Electrical Characteristics of DC Glow-Discharge Plasma under Different Operation Conditions

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Abstract
In this work, a novel design of closed-field unbalanced dual magnetrons was used in plasma sputtering system to improve the electrical characteristics of the plasma. This improvement was shown by the Langmuir probe diagnostics of the plasma and the values of plasma parameters, such as electron and ion temperatures and densities. The applicability of such design may enhance the whole sputtering process and the production of nanoscale structures with low cost, high purity and good properties.

Keywords: Magnetron sputtering; Plasma parameters; Langmuir diagnostics; Glow discharge
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1. Introduction

The principles of sputtering can be understood using a simple momentum transfer model, which enables to visualize how atoms are ejected from a surface as a result of two collisions [1-3]. The series of collisions in the target, generated by the primary collision at the surface, is known as a collision cascade. It is a matter of probability whether this cascade leads to the sputter ejection of an atom from the surface (which will require at least two collisions) or whether the cascade heads off into the interior of the target, gradually dissipating the energy of the primary impact, ultimately to lattice vibration [4]. Sputtering ejection is rather energy inefficient, with typically 1% of the incident energy reappearing as the energy of the sputtered atom [5]. The rest of the energy is lost in the form of heating of the chamber walls, parts inside the chamber and the target [6].

Sputtering is complex process, which is highly dependent on number of process parameters, such as deposition pressure, discharge voltage, discharge current, target to substrate distance, gas compositions, process gas flow rate, reactive gas flow rate in case of reactive sputtering, substrate biasing, etc. [7]. Deposition of thin films by magnetron-based sputtering systems is performed at much higher rates than diodes and operated at lower pressures, where gas-phase scattering and gas-phase impurities are minimal [8]. DC magnetron is basically a magnetically enhanced diode in which the spatial relationship of electric and magnetic field is designed to confirm secondary electrons produced by ions bombardment of the target [9]. Restricting these electrons to remain close to the target surface increases their probability to ionize the working gas [10]. This effect results in more intense plasma discharge that can be sustained at lower pressure. Since the ions are heavier than electrons, they are not affected by the confining magnetic field and may sputter much as in a diode type configuration [11].

Because of the smaller mass of electrons in typical plasma, they have higher thermal velocities than the positive ions even they both are at the same temperature. However, electrons usually have higher temperatures than positive ions [12]. Plasma is electrically neutral by definition and electron and ion densities are nearly equal, however, a floating Langmuir probe will tend to draw higher electron current because they reach the probe faster than ions due to difference in mass [13]. The probe floats to a negative potential relative to the plasma because the net current to the floating probe must be zero, therefore, further collection of electrons is retarded and ion collection is

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enhanced [14]. This is why the floating potential is less than the plasma potential, which is defined as the potential of the plasma with respect to the walls of the device at a given location in the plasma and is generally a few volts positive with respect to the walls. This is because the swifter electrons tend to escape to the walls first, leaving the plasma with a slight excess of positive space charge [15].

The bulk of the plasma is “quasineutral” where electron and ion densities are the same, and the potential difference between the bulk of the plasma and the wall is concentrated in a thin layer or sheath near the wall [16]. The gradient of the plasma potential determines the electric field that is responsible for energizing the electrons, which maintain the discharge through ionization [8].

In this work, the electrical of dc glow discharge plasma were determined under different operation conditions of a dc sputtering system. The Langmuir probe diagnostics of the plasma and the values of plasma parameters, such as electron and ion temperatures and densities, were determined.

2. Experimental Part

A closed-field unbalanced magnetron sputtering system was employed. The electrodes were connected to a DC power supply to provide the electrical power required for discharge. The lower electrode (anode) could be move vertically with respect to the fixed upper electrode (cathode) to adjust the separation of the two electrodes from 1 to 8 cm.

Pure argon gas was used to produce the discharge plasma. A DC power supply up to 5 kV was used for electrical discharge between the electrodes and both breakdown voltage (up to 1 kV) and discharge current (up to 100 mA) were monitored by two digital voltmeter and ammeter, respectively. A current limiting resistor of 6.75 kW was connected in series to the discharge circuit in order to control the current flowing in the circuit. The discharge chamber was evacuated by a two-stage rotary pump and the vacuum inside chamber was measured by Pirani gauge connected to a vacuum controller. Argon gas was supplied to the chamber through a fine-controlled needle valve (0-160 ccm) to control the gas pressure inside the chamber.

3. Results and Discussion

Figure (1) explains the effect of variation in working pressure on the current-voltage characteristics of Langmuir probe diagnostics in unmagnetized glow-discharge plasma. As shown, increasing working gas pressure results in measuring higher probe current due to the increasing density of neutral gas atoms those subjected to collisions with the available charged particle and hence producing much more charged particles those composing the drained current. However, the behaviors of these characteristics are identical with upward shift at higher pressures, as mentioned above.

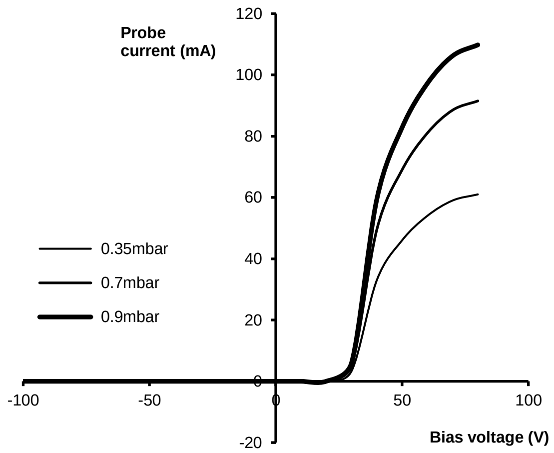

Fig. (1) The effect of variation in working pressure on the current-voltage characteristics of Langmuir probe diagnostics in unmagnetized glow-discharge plasma

In order to introduce the effects of using magnetrons on the parameters of plasma, the Langmuir probe measurements were performed when only one magnetron used at the cathode and when dual magnetrons used and then compared the obtained results to those obtained when no magnetron used, as shown in Fig. (6).

It is clear that using only one magnetron at the cathode caused to decrease the drained current by the probe by about 12%. This decrease may be attributed to the role of this magnetron in trapping a fraction of the electrons in discharge volume near the cathode to increase the ionization rate of the neutral gas atoms and hence preventing the probe from collecting more electrons.

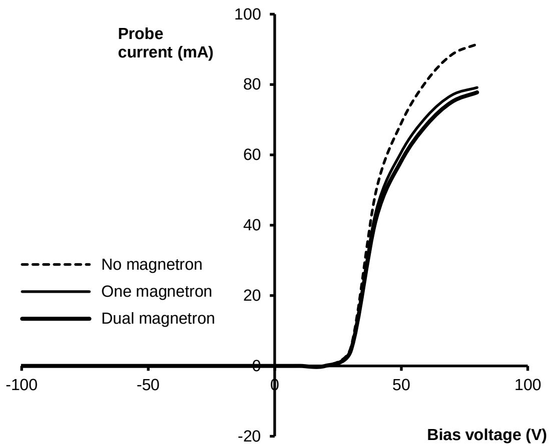

Fig. (6) Current-voltage characteristics of Langmuir probe diagnostics in glow-discharge plasma at three different cases (no magnetron, using one magnetron at the cathode, and using dual magnetrons)

Table (1) Effect of using magnetrons on the plasma parameters

	No magnetron	One magnetron	Dual magnetrons
Electron temperature (eV)	4.856	4.8711	4.8504
Electron density ($x10^{21}m^{-3}$)	1.329	1.148	1.130
Ion temperature (eV)	0.889-1.192	0.888-1.189	0.864-1.159
Ion density ($x10^{21}m^{-3}$)	1.329	1.148	1.130

4. Conclusions

From the results obtained in this work, the effect of the proposed configuration of closed-field unbalanced dual magnetrons on the electrical parameters of the discharge plasma was introduced. This configuration of magnetrons caused to increase the ionization process by confining the charged particles (especially electrons) near the electrodes and hence the number of collisions of these particle with the neutral atoms provided to the vacuum chamber was increased too. Using only one magnetron at the cathode caused to decrease the drained current by the probe by about 12%. This decrease may be attributed to the role of this magnetron in trapping a fraction of the electrons in discharge volume near the cathode to increase the ionization rate of the neutral gas atoms and hence preventing the probe from collecting more electrons. When dual magnetrons were used, the drained current by the probe was decreased by about 16% due to the roles of both magnetrons in trapping much more charged particles near the cathode and anode and hence reducing the number of particles passing the distance between the electrodes where the probe is placed.

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