Deposition of AlMgB14 films by sputtering in a non-self-sustained high-frequency discharge

V V Shugurov¹, Yu H Akhmadeev¹, I A Zhukov² and P Yu Nikitin²

¹Institute of High Current Electronics SB RAS, Tomsk, Russia
²National Research Tomsk State University, Tomsk, Russia

E-mail: shugurov@inbox.ru

Abstract. The paper presents the method of plasma-assisted deposition of AlMgB14 films in a discharge system that consisted of a large volume gas plasma generator with a thermionic and a hollow cathode. An electrode with a BAM powder was placed in plasma. High-frequency voltage of 13.56 MHz was applied to the electrode with a BAM powder. In contrast to traditional RF magnetron deposition, the use of the discharge system made it possible to significantly increase the deposition rate for BAM films and reduce the pressure of the working gas. The modes of plasma generation and the properties of the films were investigated.

1. Introduction
Al-Mg-B14 (BAM) ceramics has a low friction coefficient and high hardness and therefore meets a high interest for creating wear-resistant low-friction coatings.

Recently such coatings are mainly obtained by laser ablation and RF magnetron deposition, which are used to produce coatings from dielectric targets [1]. However, these methods demonstrate a very low rate of film production. Besides, the preparation and sintering of ceramic targets to produce BAM films is a complex technical problem that significantly increases the cost of the final product.

The authors developed a method for producing BAM films by sputtering a powder target. Intermetallic powder Al12Mg17 (average particle size 20 μm) and amorphous black boron powder (average particle size 2.1 μm) were used as source materials. The powders were mixed in the atomic ratio of Al12Mg17:B equal to 2:14 and mechanically activated in a planetary mill for 3 hours [2].

To increase the deposition rate of BAM films, the authors developed a discharge system that combined a RF sputtering system and a large volume gas plasma generator with a thermionic and a hollow cathode (PINK) [3]. The use of an independent gas plasma source made it possible to significantly intensify ion sputtering and increase the deposition rate. The experiments were carried out on the electron-ion-plasma installation, namely COMPLEX, for surface engineering. The installation was developed in the Laboratory of Plasma Emission Electronics, Institute of High Current Electronics SB RAS and included in the list of unique installations of the Russian Federation (UNIKUUM Complex http://ckp-rf.ru/usu/434216/) [4].

2. Results and discussions
The discharge system is plotted in figure 1. BAM films were deposited using an electrode system that consisted of the PINK gas plasma generator and a coaxial water-cooled shielded RF inlet. A stainless steel target with BAM powder was installed on the surface of the RF inlet facing the plasma. The
target diameter was 200 mm, and the powder thickness was 3-4 mm. The target was located at the distance of 170 mm from the outlet aperture of the PINK plasma generator. A sample holder was placed between the target and the PINK plasma generator to enable BAM coating on the sample. The temperature of the samples during the deposition was measured with a thermocouple. The samples were made of C0,12Cr18Ni10Ti stainless steel and Wc-Co8 hard alloy. The surface of the samples was pre-polished to the roughness grade no. 10 and then cleaned with isopropyl alcohol in an ultrasonic bath for 15 minutes.

**Figure 1.** Scheme of the experiment. 1 – PINK plasma generator; 2 – thermocouple; 3 – samples; 4 – RF generator with a coaxial inlet; 5 – BAM powder; 6 – sample holder; 7 – vacuum chamber.

The deposition of the BAM coating was carried out as follows: after a sample was placed inside the vacuum chamber of the COMPLEX installation, the chamber was pumped out to the pressure of at most $5 \times 10^{-3}$ Pa. Then, argon was fed into the chamber to the pressure of 0.1-0.4 Pa, the PINK gas plasma generator was turned on, pulsed negative bias voltage was applied to the sample to initiate ion-plasma cleaning and activation of the sample surface in argon plasma. After cleaning and heating the sample to the temperature of 450°, RF power was applied to the target with the BAM powder to coat the sample with a BAM film. After the deposition of the BAM film, the sample was cooled in vacuum to the temperature of less than 100°C. The main parameters of the optimal deposition of the BAM film are presented in table 1.

**Table 1.** Modes of cleaning samples and depositing BAM films.

| Parameter       | Unit | Cleaning, heating | BAM film deposition |
|-----------------|------|-------------------|---------------------|
| PINK current    | A    | 15                | 50                  |
| Argon pressure  | Pa   | 0.5               | 0.5                 |
| Bias voltage    | V    | 990               | 100                 |
| RF power        | W    | -                 | 700                 |
| Process time    | Min  | 15                | 60                  |

The thickness of the resulting film was measured using the calotest method and was 2.2 μm after 60 minutes of deposition. Figure 2 shows micrographs of the BAM film with a trace from the calotest ball at different magnifications. It can be seen that the film remains transparent up to the thickness of about 1 μm as evidenced by the interference pattern, which indicates the high quality of the film.

The rate of volumetric wear and the friction coefficient were determined with a tribotester using the pin-on-disk method in dry conditions. A 52100 steel ball was used as a counter-body. The change in the friction coefficient is shown in figure 3.
Figure 2. Micrographs of the BAM film.

Figure 3. Graph of the friction coefficient.

The average friction coefficient of the BAM film on the VK-8 substrate was 0.14. The rate of volumetric wear $V = 1.1 \times 10^{-5}$, mm$^3$/N$ \times $m, which makes these films promising for use as low-friction wear-resistant coatings.

3. Conclusions

The developed method of plasma-assisted RF sputtering makes it possible to control the properties of coatings during growth and opens up prospects for creating a wide range of functional coatings. BAM films obtained using this method show good mechanical properties and are promising for use as low-friction wear-resistant coatings.
Acknowledgment
The work was supported by the Ministry of Science and Higher Education of the Russian Federation (Number: FWRM-2021-0006).

References
[1] Cook B A, Harringa J, Anderegg A, Russell A M, Qu J, Blau P J, Higdon C and Elmoursi A A 2010 Surface and Coatings Technology 205 (7) 2296–301
[2] Zhukov I A et al. 2020 Materials Today Communications 22 100848.
[3] Krysina O V, Koval N N, Lopatin I V and Shugurov V V 2014 Izvestija VUZov Fizika 11/3 88–93
[4] Koval N N and Ivanov Yu F 2019 Russian Physics Journal 62 1161–70