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SIMULATION OF TEMPERATURE REGIME OF WATER-COOLED LOW-PRESSURE GAS MAGNETRON SYSTEM WITH INTERNAL MAGNET

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Computer simulation, based on the principles of computational fluid dynamics, of the characteristics of indirect water cooling of a disk cooper magnetron target with a diameter of 50 mm and an integrated magnet is presented. With ion heating power of 100 W, the target heats up to 30…50°C, and the magnet heats up to less than 15°C, if water with a temperature of 10°C is supplied at a rate of 30…50 mm/s (or 150…250 cm^3/min). The unevenness of the heating of the target is about one degree. This cooling mode and system can be recommended for use.

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INTRODUCTION

Modern electronics and sensor technics is mainly based on thin-film microstructures, for the production of which the technology of ion sputtering with the help of low-pressure gas magnetron system is widely used [1]. The peculiarity of this system is that about 80% of the electrical power is converted to heat, which must be removed by a cooling system. Otherwise, it may overheat and damage the target (source of depositing material), the substrate and the internal magnet [2 - 4]. This affects the reproducibility of the thin film deposition technology, too. The choice of the cooling mode is usually carried out experimentally, but it is advisable to supplement it with mathematical modeling, which allows not only to calculate the temperature but to reveal the features of cooling [3, 4]. The given work is devoted to simulation of the magnetron system for widely used VUP-5M facilities produced by Sumy-ELMI.

1. OBJECT AND METHOD OF SIMULATION

Fig. 1 shows the scheme of the magnetron system taken as an object of simulation. The materials of its parts are shown, too. The upper part of the system, a disk target (T), is a cathode for a planar magnetron discharge in low-pressure argon, which is created above the target. A permanent magnet (M) is used to generate a magnetic field above the target. The discharge plasma is a source of ions bombarding the target surface in order to generate a flow of sputtered copper atoms to the substrate (not shown in the figure) to form a thin-film coating. The ion bombardment leads not only to ion-electron emission and sputtering of the target surface, but also to its heating. For the purposes of simulation, an even heating power of 100 W, which is typical for small-sized systems [2], is specified.

The target (T) is tightly clamped to the cooper water-cooled cathode body (CB), i.e. the system uses indirect cooling of the target, but the magnet (M) is directly surrounded by water. A water flow (W) is fed into the cathode body (CB) through the outer tube, which is then discharged through the inner tube. The range of regulated water flow speed V at the inlet is 5…100 mm/s. The water temperature at the inlet is 10°C. The water pressure at the outlet is zero, i.e. we set the drain to open. The outer diameter of the inner tube is 6 or 8 mm, the wall thickness is 0.5 mm.

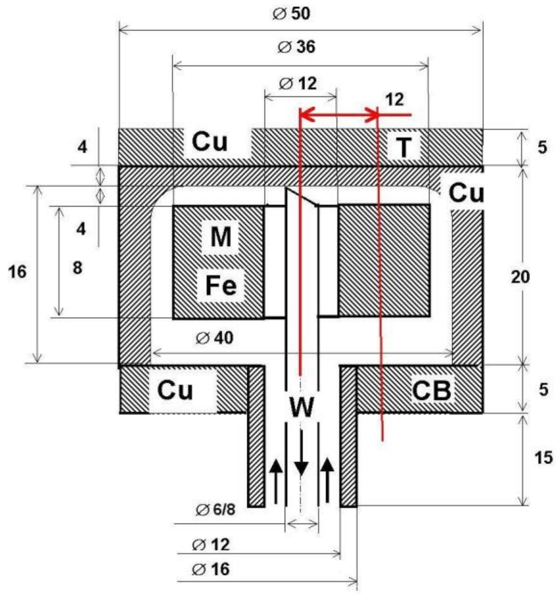

Fig. 1. Scheme of magnetron: T – target; M – magnet; CB – cathode body (target holder); W – water flow

The temperature simulation will be performed to determine the target and magnet surface and volume temperatures as functions of the flow speed V of cooling water with a temperature of 10°C when supplied to the cathode body (CB) through the outer water tube and at the target surface ion heating power of 100 W. For the calculation, the heat balance equations are to be used. An assessment of heat removal due to thermal radiation shows that it is negligible compared to water cooling, since the surface temperature does not exceed 100°C. Similarly, it is possible to ignore the cooling of the outer surface of the system due to thermal conductivity and convection of argon, since it is a heavy gas at very low pressure (~ 0.1 Pa). Thus, the simulation of the temperature regime is to be performed on the principles of computational fluid dynamics (CFD), practically using the COMSOL Multiphysics modules: CFD Module User's Guide. Version 6.1 and Heat Transfer Module User's.

Version 6.1 [5, 6], which proven itself well for solving similar hydrodynamic problems [3].

Considering the relatively low power of ion heating of the target and moderate flows of cooling water, a laminar model of water flow in the magnetron system was chosen to simulate the temperature regime.

2. RESULTS AND DISCUSSION

The simulation results of temperature distributions on the surfaces and within the cooper parts as well as in the water flows are shown in Figs. 2-4 for various values of water flow speeds V at the inlet with outer diameter of the inner tube of 6 mm.

It is evident that the target is cooled quite well with the chosen design of the cooling system, and even with a minimum water flow rate V = 5 mm/s, the target temperature is less than 105°C. When the cooling water flow rate at the inlet increases from 15 to 100 mm/s, the target temperature decreases from 57 to 32°C.

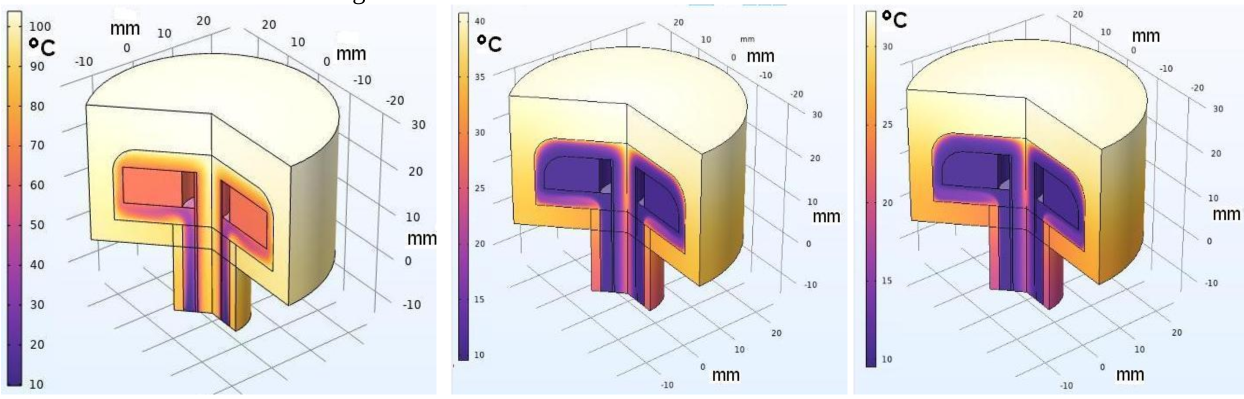

Fig. 2. 3D temperature distributions inside of the magnetron system at target heating power of 100 W. The water flow speeds at the inlet V: is 5 mm/s (a); is 50 mm/s (b); is 100 mm/s (c)

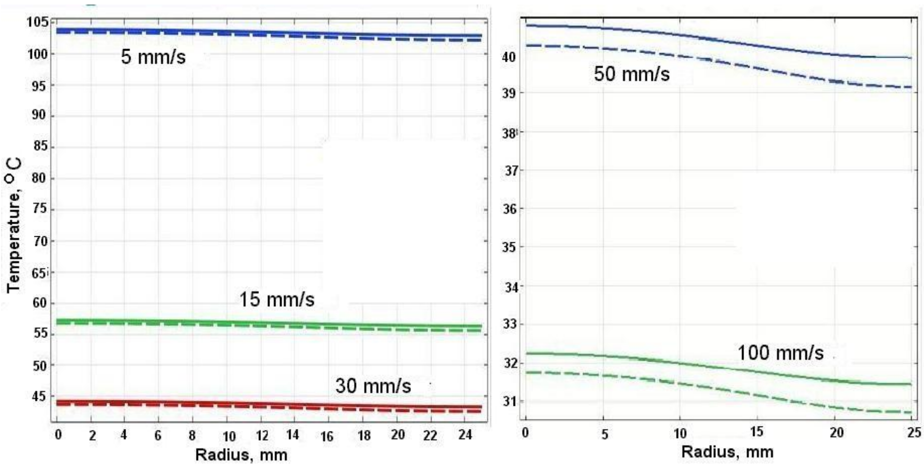

Fig. 3. Temperature radial distributions over (solid lines) and under (dashed lines) the target at various water flow speeds V at the inlet. The target heating power is 100 W

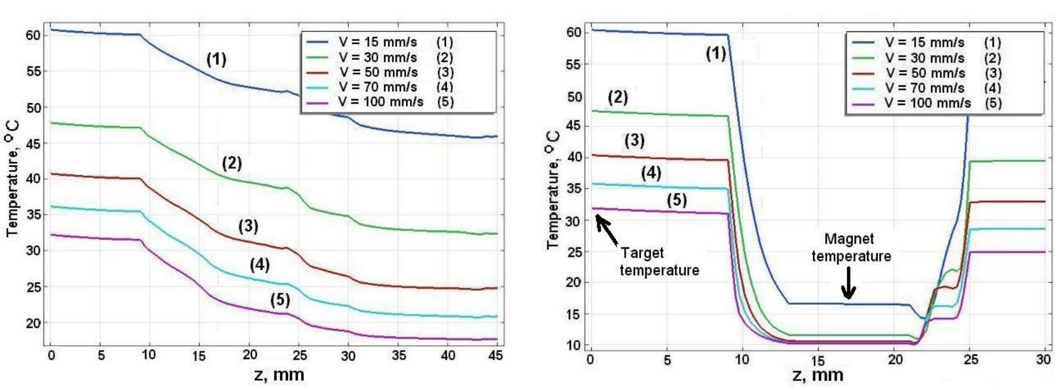

Fig. 4. Temperature vertical distributions along the central axis (a) and along the vertical line at the radius of 12 mm (b) through the magnet, see the red lines in the Fig. 1, at various water flow speeds V. The target ion heating power is 100 W. The coordinate z is measured vertically downwards from the target surface

The magnet temperature with the water flow rate V = 5 mm/s is about 60°C, but this is extremely undesirable. However at V ≥ 15 mm/s the magnet temperature is less than 20°C (see Fig. 4,b). Note the uniform temperature distribution inside the magnet.

There is also a practically uniform radial temperature distribution on the target surface (the deviation from the average along the radius is of the order of 0.5°C). With increasing water supply, the temperature difference across the target thickness decreases, and at V = 100 mm/s the deviation from the average is approximately 0.25°C (see Fig. 3).

The temperature difference along the target thickness is approximately 0.5…1°C.

The calculations performed for the variant with the inner water tube diameter of 8 mm showed an increase in the target temperature by 5…10°C relative to the graphs in the figures given. This can be explained by a decrease in the mass of water passing through the system at the same flow rate at the inlet due to a decrease in the difference between the inner diameter of the outer tube and the outer diameter of the inner tube, as well as due to the rapid flow of water along the lower surface of the cathode block cover and along the inner tube. Therefore, it can be assumed that the outer diameter of the inner tube of 6 mm, indicated in Fig. 1, is optimal.

CONCLUSIONS

Computer simulation of the characteristics of indirect water cooling of a copper disk magnetron target with a diameter of 50 mm with a built-in magnet was carried out, based on the principles of computational fluid dynamics (CFD) with the approximation of laminar water flow [5, 6]. At ion heating power of 100 W, the target is heated up to 40…50°C, and the magnet to less than 15°C, if the water flow with temperature of 10°C is supplied at the speed of 30…50 mm/s (or 150…250 cm^3/min) at the inlet. At the water flow speed of 100 mm/s, the target surface temperature was about 30°C. The average unevenness of the target heating along the radius is about 0.5 degrees. The studied cooling mode and cooling system can be recommended for use. It was successfully tested in [7].

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REFERENCES

1. A.I. Kuzmichev. *Magnetron sputtering systems.* Kyiv: "Avers", 2008, 244 p.
2. L.R. Shaginyan, M.I. Mironov, A.I. Kuzmichev. In situ calorimetric temperature measurements of Cu, Cr, Ti targets during DC magnetron sputtering // *J. Vac. Sci. Technol. A (43).* 2025, № 1, p. 013201.
3. A.A. Omar, N.F. Kashapov, A.G. Luchkin, et al. Effect of cooling system design on the heat dissipation of the magnetron sensitive components with rectangular target during sputtering by Ar^+ // *Results in Engineering (16).* 2022, p. 100696.
4. M. Salhi, S.El.H. Abaidia, B. Mohamedi, S. Laouar. Cooling enhancement of planar-balanced magnetron cathode // *Nucl. Sci. Tech. (28).* 2017, p. 111.
5. *CFD Module User's Guide*. *Version 6.1* / "COMSOL Multiphysics" 2022. https://doc.comsol.com/6.1/doc/com.comsol.help.cfd/CFDModuleUsersGuide.pdf.
6. *Heat Transfer Module User's. Version 6.1* / "COMSOL Multiphysics" 2022. https://doc.comsol.com/6.1/doc/com.comsol.help.heat/HeatTransferModuleUsersGuide.pdf
7. A.I. Kuzmichev, V.I. Ivashchenko, V.V. Perevertailo, P.L. Skrynskyi. Magnetron sputtering system for deposition of multinanolayered coatings with reactive gas activation in microwave discharge // *IEEE Trans. Plasma Sci. (44).* 2016, № 12, p. 3028-3031.

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МОДЕЛЮВАННЯ ТЕМПЕРАТУРНОГО РЕЖИМУ ВОДЯНООХОЛОДЖУВАНОЇ ГАЗОВОЇ МАГНЕТРОННОЇ СИСТЕМИ НИЗЬКОГО ТИСКУ З ВНУТРІШНІМ МАГНІТОМ

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Представлено комп'ютерне моделювання на основі принципів обчислювальної гідродинаміки характеристик непрямого водяного охолодження мідної дискової магнетронної мішені діаметром 50 мм з вбудованим магнітом. При потужності іонного нагрівання 100 Вт мішень нагрівається до 30…50°C, а магніт нагрівається менш ніж до 15°C, якщо вода з температурою 10°C подається зі швидкістю 30…50 мм/с (або 150…250 $см^3$/хв). Нерівномірність нагрівання мішені становить близько 1°. Такі режим та систему охолодження можна рекомендувати для використання.