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COMPUTER MODEL OF MAGNETRON SPUTTERING

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Summary. This work is devoted to the development and testing a new computer model of the deposition processes using magnetron systems of thin metal films on the silicon substrates. The model is a simplification of the kinetic approach[1-4] and is based on the quasi-hydrodynamic equations[5] that describe the state of a gas and a low-temperature plasma, and equations of electromagnetostatics. The model is discretized by the control volume method on an unstructured tetrahedral grid and implemented using parallel computations. The preliminary calculations have confirmed the effectiveness of the proposed approach.

1 INTRODUCTION

The problems of manufacturing coatings with desired properties are traditional for many industries, including modern and future electronics[6-9]. Today, in this area, there is a transition to nanotechnology, due to the need to create ultra-thin metal coatings and films.

Among the techniques for producing such films, magnetron sputtering has often been used. However, this technological process requires the fulfillment of a number of hard conditions that can only be accurately determined using mathematical methods and computer modeling. In this paper, we consider a problem of manufacturing vanadium nanofilms on a silicon substrate. Some aspects of computer simulation of magnetron sputtering processes are studied.

2 PHYSICAL PROBLEM

A specific physical problem is to calculate the evolution of a gas-plasma medium created by a magnetron and acting on a substrate. A fragment of a real geometry and a model of the spraying system are shown in Figure. 1. Argon is used as the work gas. Vanadium is used as a sprayed metal. The process is considered in the spraying chamber at room temperature and pressures 0.02-0.04 Pa. The average field of the magnetic system is about 0.3 Tl. The constant electric field between the anode and cathode varies from 350 to 700 V. As a substrate, pure polysilicon, silicon oxide or carbide are used.

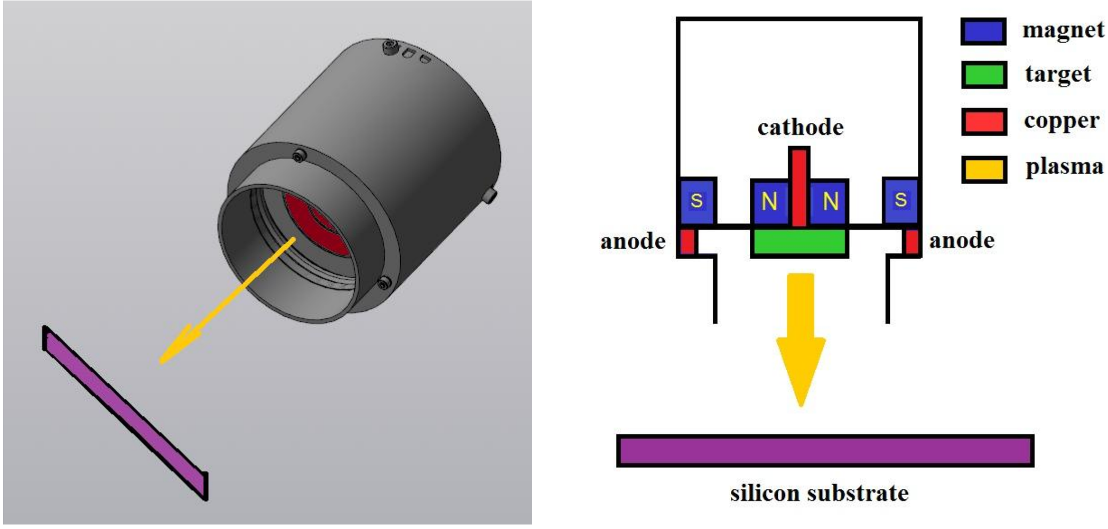

Figure 1: Real geometry (on the left) and simple 3D model (on the right).

The basis for the study of this problem is the fact that even with a stationary spraying mode, the final metallized surface of the substrate has a different coating thickness, and some areas has holes.

3 COMPUTER MODEL AND PARALLELIZM

In our study, we took into account the experience of other researchers. Many works on the physics of low-temperature plasma are based on the kinetic approach and its implementation by the Monte Carlo method[1-4]. However, this approach in the case of real geometry of the problem is still unattainable for modern supercomputers. Therefore, in this case, simplified models are implemented. Our work is based on the system of the quasi-hydrodynamic equations describing the state of argon, and equations for the density and momentum of free electrons, argon ions, ions and neutral atoms of vanadium. These equations are supplemented by the equation for the potential of the electrostatic field. The distribution of the magnetic induction vector is determined from the equations of magnetostatics. The final system of equations is supplemented by the corresponding initial and boundary conditions. An important point in this problem is the conditions for vanadium atoms to detach from the target surface and their condensation processes on the substrate surface. We select these conditions in accordance with the models of microscopic interactions on the surfaces of the target and the substrate.

The numerical implementation of the model is carried out on the basis of grid approximation of equations by the control volume method. Unstructured tetrahedral meshes are used. All unknown scalar functions belong to the centers of cells, vector quantities are determined at the centers of the faces of the tetrahedra. The final algorithm is based on a splitting scheme for physical processes. Equations containing time derivatives are approximated by explicit schemes.

The parallel implementation of discrete equations uses the technique of dividing the computational domain into domains. In the computer implementation, two levels of partitioning are introduced: the first - according to the nodes of the supercomputer (cluster), the second - according to the CPU trends[10]. Software implementation uses MPI and OpenMP technologies. In the case of clusters with graphics accelerators, the software implementation includes additional functions implemented using the CUDA Toolkit.

4 RESULTS

Разработанная программная реализация позволяет в настоящий момент рассчитывать поля в магнетронной системе, а также распределения газа и плазмы вблизи магнетронной системы (см. Рис. 2).

The developed software allows us to calculate the fields in the magnetron system, as well as the distribution of gas and plasma near the magnetron system (see Figure 2).

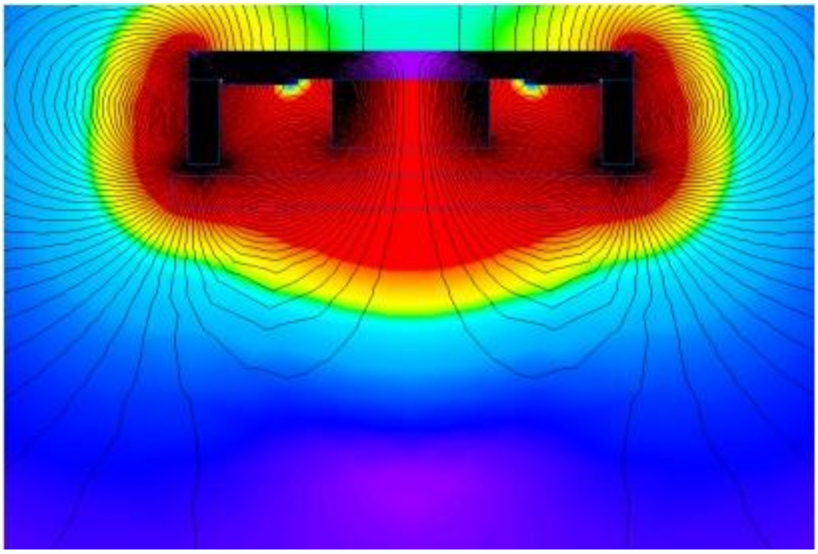

Figure 2: Distribution of electric field near magnetron system.

5 CONCLUSIONS

- A mathematical model of the deposition processes using magnetron systems of thin metal films on silicon substrates has been developed.
- For its numerical analysis, finite-volume schemes, a parallel algorithm and its software implementation have been implemented.
- The performed numerical experiments confirm the correctness of the proposed approach.

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