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The possibility of using permanent magnets in planar magnetron installations for sputtering magnetic targets

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Abstract. The paper includes the results of numerical modeling of the spatial distribution of the magnetic field strength of a magnetron discharge. Special attention is paid to the case where the cathode-target is made of a magnetic material. The paper shows that it is possible to obtain the required value of magnetic field induction above the target surface from a magnetic material either at a target thickness of less than 2 mm or by using a heat removal constraint from the target surface.

1. Introduction

The properties of the discharge depend on the complicated character of the electron motion in the cathode area of this discharge form. Due to the crossed electric and magnetic fields special conditions are created in the cathode area in the way to force, the electrons overcome the distance between cathode and anode couple thousand times. As a result, at large free paths of atoms, electrons and ions, which are characteristics of low gas pressures, it is possible to obtain conditions for efficient sputtering of target materials.

This type of discharge is widely used in magnetron sputtering systems (MSS). These systems have found wide application in manufacturing for the modification of the surface of solids [2]. The paper deals with the most common design of magnetron sputtering systems, containing a magnetic core, permanent magnets and a flat target (figure 1). This model includes “arc” type of the magnetic field distribution and the electric field strength directed normal to the target surface.

The existence of the cathode area of a magnetron discharge is associated with the presence of crossed electric and magnetic fields in it. Knocked from the target surface electrons, accelerating in the electric field, fall into a magnetic field (magnetic trap). The electron moves along the cycloid trajectory. This motion is maintained until the electron experiences a collision with a heavy particle. On the one hand, the cycloid radius should be enough to make the electron reach a certain energy level to make the gas molecules ionization possible and on the other hand, it should not allow the electron to leave the magnetic trap. These conditions define the upper and lower boundaries of the intensity of the magnetic field. Within these boundaries this form of discharge can exist.

If the intensity of the magnetic field created above the target surface is less than the lower boundary, the electron knocked from the cathode surface irrevocably leaves the magnetic trap. The magnetron discharge does not burn at that case. Thus, it is necessary to ensure the value of the longitudinal component of magnetic field induction (MF) above the target surface of at least 0.03 T [3] for the existence of a magnetron discharge. Knowing this value and the conditions under which such a value can be obtained is especially important in the design of MSS with magnetic targets [4]. The task

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of developing MSS designs can also be solved experimentally. For this, it will be necessary to create a prototype of the system and determine from the spectrum of emission of the discharge its characteristic by changing the thickness of the magnetic target [5].

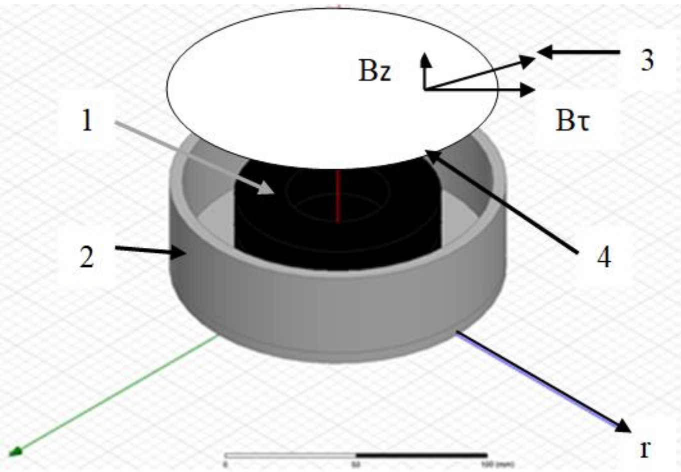

Figure 1. The geometry of studied area.

However, this way requires a considerable amount of time. Therefore, we have previously decided to determine under what conditions the discharge will burn during the design of the MSS with a target of magnetic material. This requires knowing the distribution of the induction of the magnetic field above the target surface. Determination of the induction of MF in a complex con-figuration of the magnetic circuit and permanent magnets is a difficult task. The solution of such a problem is significantly complicated by the fact that the MSSs "work" at high values of the magnetic field strength. In order to obtain adequate information on the field distribution the dependence of the induction of MF on its strength must be taken into account. The task becomes nonlinear and can be solved only by numerical modeling. The paper is dedicated to the development of a mathematical model of the magnetic field in the MSS and to its numerical realization.

2. Modeling the distribution of the magnetic field in the MSS

The real geometry of the MSS magnetic system (schematically shown in figure 1) was used in the calculations. Magnetic field is created by two SmCo magnets (1). The lines of the magnetic field are commutated through the magnetic core made of electrotechnical steel (2). The vector of the magnetic induction might be presented as vector sum of longitudinal (Br) and transversal (Bz) components (3). The target (4) is located in the immediate vicinity from the upper surface of the magnetic circuit (2 mm are necessary for vacuum isolation of the system and its uniform cooling).

The field distribution was defined by fourth Maxwell equation solution:

$$\mathrm{div}\vec{\boldsymbol{B}} = 0, \qquad (1)$$

where B – magnetic induction vector.

The induction of the magnetic field was assumed to be zero on all the boundaries at a significant distance from the investigated region. A three-dimensional model was developed. It allows us to investigate not only axisymmetric systems (as most authors), but also the variants for including complex targets, consisting of magnetic and nonmagnetic materials. This task was solved numerically with the help of the created mathematical model in the ANSYS program. The adequacy of the obtained results was determined by comparing the results of physical experiments performed with the help of the magnetometer RSh1-10. The longitudinal component of the magnetic induction experimentally was measured experimentally over the surface of a titanium target 5 mm thick. In addition, it was obtained by numerical simulation in the field of the existence of a magnetron discharge and differed from the experimental one by no more than 5 %. The accuracy of the results of

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the numerical simulation depended on the domain partition. The magnetic core, the target (especially made of magnetic material), and the region of the formation of the magnetron discharge must be broken down in detail (the maximum number of elements of the partition).

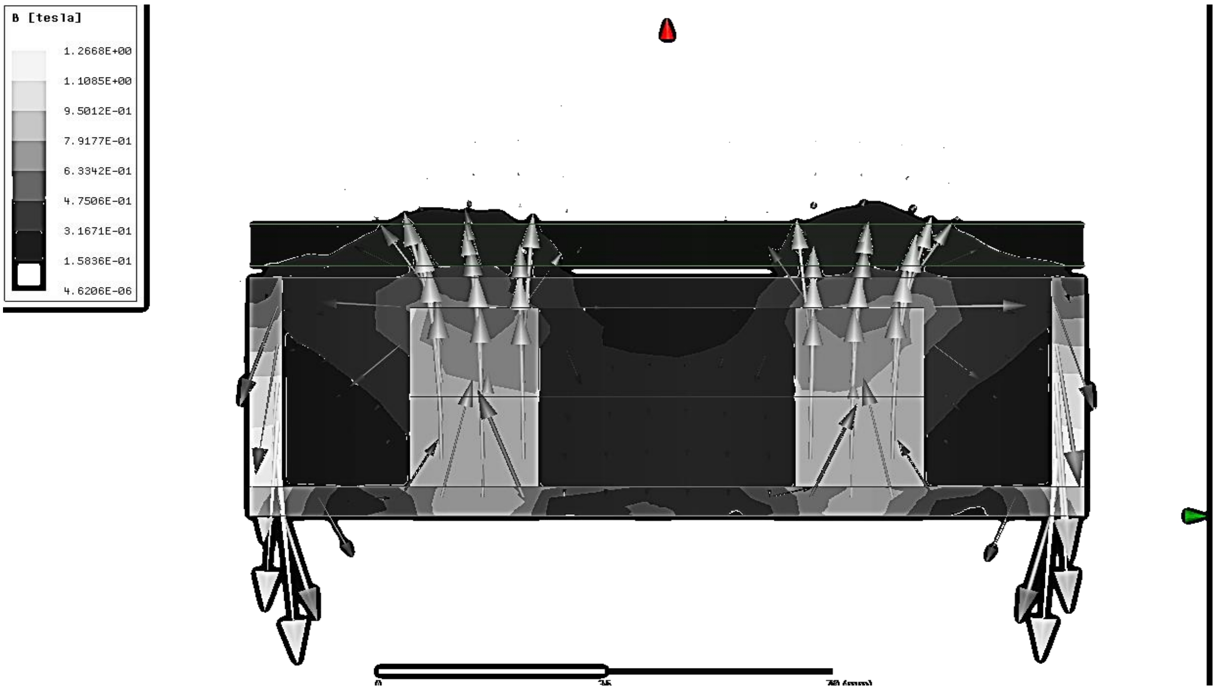

Figure 2. The results of the calculation of the field strength distribution created by the magnetic system of MSS using a non-magnetic target.

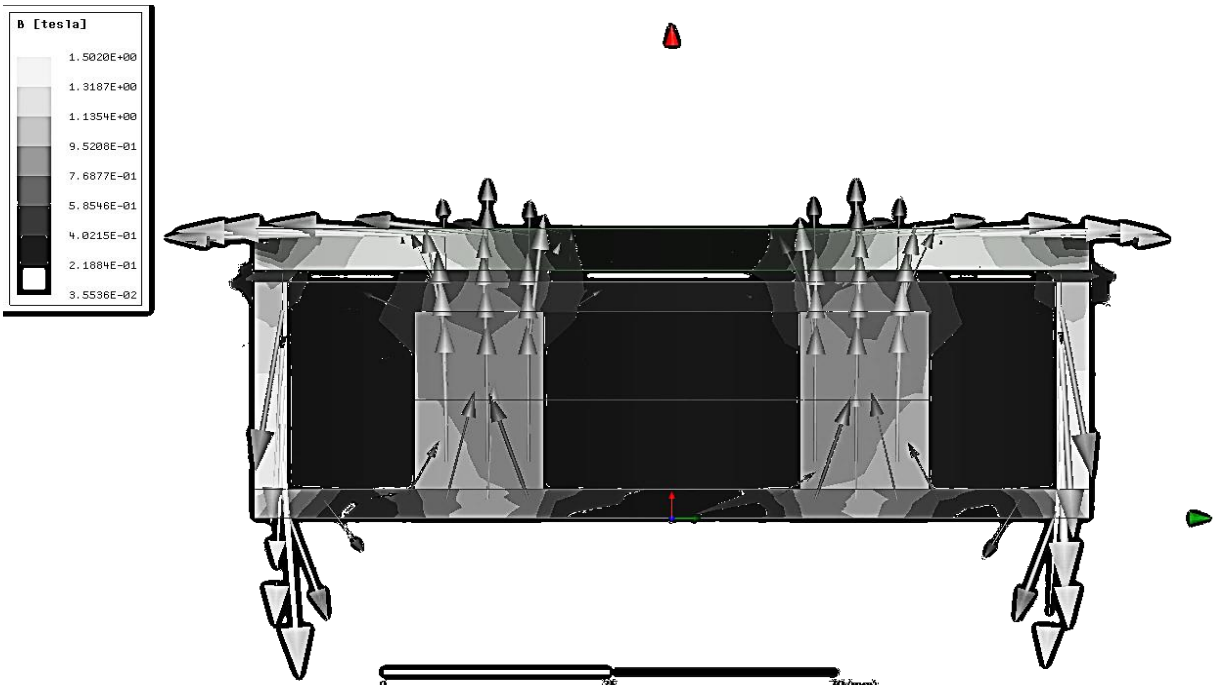

Figure 3. The results of the calculation of the field strength distribution created by the magnetic system of MSS using magnetic target.

The results of the calculations are obtained in the form of a vector distribution of the magnetic induction and can be hardly estimated in practice. These results can be used primarily as illustrations of ongoing processes. It is much easier to estimate the distribution of the MF strength in the two-dimensional approximation. In particular, figure 2 and 3 show the distribution of the magnetic induction module for the titanium (figure 2) and nickel targets (figure 3). The differences are obvious. Especially when (as in figures 2 and 3) targets are equally thick h = 7 mm.

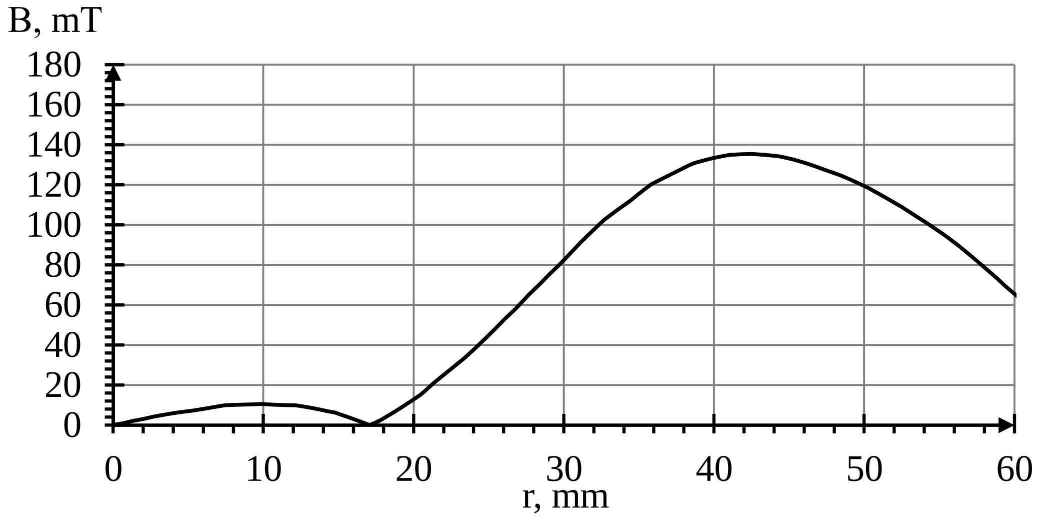

Figure 4. The results of calculating the distribution of the longitudinal component of the magnetic field strength above the target surface of titanium with a thickness of 7 mm.

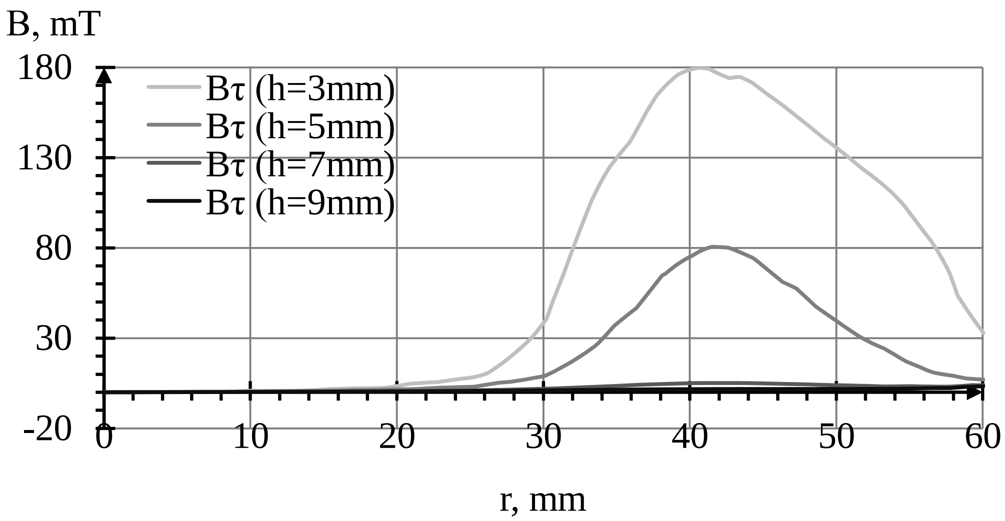

Figure 5. The results of calculating the distribution of the longitudinal component of the magnetic field strength above the target surface of nickel of a different (h) thickness.

However, the highest interest is in tangential component of magnetic induction, directed along the target. Figure 4 and 5 show the distribution of the tangential component of the magnetic induction above the target surface of titanium with a thickness of 7 mm (figure 4) and nickel of different thicknesses (figure 5). These results was obtained when the target was 2 mm from the magnetic system, that is at h = 3 mm the thickness of the target is 1 mm. The comparison of the results shows that it is possible to achieve the desired value of the magnetic induction using permanent magnets only by reducing the thickness of the target from nickel with relatively thin targets (not more than 2 mm thick).

The use of such targets is technologically unfeasible. This is complicated by the need for its frequent replacement. In addition, the use of thin targets is associated with the difficulty of uniform heat removal from their surface. As a result, there is possibility of local overheating of the target above the Curie temperature and the occurrence of temperature instability in the given region. This manifests itself strongly when more than 50 % of the target is generated. The desired value of induction can be obtained either by using combined targets with a ring-shaped liner of magnetic material in a nonmagnetic base, or by heating the nickel target above the Curie temperature. The latter can be achieved by reducing the heat removal from the target, i.e. creating a target design similar to that proposed in the paper [6]. The calculated distribution of the magnetic induction is shown in figure 6 (nickel target of thickness h = 2 mm and the limitation of the heat removal from the discharge burning region). In the calculation of the target temperature distribution, the power deposited in the target surface of 1 kW was assumed to be distributed evenly in the region of the burning discharge (ring with outer and inner diameters of 120 and 110 mm). A heat removal carried out by contacting the edges (5 mm in the outer and 10 mm in the inner diameter) of the target with a copper water-cooled disc. Numerical calculations show that in this case the tangential component of the magnetic induction was sufficient to burn the magnetron discharge.

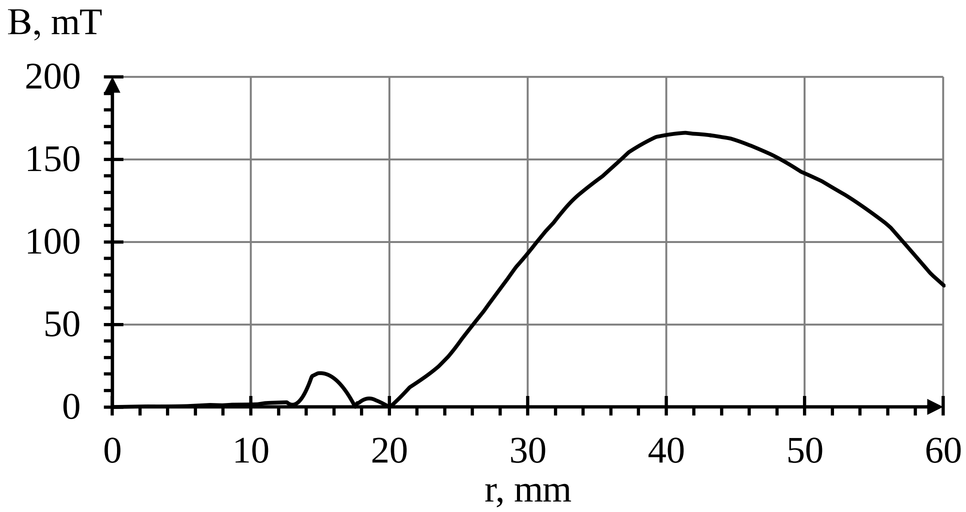

Figure 6. The results of calculating the distribution of the longitudinal component of the magnetic induction with the heat removal above the target surface of nickel with a thickness h = 4 mm.

3. Conclusions

1. The accuracy of the calculation of the MF distribution parameters depends on the domain partition of the individual elements.

2. The desired value of magnetic field induction using permanent magnets can only be achieved by reducing the thickness of the target from nickel (less than 2 mm).

3. The induction value required for the "operation" of the MSS can be achieved by warming up the nickel target above the Curie temperature (the target thickness cannot be more than 5 mm).

The accuracy of the results of the numerical simulation depended on the domain partition.

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