Presented at the COMSOL Users Conference 2006 Las Vegas

Hybrid Modeling of a DC Magnetron Plasma Discharge

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Introduction

Magnetron plasma discharge has several technological applications. In sputtering techniques, it has been utilized, to improve ionization efficiency, and hence sputtering efficiency. Sputtering technology is widely used for both industrial and research purposes. Despite its popularity, it is still not completely known how to chose the optimal conditions for a determined deposition process. Nanostructures of the growing film are affected by the choice of the process conditions. Accurate knowledge of the coupling of the internal parameters, such as plasma densities, ionization, potential drop in front of the cathode is essential in optimizing the externally controlled parameters, such as applied power, pressure, dc or rf excitation, etc, for a desired growing film properties. This work is focused on the coupling of a Monte Carlo code with Comsol multi-physics conduction/convection, and electrostatic modules in solving fluid-Poisson model for the plasma properties for a practical dc magnetron low pressure plasma discharge. Magnetostatic module was used in calculating the required magnetic field.

Model

Electron and ion transport may be described by a continuity and a drift-diffusion momentum transport.

$$\frac{\partial n_a}{\partial t} + \nabla j_a = S_a \qquad (1)$$

$$j_a = n_a v_a \qquad (2)$$

Where index, a represents ions, i and electrons, e respectively, j is the particle current density (obtained from the drift-diffusion relation), n is the particle density, v is the particle velocity, and S is the source term.
In the presence of magnetic field, v may be given by:

$$v_a = \left(z m_a \vec{E} - \frac{D_a}{n_a}\nabla n_a - \frac{w_a^2}{u_a^2}\frac{\vec{E}\times\vec{B}}{B^2} - z\frac{w_a^2}{u_a^2}\frac{kT_a}{qB}\frac{1}{n_a}\nabla n_a \right) \times \left(\frac{u_a^2}{u_a^2 + w_a^2} \right) \qquad (3)$$

where z is positive for ions and negative for electrons, all other symbols have their usual meanings. The first two terms in eq (3) consist of the sum of both parallel and perpendicular components.

Non-uniform gas rarefaction, affects particles transport. To take care of this effect, simulated gas temperatures are incorporated in the modules. Fig. 1 shows sputtered particle flux and the correspondence gas temperature profile.

The particle densities are related to the electric potential through the following Poisson's equation:

$$\nabla^2 f = -\frac{q}{e_0}(n_i - n_e) \qquad (4)$$

Densities are set to 0 on all boundaries except at the surface of the target, where the ion flux was set equal to the discharge current density. All walls and target shield were grounded, except the target assembly, which was kept at –385 V.

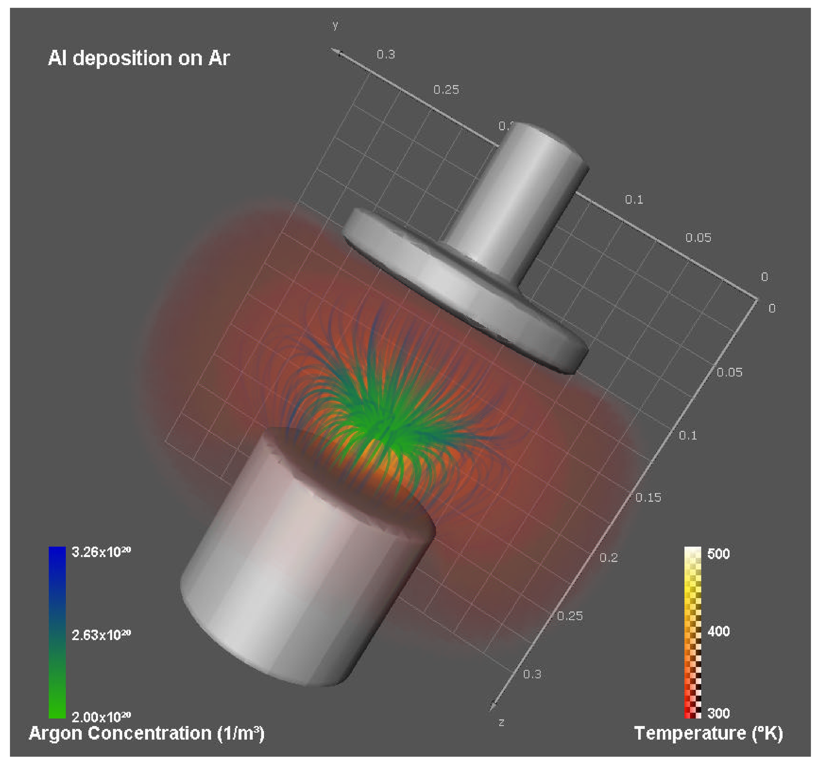

FIG 1. Al on Ar. Collision between sputtered Al particles and Ar atoms is considered to be the main source of gas heating. Greatest gas rarefaction is obtained within the plasma a short distance above the target. This distance shifts towards the target with increasing gas pressure, similar to the behavior of the sheath edge.

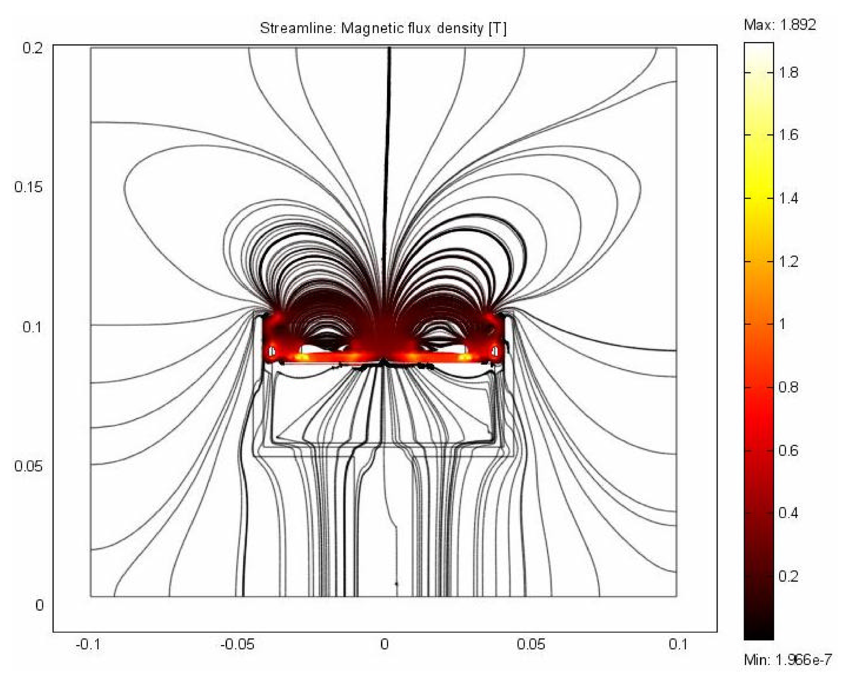

FIG 2: Magnetic field profile for a typical sputtering geometry. Close to the surface of the target, a more parallel profile is obtained above typical etch (erosion) track.

Results

A 2D geometry with axial symmetry is considered for the study. Aluminum target of diameter 7.6 cm is used. Argon gas pressure is at 1 Pa with an applied power of 200 W. Figure 2 shows the magnetic flux density used for the study.
Results for the densities of ion and electrons are shown in figures 3 and 4, respectively.

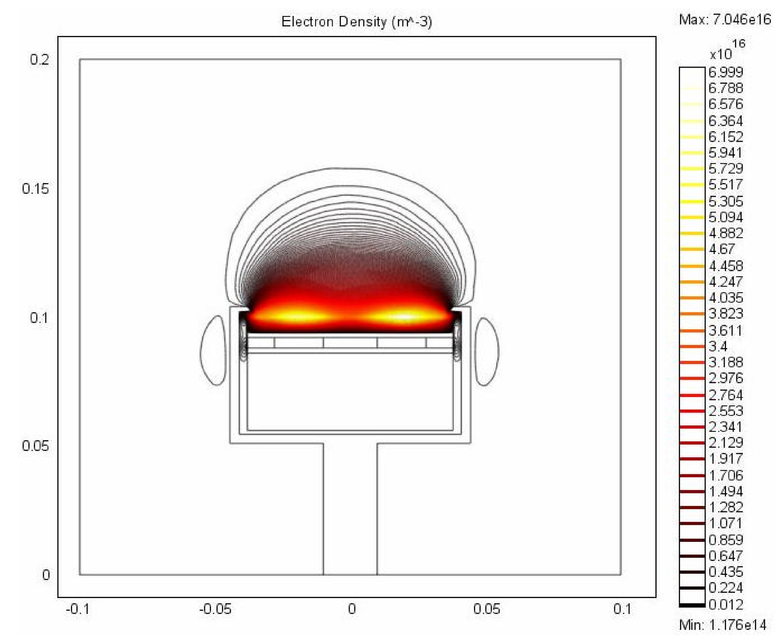

FIG 3. Ion density profile. The densities are greatest at the etch track, but fall off toward the substrate region. The trend of the data compare very well with experimentally determined data.

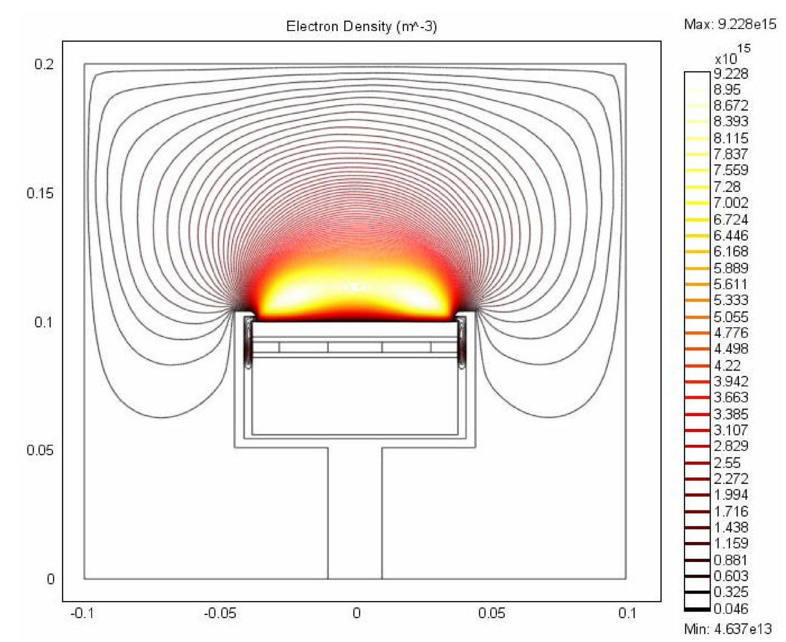

FIG 4. Electron density profile. The trend is similar to that of the ions. The effect of the target shield edge can be clearly noticed. The densities are lower at this zone than the nearby regions, even farther away from the target. Similar trend is observed in the data from experiment.

Conclusions

Plasma densities have been successfully determined using Comsol Multi-physics modeling tool through a hybrid model, which combines Monte Carlo, fluid and Poisson models. The modeling integrates gas heating effect, and magnetic flux density to give a complete tool for understanding the dependence of plasma properties on process conditions. The densities profiles follow the profile of magnetic field, and define an erosion pattern usually observed in a used target. Simulated results compare well with experimentally determined data.

Acknowledgments

Thanks to NSERC / Faculty of Engineering, Univ. of Alberta

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