد الكهربائي (250-2000) فولت وتغير ضغط غاز حجرة التفريغ –(3.5×10^{-2} 1.5) ملي بار. فولتية الانهيار، ضغط غاز الاركون، المسافة بين اقطاب الفضة هي المتغيرات الخارجية المستخدمة. لقد تم دراسة خصاص التفريغ الكهربائي من خلال توصيف منحني تيار التفريغ الكهربائي – الفولتية المجهزة، منحني باشنت، و منحني تيار التفريغ- ضغط الغاز السلط. كذلك تم دراسة خصائص البلازما المنتجة بأستخدام مجس لاتكميور في المنطقة الداخلية لعامود البلازما. حيث تبين ان قيم درجة حرارة الالكترونات (2.93 –5.3) الكترون فولت وكثافة الالكترونات (10^{-16}-10^{-17}).

Introduction

DC glow discharges are very important technique used for depositing thin films, oxidization, plasma polymerization, etching, and pumping gas discharge lasers, etc, for this reason the research in the glow discharge is of considerable interest [1, 2]. Plasmas are ionized gases; where, consist of electrons, positive ions and neutral particle gas. For these reason, the ignition of the dc glow discharge at low pressure was one of the earliest problems in the study of gas discharges. When a sufficiently high potential difference is applied between two electrodes placed in a gas, a break down into the gas space where generate a positive ions and electrons, giving rise to a gas discharge [3, 4]. Due to the large chemical freedom offered by the non-equilibrium aspects of the plasma, therefore, the gas discharge plasma applications has rapidly expanded in the resent years [5, 6]. The possibility of external control of chemical non-equilibrium conditions of plasma will making easily be modified chemical input gases, the pressure (ranging from about 0.1 mbar to atmospheric pressure).

The use of electrostatic probes is the simplest experimental technique to measure the properties of the plasmas [7]. This technique was introduced and developed by Irvin Langmuir about fifty years ago, and contently is sometimes called the method of Langmuir probes. Basically electrostatic probe is merely a small metallic electrode, usually a wire inserted into plasma. The probe is attached to a power supply capable of biasing it at various voltages positive and negative relative to the plasma, and the current collected by the probe then provides information about the conditions in the plasma. Electrostatic Langmuir probes are one of the basic tools of the plasma physicist for measuring electron densities, temperatures, and energy distributions. The technique has been extensively used and in many cases the quantities measured compare very well with those obtained by other techniques [8, 9]. Hence, the plasma parameters; electron temperature, electron density and axial electric field will be changed from one region to another under the same condition. The probe technique is an important one because it can make local measurements. Almost all other techniques, such as spectroscopy or microwave propagation, give information averaged over a large volume of plasma [10].

This paper reports the results of electrical and plasma parameter of homemade DC glow discharge plasma system where it can be used to enhance the sputtering process. Experimental study of breaking down voltage in cylindrical discharge vessels with various inter-electrode gaps and Argon gas pressure supply were tested. The plasma sources are analysis as Paschen characteristics curve, pressure-discharge current curves and discharge current- voltage curves. The behavior of space potential, floating potential, electron temperature, and plasma density as functions of discharge pressure were examined.

Materials and methods

The plasma system is made of a stainless steel cylinder (inner diameter 30 cm, height 34 cm), closed by stainless steel plates and sealed by O-rings. The electrodes and the metallic rods are encapsulated in Teflon shell so that only the electrode surfaces are attaches with the discharge gas and avoided edge effects. The effective surface area of the electrode in contact with the argon gas is 78.5 cm^2. The electrodes are made of stainless steel of 15 mm in thickness and100 mm in diameter as shown in Fig. 1. Before each experiment the electrodes are mechanically polished and chemically cleaned in dichloromethane. The pressure is controlled by a manual throttle valve mounted between the reactor and the pumping unit. The pumping system is composed of a rotary vane pump and a diffusion pump. The gas through put is set at 300 SCCM a gas flow-controller. Target used silver for the experiment with purity of 99.99 %. A high voltage dc power supply is used for delivering 2 kV between two electrodes.

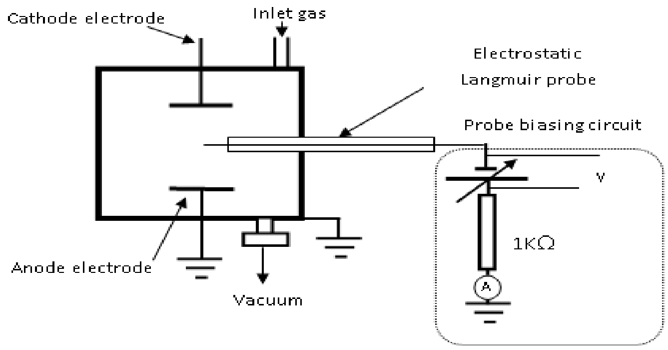

Fig. 1: Schematic diagram of the DC glow discharge sputtering chamber and Langmuir probe circuit.

Results and discussion

The current-voltage characteristics of the dc glow discharge for different pressures and varies distance between electrodes (d) for argon gas presented in Fig. 2 for copper. The current was varied by changing the dc power supply voltage with a fixed controller resistance. The discharge in our devices is operated in the abnormal regime. In this regime the cathode surface is fully covered by the discharge and an increase of the voltage leads to increase of the current density. The plasma behaves electrically rather similar to a resistance [11]. The work function which has inverse relation with secondary electron coefficient. The value of the work function for used metals is (ΦAg=4.25 eV).

Fig. 3 shows a comparison between the current-voltage characteristics of the dc glow discharge for constant pressure (0.055 mbar) varies distance between electrodes (d) for argon gas presented for copper. From this figure, it can be seen that at 5 cm inter-electrode spacing the discharge current become higher compared to other distances for silver target.

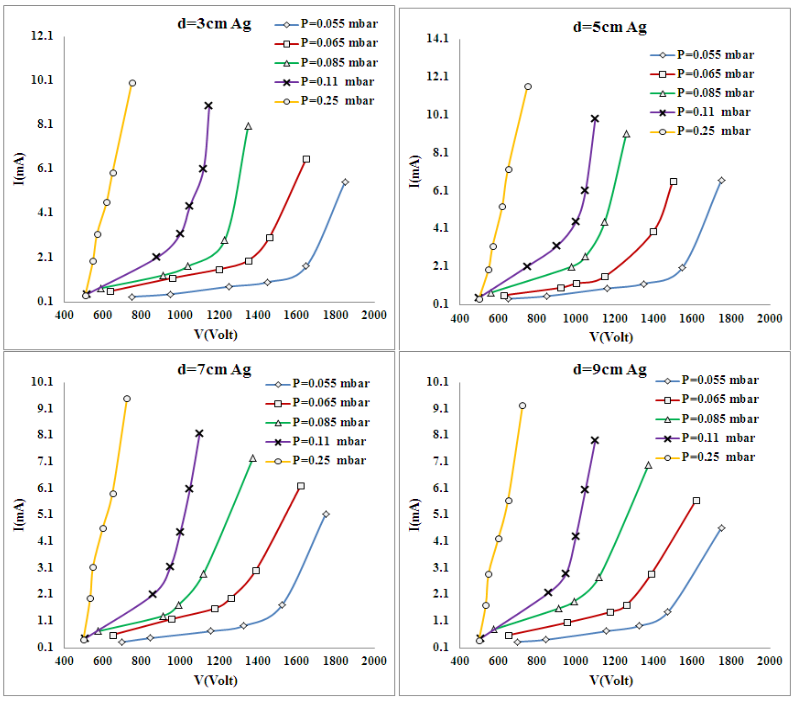

Fig. 2: The variation of discharge current as a function applied voltage at different Argon gas pressure.

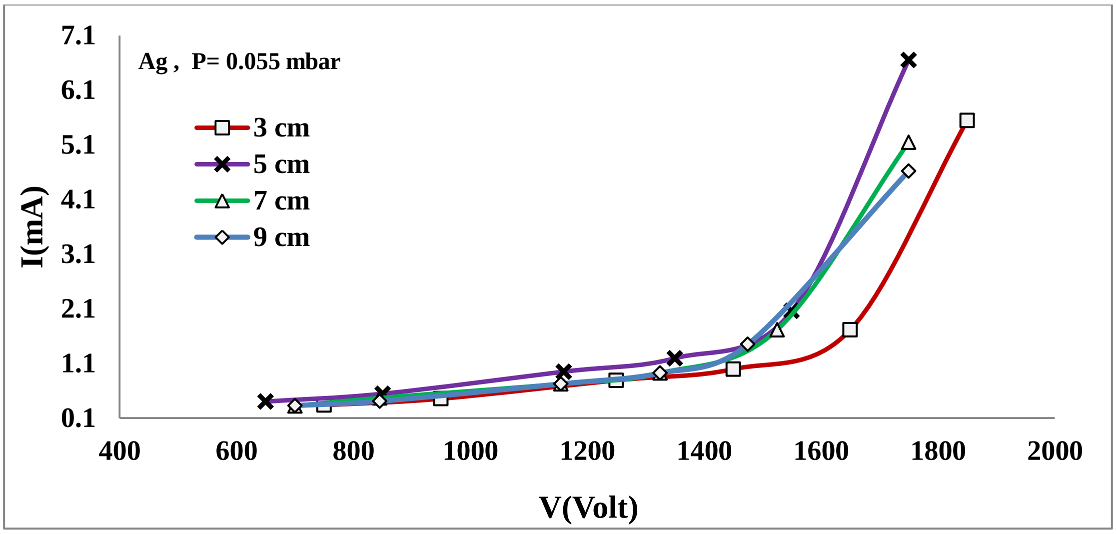

Fig. 3: The variation of discharge current with applied voltage at different distances of Ar gas for silver target.

The current-pressure characteristics of the dc glow discharge for different electrodes materials at constant inter-electrode spacing (d =5 cm) and constant applied voltage (V=1000 volt) for argon gas presented in Fig. 1 using silver. The current was varied by changing the working pressure. It can be seen from this figure that the I-P relation is non linear, where the current increase with increasing pressure reaching maximum values then decrease at high pressure as shown in Fig. 4.

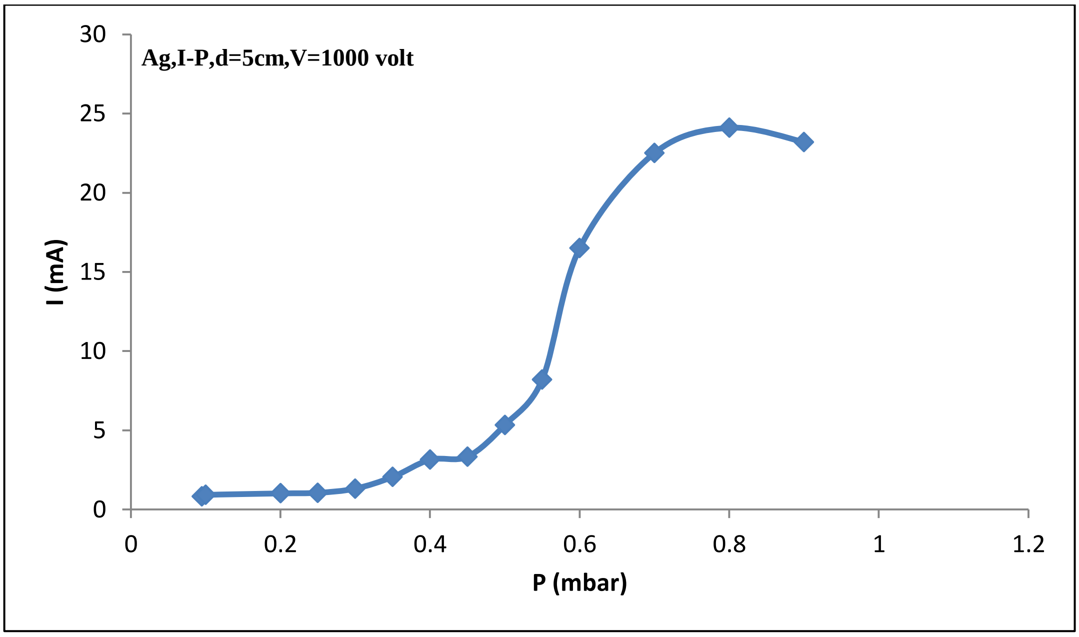

Fig. 4: The variation of discharge current with different working pressures for silver target.

Electrical breakdown of gases is the transition from an insulator to a conducting state and the minimum voltage at which this transition occurs is called the breakdown voltage V_B [12]. As far as it is known, the breakdown curves of the glow discharge are described by Paschen's law V_B = f (Pd), i.e. the breakdown voltage depends on the electrode spacing (d) and the gas pressure (P), The breakdown voltage also depends on factors such as type of gas, cathode material and magnetic field strength.

Fig. 5 shows the breakdown curves for argon measured with different inter-electrode spacing for targets (Ag). At low pd values before the Paschen's minimum the average length of 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 [13].

It follows from this figure that on increasing the gap (d) the breakdown voltages has a few increment, but the pd values being near constant due to losses of charged particles on the lateral walls of the discharge tube due to the diffusion across the electric field [14].

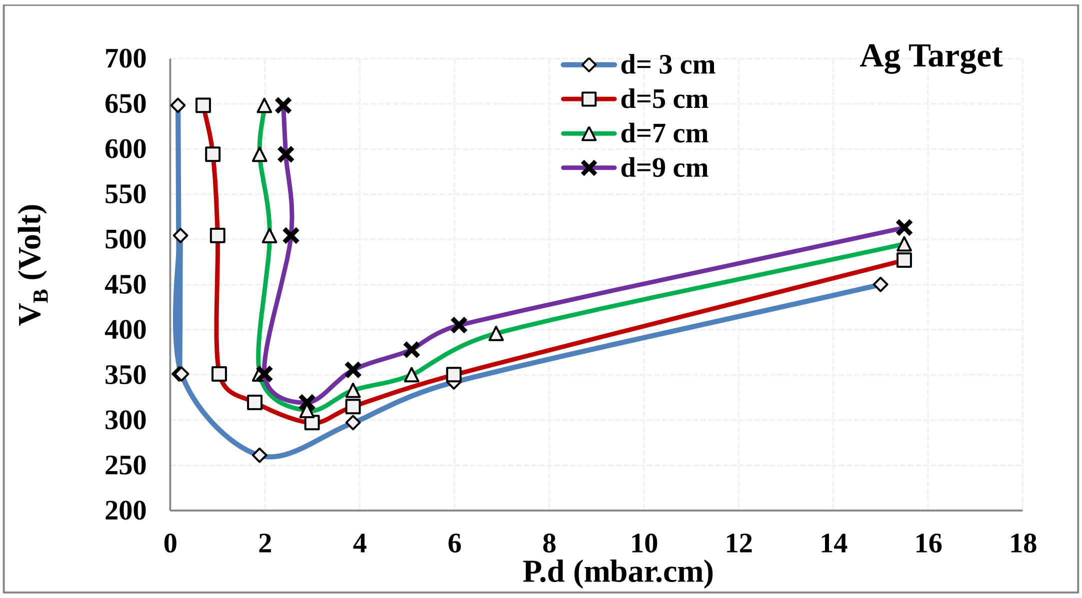

Fig. 5: Paschen curves of the glow discharge in argon for the Ag cathodes for different inter-electrode gaps.

The description of the *I-V* characteristics of an electrostatic probe depends not only on the plasma investigated but also on the geometry of the probe used. In the present investigation a cylindrical probe of radius 0.2 mm and length 5mm was used. Since, in weakly ionized argon plasma, at (0.015-0.15) mbar pressure, mean free path for charge particle-neutral collision is in the order of centimeters, charged particle collection is collisionless. Furthermore, for all the plasmas studied, as we seen in Table 1, the condition $r_p<3\lambda_D$ (r_p =probe radius, λ_D=Debye length) was satisfied which means that charged particle collection was orbital-motion limited.

Table 1: The plasma parameters with different discharge pressure.

P(mbar)	T_e(eV)	I_d(mA)	n_e*10^{+16}electron/m^3	N_i* 10^{+14}	V_f(volt)	V_p(volt)	λ_d(cm)
0.015	5.3	4.8	2.476	2.088	-12	110	0.0108

The experimental setup used to measure the plasma characteristics is shown in Fig. 1. Variable resistor is used to bias the probe continuously from -200 to +200 and probe current is measured by the voltage drop across *R*=1 kΩ.

Fig. 6 shows the variation of the plasma electrons density and, electron temperature as a function of pressure. As in this figure the electron temperature decreased gradually with increased of working pressure, while the electron density increase. The mean free path and acquired energy of electron decrease with increasing working pressure, therefore reducing the ionization process.

These results can be explained as the working pressure decrease where these means decreasing in number of gas molecule in chamber and the accelerated free electron show fewer molecules for bombard, therefore smaller amount energy to form new free electrons and positive ions.

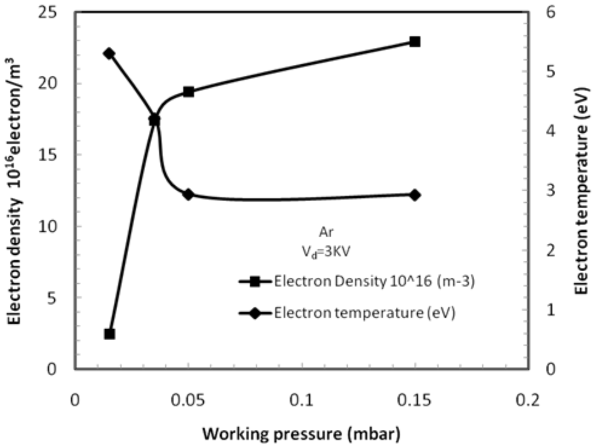

Fig. 6: Variation of the working pressure as function of plasma electron density and temperature.

The variation of working pressure as a function of floating potential and space potential as a function is shown in Fig. 7. The plasma parameters were measured from I-V characteristic curve, where, the floating potential increase, and space potential decrease with increasing working pressure.

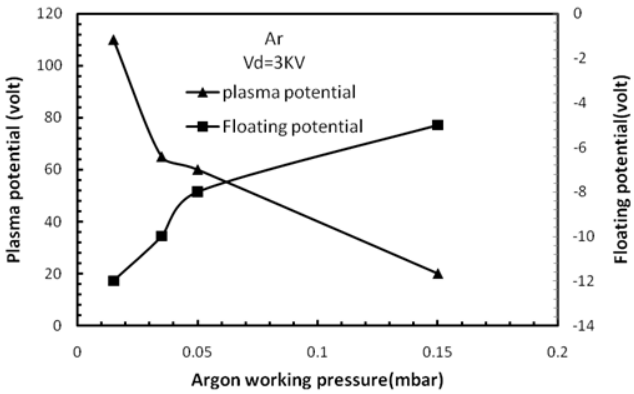

Fig. 7: Working pressure as a function of Floating potential, and space potential.

The ion current and density in Ar plasma can be calculated corresponding to orbital motion limit (OML) theory [15]. The Ip^2 vs. V, plots for the ion collection range (V<0) were obtained. The slope of the linear region of these Ip^2 vs. V curves was used to calculate the ion density. The Fig. 8 shows the evaluation of ion current and density in Ar plasma as a function working pressures.

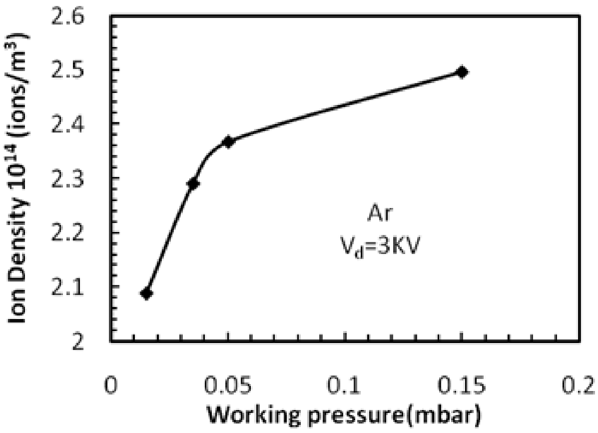

Fig. 8: The Ion density of Ar plasma measured as function of working pressure.

The ion density measured in the Ar plasma was increased with increasing of gas pressure due to the frequency of collisions became higher. Electrons suffer collisions with neutral particles, ionizing them. They lose their energy and are accelerated in electron field gaining again energy to produce ionization. The obtained ion current and density of Ar plasmas are different for the same operating conditions due to the difference in mass and ionization potential.

Conclusions

This home-built dc- sputtering system has long stable operation using argon gases. The present investigations show that an increase of the discharge voltage was accompanied by an increase of the discharge current, where the characteristics of such discharge is characterized by abnormal glow discharge.

The Present investigation shows that electrostatic Langmuir probes can be used effectively to measure the properties of the plasma sputtering. The observed dependence of the plasma parameters and the sputtering variables makes this technique useful not only in controlling the stability of the discharge during sputtering deposition but also in enhancing the repeatability of the sputtering process for a given system.

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