Design and fabrication of a semi industrial cylindrical magnetron discharge

J. Payamarar*
Plasma Physics Research center, Science and Research Branch, Islamic Azad University, Tehran, Iran
K. Yasserian
Physics Department, Shahed University, Tehran, Iran
M. Ghoranneviss
Plasma Physics Research center, Science and Research Branch, Islamic Azad University, Tehran, Iran

Abstract
A semi industrial cylindrical magnetron discharge is designed and fabricated and experimental results which we are going to discuss in this paper are reported. This system which usually called CMD contains of two coaxial metallic cylinders with different diameters, serving as the cathode and the anode. In post magnetron mode the inner one is cathode and the other is anode. Two magnetic coils are placed around the outside of the anode and inside the cathode. The working gas in this investigation is Argon. By this system, copper thin films are sputtered at different pressures and then are analyzed by different methods and finally the dependence of thickness of thin films on pressure is obtained.

Keywords: Discharge, Magnetron, Sputtering, Thickness of thin film, XRD, AFM

1. Introduction
Low pressure discharges, particularly those in magnetron configuration, are used in plasma processing, surface etching and thin film deposition. Due to the wide applicability of this plasma source to various field of industry, magnetron sources in various shapes have been developed. Two types of magnetron sources, the cylindrical and planar types of magnetrons, are the most popular. A distinction feature of the magnetron discharge is the presence of an especially designed magnetic field that enables denser plasma to be achieved as compared with other types of glow discharges.

The magnetic field in this plasma sources plays an important role in trapping energetic electrons so that the high ionization and sputtering rates are achieved even at low pressures. Typically, in many industrial devices the maximum B-field strength parallel to the target is between 0.02 and 0.1 Tesla. Trapped electrons in this system have long path length and

* Corresponding author

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therefore an increased probability on ionization of the background gas. Magnetized electrons (i.e. those with larmor radii \( r_L \) less than scale of the plasma) in this confined plasma, and also those liberated directly from the target (through ion bombardment) will therefore experience an \( E \times B \) drift. Since the plasma ions are massive (the \( \text{Ar}^+ \) ion to electron mass, \( \frac{M_i}{M_e} \) is \( 40 \times 1835 \)), their larmor radii are typically greater than the dimensions of the plasma.

The probability of ionization relates to the pressure and therefore this parameter is important in operation mechanism. Furthermore the dimensions of the system can affect the mechanism.

The quality of film deposition in magnetron sputtering system depends on the energy of sputtered atoms reaching the substrate. Therefore to obtain a dense film, the distance between the target and the substrate has to be about equal to or less than the mean free path of sputtered atoms to prevent a significant slowdown of sputtered atoms via collisions with the background gas. Taking into account that the mean free path of ions is of order of the mean free path of sputtered atoms (because the ions mainly collide with neutrals) we will choose the pressure in the range of mTorr and locate the substrates on the anode.

Basic scientific concern is focused on film formation processes in order to obtain the insight into mechanism leading to special structural properties. It is however not only the film structure, but also the thickness which determines the physical properties of the film. The challenges in the thin film research thus lies in the optimization of the thin film properties of required thickness under various deposition techniques to tailor for specific application.

Copper (Cu) thin films with sub-nano or sub-micro geometric and microstructural dimensions are ubiquitous of modern technology, with uses spanning the range from the catalysis to microelectronic device. Due to the noticeable advantage as interconnection candidate in terms of low electrical resistivity, good electromigration resistance and high melting temperature, the study of Cu thin films has been generally centered on the electrical and micro structural properties of the Cu films deposited on various substrates.

In this paper we have designed and fabricated a D.C cylindrical magnetron sputtering in semi industrial scale and have coated copper thin films. By this customized CMD, these thin films are analyzed to obtaining the optimum condition.

2. Experimental setup

The experiment device consists of two coaxial stainless steel cylinders. The outer one (anode) is 43 cm in diameter and 70 cm in length. The inner one (cathode) is 23 cm in diameter and 60 cm in length. The schematic of the system is shown in Fig. 1.

To prevent the end loss of energetic electrons the cathode is edged as shown in Fig1. This edges lead to form a denser plasma near the cathode. Due to the bombardment of energetic ions during the operation, the temperature of the cathode increases. Therefore we design a cooling system for the cathode. Two pipes of water lead into the cathode. To insulating we use two pieces of Teflon between cathode and anode. Two magnetic fields are designed and fabricated to confining the plasma. One of these coils is placed in the cathode. The length of this coil (internal coil) is same to the length of cathode and is 10 cm in diameter. This coil cause to modifying the magnetic field line in front of the cathode. However the outer one coil (external coil) is responsible to generating magnetic field to magnetized electrons. The length of this coil is same to the length of the cathode and 45 cm in diameter and have 4500 turns and we apply a current up to 10 A. This coil is similar to magnetic mirror. The magnitude of its magnetic field can reach up to 600 G. The region between the cathode and the anode is
vacuumed by means of a rotary and a turbo-molecular pump up to $6 \times 10^{-6}$ torr. The system which fabricated is shown in fig 2.

The base pressure of the chamber is $6 \times 10^{-6}$ torr and working argon pressure is about a few mTorr.

3. Results

The pressure of the chamber increased by argon gas. The argon gas injected to chamber at a flux equal to $20 \frac{lit}{min}$. The surface of the cathode is covered by a copper sheet. The substrates were glass slides. These glasses located on the anode. A magnetic field applies to the plasma by means of two magnetic coils.

The left – hand of Paschen curve is obtained as shown in fig 3. It can be seen that by increasing the pressure the breakdown voltage decrease. The power applies to the cathode and anode was 800 watt. The various copper thin films were sputtered and coated at different pressures. The deposition time was 15 min.

The dependence of thickness of thin films on pressure is presented in Fig.4. At low pressure the collision frequency is negligible and therefore the degree of ionization is low too. At high pressure the collisions become important and therefore the current increases. However this enhancement of current is not necessary condition to increasing the sputtering yield. Because at high pressure the sputtered atoms which liberated from the cathode can not be reached to the substrate.

The dependence of structure of thin films on deposition time is shown in Fig .5. From the intensity of different peaks, Cu film with higher thickness exhibits enhanced crystalline nature than thinner film with preferential orientation of (111) observed at $2\theta =43^\circ$. Also, from the XRD spectra, the film thickness was observed to have no significant influence on the preferred orientation for the D.C magnetron sputter-deposited Cu films. The increasing film thickness promotes the preferred (111) orientation but not (200) orientation because Cu has the face centered cubic (FCC) crystal structure and for this structure (111) face has the lowest surface energy.

The influence of pressure on the surface morphology was examined by the atomic force microscopy (AFM) as shown in Fig .6. This figure shows the feature of structural change and grain growth for Cu films with different pressure ranging from 5 to 20 m torr. It was observed that the AFM micrograph of film which coated at 5 mTorr deposited at room temperature exhibit uniform surface, indicating its amorphous like behaviour. Fig 6-b shows the AFM micrograph for Cu film deposited at 10 m Torr. In this micrograph grain feature protruding from the film surface developed in Cu film. The grains are smaller less definable producing smoother surface in micrograph of Fig.6a and Fig 6c and larger in fig 6b. This can be explaining by the film structural evolution with thickness.

The transformation from the uniform smooth amorphous – like film structure to the fine grain features, followed by the growth in the grain for Cu films with increasing film thickness as demonstrated in Fig .3 can be attributed to the surface energy minimizing during the growth process to achieve thermodynamic equilibrium.

4. Conclusion

In this work we have designed and fabricated a D.C cylindrical magnetron discharge in semi industrial scale and experimental results were reported. Firstly the left – hand of Paschen Curve was obtained. The substrates were located on the anode and several Cu thin films were coated at different pressures and at different deposition time at room temperature. We have
qualitatively evaluated the influence of pressure on the sputtering rate of a customized cylindrical magnetron sputtering. The dependence of thickness of thin films on pressure has investigated. It was shown that when the pressure is equal to 10 m Torr, sputtering rate is maximum. The structures of these thin films were investigated by X – Ray – Diffraction. The XRD pattern shows that the at higher deposition time the nature of crystalline increases. The surface morphological study with AFM generally shows the enhanced size of grain of Cu films at \( P = 10 \) m Torr. All the designing, fabricating and experiments have performed in plasma physics research centre, Islamic Azad University.

5. Figures

Fig1. Schematic of fabricated device.

Fig2. The photograph of the experimental setup.
Fig3. The breakdown voltage versus pressure when magnitude of magnetic coil is 100 G.

Fig4. The dependence of thickness of thin films on pressures.
Fig 5. The dependence of structure of thin films on deposition time. a) $t = 5$ min, b) $t = 10$ min and c) $t = 15$ min.
Fig6. The dependence of surface morphology of thin film on pressure. A( p = 5 mTorr, b) p = 10 mTorr and c) p = 20 mTorr . In this experiment the deposition time = 15 min.

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