

Simulation of plasma properties in magnetron sputtering with Kr gas

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ABSTRACT

The electron, ions, and total density of the plasma generated in the magnetron sputter system have been studied by using a simulation program. Our study was concentrated on taking the krypton Kr as a background gas for the system. The external magnetic field B, the temperature of the electrons T_e and ions T_i , voltage of plasma sheath V and the pressure P of Kr gas has been taken into account; The readings at four different times of simulation have been investigated, the times were: electron plasma period T, end of the ion flow, the time 280T, and the time 420T. The results have been plotted and discussed for the spatial profile of ions and electrons positions, the time profile for the total plasma density, three-dimensional spatial profile density of ions and electrons, and finally examining the behavior of voltage change of the plasma sheath with the spatial coordinates. The change of the properties of the plasma near the cathode has been noticed significantly as a result of the interaction of electrons with neutral Kr gas atoms and also taking into account the strength of applied magnetic field.

Keywords: Magnetron, sputter, OOPIC Pro, ionization, plasma, ion density, electron density, total plasma density, plasma simulation.

1. INTRODUCTION

Planar magnetron sputter is widely used as a plasma processing device. The field of application is sputter deposition, reactive sputter deposition, reactive ion etching, and coating of thin films [1], taking the advantage of magnetic field, magnetron sputter operates at both low pressure and low voltage.

The sputtering is a process whereby atoms of a solid target are ejected (or vaporized) due to the momentum transfer from an atomic-sized energetic bombarding particle impinging on the target surface. Sputtering is performed using gaseous ions from plasma that are then accelerated and directed toward the target [2].

Applied magnetic field confines energetic electrons near the cathode. These confined electrons ionize neutral gas and form high density plasma near the cathode surface. Ions produced by these electrons are accelerated toward the cathode surface with high energy. This bombardment of ions not only sputters out target materials, but also produces secondary electrons which maintain discharge [1].

The three most important parameters of this process are the homologous temperature, the ratio of the fluxes of bombarding ions and depositing atoms, and the energy of the bombarding ions [3].

The basic idea in magnetron is to plunge a substrate in plasma and apply high voltage to it; as a result, a high voltage sheath forms between plasma and substrate [4].

Many materials have been limited by low deposition rates, low ionization efficiency in the plasma, and high substrate heating effects. These limitations have been overcome by the introduction of magnetron sputtering [5].

In its simplest form, a magnetron discharge consists of a grounded vacuum chamber, filled with a gas (generally pure Ar), which contains a so-called target at cathode potential. This results in an electric field inside the plasma, accelerating the electrons away from the cathode, and positive ions towards it. A magnetic circuit is located behind the target, creating a magnetic field in the plasma. The electrons circulate around the magnetic field lines, and hence travel for a much longer time in the plasma than in normal, non-magnetized plasmas. This gives rise to a large amount of ionization, and therefore large ion fluxes towards the cathode, increasing the amount of sputtering, compared with non-magnetized plasmas. Due to the long path lengths of the electrons in the plasma, the pressure can be low, typically in the range 0.1–1 Pa [6].

Magnetron plasma configurations use magnetic field "to confine the electron path so that it remains close to the surface of the cathode. In this case, the cathode is the target material to be sputtered and acts as the negative terminal in that it provides an electron emitting surface. Some of the electrons emitted from the cathode are normal to the magnetic field lines. Due to the Lorentz force, these electrons will then spiral around the magnetic field lines. The gyrofrequency, or frequency of the spiraling motion, and gyroradius, or the radius of the spiral, will depend on the exact magnitude and direction of the magnetic field [2].

The dc magnetron discharge has been investigated in many fields like sputter deposition by use of energy resolved mass spectroscopy [7]. On the other hand, Belkind, et al [8] have analyzed pulsed dc magnetron plasmas during sputter deposition of Ti and TiO₂ thin films by using time-resolved optical emission spectroscopy.

There is another kind of magnetron sputter that is well known RF magnetron sputter. M. Hari Prasad Reddy ,A. Sreedhar and S. Uthanna have studied Structural, surface morphological and optical properties of nanocrystalline Cu₂O films prepared by RF magnetron sputtering [9].

Radio Frequency Magnetron Sputtering Technique has been employed to prepare metal oxide thin film of ZnO and CdO [10].

The aim of this study is to show the spatial and temporal variation of plasma ions and electrons density in term of simulation.

2. THE SYSTEM CONFIGURATION

The schematic geometry of the rectangular magnetron sputter used in our simulation is shown in Fig. 1. The simulation region is the square with L_x of 9 cm and L_y of 8 cm. Magnets are located behind the cathode. L_x is the distance between the anode at x=0 and the cathode at x=L_x. There is also a copper plate below the permanent magnets [1]

In our simulation of sputtering, Kr gas was used because it has lower potential energy than argon gas .It can provide plasma with higher level of ionization, with pressure 3mtorr and the voltage if the sheath has been taken to be 220V and assume that electron and ion temperature of plasma were 10 and 0.5 eV respectively. The region of simulation has dimension width=2μm and height=5μm.

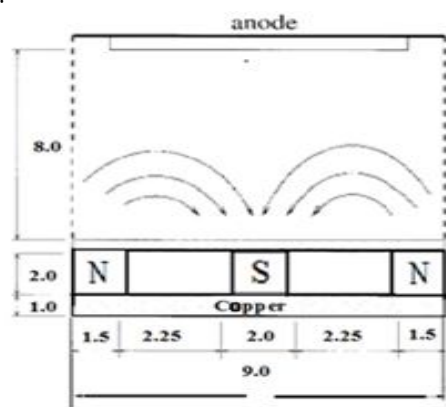


Figure 1 Schematic diagram of magnetron sputter used in the simulation (all dimensions are in cm)

3. RESULTS AND DISCUSSION

By using OOPIC Pro code program [11] for deposition with the information data above The results at different times of simulation were found as follows:-

3.1 At electron plasma period T

The first time was electron plasma period T which calculated from $T = \frac{2\pi m}{qB} = 0.714ns$, at this time we examined the properties of plasma.

Figure (2) shows the total density of plasma at early time of simulation, the electron plasma density is constant and equal to zero, but at t=0.4ns the electron density becomes high (10⁴ m⁻³) and will be fluctuate as sputtered points.

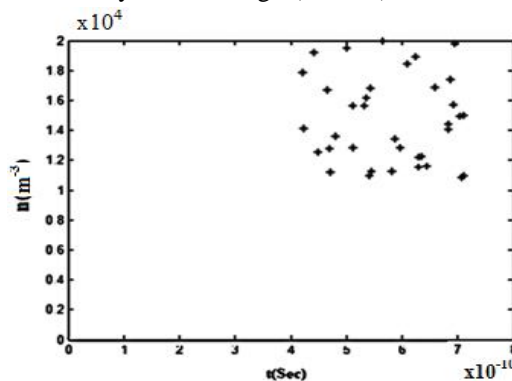


Figure 2 The total density of Plasma at t=0.714ns

The electrons near the cathode will be limited by applied magnetic field (500G) and these confined electrons ionize neutral atom gas (Kr gas) and form high density plasma near the cathode surface as shown in fig.(3) ,one can notice that at y=5μm near the cathode surface the ion density is high and varies according to the applied external magnetic field and decrease and dip as proceed to the anode surface.

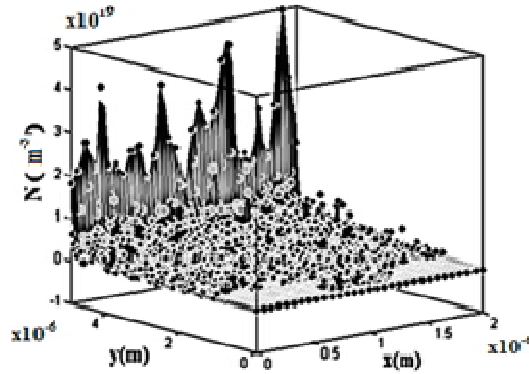


Figure 3 The ion density at $t=0.714\text{ns}$

Figure (4) represents spatial profile of potential of plasma in 3-D. As y increases the Φ decreases gradually and reaches minimum at the cathode surface while it increases also gradually toward the anode surface and reaches maximum 220V near the anode surface to make the anode positive charge to attract the electrons.

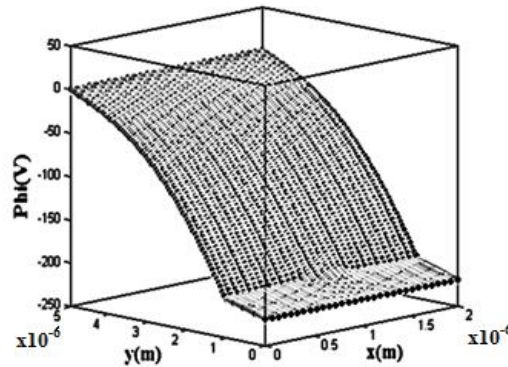


Figure 4 The Phi potential of Plasma at $t=0.714\text{ns}$

3.2 At steady state $t=56.4\text{ns}$

The steady state means there is no Additional ions emitted from the cathode to ionize neutral atoms of Kr gas; this time has been found to be 56.4ns from the simulation in program OOPIC Pro. The results are shown in figures (5-7).

In fig.(5) the spatial profile of e density has been plotted in 3d it increased rapidly at cathode surface as a result of bombardment of ions with neutral atoms of Kr gas.

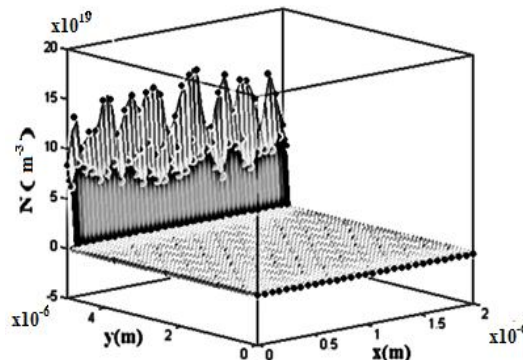


Figure 5 The electron density at steady state $t=56.45\text{ns}$

Figure (6) represents spatial profile of ions density, at cathode surface the ion density is maximum and leads to increase the total density of plasma at cathode surface.

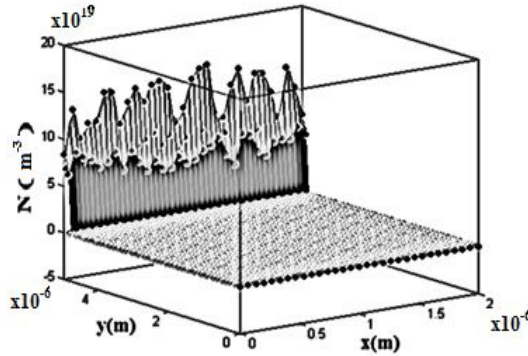


Figure 6 The ion density at steady state $t=56.45\text{ns}$

Figure (7) shows the potential of plasma in 3d versus the coordinates x and y . There is graduate fall of the potential from the cathode to the anode and at anode the potential is 220V and at cathode is zero.

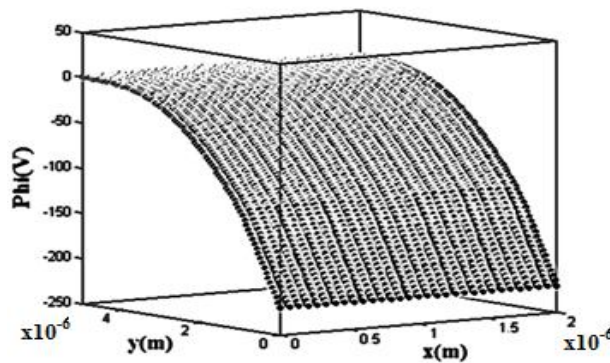


Figure 7 The Phi potential of Plasma at steady state $t=56.45\text{ns}$

3.3 At $t=200\text{ns}$

As the runtime of simulation increases, the properties of plasma vary, at $t=200\text{ns}$, Fig.(8) represents time profile of total density of plasma, between the interval (0-47ns) the density is zero, after $t=47\text{ns}$ the plasma density rises abruptly to the value $11 \times 10^7 \text{ m}^{-3}$ and then it falls sharply to the value zero and also rises to higher than before, and so on. The reason of increasing plasma density is the interaction of the electrons with neutral atoms of Kr gas near the cathode surface and ionizes it and resultant ions will bombard with cathode material to sputter its atoms and generating secondary electrons which maintain the ionization process.

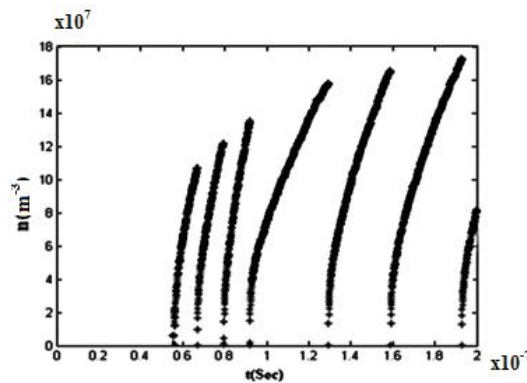


Figure 8 The total density of Plasma at $t=200\text{ns}$

Figure (9) shows the spatial profile of e density as mentioned previously, the magnetic field will trap electrons near the cathode surface and as a result the electron density will focus on the cathode surface at $y=5 \times 10^{-8}\text{m}$ and reach maximum where the magnetic field is maximum.

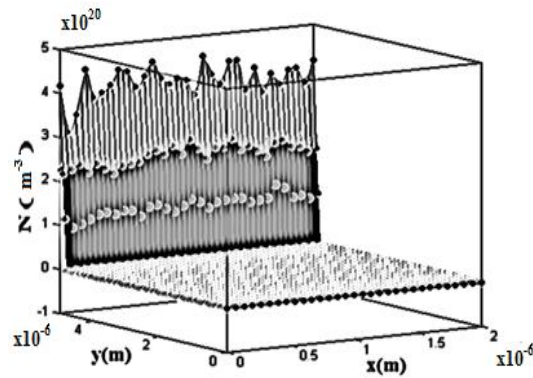


Figure 9 The electron density at t=200ns

Figure (10) represents the spatial profile of the ion density and for the same reason explained above it will be maximum near the cathode surface due to the ionization of neutral atoms of Kr gas by the confined electrons and also depends on the strength of magnetic field.

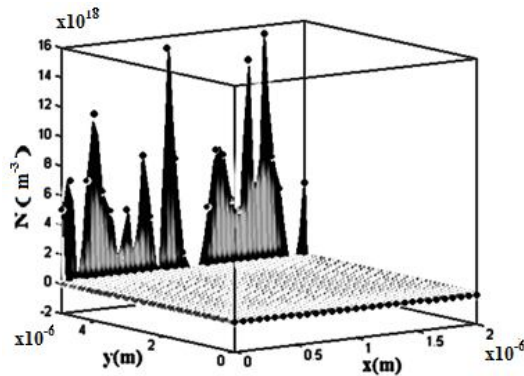


Figure 10 The ion density at t=200ns

In fig. (11), the Phi potential of plasma has been plotted with its spatial profile and indicates gradual fall from the cathode to the anode and reaches maximum at anode -220V.

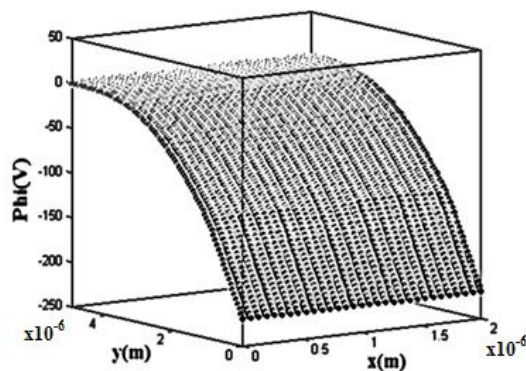


Figure 11 The Phi potential of Plasma at t=200ns

3.4 At t=300ns

Now, let us take final simulation measurement time and it equals to 420T where T as mentioned earlier is the electron plasma period. In fig.(12), the time profile of the total density of plasma and its interpolants were plotted.

It fluctuates up and down sharply versus the time of simulation. The sparky shape of simulation due to the ionization process which occurs near the cathode surface.

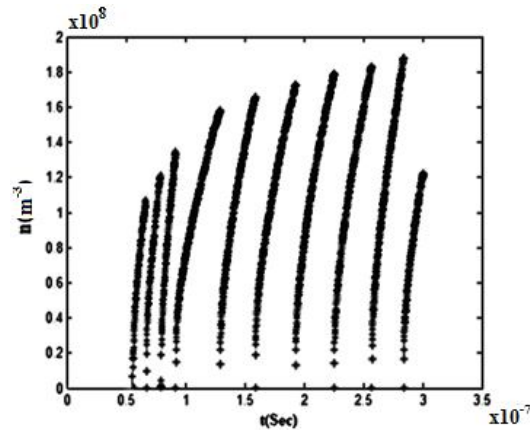


Figure 12 The total density of Plasma at $t=300\text{ns}$

Figure (13) represents the spatial profile of the electron density and also it shows large electron density at cathode surface due to the confinement of electrons by the applied external magnetic field.

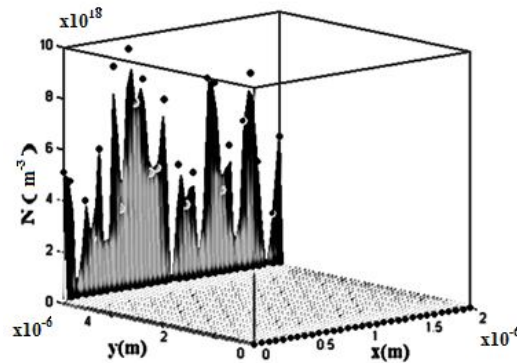


Figure 13 The electron density at $t=300\text{ns}$

This confinement will lead to more ionization of Kr gas neutral atoms and convert them to ions which also are in high density near the cathode surface as shown in Fig. (14).

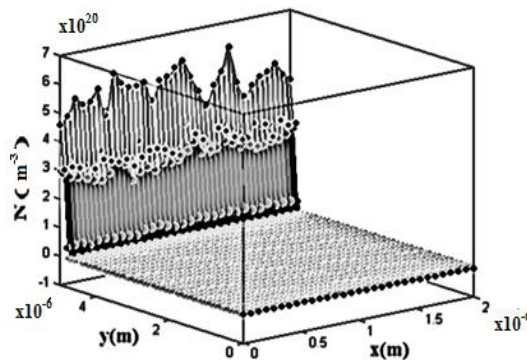


Figure 14 The ion density at $t=300\text{ns}$

Finally in fig. (15), the Phi potential of plasma has been drawn and reaches maximum value at anode surface -220V and it increases smoothly from 0 to -220V.

4. CONCLUSION

The ionization process near the cathode plays an important role to affect the plasma (electrons and ions) density and potential. The electrons confinement near the cathode will ionize the neutral atoms of Kr gas which leads to increase the ions density near the cathode. Therefore the total density of plasma will vary with time according to the ionization process and confinement of the electrons near the cathode. The Phi potential of plasma sheath varies as descent with the x and y axes from the cathode 0 to the anode 220V. Finally all the plasma parameters mentioned were studied with OOPIC Pro simulation program.

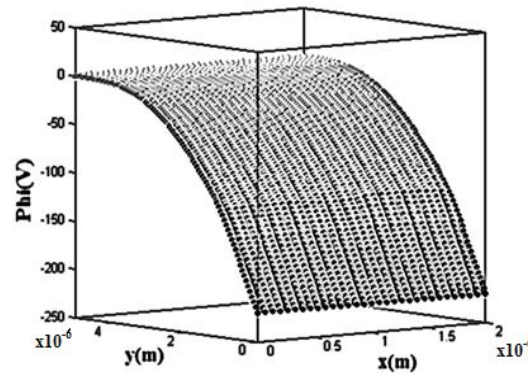


Figure 15 The Phi potential of Plasma at t=300ns

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