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Numerical Simulation of Glow Discharge Plasma in Anode Barrel

Yifei Zhu [1, 2], Xing Yu [1], Hui Shi [1], Lei Zhao [1], Haizhou Wang [1, *]
[1] Beijing Advanced Innovation Center for Materials Genome Engineering, Beijing Key Laboratory of Metal Materials Characterization, Central Iron and Steel Research Institute, Beijing 100081, China
[2] Material Digital R&D Center, China Iron & Steel Research Institute Group, Beijing 100081, China
*Corresponding Author.

Abstract:

Glow discharge cold plasma sputtering denudes the sample surface, so the plasma concentration near the sample surface directly affects the flatness of the pits on the denuded surface during glow discharge. In this paper, the plasma field in the Anode barrel of glow discharge device is studied by using commercial numerical simulation software COMSOL multiphysics to obtain the distribution of plasma, Firstly, the influence of different wall thickness on the plasma field is studied. It is obtained that the larger the wall thickness is, the higher the electron density is, but the distribution law is relatively consistent; Secondly, the plasma field under different pressures is studied. It is found that the higher the pressure is, the higher the electron density is, and the same distribution law changes little.

***Keywords**: Glow discharge, plasma, numerical simulation, electron density.*

I. INTRODUCTION

Glow discharge cold plasma sputtering belongs to a low-pressure gas discharge process [1,2]. The sample is placed on the excitation source as the cathode, the anode is grounded, and a certain voltage is applied between the two poles, so that the gas in the field is broken down and dissociated into positive ions and electrons to form plasma [3-5]. Under the action of electric field, positive ions accelerate to move towards the cathode, collide with the cathode, release secondary electrons and enter the plasma. The particles in the plasma collide to produce new positive ions and electrons. This process goes back and forth, and the sputtering process on the sample surface is formed in this way. The pit flatness of the sample surface depends on whether the plasma concentration near the sample surface is evenly distributed during the glow discharge [6-9]. Therefore, the mechanism of glow discharge can be revealed by studying the glow discharge process with the help of commercial numerical simulation software COMSOL Multiphysics, and the optimal sample preparation scheme can be found through variable parameter research.

II. NUMERICAL MODEL

Based on the finite element method, COMSOL Multiphysics realizes the simulation of real physical phenomena by solving partial differential equations (single field simulation) or solving partial differential equations (multi field simulation). In the calculation of electrostatic field, the potential of plasma is calculated by Poisson equation, and the charge is calculated by the number density of electrons and other charged particles. Because particles and electrons have different transmission time scales, surface charges can be accumulated on the dielectric surface, which is used as the boundary condition of the electrostatic physical field interface. Heavy matter transport (non-electronic matter) mainly solves the mixture average diffusion model (an improved form of Maxwell Stefan equation), and adopts an integrated reaction manager to track all electron collision reactions, bulk reactions, surface reactions and substances. In the surface reaction, the flow of each heavy substance on the reaction wall is automatically calculated based on the surface reaction and drift [10].

TABLE 1: Argon reaction equation

REACTION	FORMULA	TYPE	$\Delta\varepsilon(eV)$
1	$e+Ar=>e+Ar$	Momentum	0
2	$e+Ar=>e+Ar^{*}$	Excitation	11.56
3	$e+Ar=>e+e+Ar^{+}$	Ionization	15.80
4	$e+Ar^{*}=>e+Ar$	Superelastic	-11.56
5	$e+Ar^{*}=>e+e+Ar^{+}$	Ionization	4.24
6	$Ar^{*}+Ar^{*}=>e+Ar+Ar^{+}$	Penning ionization	0
7	$Ar^{*}+Ar=>Ar+Ar$	Quenching	0

The behavior of plasma largely depends on plasma chemistry, which may be quite complex. Among them, argon is the simplest one, involving seven reactions (as shown in Table 1) and substances in 4.

In the calculation, the discretization method is the finite element scheme, and the face center point volume discretization scheme of Schefter-Gimmel upwind scheme can be used.

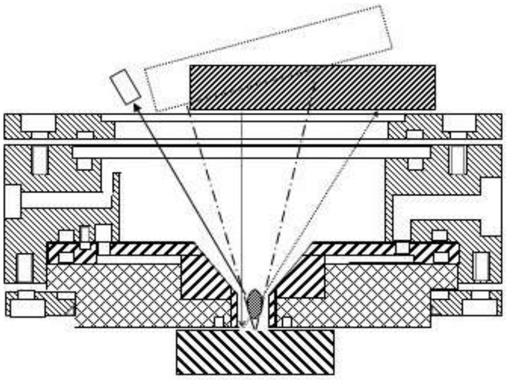

Figure 1 light source assembly

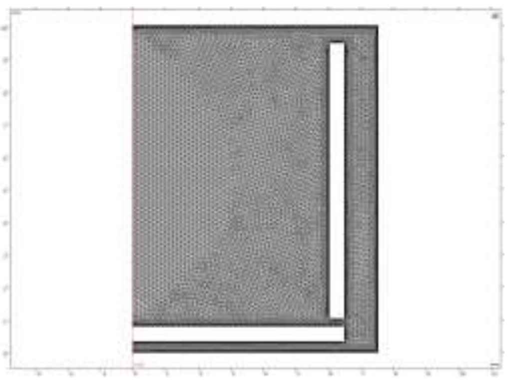

Figure 2 simulation model and grid

According to the light source assembly Figure. 1, the structure in the anode barrel can be simplified. Since the structure outside the anode barrel is not the area we care about, the redundant structure can be removed and only the area generated by the glow of the anode barrel can be retained. At the same time, the internal structure of the anode barrel is axisymmetric, so the axisymmetric boundary can be set with two-dimensional graphics for simulation calculation. The simplified model is shown in Figure. 2, The model is a physical model used for plasma numerical simulation. Through the mesh independence analysis, the mesh of the model is determined, as shown in Figure. 2. The total number of meshes is 100000 surface elements. In the calculation of example 1 (hereinafter collectively referred to as example 1), the reaction pressure in the anode barrel is set to be 100Pa, the DC voltage is 1000V, the boundary of the hollowed-out part of the lower end is the surface of the material sample, that is, the cathode, and the surface of the hollowed-out area on the side of the anode barrel is the anode.

III. ANALYSIS OF CALCULATION RESULTS

3.1 Analysis of basic model results

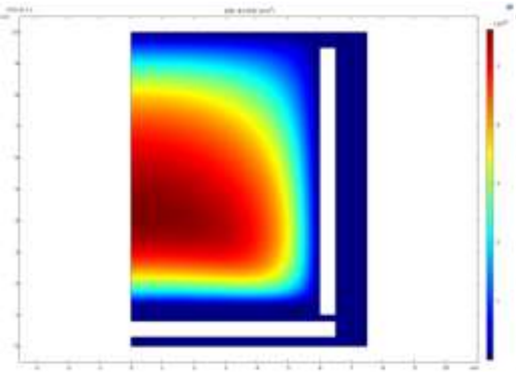

Figure 3 Electron density distribution nephogram

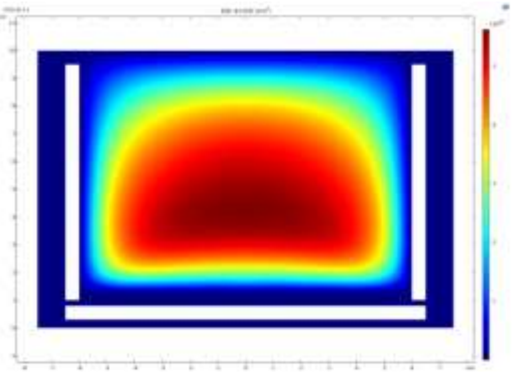

Figure 4 Image electron density distribution cloud

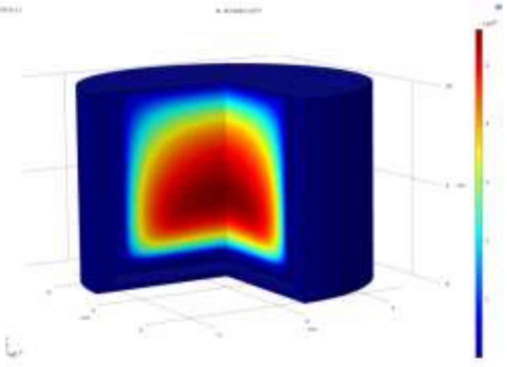

Figure 5. 3D electron density distribution cloud map

Figure 3~5 are the distribution nephogram of various forms of electron density in example 1, including cross-sectional electron density distribution nephogram, mirror image electron density distribution nephogram and three-dimensional electron density distribution nephogram. It can be found that the center of the glow generation area in the Anode barrel is close to the surface of the cathode sample, and the electron density concentration in the center area is the highest, reaching 5.5 * 1018 / m3. The electron concentration decreases significantly along the center point, this distribution law basically conforms to the plasma field characteristics of glow discharge, and the calculation is reasonable.

Figure 6 shows the position distribution of the radial line, and Figure 7 is the electron density curve at the position of the radial line. It can be found from the figure that the electron density is zero when it is closest to the sample surface. With the increase of height, the density increases and reaches the maximum at 0.52mm. When the height continues to increase, the density decreases. In subsequent research, if you want to improve the etching speed of the sample surface, some parameters can be changed to make the maximum electron density close to the sample surface.

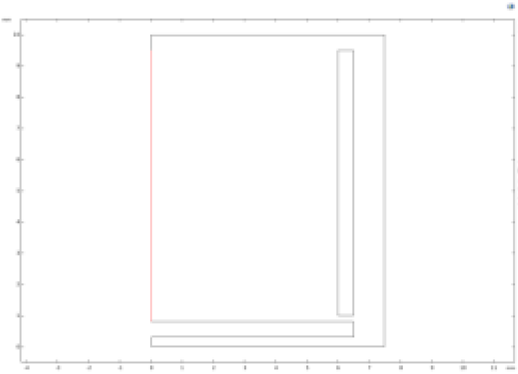

Figure 6 Radial line position Figure

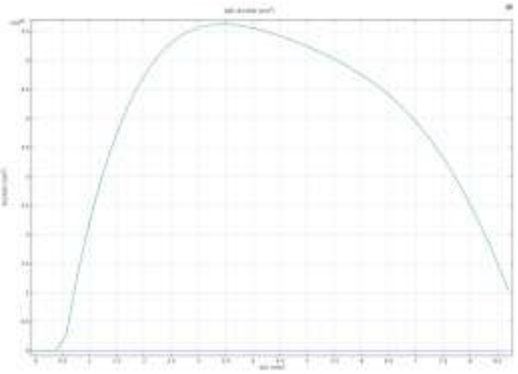

Figure 7 Radial position electron density curve

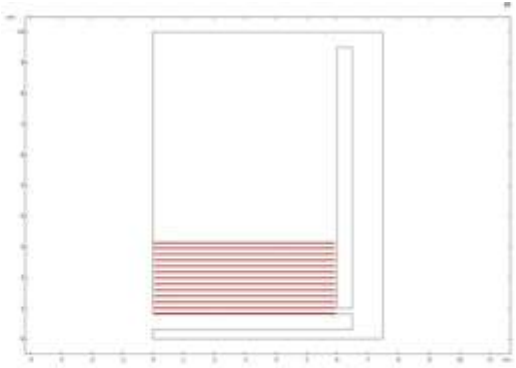

Figure.8 Position diagram

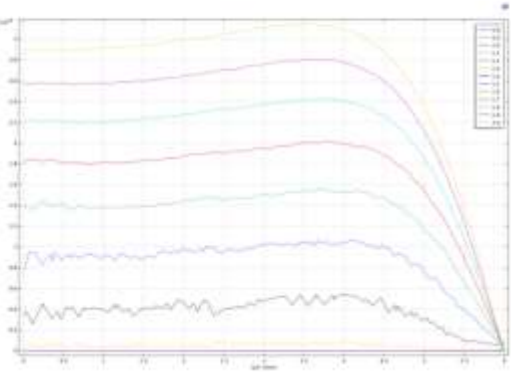

Figure.9 Curve diagram of electron density at different heights

Figure 8 is the position distribution diagram of different height lines. The first line is on the sample surface, increasing the height by 0.2mm in turn. Figure 9 is the electron density distribution curve at different heights. It can be seen from the figure that the electron density increases with the increase of height; At the same height, the electron density near the axial center is relatively stable, and when it extends outward to the edge, the electron density decreases sharply. Therefore, in practice, the sputtering

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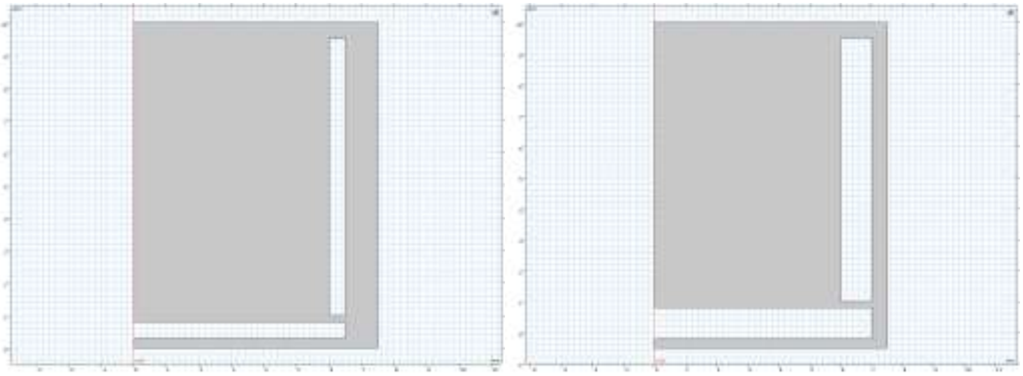
pit on the sample surface is always flat in the middle area, while the sputtering effect on the outer edge is poor, and the sputtering pit will be shallow. Therefore, in the subsequent research, some parameter conditions can be changed to make the electron density at the same height tend to be constant, which will help to improve the depth uniformity of the sputtering pit.

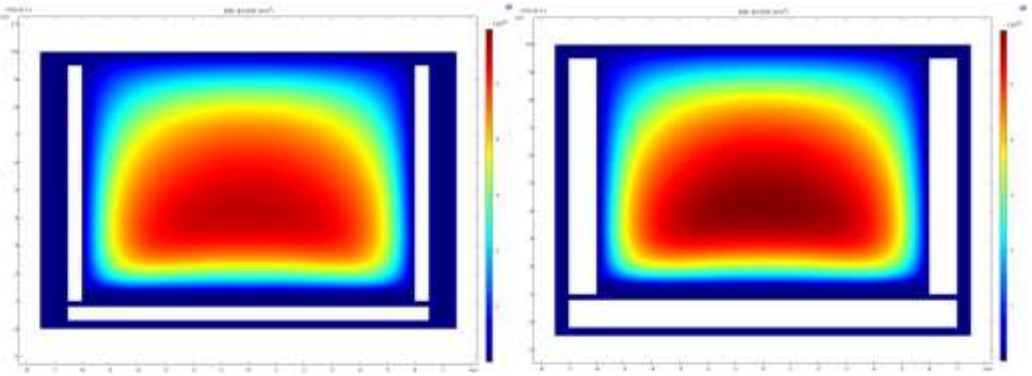
3.2. Simulation results of different wall thickness

Figure 10(a) and Figure 10(b) show the calculation models of sample and Anode barrel wall thickness of 0.5mm and 1mm respectively. From the electron density distribution nephogram of different thicknesses in Figure 11(a) and Figure 11(b), it can be significantly found that the electron density of example 1 and example 2 is different. With the increase of thickness, the electron density increases, but the distribution law is basically the same. Similarly, the electron density in the lower area of the geometric center is relatively large, which decreases from the outside of the highest concentration to zero at the edge.



(a) Wall thickness is 0.5mm (b) Wall thickness is 1mm

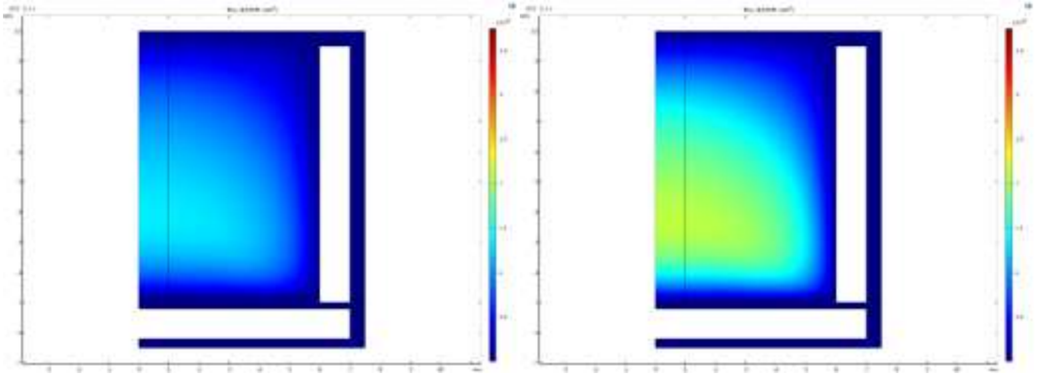
Figure 10 model with sample and Anode barrel



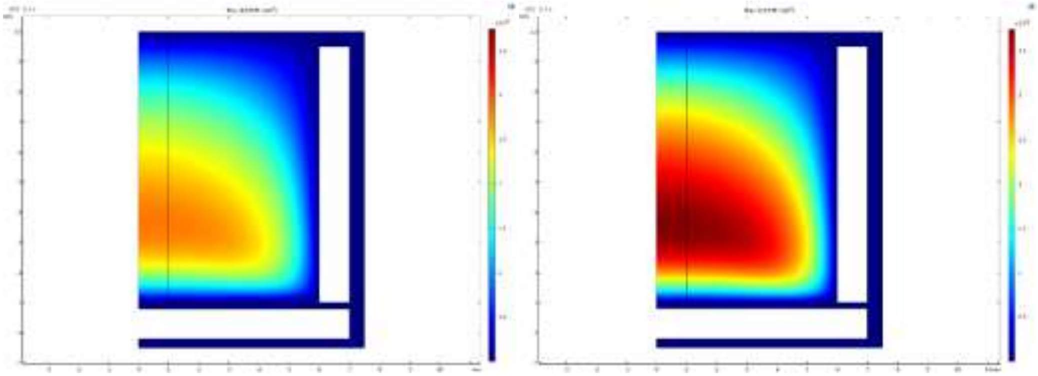
(a) Wall thickness is 0.5mm (b) Wall thickness is 1mm

Figure 11 cloud diagram of electron density distribution

3.3. Simulation results under different pressures

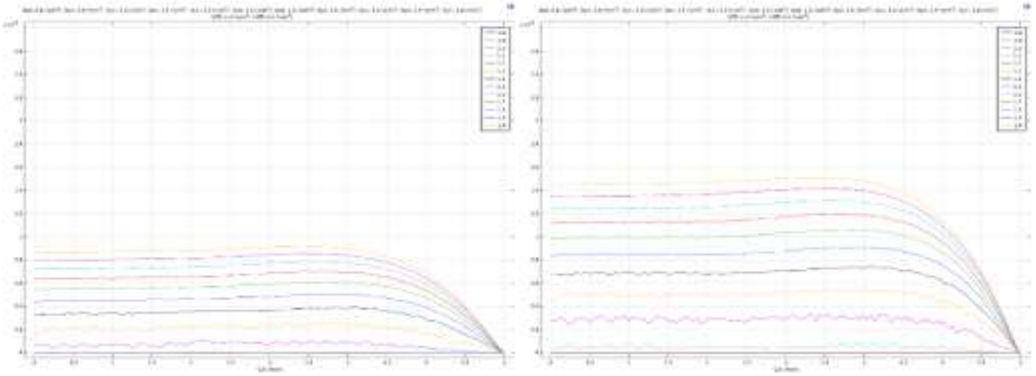


(a) Pressure is 200Pa (b) Pressure is 300Pa

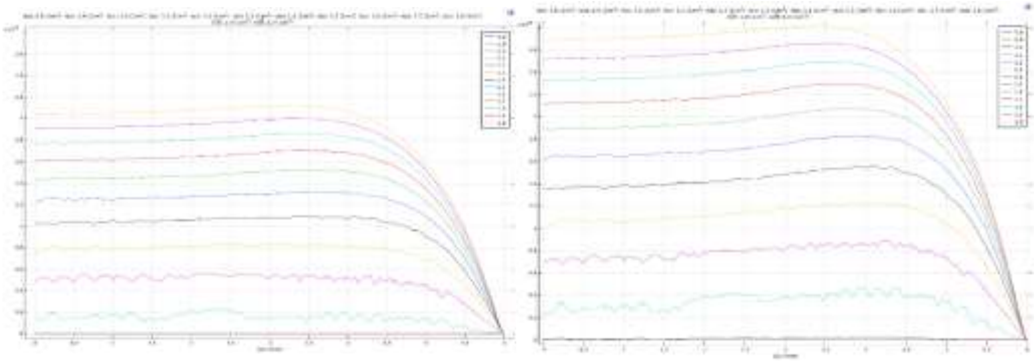


(c) Pressure is 400Pa (d) Pressure is 500Pa

Figure 11 Nephogram of electron density change under different pressure



(a) Pressure is 200Pa (b) Pressure is 300Pa



(c) Pressure is 400Pa (d) Pressure is 500Pa

Figure 12 Electron density curves at different pressures

From Figure 11 and Figure 12, the plasma electron density distribution nephogram under different pressure conditions and the electron density value curve at different positions are shown respectively. It can be seen from the two figures that with the increase of air pressure, the distribution law of electron density is basically the same, showing the distribution of low outer ring density and high center density, but the value gradually increases with the increase of air pressure. Therefore, if we want a higher sputtering speed, we can increase the air pressure value to increase the electron density value, increase the electron density on the sample surface, increase the particle concentration and intensify the impact, Thus, the falling off of the sample surface is accelerated.

IV. CONCLUSION

Through the numerical simulation of the plasma field in the Anode barrel of glow sputtering device, the distribution of electron density is obtained, which is basically in line with the actual situation, and some results are obtained.

(1) It is preliminarily considered that the numerical simulation method can be used to calculate and analyze the plasma field in the anode barrel during glow sputtering, and the results are reliable.

(2) The plasma field distribution in the Anode barrel has a certain regularity. The electron density in the outer ring is relatively low, and the electron density along the center of the diameter increases.

(3) By changing the thickness of the Anode barrel wall to study the variable parameters, it is concluded that the electron density distribution in the plasma field is basically the same with the increase of the thickness of the cylinder wall, but the absolute value of the electron density increases with the increase of the thickness of the cylinder wall.

(4) The results show that with the increase of air pressure, the absolute value of electron density increases, but the distribution law is basically the same, the outer ring is low and the center is high.

Based on the above research, it can provide some reference for seeking the optimal scheme of sample preparation.

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