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Detonation Technology in Producing Metal–Ceramic Powder Targets for Magnetron Sputtering

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Abstract—An innovative approach is proposed to the production of plane and cylindrical composite metal–ceramic targets (cathodes) for magnetron sputtering: the use of high-frequency multichamber detonating accelerators. Powder composites are produced from Russian industrial metallic and ceramic powders and then used to produce dense metal–ceramic coatings by detonation spraying on the surface of plane and cylindrical copper substrates.

Keywords: multichamber detonation device, detonation spraying, multicomponent cathode, target, magnetron sputtering

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INTRODUCTION

Magnetron sputtering is of particular interest among the methods of deposition from the vapor phase for a broad range of multicomponent coatings. It is based on cathodic sputtering of a target (cathode) in magnetron discharge plasma, within crossed electric and magnetic fields. Benefits of this approach include flexible adjustment of coating application; uniform coatings over large areas; and ease of scaling for industrial use. What is needed is an effective method of producing the composite targets for magnetron sputtering [1–4].

Several methods are used to manufacture the composite targets: for example, hot pressing, hot extrusion, and hot isostatic pressing [5]. In most cases, serious deficiencies limit the industrial use of these approaches. As a rule, powder technology is employed. Another option is self-propagating high-temperature synthesis in powder mixtures, in combination with pressing of the hot porous product [6–8]. The elemental composition that may be used in producing complex compositions by self-propagating high-temperature synthesis is limited, since reaction is only possible in mixtures with sufficient heat liberation [9]. In hot pressing and subsequent cooling, great internal stress of the first kind develops in the cathode target, leading to its partial destruction in magnetron sputtering.

These problems may be overcome by creating mosaic ceramic cathodes in a metallic matrix. However, the manufacture of such targets is very difficult, and control of the final coating composition is complex.

Accordingly, we propose a new approach to the manufacture of both plane and cylindrical metal–ceramic targets for magnetron sputtering. By detonation spraying, a broad spectrum of powders may be applied as thick protective coatings on the surfaces of components that are subject to severe wear [10–14].

In detonation spraying, the kinetic energy of the powder may exceed 1000 m/s. That prevents decomposition and oxidation of the powder. The coating formed is characterized by dense microstructure; low porosity (<1%); good adhesion, without defects at the substrate boundary; and uniform distribution of the chemical elements present in the powder.

In the present work, we demonstrate the effectiveness of detonation spraying in producing metal–ceramic targets for magnetron sputtering, with controllable target composition. This approach ensures

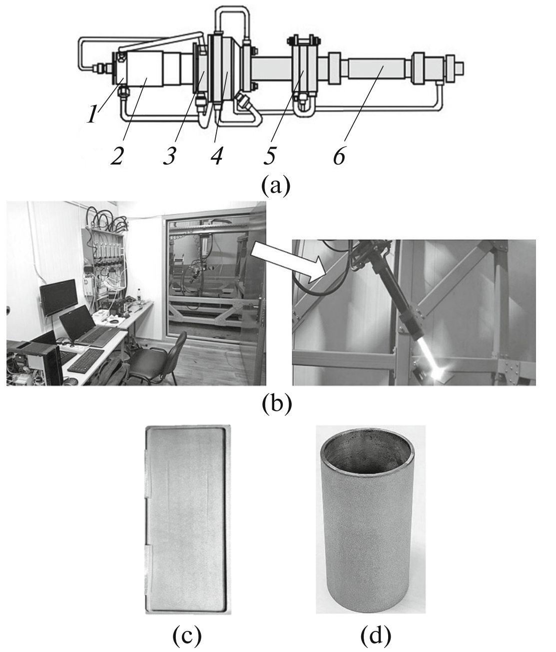


Fig. 1. (a) Configuration of high-frequency multichamber detonating accelerator: (*1*) gas mixing unit; (*2*) intake chamber; (*3*) detonation chamber; (*4*) accumulation and detonation chamber; (*5*) unit for gas-dynamic synchronization of the gas–powder jet and the combustion products; (*6*) chamber for acceleration and heating of powder portions; (b) robotic system for detonation coating application; (c) external appearance of plane magnetron sputtering targets with a composite metal–ceramic coating; (d) external appearance of coated cylindrical sputtering targets.

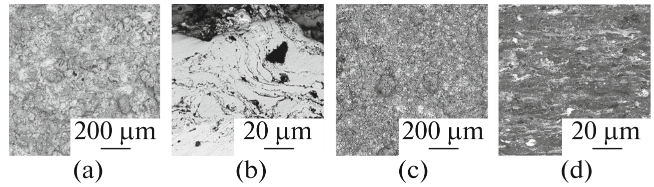


Fig. 2. Surface (a, c) and cross section (b, d) of composite metal–ceramic target: (a, b) Ni–Cr–B_4C; (c, d) Mo–Al–W–B_4C.

uniform distribution of the powder within the volume and over the surface of the applied layer. Hence, thin composite coatings with unique composition and characteristics may be synthesized.

EXPERIMENTAL METHODS AND RESULTS

To manufacture metal–ceramic composite targets for magnetron sputtering from powder, we use high-speed gas-dynamic coating application by means of a multichamber detonation accelerator. The basic structure of the accelerator is shown in Fig. 1a.

The multichamber detonation accelerator consists of a detonation spraying system, characterized by non-steady combustion of a gas mixture at a frequency of 20–50 Hz in specially shaped chambers. The combustible gas employed is a mixture based on oxygen and propane–butane, which forms combustion at moderate temperatures (up to 2000°C), without overheating of the micropowders. The high speed of the combustion products is associated with their accumulation from cylindrical and hemispherical chambers and the formation of a region of high pressure (up to 35 atm) ahead of the nozzle input.

Thanks to the rapid pressure increase of the combustion products and the large pressure difference, shock waves form in the nozzle, and the combustion products exit at high speed (up to 1600 m/s). The preliminary introduction of a dose of the micropowder mixture in the nozzle ensures their heating and acceleration to 1000 m/s. The hot micropowders are pressed at high speed into the target surface, creating a dense coating with a uniform distribution of chemical elements. This system may use two or more devices for dosing and introduction of the micropowder mixture. That increases its flexibility and permits the creation of a target with a mosaic coating from any powder mixture.

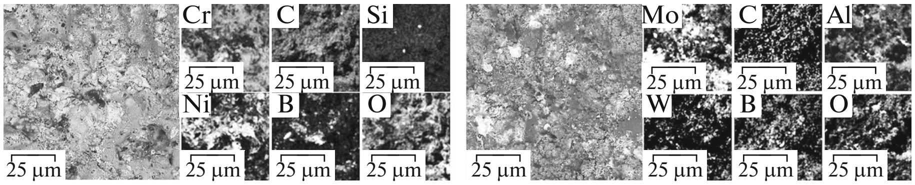
In Fig. 1b, we show a robotic system for coating application by detonation spraying, which was produced by IntelMashin (Russia) for Shukhov Belgorod State Technological University (Belgorod).

In the research, we use Russian powder from Volzhsky Abrasive Plant: PNE-1 powder (99% Ni); PKh1M powder (99.2% Cr), MPCh powder (99.5% Mo), PVT powder (99.6% W), AS powder (99.7% Al), and F400 FEPA B_4C powder. A Fritsch Pulverisette 6 planetary mill is used for mixing and homogenization of powders, with a 2 : 1 mass ratio of the vapor and

Table 1

Powder	Consumption of combustible materials, m^3/h			Powder supply, g/h	Spraying distance, mm	Application rate, μm/min
	air	oxygen	propane			
Ni–Cr–B_4C	1.6/1.4	2.5/2.8	0.5/0.6	700	60	500
Mo–W–Al–B_4C	1/1.12	3.22/3.50	0.73/0.73	700	60	455

Cylindrical/annular combustion chamber.



(a) (b)

Fig. 3. Surface elemental distribution of composite metal–ceramic targets according to energy-dispersive X-ray spectroscopy: (a) Ni–Cr–B_4C; (b) Mo–Al–W–B_4C.

mixture, at a speed of 200 rpm for 20 min, in isopropyl alcohol.

The metal–ceramic powder is applied to a copper plate (198 × 78 × 4 mm) and a cylinder (diameter 71 × 100 × 5 mm). Before coating application, oil deposits are removed from the copper plate by means of hexane, with subsequent shot blasting of the plate at a pressure of 0.3 MPa. Table 1 summarizes the operating conditions of the detonation system in coating application.

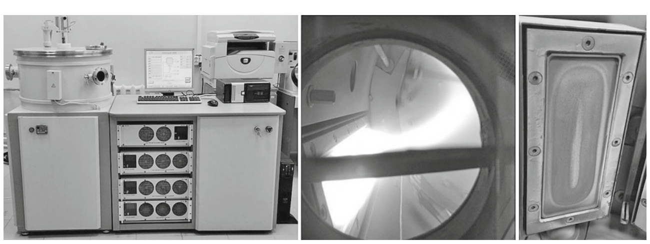
In Figs. 1c and 1d, we present composite metal–ceramic targets produced by detonation spraying. Visually, the target surface is smooth, without defects. It is silvery gray in color.

Electron-microscope images of the surface and cross section (Fig. 2) show that the target with a composite metal–ceramic coating has a dense and uniform structure, without visible defects or pores. The coating consists of molten and partially molten particles distributed over the surface. The molten metal particles may flow over the surface on impact. Then the flattened plates harden and form layers. The partially molten B_4C particles may collide with the substrate and take on irregular form. Therefore, the metallic binder is partially or completely molten, and most of the B_4C particles remain solid in spraying.

In Fig. 3, we show the elemental distribution in the composite metal–ceramic targets according to energy-dispersive X-ray spectroscopy. Analysis shows that the initial powders are well mixed and their distribution in deposition is uniform. The presence of a small quantity of oxygen at the surface may be attributed to the great activity of the hot metal surface, with partial oxidation on cooling.

A UniCoad 200 vacuum unit with an unbalanced magnetic system is used for magnetron sputtering (Fig. 4a). A planar magnetron with an IVE-143D power supply permits application of the composite coating. The magnetron operates in current stabilization mode (at 2 A) with a voltage up to 580 V, at a pressure of 0.17 Pa.

In magnetron sputtering, stable combustion of the magnetic discharge plasma is observed, without pulsations (Fig. 4b). In coating application, no microscopic arcs are seen. In sputtering, traces of annular erosion appear on the target surface, on account of the loss of Ar^+. The erosion is uniform over the whole surface of the target (Fig. 4c).



(a) (b) (c)

Fig. 4. External appearance of UniCoad 200 vacuum unit (a); magnetron sputtering with composite metal–ceramic target (b); and surface of target after sputtering (c).

CONCLUSIONS

1. A new approach is proposed to the production of plane and cylindrical composite metal–ceramic targets (cathodes) for magnetron sputtering, with controllable chemical composition. This approach ensures uniform distribution of the powder over the surface of the applied layer. Hence, thin composite coatings with unique compositions and characteristics may be synthesized.

2. The experimental results show that detonation technology is promising in the production of metal–ceramic targets for magnetron sputtering.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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