Target heating in sputtering unit of magnetron

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Abstract. The thermal process in a sputtering magnetron unit with a sandwich-target was studied. The unit contains two targets located on the same axis. The inner target is effectively cooled by running water; the outer target is cooled through the fastening elements and by radiation. The study was performed by modeling in the COMSOL Multiphysics using the Heat Transfer Module. A 3D-model of the sputtering unit has been developed in order to thoroughly analyze the thermal processes in a unit with a cold chromium target and a hot titanium one. The influence of the target thickness and magnetron discharge power on the outer target temperature is found. The model can be used to study a magnetron with any metallic target.

Magnetron sputtering is a commonly used technique to deposit films of metal alloys or solid solutions of simple compounds (nitrides, oxides, etc.). In order to create two fluxes, various sputtering systems are used; the simplest one contains two magnetrons with targets of different metals [1, 2] or one magnetron with a composite target [3, 4]. Traditionally, the target is cooled effectively in these devices. Besides, sputtering systems with hot targets are being studied [5–7], where a single target can be heated up to the melting point and higher [8, 9]. The hot target mode is maintained by heat transfer through a gap (up to 1 mm thick) and by fastening elements [10].

Heating the target sputtered in inert and reactive gas environments changes the physicochemical processes on the target surface, in the gas and on the substrate. In order to understand the influence of the target surface temperature on the composition, crystal structure, and properties of the films, the value of the temperature should be determined. Besides that, it is used as a parameter in modeling of the reactive sputtering process [7, 11, 12].

Direct measurement of the target surface temperature is a complex technical task. To that end, noncontact pyrometric methods [10, 12–14] are used most often. But they give a significant error, since the pyrometer integrates the discharge optical spectrum in the IR region, which is a combination of the glow discharge emission and target thermal radiation spectra. Another approach is based on modeling in various software packages, where a thermal problem is solved numerically for a given model of a device with given boundary conditions.

In this paper, we describe a new type of magnetron with a sputtering unit, which contains two targets located on the same axis. The inner metal target is sputtered through the slots in the outer target and operates in a cold mode. The outer target made of another metal operates in a hot mode. The sputtering unit will be referred to hereinafter as the "sandwich-target".

In order to solve this problem, a 3D-model of a magnetron with a sandwich-target was developed in the COMSOL Multiphysics (figure 1). In the model, the sputtering unit consists of: an inner 4 mm thick target *3* made of chromium; an outer target *1* made of titanium and fastening elements *2* and *4*. In the area of the outer target erosion, an even number of slots *5* of a predetermined diameter are arranged symmetrically about the center of the target. In the calculations, it was assumed that the discharge power is uniformly distributed in the annular region where the greatest erosion is observed. The power incident on the target, the outer target thickness, and the diameter of the slots in the outer target may vary in the model.

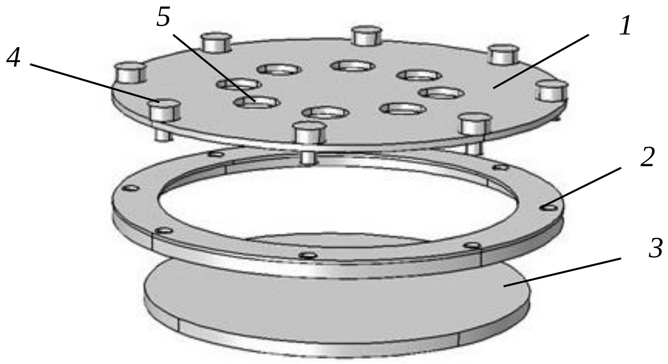

Figure 1. 3D-model of a magnetron with a hot sandwich-target: *1* – outer target; *2* – fastening ring providing a gap between the targets; *3* – inner target cooled by running water; *4* – the bolts; *5* – slots.

Figure 2 shows the temperature distributions over the surface of the outer target in the longitudinal and transverse directions, obtained as a result of calculations. Since Figure 2 reflects the results including those for sections containing slots, discontinuities are observed in the temperature distribution at the edges of the slots.

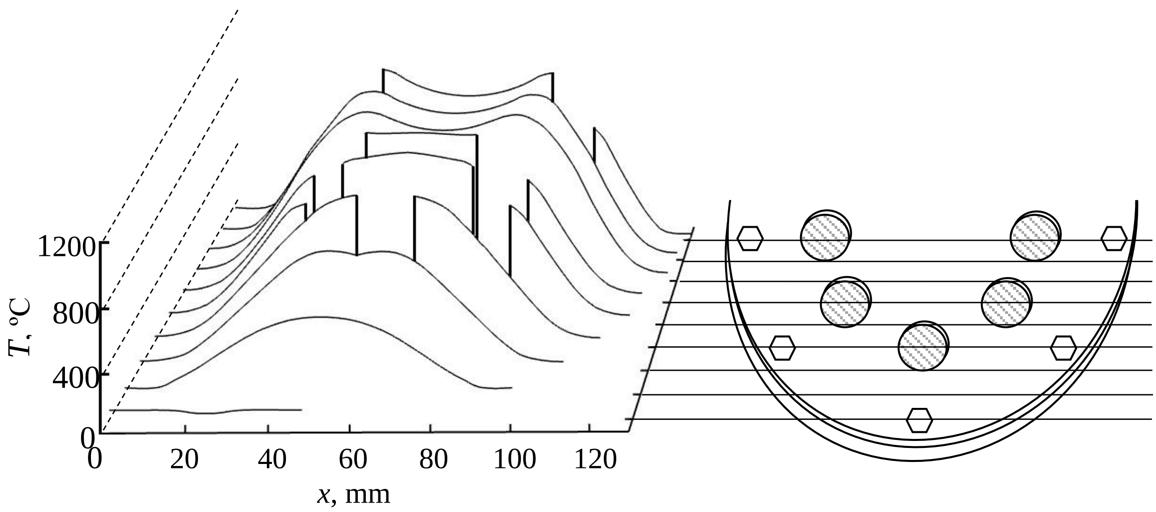

Figure 2. Temperature distribution over the surface of the outer target. Only half of the target is considered.

Since the temperature is distributed unevenly over the target surface, the concept of the effective temperature T_{eff}, which determines its average heat flux, was introduced. It can be calculated by averaging the distribution over the entire surface of the outer target:

$$T_{eff} = \frac{1}{S} \int_{-\infty}^{\infty}\int T(x, y) dxdy, \quad (1)$$

where $T(x, y)$ – is the surface temperature distribution, S – is the surface area of the target, and x and y are the transverse and longitudinal coordinates, respectively.

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Figure 3 shows the dependence of the effective temperature on the thickness of the outer target at different powers. Figure 3 demonstrates that an increase in the thickness of the outer target leads to drop of the effective temperature(at fixed power).

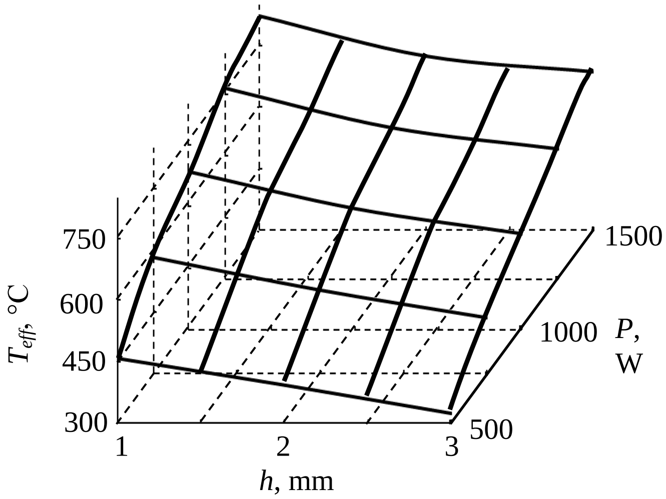

Figure 3. The dependence of the effective temperature of the outer target on its thickness and the incident power.

Based on the received data, it took two steps to develop the model $T = f(P, h)$:

1. determination of the dependence $T = f(h)$ for P = const in the form of a polynomial of the second order:

$$T = b_0 + b_1 h + b_2 h^2. \quad (2)$$

The values of the coefficients b_0, b_1 and b_2 in (2), calculated by the Ordinary Least Squares (OLS), are summarized in table 1.

Table 1. The values of the coefficients of the polynomial (2).

P, W	b_0	b_1	b_2
500	519	–59.0	–2.0
1000	804	–133.5	14.5
1500	980	–188.0	30.0

2. the definition of the dependencies $b_i = f(P)$, i = 0, 1, 2 in the form of a polynomial of the second order:

$$b_0(P) = (125 + 0.897P - 2.18 \cdot 10^{-4} P^2); \quad (3)$$

$$b_1(P) = (35.5 - 0.209P - 4 \cdot 10^{-5} P^2); \quad (4)$$

$$b_2(P) = (-19.5 + 0.036P - 2 \cdot 10^{-6} P^2), \quad (5)$$

the parameters of which are also determined by the OLS.

Using (2)–(5), we write the general expression describing the change in the effective temperature caused by the power and thickness of the outer target:

$$T_{eff}(P, h) = b_0(P) + b_1(P)h + b_2 h^2. \quad (5)$$

Table 2 summarizes the results of calculations in the COMSOL package and based on the model (5). Table 2 confirms the relevance of the model.

Table 2. Comparison of the calculation results.

h, mm	*P*, W	*T*, °C	
		COMSOL	Model
1	500	458	458
2	500	393	393
3	500	324	324
1	1000	685	685
2	1000	595	595
3	1000	534	534
1	1500	822	822
2	1500	724	724
3	1500	686	686

As a result of the performed research:

- a 3D-model of a sputtering unit containing a cold chromium and hot titanium target was developed;
- it is revealed that the temperature over the surface of the target is distributed unevenly and strongly depends both on the design parameters and on the power incident on the target;
- a relevant mathematical model has been created in the form of a second-order polynomial, which determines the dependence of the effective surface temperature of the outer target on its thickness and incident power.

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References

[1] Stone D S, Gao H, Chantharangsi C et al. 2014 *Sur. Coat. Technol* **244** 37
[2] Greczynski G, Lu J, Jensen J et al. 2014 *Sur. Coat. Technol.* **257** 15
[3] Zhang W, Li Y, Zhu S and Wang F 2003 *Vac. Sci. Technol.* **21** 1877
[4] Zaleska A 2008 *Recent Patents on Engineering* **2** 157
[5] Tesař J, Martan J and Rezek J 2011 *Sur. Coat. Technol.* **206** 1155
[6] Mercs D, Perry F and Billard A 2006 *Sur. Coat. Technol.* **201** 2276
[7] Shapovalov V I, Karzin V V and Bondarenko A S 2017 *Phys. Lett. A.* **381** 472
[8] Bleykher G A, Krivobokov V P and Yuryeva AV 2015 *Techn. Phys.* **60** 1790
[9] Bleykher G A, Borduleva A O, Krivobokov V P and Sidelev D V 2016 *Vacuum* **132** 62
[10] Lapshin A E, Levitskii V S, Shapovalov V I et al. 2016 *Glass Phys. Chem.* **42** 359
[11] Bondarenko A S, Kolomiytsev A A and Shapovalov V I 2016 *J. Phys.: Confer. Series.* **729** 012006
[12] Shapovalov V I and Smirnov V V 2017 *J. Phys.: Confer. Series.* **857** 012039