The axial profile of plasma characteristics of cylindrical magnetron sputtering device

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Abstract

In the present work, a d.c. magnetron sputtering system was designed and fabricated. The chamber of this system was includes from two copper coaxial cylinders where the inner one used as a cathode (target) while the outer one used as the anode with Solenoid magnetic coil located on the outer cylinder (anode). The axial profile of magnetic field for various coil current (from 2A to 14 A) are shown. The plasma characteristics in the normal glow discharge region are diagnostics by the 2.2mm diameter Langmuir probe with different length along the cathode and located at different radial positions 1cm and 2cm from the cathode surface. The result of this work shows that, the electron energy distributions at different radial positions along the cathode surface are non-uniform. Therefore, the plasma characteristics at these radial positions along the cathode surface are non-uniform. So that, the ion bombardment along the cathode are non-uniform in this glow discharge region.

Keywords
Cylindrical magnetron
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توزيع الطولي لخصائص البلازما لمنظومة الترذيذ الماكنترون ذات الأبعاد الأسطوانية

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الخلاصة:

في هذا العمل تم تصميم وتكوين منظومة الترذيذ المستمر. ان حجرة هذه المنظومة تتكون من اسطوانتين نحاسيتين ذات محور مشترك حيث تكون تستخدم الاسطوانة الداخلية كقطب كاثود (هدف) أما الخارجية فتستخدم كقطب موجب حيث تم وضع ماف مغناطيسي على السطح الخارجي الاسطوانة الخارجية (الانود). ان توزيع الطولي للمجال المغناطيسي المتولد من الملف المغناطيسي لمختلف التيارات من 2 أمبير إلى 14 أمبير قد بينت. ان خصائص البلازما المتولدة في منطقة التوهج الاعتيادي قد تم تشخيصها باستخدام مختلف الأطوال من مجس لانجمور وعلى أبعاد مختلفة من سطح الكاثود وهي 1 سنتيمتر و 2 سنتيمتر. ان نتائج هذا البحث قد بينت بان توزيع طاقة الإلكترون على طول الكاثود لمختلف المواقع الشعاعية غير منتظمة. لذلك فان توزيع خصائص البلازما على طول الكاثود لمختلف المواقع الشعاعية غير منتظمة. لذا فان القصف الأيوني في منطقة التوهج هذه غير منتظم أيضا.

Introduction

Magnetron sputtering deposition techniques are widely applied both in industrial processes and in advanced material developments or treatment [1, 2]. The first paper on the magnetron was reported in 1960s, but the physical basis originates back to the later [3]. Since then, magnetrons have known a continuous development in various industrial fields, especially microelectronic, surface processing and widely used for thin film deposition [4]. As well as, the field of applications is sputter deposition, reactive sputter deposition, reactive ion etching, and coating of thin films. Taking the advantage of magnetic field, magnetron sputter operates at a low pressure and low voltage [3].

Basically magnetrons utilize an external magnetic field parallel to the cathode (target). The component of this field parallel to target traps energetic electrons in their travel from the cathode to the anode leading to an amplification of gas ionization and form high density plasma near the cathode surface [3,4].

Ions produced by these electrons are accelerated toward cathode surface with high energy. This bombardment of ions not only sputters out target material, but also produces secondary electrons that maintain discharge [5].

Experimental Set up

A d.c. cylindrical magnetron sputtering is designed and fabricated (as shown in figure (1)). The chamber of this system is consisting of two coaxial copper cylinders the inner one used as a cathode and the outer one used as anode. The diameters of the inner and outer cylinders are 1.9 cm and 9.8 cm respectively and 22cm length. The diagram of the chamber of this system is shown in figure (2).

Figure (1): Schematics of cylindrical magnetron device.

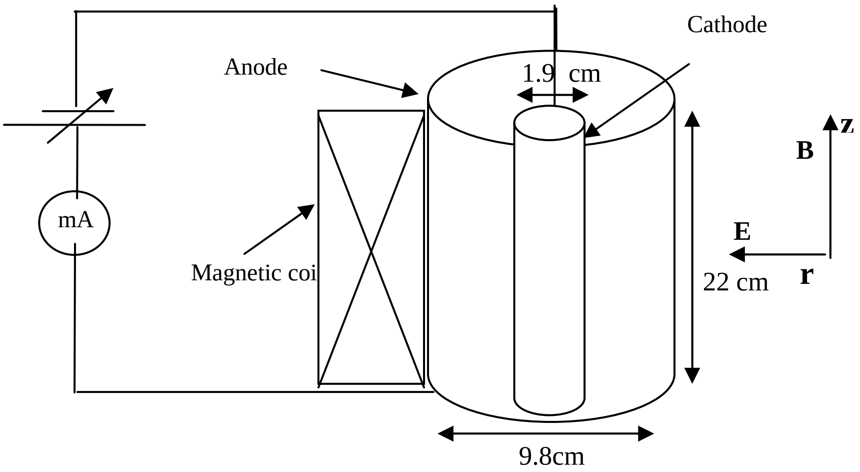

Figure (2): the diagram of the chamber of device.

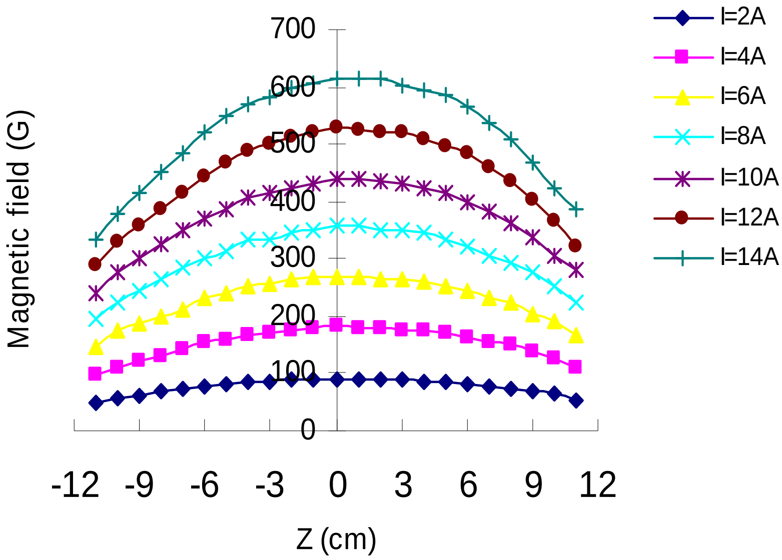

Figure (3): The magnetic field strength as a function of coil current.

The axial profile of the magnetic field strength of the coil that is located around the outer cylinder (anode) at different coil current is estimated in figure (3).

The working principle of this device is the glow discharge between the cathode and the anode (vacuum vessel). Where the discharge gas used in this device is the argon gas (99.998% purity) at pressure of $4x10^{-4}$mbar. The normal mode of the glow discharge was produced when a constant potential about 2.4kV was applied between the two coaxial electrodes. The chamber of this device was clean by using the glow discharge cleaning method.

Axial Profiles of Plasma Characteristics

This section investigates the effect of the magnetic field strength on the axial profiles of the plasma characteristics along the cathode surface at radial positions 1cm and 2cm from the cathode surface. The discharge characteristics are diagnosed using cylindrical Langmuir probes of different lengths. Where the tungsten probe tip had a diameter of 2.2mm and length 4mm. These probes are situated halfway up the cylinder axis oriented parallel to the cathode.

From the experimental data of I-V curve of these probes, we note that there are two Maxwellian electron groups with different energies, cold and hot electrons with temperatures

T_{ec} and T_{he}, respectively. Figure (4) illustrates the axial profile of hot electron temperature at different radial positions. It should be remarked that in the absence of magnetic field (I_{coil}=0A), the axial behavior shows non-homogeneous distribution along the cathode surface at both radial positions. When the coil current increases to 4A, the axial behavior shows that decreases along the cathode surface due to the collisions with argon gas atoms in both radial positions. When the coil current increases to 6A, the axial behavior shows that: (i) at a radial positions 1cm, the hot electron temperature decreases to become zero along the upper half of the cathode except at Z=7cm, (ii) at radial distance 2cm, the hot electron temperature becomes zero at the cathode center and increases slightly toward the cathode end. Consequently, these facts verify that the cathode sputtering along the cathode is non-homogeneous in this glow region.

The effect of the magnetic field strength on the axial behavior of cold electron temperature for different radial positions is shown in figure (5). It can be seen that when there is no magnetic field, the axial profile shows non-homogenous distribution along the cathode surface. When the coil current increases, the cold electron temperature behavior shows further increase at Z=3cm and cathode end than the other distances along the upper half of the cathode. This behavior occurs in both radial positions.

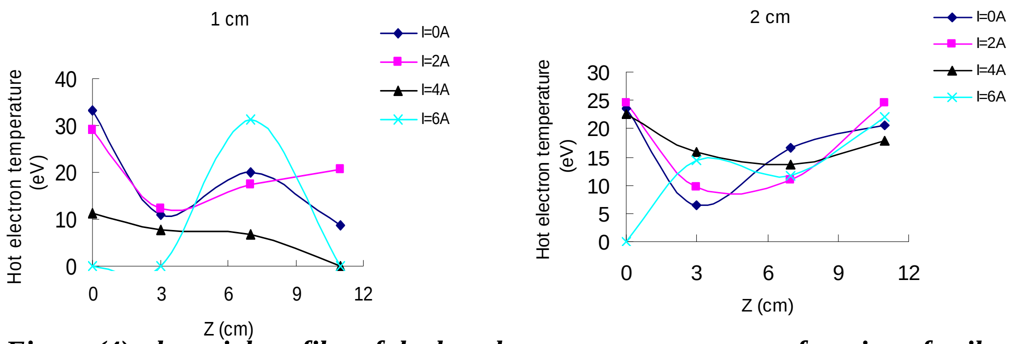

Figure (4): the axial profiles of the hot electron temperature as a function of coil current at different radial positions.

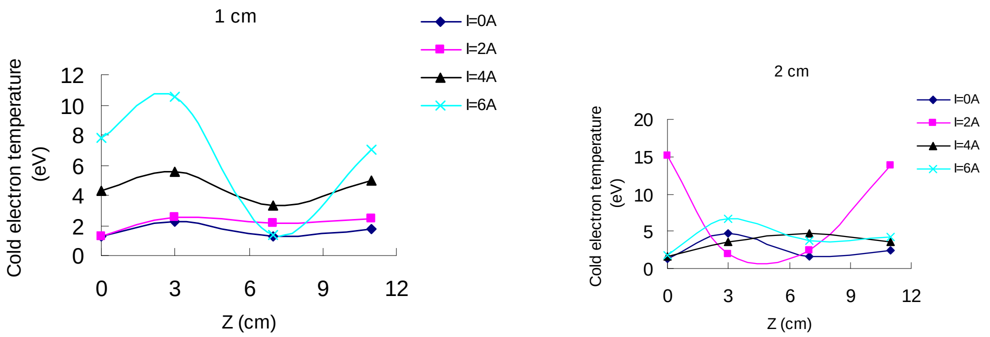

Figure (5): A typical axial behavior of cold electron temperature as a function of magnetic field strength at different radial positions.

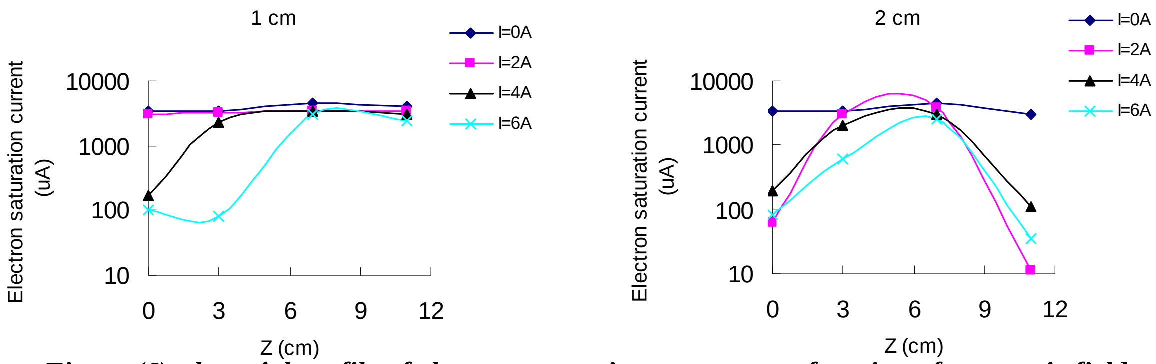

Figure (6): the axial profile of electron saturation current as a function of magnetic field strengths at different radial positions.

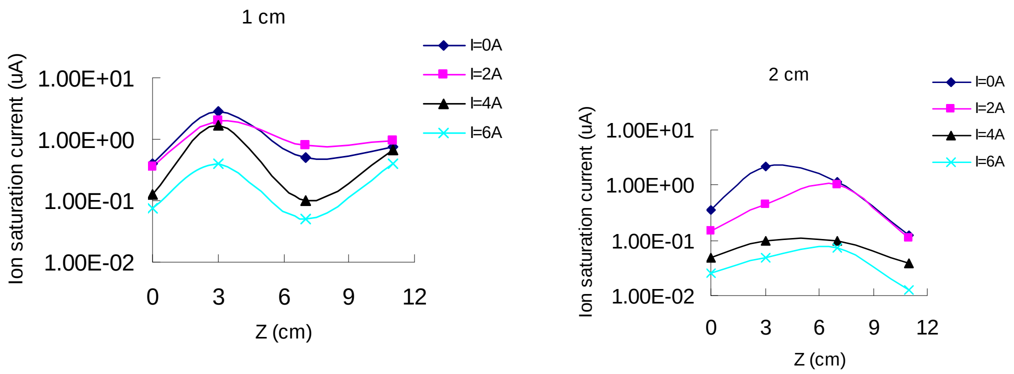

Figure (7): The axial profile of ion saturation current as a function of magnetic field strengths at different radial positions.

Since the temperatures of both electron groups are non-homogenous, the electron and ion saturation currents are non-homogenous along the cathode surface (see figures (6) and (7)).

The hot and cold electron densities, n_{eh} and n_{ex}, respectively, are found from each component using [6]:

$$n_{e c,h} = \frac{4 I_{es}}{eA_{probe} \sqrt{kT_e / 2\pi m_e}} \quad (1)$$

Here T_e is the electron temperature, I_{es} gives the electron saturation current, A_{probe} the probe area, and m_e is the electron mass, k is Boltzmann constant. The results of this equation are shown in figures (8) and (9).

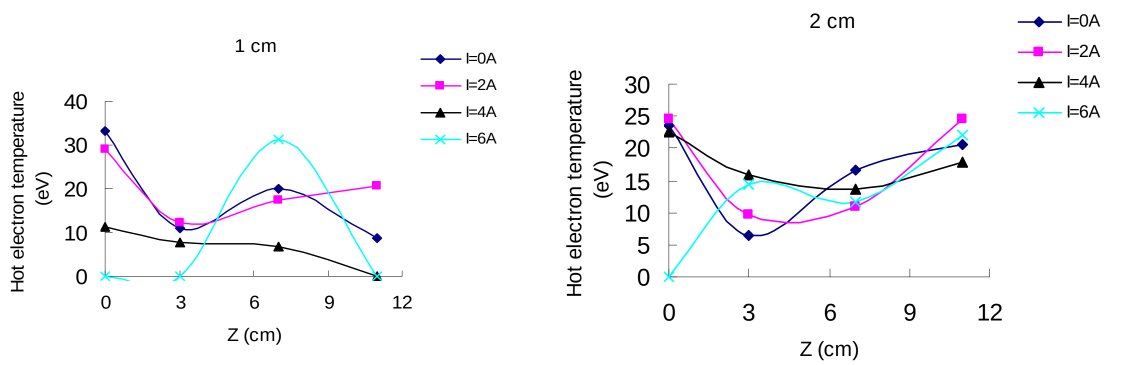

Figure (8): The axial profile of hot electron temperature as a function coil currents at [illegible] posi

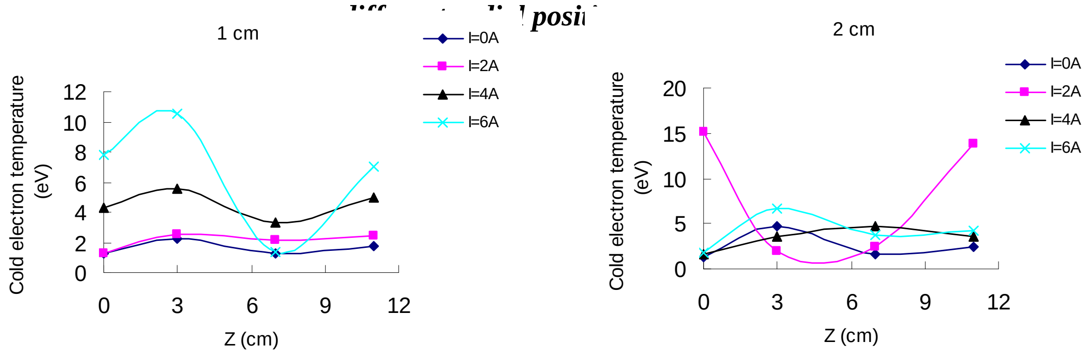

Figure (9): The axial profile of cold electron temperature as a function of coil current at different radial positions.

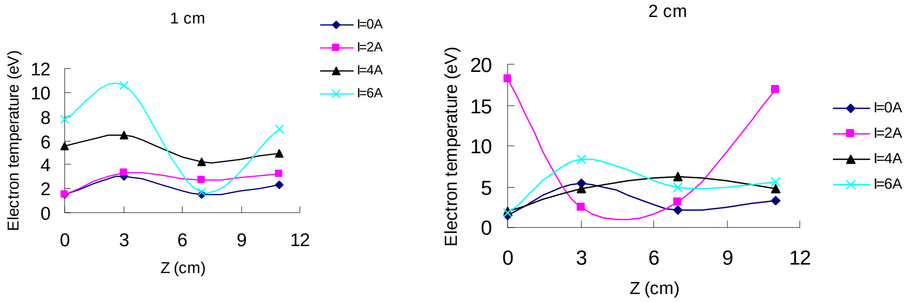

Figure (10): The axial profile of electron temperature versus coil current at different radial positions.

One should observe from figures (8) and (9) that the densities of the two electron groups are non-homogenous in the present and absence of magnetic field that associated with coil current. This behavior is observed in both radial positions towards the plasma center.

In the present of two electron groups which have different temperatures, the total electron temperature is evaluated as [7]:

$$\frac{1}{T_e} = \left(\frac{n_{ec}}{n_e}\right)\frac{1}{T_{ec}} + \left(\frac{n_{eh}}{n_e}\right)\frac{1}{T_{eh}} \qquad (2)$$

The results of this equation are plotted in figure (10). It is observed from this figure that the electron temperature distribution along the cathode surface is non-homogenous in the absence or present the magnetic field. As well as, this behavior occurs in both radial positions.

The ion density is evaluated from [7]:

$$n_i = \frac{I_{is}}{0.6eA_{probe}\sqrt{kT_e/M}} \qquad (3)$$

where M is ion mass. After substituting the experimental data of T_e (from figure (10)) and I_{is} (from figure (7)), the axial behavior of ion density along the upper half of the cathode surface at different radial positions for different coil current is illustrated in figure (11). The qualitative behavior of the figure shows that, since the electron temperature distribution are non-homogenous, so that the axial profile of ion density are non-homogenous too.

In addition to the above parameters, the axial behavior of plasma potential as a function of coil currents is determined from the knee of the curves of the logarithm of probe current versus probe voltage. Figure (12) illustrates the axial behavior of plasma potential versus coil currents at different radial positions. It should be pointed out from this figure that when I_{coil}=0A, the plasma potential is reduced from the maximum value in the cathode center to a minimum value at Z=3cm before to starts increase towards the cathode end. This behavior can be seen at both radial positions. When the magnetic field increases (by increasing coil current), the axial behaviors of V_p shows the same behavior to that in the absence of the magnetic field but the plasma potential is reduced further along the cathode surface except at the cathode end where an increase is observed in plasma potential with the increase of the magnetic field strength. This behavior can be seen at both radial positions.

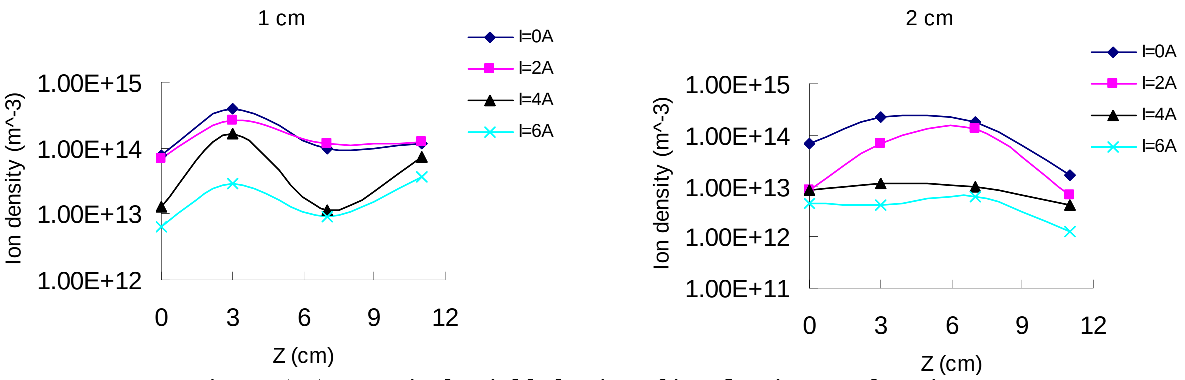

Figure (11): A typical axial behavior of ion density as a function of coil current for different redial positions.

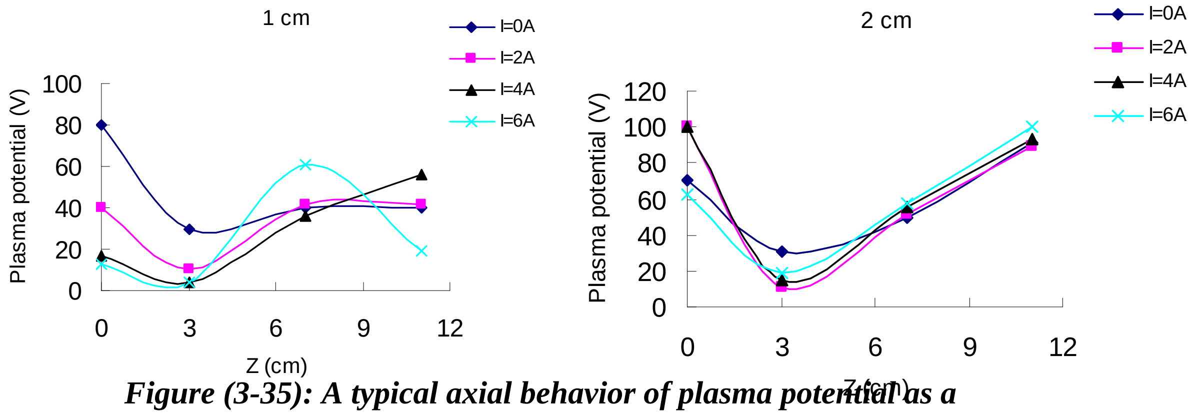

Figure (3-35): A typical axial behavior of plasma potential as a function of coil current for different radial positions.

Conclusion:

The results of this work estimated that: there are two electron Maxwellian groups with different energies present in the normal glow discharge region. The distribution of electron energy is non-uniform along the cathode surface. So that, the plasma characteristics found are non-uniform along the cathode at these radial distances. Consequently, it can be concluded that the ion bombardment is non-uniform along the cathode surface in the normal glow discharge. Therefore, the normal glow discharge region are not suitable in sputtering process.

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