Design of a liquid-phase magnetron sputtering small-sized source for the vacuum coating system MVTU-11-1MS

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Abstract. The relevance of magnetron sputtering to obtain conductive metallized coatings with a thickness of up to tens of micrometers is indicated. Attention is paid to the features of magnetron sputtering with a liquid target. It is noted that this process is currently being implemented using magnetrons with size from 3” to 6”. The design flaws of the existing NMSA-52M magnetron and its mounting unit to the chamber of the vacuum coating system MVTU-11-1MS are considered. The design of a magnetic system with an increased value of magnetic induction on a 2” magnetron surface has been developed. The magnetron sputtering source were designed: a housing, a chamber mounting unit and a cover. As a result, a variant of the improved design of the magnetron sputtering source is presented, which takes into account the disadvantages of the existing NMSA-52M magnetron.

1. Introduction
Metal conductive layers with a thickness of 20 to 50 μm are widely used in the fields of mechanical engineering and electronics: they are used in rocket science [1], thermonuclear fuel capsules [2, 3], power electrodes [4], thermoelctric coolers [5]. Various methods are applicable for the formation of such coatings: galvanic build-up, DBC technology, arc evaporation, and magnetron sputtering. The latter method has advantages in terms of purity, adhesion to the substrate, economy and environmental friendliness, however, the deposition rate with classical magnetron sputtering (MS) is 1–2 orders of magnitude lower than in other indicated methods. However, a variation of this method – liquid-phase magnetron sputtering (LPMS) makes it possible to provide comparable deposition rates for coatings [1, 2, 6–8].

In classical MS, the atoms of an inert gas of argon are bombarded by electrons. This is how the ionization and excitation of a glowing plasma discharge above the surface of the magnetron occurs, where the target from the sprayed material is located. Ions with energies from 100 to 1000 eV bombard the target, knocking out the ions and atoms of the material deposited on the substrate. Approximately 95% of the ion energy is consumed in the target in the form of heat [9]. In traditional MS systems, the target is attached to the magnetron cover and cools with it [10].

In the LPMS method, the target is placed in a crucible of refractory material and insulated from the lid (cooling system), while providing sufficient power, the target material melts, and thermal evaporation is added to the sputtering process. The process goes into self-atomization mode, in which the discharge burns in the vapor of the target material without the presence of a working gas. This leads to an increase in the deposition rate from 5 to 10 times in comparison with the classical MS, an increase in the purity of the coating, and a decrease in energy consumption to 50–100 V/Atom [1, 6, 11–18].
In most cases, the LPMS process is implemented using magnetrons with sizes from 3” to 6” [13, 19]. The existing NMSA-52M magnetron module has dimension 2”. To melt a 2” target and switch the process to self-atomization, it is necessary to achieve a discharge power of 400 to 550 watts. The main parameters affecting the power are: discharge voltage, operating pressure of the process, as well as the value of the tangential component of the magnetic field induction on the target surface. Variation of the first two parameters is possible in the range determined by the parameters of the power supply (current from 100 to 2000 mA and voltage from 50 to 800 V) and the quality of pressure regulation in the vacuum chamber of the installation, and the value of magnetic induction on the target surface is determined by the design features of the magnetron and the magnetic system.

The NMSA-52M magnetron due to small size has a low magnetic induction above the surface of the magnet cover 175 mT which is not enough to implement the LPMS method. In addition, the existing magnetron has an uncomfortable fastening to the port of MVTU-11-1MS vacuum coating system [20], which leads to the complication of its installation and leaky seal.

Thus, the aim of this work is to design a new magnetron with an increased value of the magnetic induction of the magnetic system and ergonomic fastening to the nozzle of the vacuum chamber of the MVTU-11-1MS vacuum coating system.

2. Magnetron design analysis
In the design of the small-sized magnetron NMSA-52M [21], based on its detailed analysis, the disadvantages of three main nodes are identified (figure 1). At unit 1, where the magnetic system is located, a small value of magnetic induction on the surface of the magnetron is found, which is not enough for the LPMS mode. The NMSA-52M magnetron is generally inconvenient during assembly: the complexity of the seal deformation unit (figure 1, node 2), the complexity of fixing the module to the chamber (figure 1, node 3).

![Figure 1. NMSA-52M magnetron design: 1 – sputtering unit; 2 – magnetron holder; 3 – magnetron mounting unit.](image)

The thickness of the lid at the contact point of the ring magnet is 0.7 mm (see figure 1, node 1). When moving away from the magnets, the magnitude of the magnetic field induction decreases, and since the efficiency of the MS depends on the magnitude of the magnetic field, it is necessary to minimize the loss of magnetic induction. The cover is fixed to the magnetron body with screws, which takes up space. When using another method of cooling the magnets, you can increase the size of the ring magnet by removing the cylindrical part where the screws are located.

In the magnetron housing (see figure 1, node 2), two through holes with a diameter of 6 mm are provided for supplying cooling water to the magnetic system from overheating. The holes are offset, which can lead to breakage of the drill from the cutting force during drilling.
In node 2 there are screws M4, pressing the clamping plate for deformation of the seal, ensuring the sealing of the sputtering unit. When assembling the module, it is difficult to control and ensure uniform tightening, and hence the uniform deformation of the seal. The tightening of the M4 screws is possible due to the split ring installed in the groove of the magnetron housing. The groove has an identical radius that prevents this ring from being cut. Since the magnetron housing is small, access to the ring is limited and it is difficult to disassemble the assembly without special equipment.

For more details, the magnetron mounting unit 3 on the chamber flange is shown in figure 2.

An O-ring 2 is placed on the KF flange 1 of the vacuum chamber, squeezed by the counter flange 3. The flanges are fastened with a clamp 4. The seal 5 ensures tightness when deformed from the sleeve 6, which is fastened with four screws 7. The split washer 8 prevents the module from moving in chamber because of pumping, connecting two screws 9 with the sleeve 6. The tight fit of the washer 8 and the pipe 10 provides a screw 11.

![Figure 2. Mounting unit of the NMSA-52M magnetron on the chamber flange: 1 – KF flange; 2, 5 – seal; 3 – counter flange; 4 – clamp; 6 – clamping sleeve; 7, 9, 11 – screws; 8 – split washer; 10 – magnetron tube.](image)

The difficulty of installing and securing the assembly is the fact that the operator needs to hold the attachment unit of the assembly with one hand, and screw the screws with the second hand with a screwdriver or key (this is problematic and inconvenient). Additional problems are that the knot elements are installed in only one position, and it is impossible to rotate around their axis, respectively, some screws have to be twisted “by touch” since access to them is limited by external accessories installed on the chamber.

Thus, the existing shortcomings in the design of the magnetron system do not allow the process to sputter the target in the liquid phase due to the small magnetic field induction above the target surface, and also complicate the mounting process and can lead to leaks in the mount.

3. Upgraded design development

As a result of the analysis of the shortcomings of the current design of the magnetron module, a modernized unit was developed in the Compas-3D CAD (figure 3).

The cooling channel is assembled by soldering copper pipes to the magnetic circuit, which made it possible to increase the size of the ring magnet due to the absence of fixing screws. Based on the simulation data, the magnetic induction on the surface of the magnetron does not increase by 83% relative to the base value of 175 mT. To exclude contact of the crucible with magnets, the height of the magnets is less than the height of the cooled channel. The magnetic system consists of rare-earth permanent magnets made on the basis of NdFeB (N52). An annular magnet 1 and a columnar magnet 2 are pressed onto a copper cover 3 to increase the cooling efficiency, which is soldered to the magnetic circuit 4 to reduce overall dimensions. The unit is non-separable, provides vacuum and water tightness.

Using screws 5, the magnetic system is connected to the magnetron housing 6. An annular rubber seal 7 provides a seal between the magnetic system and the housing. The magnetron anode 8 is mounted on the cup 9. The parts are electrically isolated from the magnetron body through fluoroplastic sleeves 10 and 11. A rubber seal 12 provides vacuum tightness, which deforms when the nut 13 is pressed through
the pressure ring 14. The magnetron module is mounted on the lower flange 20 of the vacuum chamber to the magnetron strut 15 connected to the magnetron cup with screws 16 and the seal 17.

Figure 3. The upgraded design of the NMSA-52M magnetron: 1, 2 – magnets annular and columnar; 3 – cover; 4 – magnetic circuit; 5, 16, 21, 28 – screws; 6 – magnetron body; 7, 12, 17, 24 – ring seal; 8 – anode; 9 – cup; 10, 11 – insulating bushings; 13 – tightening nut; 14 – pressure ring; 15 – tube; 18 – cooling supply tubes; 19 – fitting; 20 – camera flange; 22 – clamping flange; 23 – clamp KF; 25 – bushing clamp; 26 – tightening nut; 27 – split ring.

The cooling of the magnetic system is carried out using running water supplied through polyurethane tubes 18, which are connected to the fitting 19. The tube 15 is mounted on the flange of the chamber 20. Vacuum tightness is ensured by the seal 21, which is pressed by the flange 22 using the clamp 23. Tightness also provides a seal 24, pressed by the sleeve 25 with the nut 26. The split ring 27, which prevents the magnetron from being sucked into the chamber during pumping, is fixed on the tube 15 with the screw 28.

4. Conclusions
The developed magnetron module has an enlarged ring magnet, as well as a soldered cooling channel, which will allow obtaining a magnetic induction higher by 83% over the surface of the magnets with a smaller size of the body of the magnetic system and to carry out magnetron sputtering processes in the liquid phase mode. The absence of direct contact of magnets with water will increase their service life. The assembly providing vacuum tightness has been changed, which will allow for structural analysis without damage to the elements. A simple and quick-detachable system for fastening the magnetron module to the vacuum chamber flange was developed.

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