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SIMULATION OF REACTIVE MAGNETRON SPUTTERING SYSTEM FOR DEPOSITION OF THIN FILMS

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Annotation. This paper simulates a magnetron sputtering system based on main design features to visualize the thin film formation process. The article presents the main design features of the magnetron sputtering system that affect the speed and quality of sputtering, contributing to an increase in the productivity of thin film deposition.

Keywords: magnetron system, magnetron sputtering, rotating structure.

Introduction. One of the most urgent problems of modern microelectronics is the introduction of new materials into technological processes. One of such groups of materials are complex multicomponent oxides. There are various ways to form nanoscale layers, but the most widely used method is magnetron sputtering [1] due to its low cost, scalability, and reproducibility. Microwave devices to produce an EM-field in the MW frequency range. Magnetrons are the high power microwave source designed for commercial and military radars for detecting aircraft, also used to observe and track the weather patterns. Due to its advantages of low cost and higher efficiency it becomes the most widely used microwave devices in the world [2-4].

Experiments and modeling. The reason for some scatter in the parameters of working processes leading to the deposition of thin films with optimal characteristics can be associated with the use of magnetron deposition units that differ in the design of the growth chamber. A typical magnetron sputtering chamber includes a rotating metal disk (substrate holder) and one or more magnetrons with sputtering materials (targets) attached to them at some distance. In this case, the distance from the target to the substrate holder and their mutual arrangement can vary significantly depending on the setup design. The plasma cloud of the working gas above the target is kept due to the magnetic field, the strength of which can also vary depending on the design of the magnetron. High-energy gas particles in the plasma knock out the target material into the surrounding space of the chamber and, depending on the shape of the plasma cloud, the trajectory of the sputtered atoms and oxygen can vary significantly, which can affect the stoichiometry of the formed material, and this leads to changes in its electronic and optical properties. Thus, the purpose of this study is to study the influence of the design features of the rotating magnetron of the sputtering system on the properties of the formed thin film.

The method of reactive magnetron sputtering has great prospects for the formation of thin films. The method makes it possible to obtain multicomponent films with an arbitrary number and content of elements using a single magnetron, provides high film deposition rates, their high chemical purity, density, and adhesion to the substrate. The main disadvantage of this method is the complexity of selecting the size and number of inserts to obtain the required concentration of elements in the film. Practice shows that the composition of deposited films during magnetron sputtering of composite targets depends on a number of factors (the area of the inserts, the sputtering coefficient of each of the elements, the distribution of the ion current density on the target, the energy of the ions bombarding the target, etc.). Improving the stability of the reactive sputtering process and the composition of deposited films during sputtering of composite targets is possible by reducing the effect of reactive gas (oxygen) on sputtering processes.

With the advent and development of magnetron sources, magnetron sputtering has firmly entered the practice of obtaining metallization of modern hybrid integrated circuits. Magnetron sputtering is used in a large number of different sputtering, both newly developed and modernized vacuum plants of previous years of production.

Magnetron sputtering systems are systems that use inhomogeneous crossed magnetic fields. Structure and arrangement relative to the substrates and magnetron of the sputtering system is shown in Figure 1. The electrical parameters of the discharge in the magnetron system largely depend on the operating pressure, the magnitude and configuration of the magnetic field, and the design characteristics of the sputtering system. Magnetron systems are ion sputtering systems in which material is sputtered by bombarding the target surface with ions of the working gas (usually argon) formed in the plasma of an anomalous glow discharge.

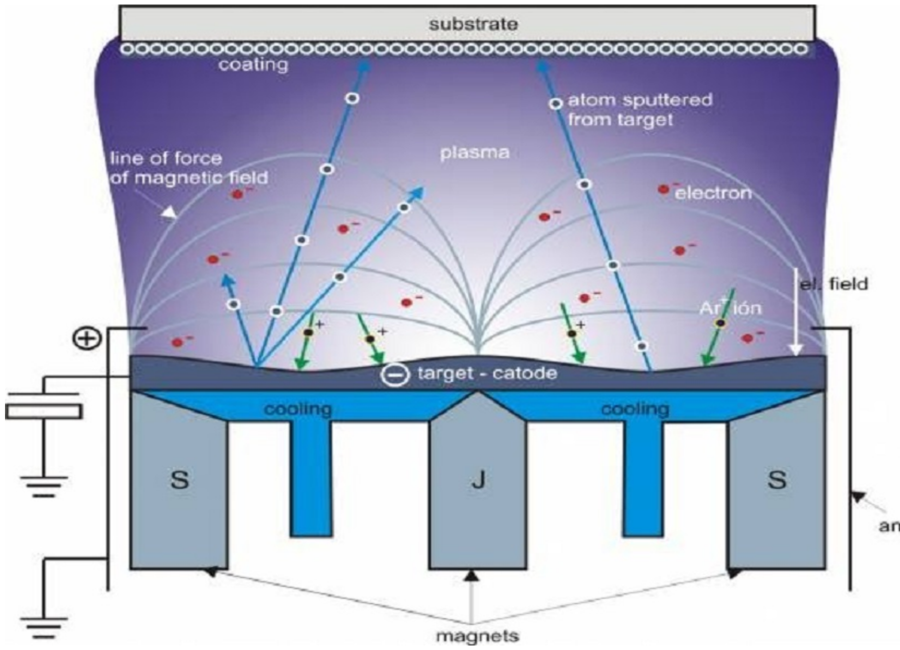

Figure 1 – Structure and arrangement relative to the substrates and magnetron of the sputtering system

The layout of the experimental setup for applying layers of thin films by reactive magnetron sputtering is shown in Figure 2. The installation is based on the VU-1BSp vacuum station. The setup chamber was equipped with a MARS.011-80 high-vacuum magnetron sputtering system (MSS) with a target ∅ 80 mm and an ion source based on an end Hall accelerator (EHA). The substrate holder was located at a distance of 120 mm from the target surface. An annular gas distributor was located along the contour of the substrate holder.

In the course of the experiments, two methods of supplying working gases to the chamber were used: 1. a mixture of gases (Ar/O_2) was supplied to the gas distribution system of the magnetron (joint gas supply or SG); 2. Inert gas (Ar) was supplied to the gas distribution system of the magnetron, and reactive gas (O_2) was supplied to the gas distributor in the substrate area (separate gas supply or DG). To maintain the specified gas flow rates, automatic gas flow regulators RRG-1 were used.

Thin films were deposited on substrates of highly doped single-crystal silicon EKES 0.01 (100) and optical quartz. During the experiments, the substrates were mounted on a rotating carousel-type substrate holder at a distance of 85 mm from the surface of the magnetron target. The chamber of the vacuum setup was evacuated to a residual pressure of 10^{-3} Pa and preliminary ion cleaning of the substrates was carried out, as a result of which surface contaminants and a layer of natural oxide on the surface of the silicon substrate were removed. For this, the working gas Ar was supplied to the ion source up to a working pressure of 2.0×10^{-2} Pa. The cleaning time, ion energy, and discharge current were constant in all experiments and amounted to 6 min, respectively (substrate holder rotation mode), 500 eV, and 70 mA, respectively.

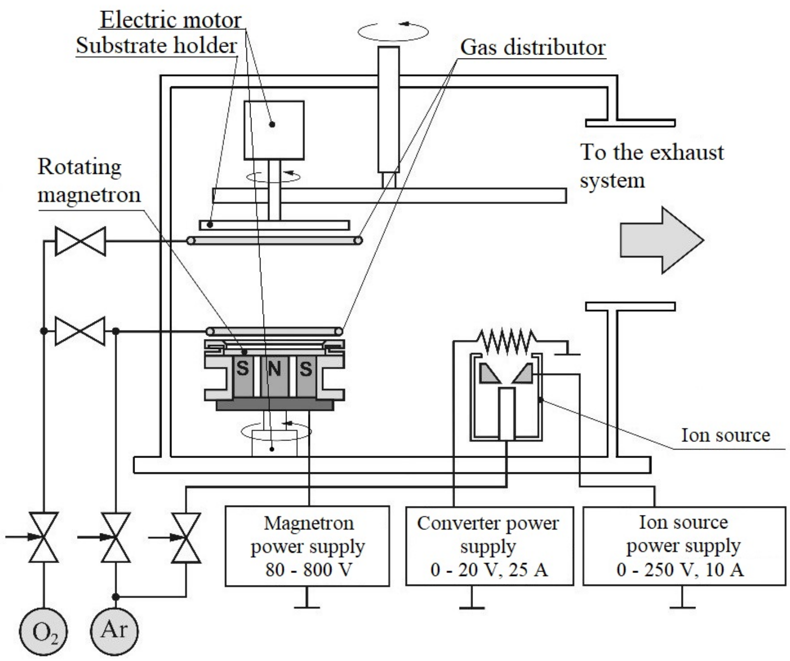

Figure 2 – Scheme of an experimental setup for deposition of thin films by reactive magnetron sputtering

The high sputtering rate and uniformity characteristic of these systems is achieved by increasing the ion current density by localizing the plasma near the sputtered target surface using a strong transverse magnetic field with a rotating design of the magnetron system (Figure 3).

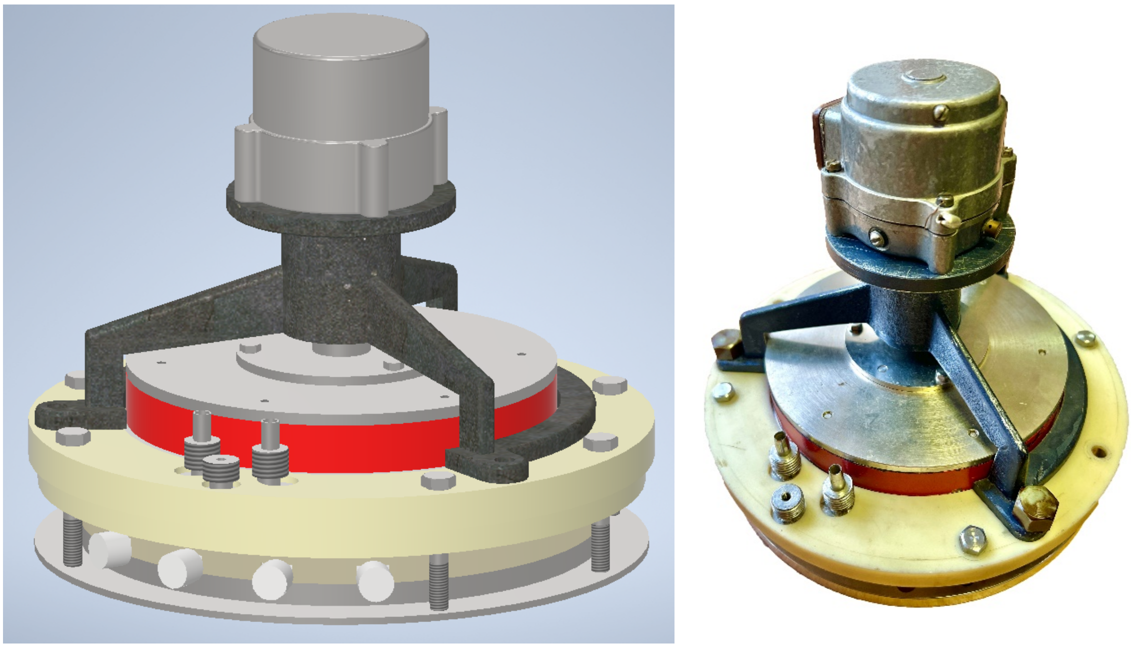

Figure 3 – 3D model of rotating magnetron sputtering system

The rotating magnetron system is capable of overcoming many of the traditional difficulties experienced when performing high-rate reactive deposition like nodule growth rates, but increasing the total target surface sputtering area. It can vary the level of magnetic unbalance/balance and hence vary the level of ion bombardment of the growing film. This is very useful in determining the optimum level of bombardment for specific processes.

In order to increase the effectiveness of the magnetron's bombardment on the target, it is necessary to increase the range of the magnetic field. Besides choosing the right magnet material, the size, position, and structure of the magnet also determine the above characteristics. In addition to the rotating the magnetic field, adding magnets is also a way to increase the area of the magnetron's bombardment on the target.

The magnetic flux density distributions around the target surface region with and without the refinements are depicted in Figure 4. Comparatively, enhanced operational flux densities at the target surface in the system with refinements can be clearly observed.

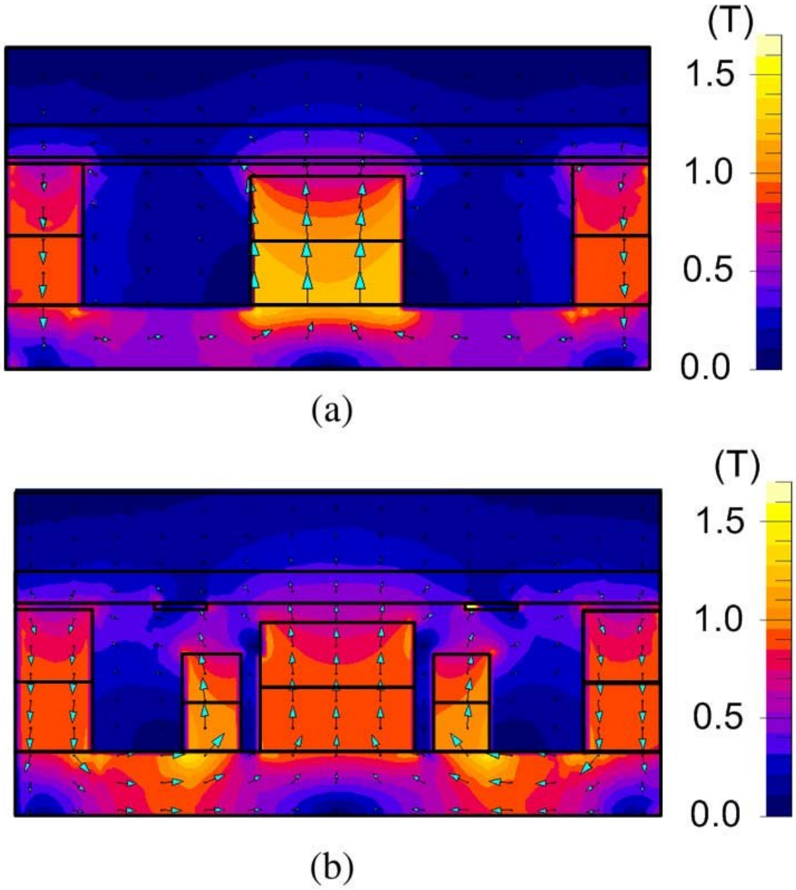

Figure 4 – Magnetic flux density norms in the magnetron sputtering system: (a) In the original system, (b) In the refined system

Conclusion. In this paper, magnetron sputtering system has been examined using the 3D modelling tool Autodesk Inventor and COMSOL – software for multiphysics simulation. By using the measure values the 3D design is formed and simulated. The 3D model and visualization of magnetic flux density distribution in the magnetron sputtering system verified that the derived designed calculations and the results of the proposed design method for magnetron are relatively in good agreement.

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