

THE EFFECT OF THE SUBSTRATE POTENTIAL DURING DEPOSITION ON THE STRUCTURE AND PROPERTIES OF THE BINANOLAYER MULTIPERIOD COMPOSITES (TiAlSi)N/MeN (Me – Zr, Nb, Cr, Mo)

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It is proposed to use the multiperiod binanolayer composites (TiAlSi)N/MeN (Me-Zr, Nb, Cr, Mo) for controlling the structure, stress state and mechanical properties of a multi-element nitride (TiAlSi)N. The deposition of the layers was carried out by the method of vacuum-arc evaporation at different bias potentials on the substrate $U_b = -110$ and -200 V. It has been determined that mononitrides with a high Me-N binding energy in the binanolayer composite determine the crystallite growth in thin (nanometer) layers. The growth texture is formed in composites containing mononitrides based on transition metals with a relatively small atomic mass (Cr, Mo) at $U_b = -110$ V. The growth texture is formed at a larger $U_b = -200$ V when dealing with mononitride based on heavy metal (Zr). The greatest hardness is achieved in textured materials deposited at $U_b = -200$ V. This is typical both for a monolayer multi-element nitride (TiAlSi)N (hardness is 42.5 GPa) and for multiperiod nanolayer composites based on it (the highest hardness is 47.9 GPa for a composite (TiAlSi)N/ZrN).

PACS: 81.07.Bc, 61.05.cp, 68.55.jm, 61.82.Rx

INTRODUCTION

Reduction of wear and corrosion, along with increasing thermal stability of tools and mechanical components presents industrial challenges which demand continuous development of new coating materials and coating design concepts. TiN coatings have high mechanical properties [1, 2], but rather low thermal stability [3]. Their mechanical and tribological properties along with their thermal stability and oxidation resistance can be significantly improved by the addition of Al [4, 5]. The Al-Ti-N system coatings have rather high thermal stability, but they are exposed to mechanical properties loss and oxidation resistance at temperatures above 900°C [6]. Silicon is another alloying element that increases hardness and oxidation resistance at high temperatures [7]. As was shown in [8], the addition of a small amount of Si in (TiAl)N significantly increases the oxidation resistance at a high temperature of 950°C. Silicon atoms tend to segregate at the grain boundaries at a high concentration. Such a material can have unique mechanical properties and thermal stability and thus is very promising for high-temperature applications [9]. In addition, silicon use leads to a decrease in the overall stress level of coatings [10].

In most works, ion-plasma (magnetron-type) sputtering is used to produce nitride coatings of the Ti-Al-Si-N system [11]. At the same time, a mixture of Ar/N₂ gases is used as the atomizing atmosphere. In this case, with a silicon content of less than 8 at.%, a single-phase solid solution state is formed with a predominant orientation of the crystallites with texture axis [11]. The crystallite size (at which the highest hardness is reached) is about 17 nm [11].

Coatings obtained by magnetron sputtering usually have a hardness of less than 40 GPa, even under optimum production conditions [12].

It should be noted that issues related to the reasons for achieving high physical and mechanical properties in the surface layers and the ability to control these properties remain still open [13, 14]. Even though methods of low-temperature deposition of PVD methods, which include magnetron sputtering, are very popular and used for the coatings production of this type, yet low temperature makes significant kinetic limitations. Such kinetic limitations during coatings formation lead to the formation of supersaturated solid solutions in the metastable state [15, 16].

Recently, the main attention has been focused on research and application of multilayer and nanocomposite coatings.

The work [17] states that the increased pressures of the nitrogen atmosphere (more than 0.5 Pa) with the magnetron method for obtaining coatings lead to a transition to the nanocomposite. At the same time, the metal coating AlTiSi deposited in the absence of reactive gas (nitrogen), demonstrated strong columnar growth. Columnar grains boundaries often serve as sites for nucleation and growth of cracks, which leads to the coatings destruction. Addition of nitrogen to the process gas leads to the creation of a nanocomposite structure consisting of crystalline TiAlN nanograins with a size of 2...3 nm surrounded by an amorphous Si_xN_y phase (and/or an AlN matrix) [17].

It is found that the friction coefficient does not depend on the Si content, while the wear rate is strongly reduced at a higher Si content [18]. It is shown in [19] that the appearance of the texture (200) increases the wear resistance of the coating. The intensity of the XRD peaks from the plane (111) decreases, and from the plane (200) increases with a rise in the ion source voltage from 0 to 600 V. Studies of the tribological properties of Ti-Al-Si-N nanocomposite coatings at high operating temperatures have shown that only coatings of

Ti-Al-Si-N systems applied at a voltage of 600 V ion source show high friction characteristics at high temperatures (500 °C). At the same time, the friction coefficient decreased to 0.27. This result indicates that ion bombardment can significantly increase the wear resistance of Ti-Al-Si-N coatings. The reason for this may be an increase in the adhesive bonding strength with the substrate and an achievement of relatively high hardness caused by the coating sealing during bombardment [19].

The use of the condensation method during ion bombardment (CIB) makes it possible to obtain coatings with higher hardness and good adhesion to various materials of the substrate [20]. For coatings obtained by this method, it was found in [21] that there is a transition from a nanocrystalline state (at a pressure up to 0.04 Pa) and a nanocomposite (0.04...0.66 Pa) to the amorphous state (0.66...1.1 Pa) as nitrogen pressure increases during deposition in the Ti-Al-Si-N system. At the same time, the highest mechanical characteristics and thermal stability were achieved by a coating having a nanocomposite structure with a low content of the amorphous phase.

An even greater effect can be obtained by using a multilayer composite material [22]. Multilayer coatings can be divided into two categories: isostructural (the composite layers have the same structure) and non-isostructural (the composite layers have a different structure) [23]. Multilayer coatings have a great potential for the development of new materials with special properties [24]. In the last decade, a new class of nanoscale coatings has been created with even higher functional properties [25, 26]. This became possible due to the combination of the nanostructural state and the multilayer concept with structural ordering at the nanoscale [27, 28]. Such multifactorial structural engineering leads to a significant increase in the functional properties (especially mechanical) [29].

The purpose of this work was to determine the effect on the structure and properties of multi-element nitride (TiAlSi)N sublayers of transition metal monomerides. Four types of nitrides with different enthalpies of formation were used as the second layers (MeN) in the bilayered period (TiAlSi)N/MeN: ZrN with the greatest enthalpy -371.5 kJ/mol, NbN with enthalpy -255.3 kJ/mol, CrN with enthalpy -123.4 kJ/mol and MoN c enthalpy -37 kJ/mol.

SAMPLES AND RESEARCH METHOD

The samples were obtained by vacuum-arc method at the modernized installation Bulat-6 [30]. The pressure of the nitrogen atmosphere during deposition (P_N) was $2.3 \cdot 10^{-1}$ Pa. The deposition was carried out from one (TiAlSi) or two (TiAlSi and (Mo or Cr or Nb or Zr)) ion sources with continuous rotation of the samples mounted on the substrates (at the speed of 8 rpm). This allowed to obtain layers with thickness (d) of about 6...8 nm with a period (Λ) of about 15 nm and a total thickness of the coating (h) of about 9 μm . The total deposition time of the coating was 1 hour. During the deposition process, a constant negative potential of $-U_b = -110$ or -200 V was applied to the substrates. The deposition was carried out on samples of 20x20x2 mm

in size of 12Cr18Ni10Ti (analog of stainless steel SS 321) austenitic steel ($R_a = 0.09 \mu\text{m}$).

Phase-structural analysis was performed by X-ray diffractometry in $\text{Cu-K}\alpha$ at DRON-4. A graphite monochromator was used to monochromatize the detected radiation and was installed in a secondary beam (in front of the detector). The study of phase composition, structure (texture, substructure) was performed using traditional methods of X-ray diffractometry by analyzing the position, intensity and shape of the diffraction reflexes profiles. The tables of the international center of diffraction data Powder Diffraction File were used to decode the diffractograms.

Substructural characteristics (microdeformation $\langle \varepsilon \rangle$ and size of crystallites L) were determined by the approximation method by varying the diffraction reflexes width from several orders of reflection [31].

The hardness was measured by the microindentation method with the Vickers diamond pyramid as an indenter under loads of 50 g.

Elemental composition analysis was carried out based on the data of energy-dispersive X-ray spectroscopy.

High-resolution electron microscopic investigations into the VEMP gap (highly resolvable, translucent, electron microscopy) were performed on the electron microscope PEM-125K (Selmi, Ukraine).

RESEARCH RESULTS OF STRUCTURE AND MECHANICAL PROPERTIES OF COATINGS

High-resolution “cross-section” electron microscopic coating images reveal good planar layers (Fig. 1). The average thickness of the layers (TiAlSi)N (light) is about 8 nm, and for the second type of layers (in a bilayered composition) of heavy transition metals nitrides (Zr, Nb, Mo, Cr), the thickness of the layers is 4...6 nm (see dark layers in Fig. 1). The relatively large thickness (TiAlSi)N layers is determined by their lower density and, consequently, by a higher rate of deposition.

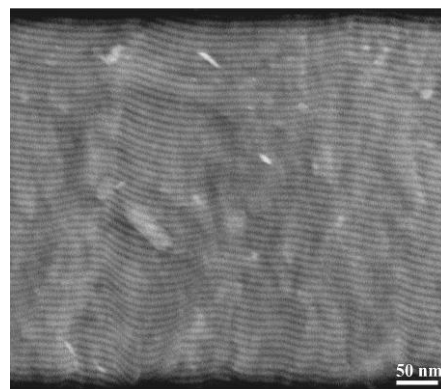


Fig. 1. High-resolution “cross-section” electron microscopic image of coating (TiAlSi)N/ZrN obtained with $U_b = -200$ V

It should be noted that the coating distortions (microflaws) include several layers. It shows that there is an inheritance of the layers structure with the coating growth.

According to the energy-dispersive spectroscopy data, the elemental composition of the monolayers (TiAlSi)N includes Ti and Al atoms in the ratio

$C_{Ti}/C_{Al} \approx 2/1$ (Table). In addition, if the nitrogen content is not taken into account, then by heavy atoms the Si content is close to 3.3%.

Elemental analysis of coatings based on (TiAlSi)N obtained at $U_b = -110$ and -200 V

System	Series number	U_b , V	Content of elements, at.%				
			Ti	Al	Si	Me (Zr, Nb, Cr, Mo)	N
(TiAlSi)N	1	-110	31.63	17.52	1.64	-	49.2
	2	-200	28.65	18.67	1.62	-	49.44
(TiAlSi)N/ZrN	3	-110	20.33	6.9	0.41	22.06	50.30
	4	-200	21.8	5.03	0.37	23.10	49.7
(TiAlSi)N/NbN	5	-110	23.20	8.39	0.81	19.70	47.9
	6	-200	24.70	8.65	0.67	17.98	48.1
(TiAlSi)N/CrN	7	-110	24.60	7.33	0.92	19.98	47.17
	8	-200	33.22	4.94	0.68	14.78	46.38
(TiAlSi)N/MoN	9	-110	21.54	7.21	0.79	21.14	49.32
	10	-200	26.67	5.91	0.45	18.87	48.1

In a multilayer composite, the second nitride layer (based on heavy transition metal) changes the C_{Ti}/C_{Al} ratio. This ratio is about 3/1 for $U_b = -110$ V and 5/1 for $U_b = -200$ V. The most justified reason for such a change in the ratio is the secondary atomization of the atoms from the surface during the coating formation. In this case, bombardment with heavy metal atoms leads to a selective sputtering of lighter (compared with titanium) aluminum atoms.

The phase composition formed during coating deposition was determined by X-ray diffractometry. The obtained X-ray diffraction spectra with the separated peaks are shown in Figs. 2–4. It is evident that a monolayer coating (TiAlSi)N is characterized by the formation of a single-phase state based on the FCC metal sublattice (structural type NaCl). As with $U_b = -110$ V (see Fig. 2,a, spectrum 1), and with $U_b = -200$ V (see Fig. 2,b, spectrum 1), a texture with an axis [111] perpendicular to the growth surface is formed.

In multilayer coatings, the effect of the second layer in a period impacts the structure (TiAlSi)N layer. Thus in the multiperiod coating (TiAlSi)N/ZrN, the presence of the ZrN layer at $U_b = -110$ V results in the absence of a texture, both in the ZrN layers and in (TiAlSi)N layers (see Fig. 2, spectrum 3). When CrN is used as the second layer with $U_b = -110$ V, the texture [111] is formed, both in the (TiAlSi)N and CrN layers (see Fig. 2,a, spectrum 2).

The crystal lattice period for crystallites (TiAlSi)N in monolayers is 0.4149 nm. The obtained value is smaller than the typical for TiN (0.424 nm), due to the substitution in the lattice of about 1/3 of the titanium atoms into aluminum atoms having a smaller atomic radius ($r_{Ti} = 147$ pm, and $r_{Al} = 143$ pm). In the system (TiAlSi)N/CrN in layers (TiAlSi)N, the lattice period is 0.4131 nm, while in the CrN layers the period is about 4 nm (with a table value of 0.414 nm). The latter may

indicate the formation of a tensile stress state in CrN layers.

The crystal lattice period of multi-element nitride in the coatings (TiAlSi)N/ZrN is much larger and is 0.4391 nm (for the ZrN layer the period is 0.4561 nm). The considerable increase in the lattice period in the multi-element nitride layer may be due to the dissolution of some of its heavy atoms Zr during the layer formation.

The peculiarity of the (TiAlSi)N/MoN system is that the presence of the MoN layer results in a change in the growth texture in the layers (TiAlSi)N. The above mentioned texture [111] changes to [100] (see Fig. 4). The interplanar distance in the direction of growth [100] is 0.212 nm. In this case, the crystal lattice period in the multi-element nitride layer is 0.4153 nm. In this case, the major factor in increasing the period (compared to 0.412 nm for a monolayer state) is large compressive stresses. The fact that a large line shift (which corresponds to an increase in the period) is due to stresses showed annealing at which stress relaxation occurred. The vacuum annealing (700 °C, 1 hour) was conducted to determine the effect of this factor and led to the diffraction peak shift towards the large angles (Fig. 4b, shown by the arrow), which is determined by a decrease in the lattice period to 0.4121 nm. The displacement of the diffraction peak position due to annealing corresponds to the macrodeformation relaxation by -2.3% (this corresponds to a compression stress relaxation of -5.4 GPa). Therefore, it is assumed that compressive stresses are greater than 5 GPa in multi-element layers after their deposition.

In coatings obtained with greater $U_b = -200$ V, in the layers of the system (TiAlSi)N (monolayer coatings), as well as systems (TiAlSi)N/CrN, (TiAlSi)N/NbN, (TiAlSi)N/ZrN, a texture with the axis [111] is formed, and in the system (TiAlSi)N/MoN the texture [100] is formed.

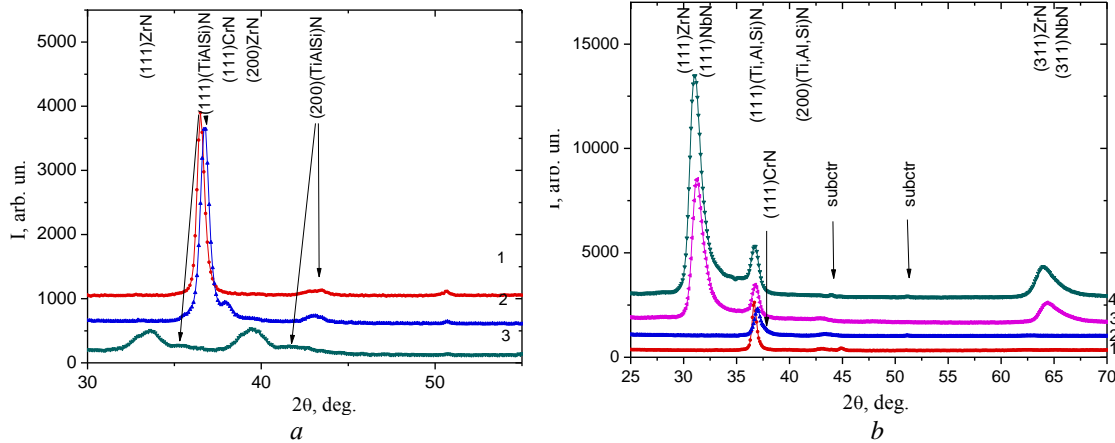


Fig. 2. Diffraction patterns spectrums of coatings obtained at $U_b = -100$ (a) and -200 V (b) for different systems: 1 – (TiAlSi)N; 2 – (TiAlSi)N/CrN; 3 – (TiAlSi)N/NbN; 4 – (TiAlSi)N/ZrN

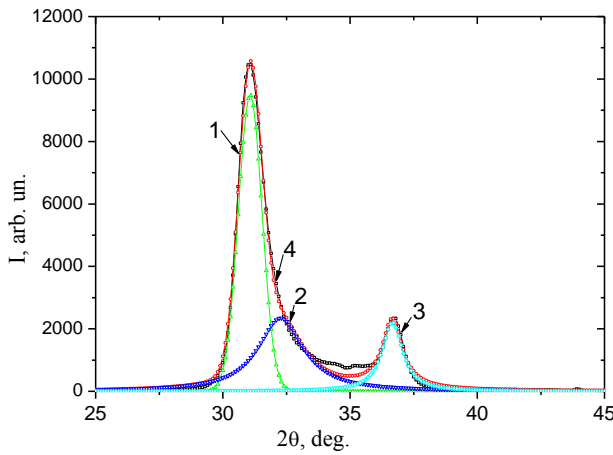


Fig. 3. The area of the complex profile of the diffraction spectrum from the coating (TiAlSi)N/ZrN divided into components. 1 – (111) ZrN; 2 – solid solution based on multi-element nitride; 3 – (111) (TiAlSi)N; 4 – total complex profile

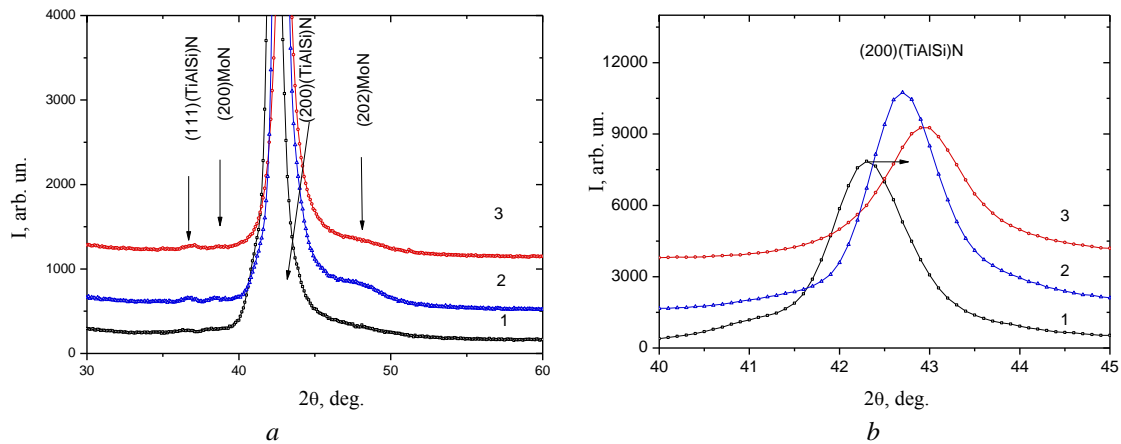


Fig. 4. Diffraction patterns spectrums of the system's (TiAlSi)N/MoN coatings (a – is a general view, b – is the detailing of the peak displacement area) obtained at: 1 – $U_b = -110$ V; 2 – $U_b = -110$ V (1) and vacuum annealing (700 °C, 1 hour); 3 – $U_b = -200$ V

The presence of a strong texture [111] in the multiperiod composite layers leads to a high intensity of diffraction peaks, which allows them to be isolated in the case of a close arrangement. This proved to be an important factor in understanding the results obtained for the multiperiod composite (TiAlSi)N/ZrN. For this composite, the diffraction spectrum has a complex profile. Its separation leads to the separation of 3 characteristic peaks (see Fig. 3). Two peaks (from crystal lattices with periods of 0.483 and 0.421 nm (see peaks 1 and 3 in Fig. 3) correspond to ZrN and

(TiAlSi)N phases under high compression stresses. Peak 2 (with wide diffraction profile) corresponds to a multi-element solid solution, which is formed on the interphase boundary during deposition. Calculations carried out from the diffraction profile width show that the intermixed area between the layers has an average size of about 3 nm. Based on the previously obtained results for $U_b = -110$ V (see Fig. 2,a) for this system, it may be assumed that such a mixed region is mainly formed at the boundary of (TiAlSi)N layers when they

are bombarded with heavy Zr ions (at the initial growth time of the ZrN layer).

The comparison of the diffraction spectra of the coatings obtained at $U_b = -110$ and -200 V for the (TiAlSi)N/MoN system (see Fig. 4, spectra 1 and 3) shows that the use of large U_b results in a decrease in the lattice period (the position of the diffraction peak is shifted to the big corners). This correlates with the earlier observed change in this system during annealing, when the relaxation processes take place. In this connection, it can be assumed that such relaxation processes occur during the particles deposition at large U_b . Such processes are determined (at large U_b) with a high density of nonequilibrium defects formed during surface bombardment with accelerated ions during their growth.

At substructural level, the average crystallite size in single-layer (TiAlSi)N coatings was 280 nm ($U_b = -110$ V) and 120 nm ($U_b = -200$ V). In multilayer systems, the average size in the nitride layers was about 10 nm. At the same time, the average microdeformation in the layers was close to 0.75%. A significant difference was observed only in the system (TiAlSi)N/MoN, where the average microdeformation is much higher and reaches 1.5%.

As a universal characteristic of the mechanical properties of the coatings, microhardness was studied. Fig. 5 shows a histogram of a hardness change at $U_b = -110$ and -200 V for different systems.

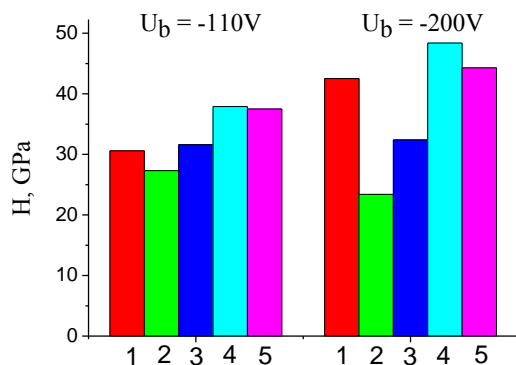


Fig. 5. Histogram shows the changes in the hardness of the coatings obtained at $U_b = -110$ and -200 V for systems: 1 – (TiAlSi)N; 2 – (TiAlSi)N/CrN; 3 – (TiAlSi)N/NbN; 4 – (TiAlSi)N/ZrN; 5 – (TiAlSi)N/MoN

As can be seen from the results obtained, the supply of the potential $U_b = -200$ V for (TiAlSi)N/MoN and (TiAlSi)N/ZrN systems leads to a significant increase in hardness. Based on structural research results, this result can be related to relaxation processes that lead to an increase in the density of a material at a high density of allocated energy.

It should be noted that monolayers of multi-element (TiAlSi)N nitride (42.5 GPa) have high hardness. The reason for the increased hardness in this system may be that the substitution of Ti at Al atoms leads to a distortion of the (TiAl)N lattice causing compressive stresses. This prevents the dislocations movement and thus increases hardness. Moreover, the additional introduction of Si atoms into the FCC (TiAl)N lattice

causes local stresses and, consequently, contributes to increased hardness.

At the same time, the use of (TiAlSi)N layers in bilayered multi-period systems leads to different effects (depending on the contacting mononitride layer). So, in the (TiAlSi)N/ZrN system, the highest hardness is 47.9 GPa, whereas in the (TiAlSi)N/CrN system the hardness is the smallest (23.4 GPa). The reason for the difference in the hardness of these systems may be the difference in the stress state in the mononitridium layers. As shown above, in the ZrN layers of the (TiAlSi)N/ZrN system, formation of compressive stresses occurs, and the tensile stresses are formed in the CrN layers of the (TiAlSi)N/CrN system. The formation of tensile stresses promotes the formation and propagation of cracks, which leads to the hardness decrease.

RESULTS DISCUSSION

As can be seen from the results obtained: the structure and mechanical properties of (TiAlSi)N coatings can be effectively controlled by feeding U_b or creating multi-period composites. In particular, the change in the energy of the incident particles substantially affects the growth mechanisms and, thus, the properties of the coating. The process of vacuum-arc evaporation provides high-ionization plasma, where metal ions have several charge states [32]. The presence of several charge states leads to a higher energy of ion impact on the substrate when the negative displacement voltage is applied to the substrate. The high energy of the incident ions leads to an increase in the coating density and, thus, the coatings deposited with larger U_b are characterized by a dense (pore-free) structure.

It is believed that almost all the volatile particles spontaneously react with dissolved nitrogen. In this case, the Me–N (Me = Al, Ti) molecules are formed on the growth surface. Such molecules (as opposed to weakly bound metal atoms) have a small probability of re-sputtering even with a relatively intense high-energy ion bombardment [33].

It is known, however, that when aluminum content is less than the critical concentration, a solid solution (TiAl)N based on the cubic (structural type NaCl) crystal lattice is formed.

However, with a relatively high content of aluminum atoms in the solid solution (40...60 at.%), due to the discrepancy of atomic radii, the crystal lattice is subject to a large deformation (distortion). This contributes to its embrittlement and the formation of nanocracks [33]. That is the reason why the Al content in the Ti–Al system did not exceed 30 at.%.

For the same reason (high deformation of the crystal lattice), the Si content in the coating was about 3 at.%. According to [34], such silicon content in the solid solution formation does not lead to a significant decrease in hardness. However, it can lead to the formation of high-temperature segregation of titanium silicides in the grain boundaries at high temperature. This leads to increased strength [35, 36].

At the same time, with greater silicon content, the functional properties are lowered. Thus, it was shown in [37] that a higher content (10 at.% Si), although leads to

an increase in the hardness of the coatings (TiAlSi)N, at the same time, the adhesive strength of such coatings is reduced.

We note that nanolayer multiperiod structures consisting of materials having different crystal lattices (under thermodynamic equilibrium conditions) tend to form coherent boundaries between layers through epitaxial stabilization. This means that the thermodynamically disadvantageous state of the incoherent surfaces of the section is balanced by the metastable structure growth for one of the layer materials, which is capable of constructing a coherent surface of the section with another layer. Consequently, minimizing interphase energy is the driving force behind the epitaxial stabilization effect.

The factor contributing to the stabilization of the nanostructural state and the enhancement of functional properties is the creation of multi-period systems with a nanosized modulation period. The preparation of coatings in the form of multiperiod composites was used in the work to control the structural-stress state in the layers of the modulation period components. As components of bilayered compositions (TiAlSi)N and MeN (Me – Zr, Nb, Cr, Mo) were used. The results obtained showed that at $U_b = -110$ V, a mononitride based on relatively light metal Cr inherits the growth texture [111] of the (TiAlSi)N layer. Molybdenum (having an average mass) forms a mononitride which indicate the growth texture [100] at $U_b = -110$ V in (TiAlSi)N layers. Mononitride based on the heavier metal (Zr) at $U_b = -110$ V leads to disorientation in the TiAlSi layers and interfacial mixing (the thickness of the stirred region is about 3 nm). Only with large $U_b = -200$ V the texture [111] in the ZrN layers is formed, as well as its inheritance in (TiAlSi)N layer occurs. We note that compressive stresses are formed during deposition in multi-element (TiAlSi)N layers, and the period of the lattice of crystallites (as compared to TiN) is reduced due to the dissolution of aluminum atoms. In the zirconium nitrides, niobium and molybdenum, compressive stresses are also formed, but tensile stresses are formed in chromium nitride, which leads to a relatively low hardness of the composite on its basis.

CONCLUSIONS

– In multi-element nitrides (TiAlSi)N, due to the high microdeformation of the crystal lattice, the interatomic bond is weakened. In the case of the creation of a bilayered composition ((TiAlSi)N and MeN (Me – Zr, Nb, Cr, Mo)), more stable mononitrides have a preferential orientation of crystallite growth in thin (nanometer) layers;

– the most mobile (having a smaller atomic mass) transition of metal atoms (Cr, Mo) stimulate the growth texture in mononitrides at a relatively low displacement potential ($U_b = -110$ V), and the heavier (Zr) with a higher potential $U_b = -200$ V;

– an increase in U_b from -110 to -200 V results in (TiAlSi)N/MeN systems having a strong interatomic Me – N bond in mononitrides (based on Zr, Nb and Mo) to increase the hardness. The highest hardness of 47.9 GPa is achieved in the (TiAlSi)N/ZrN system with

the axis [111] of the preferential orientation of crystallite growth.

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ВЛИЯНИЕ ПОТЕНЦИАЛА ПОДЛОЖКИ ПРИ ОСАЖДЕНИИ НА СТРУКТУРУ И СВОЙСТВА БИНАНОСЛОЙНЫХ МНОГОПЕРИОДНЫХ КОМПОЗИТОВ (TiAlSi)N/MeN (Me – Zr, Nb, Cr, Mo)

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Предложено использовать многослойные бинанослойные композиты систем (TiAlSi)N/MeN (Me – Zr, Nb, Cr, Mo) для управления структурой, напряженным состоянием и механическими свойствами многоэлементного нитрида (TiAlSi)N. Осаждение слоев осуществлялось методом вакуумно-дугового испарения при разных потенциалах смещения на подложке $U_b = -110$ и -200 В. Установлено, что в бинанослойном композите монослои с большой энергией связи Me–N задают преимущественную ориентацию роста кристаллитов в тонких (нанометровых) слоях. При $U_b = -110$ В текстура роста формируется в композитах, содержащих монослои на основе переходных металлов с относительно небольшой атомной массой (Cr, Mo). В случае монослоя на основе тяжелого металла (Zr) текстура образуется при большем $U_b = -200$ В. Наибольшая твердость достигается в текстурированных материалах, осажденных при $U_b = -200$ В. Это характерно как для монослойного многоэлементного нитрида (TiAlSi)N (достигнута твердость 42,5 ГПа), так и для многослойных нанослойных композитов на его основе (наибольшая твердость 47,9 ГПа получена для композита (TiAlSi)N/ZrN).

ВПЛИВ ПОТЕНЦІАЛУ ПІДКЛАДКИ ПРИ ОСАДЖЕННІ НА СТРУКТУРУ І ВЛАСТИВОСТІ БІНАНОШАРОВИХ БАГАТОПЕРІОДНИХ КОМПОЗИТІВ (TiAlSi)N/MeN (Me – Zr, Nb, Cr, Mo)

О.В. Соболев, А.О. Андреев, Р.П. Мизущенко, В.О. Столбовий, Г.О. Постельник, А.О. Мейлехов, А.В. Доломанов, О.М. Реброва

Запропоновано використовувати багатоперіодні бінаношарові композити систем (TiAlSi)N/MeN (Me – Zr, Nb, Cr, Mo) для управління структурою, напруженим станом і механічними властивостями багатоелементного нитриду (TiAlSi)N. Осадження шарів здійснювалося методом вакуумно-дугового випаровування при різних потенціалах зміщення на підкладці $U_b = -110$ і -200 В. Встановлено, що в бінаношаровому композиті монослої з великою енергією зв'язку Me–N задають переважну орієнтацію росту кристалітів у тонких (нанометрових) шарах. При $U_b = -110$ В текстура зростання формується в композитах, які містять монослої на основі перехідних металів з відносно невеликою атомною масою (Cr, Mo). У разі монослою на основі важкого металу (Zr) текстура утворюється при більшому $U_b = -200$ В. Найбільша твердість досягається в текстурованих матеріалах, осаджених при $U_b = -200$ В. Це характерно, як для моношарового багатоелементного нитриду (TiAlSi)N (досягнута твердість 42,5 ГПа), так і для багатоперіодних наношарових композитів на його основі (найбільша твердість 47,9 ГПа отримана для композиту (TiAlSi)N/ZrN).