Investigation of a small-sized source parameters for magnetron sputtering with liquid-phase target

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Abstract. The article describes an investigation of a small-sized source called NMSA-52M for magnetron sputtering with liquid-phase target. Causes and features affecting the discharge power required for the target melting are considered. Methods of increasing the discharge power of a given source are proposed. The design of the crucible reducing the intensity of the heat sink is given.

1. Introduction

Thick conductive films (from 20 to 50 μm) are widely used in electronics and power engineering: they are used in power microelectronics, in thermoelectric modules production, in hybrid and traction engines manufacture, as well as in wind power and rocket engineering [1–2, 14]. There are various methods of forming such coatings: copperplating, DBC technology, vacuum arc deposition and magnetron sputtering (MS). For a number of factors, such as the rate of deposition, the cleanliness of the coating, the economy and environmental friendliness, MS exceeds the other methods by 30–100 % [1–5]. However, during the MS process the biggest amount of energy transferred to the target goes to its heating. As a development of this method MS with liquid-phase target was invented. To implement this method, the target is placed in a refractory crucible and is insulated from the cooling system, due to what the target material melts, and thermal evaporation is added to the sputtering. As advantages of this method comparing to standard MS it is possible to list 5- to 10-fold increase in deposition rate, an improved cleanliness of the coating by a factor of 20 to 50, an energy consumption reduction to 50–100 V/Atom [1, 5–10].

To melt the target and initiate the "self-sputtering" process mode, it is necessary to achieve a certain discharge power. The main parameters affecting the discharge power are: the discharge voltage, the working pressure, and the value of the of the magnetic field induction on the target surface. The first two parameters are limited by the plant technological capabilities, while the magnetic induction tangential component value on the target surface is determined by the magnetron and magnetic system constructional features. Nowadays, the MS with liquid-phase target process is investigated using magnetrons with overall dimensions from 80 mm to 150 mm [8, 16]. The magnetron presented in this paper is small-sized (its target diameter is 50 mm), which is one of the reasons for requiring a larger magnetic field induction tangential component value to achieve the required discharge power for the target melting. Also, the design and the crucible material influence the discharge power supplied to the target [6, 10–14]. The aim of this paper is to investigate a small-sized source for magnetron sputtering with a liquid-phase target.

2. Magnetron NMSA-52M construction

The target diameter of small-sized magnetron NMSA-52M is 50 mm (2"). In the magnetron frame there are holes for water cooling with a diameter of 6 mm (figure 1(a)). The magnetic system consists of cylindrical and circular magnets made of SmCo material (figure 1(b)).
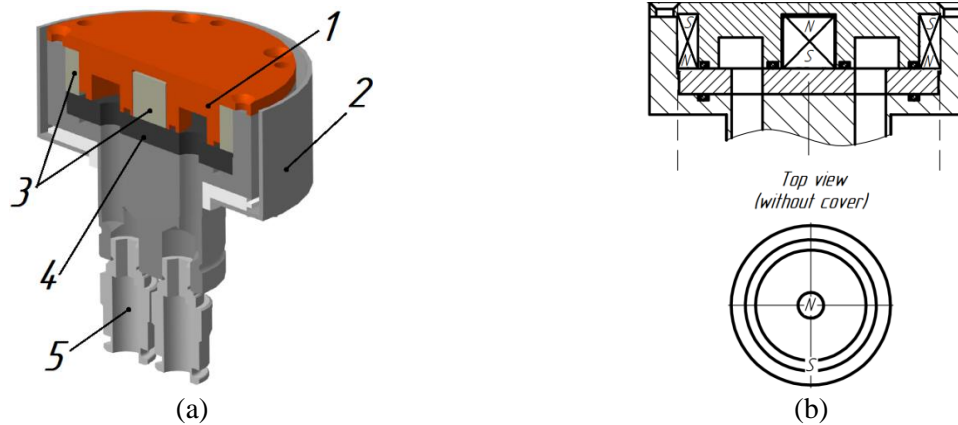

| (a) | (b) |

Figure 1. Magnetron NMSA-52M: section of the body (**a**): 1 – cover, 2 – frame, 3 – magnets, 4 – magnetic core, 5 – holes for cooling; general view (**b**).

During the magnetron sputtering with liquid-phase target process, the target material is often placed in a refractory crucible made of molybdenum which is located at the magnetron surface. The gap between the crucible and the cover is maintained by crucible legs (figure 2), which ensures thermal insulation of the crucible from the cooled magnetron cover [15].
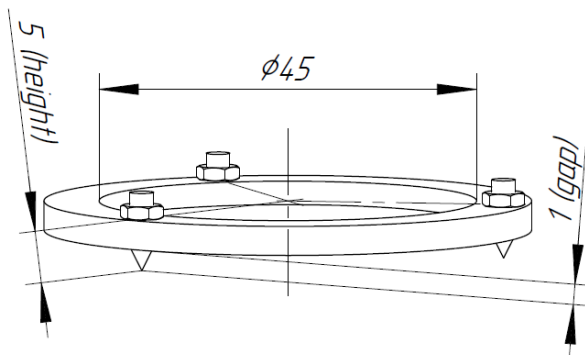

Figure 2. Molybdenum crucible with legs.

3. Magnetron NMSA-52M construction features analysis

3.1. Small overall dimensions

The magnetron for MS with liquid-phase target process presented in this article is small-sized, which allows its use it as a technological source in laboratory vacuum plants. However, in case of a small-sized source a larger value of the magnetic field induction on the target surface is needed to achieve a discharge power sufficient to melt the target. This may be due to the fact that the value of the Lorentz force sufficient to hold electrons in the plasma region is inversely proportional to the electron trajectory radius. Earlier studies were carried out for the presented magnetron [17], where a magnetic system with two plasma regions was modeled and implemented to increase the value of the magnetic field induction tangential component (figure 3). When the magnetron was powered, discharge combustion was observed only in the magnets outer the ring region, in spite of the fact that the value of the magnetic field induction tangential component on the target surface in both regions was equal (figure 4).
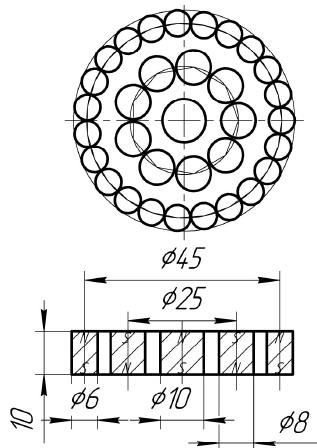
Figure 3. The magnetic system construction of the magnetron NMSA-52M with two plasma regions.

Despite the increase of the magnetic induction tangential component value, the use of such magnetic system did not lead to a discharge power increase. It can be concluded, that the discharge power is affected both by the magnetic field induction tangential component value on the target surface and the magnetron discharge plasma region geometric parameters. Experiments carried out to study the ring magnet diameter influence on the discharge power showed that a decrease in the ring magnet diameter leads to a decrease in the discharge power, despite the increased tangential component of the magnetic field induction on the target surface. Thus, the small overall magnetron dimensions prevent achieving larger discharge power values.
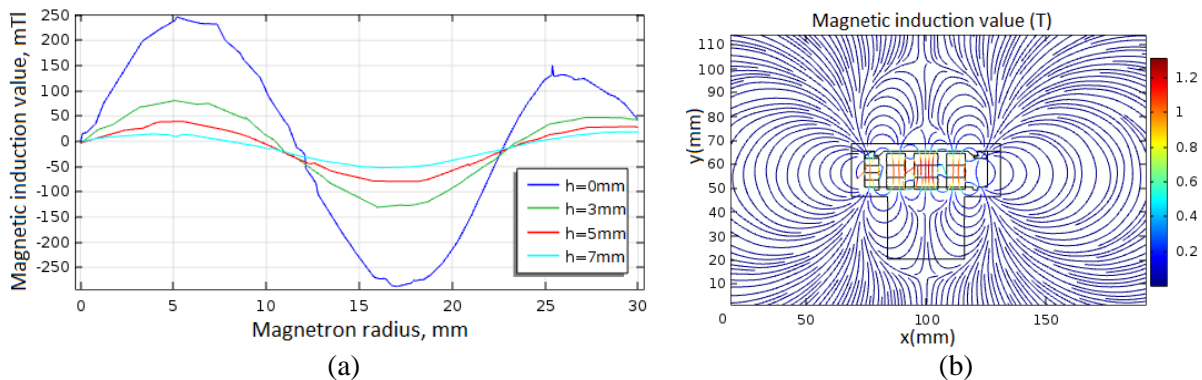

(a)   (b)

Figure 4. Magnetic system with two plasma regions magnetic field characteristics: the dependence of the magnetic field induction tangential component on the distance to the magnetron center (**a**); the magnetic field distribution (**b**).

3.2. Magnetic system

To obtain the required discharge power value, it is not sufficient to increase only the magnetic field induction tangential component on the target surface. It is also necessary for the magnetic system to create a magnetic field uniform distribution in the plasma region [17]. For this purpose, in the described case of a planar magnetron with axial symmetry, the magnetic system must also possess axial symmetry. For magnetron NMSA-52 such a system is an annular magnetic system (figure 5), consisting of a central cylindrical and peripheral annular magnets mounted on a magnetic core made of ferromagnetic material.

In addition, the strongest magnet material should be used. In the original construction magnets made of SmCo material are used, its residual magnetic induction value is 1.07 T. To increase the magnetic field induction tangential component, one can use, for example, magnets made of NdFeB N45 material, which has a higher induction value of 1.35 T.
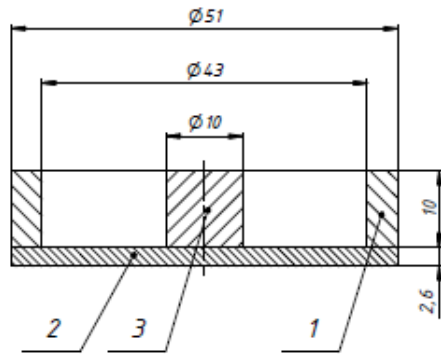
Figure 5. Magnetron NMSA-52M annular magnetic system: 1 – annular magnet; 2 – magnetic core; 3 – central cylindrical magnet.

3.3. Crucible material and construction

The crucible must be made of refractory material, for which the melting point is much higher than the target material melting point. Therefore the most suitable materials for the crucible are molybdenum and tantalum. The latter is a more technological material for making crucibles by means of cold stamping.

The crucible thickness, the gap size when installed on the magnetron cover, and the target thickness (or material granules) contribute to the magnetic field induction value on the target surface. To ensure the discharge power required for the target melting and initiate the process in "self-sputtering" mode, the crucible thickness and the gap size should be minimal. A new construction of crucible shown on the figure 6 was developed to increase discharge power. The crucible is made from a 0.5 mm thick tantalum sheet which reduces the crucible thickness by 2 mm in comparison with the standard molybdenum crucible showed in figure 2. The tantalum crucible is screwed to the magnetron cover, which ensures a more stable electrical contact between the magnetron cover and the crucible. It was established experimentally that a gap size of 1 mm is sufficient to thermally insulate the crucible and provide a guaranteed gap in the target melting process, taking into account the crucible deformation due to thermal expansion.

In order to solve the problem of target melting using a small-sized magnetron, a decrease is considered in the necessary discharge power value for target melting by reducing heat removal from the crucible. Two heat removal mechanisms take place: due to the thermal conductivity of the crucible legs connected to the cooled magnetron frame, and by means of radiation. To reduce the heat dissipation due to thermal conductivity, it is necessary to use a material with a low thermal conductivity coefficient value. The heat sink can be reduced by increasing the legs length, as well as their contact with the crucible at points, where the temperature differs the most from the molten target temperature, which explains the unusual crucible legs shape (figure 6). To reduce the heat removal intensity due to radiation, it is necessary to use a material with a low radiation coefficient value [8, 16].
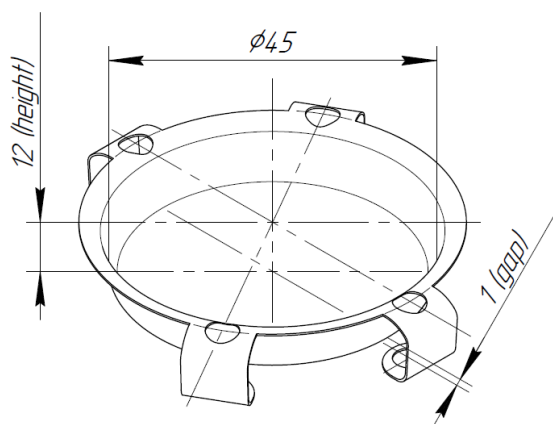

Figure 6. Tantalum crucible with legs.

4. Results and conclusions

Varying the voltage and working gas pressure in the range determined by the technological capabilities of the installation does not allow to achieve the required discharge power value when using a small-sized source for MS with liquid-phase target. A discharge power increase in this case is possible due to a magnetic field induction increase on the target surface, at the same time a decrease in the source size for MS with liquid-phase target leads to an increase in the magnetic field induction necessary value to achieve the required discharge power value. The magnetic field above the magnetron surface must be uniform to guarantee axial symmetry of the magnetic system, provided the magnetron is co-planar and axially symmetric. The discharge power is influenced both by the magnetic field induction tangential component value on the target surface, and by the discharge plasma region geometric parameters, the small dimensions of the magnetron hinder the achievement of significant discharge power values. Another way to achieve a sufficient power to melt the target is to reduce the heat removal intensity from the crucible, which leads to a decrease in the discharge power required for the target melting. The proposed crucible design makes it possible to reduce the heat sink intensity.

References

[1] Sidelev D V, Yuryeva A V, Krivobokov V P, Shabunin A S, Syrtanov M S and Koishybayeva Z 2016 *Journal of Physics: Conference Series* **741** 012193

[2] Asainov O H, Bainov D D, Krivobokov V P, Romanenko S E and Chernyatina A A 2011 *Russian Physics Journal* **54** 158–61

[3] Erofeev E V, Kagadei V A, Kazimirov A I and Fedin I V 2015 *Proc. Int. Sib. Conf. on Control and Communications SIBCON (Omsk)* 7147054

[4] Kashkarov E B, Nikitenkov N N, Syrtanov M S, Sutygina A N, Shulepov I A and Lider A M 2016 *Applied Surface Science* **370** 142–8

[5] Bleykher G A, Krivobokov V P and Yuryeva A V 2015 *Russian Physics Journal* **4** 431–7

[6] Danilin B S, Kakurin M V and Minaichev V E 1978 *Elektr. Tekh. Ser. Mikroelektr.* **24** 84–7

[7] Bleykher G A, Krivobokov V P and Tret'yakov R S 2011 *Izv. Vyssh. Uchebn. Zaved. Fiz.* **11/2** 148–53

[8] Musil J, Lestina J, Vclek J and Tolg T 2001 *Journal of Vacuum Science and Technology A* **19** 420–4

[9] Yuryeva A V, Shabunin A S, Korzhenko D V, Korneva O S and Nikolaev M V 2017 *Vacuum* **141** 135—8

[10] Bleykher G A, Krivobokov V P, Yurjeva A V and Sadykova I 2016 *Vacuum* **124** 1–7

[11] Breauer G, Szyszka B, Vergohl M and Bandorf R 2010 *Vacuum* **84** 1354–9

[12] Bleykher G A and Krivobokov V P 2012 *Nucl. Instr. Meth. Phys. Res.* **292** 34–9

[13] Sakurai Y, Nakajima R and Nakamura H 2009 *Solid State Phenomena* **154** 175–9

[14] Khramova A A, Matanin A R, Polin D A, Vasiliev D D and Moiseev K M 2018 *13th Int. Scientific and Technical Conf. "Vacuum Technique, Materials and Technology"* ed S B Nesterov (Moscow: NOVELLA) pp 124–8

[15] Akishin M Y, Rogozhin A A, Vasiliev D D and Moiseev K M 2016 *The Future of Mech. Eng. in Russia: a collection of works of the 9th All-Russian Conf. of Young Scientists and Specialists* (Moscow: BMSTU Publishing) pp 290–2

[16] Musil J, Rajský A, Bell A J, Matouš J, Čepera M, and Zeman J 1996 *J. Vac. Sci. Technol. A* **4** 2187–91

[17] Khramova A A, Matanin A R, Vasiliev D D and Moiseev K M 2017 *Materials of the 24th Scientific and Technical Conf. with the participation of foreign specialists "Vacuum science and technology"* ed S B Nesterov (Moscow: NOVELLA) pp 187–92