STUCTURE AND MECHANICAL CHARACTERISTICS OF VACUUM ARC TiN COATINGS DEPOSITED WITH HIGH-VOLTAGE HIGH FREQUENCY PULSES ON THE SUBSTRATE

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In order to improve the functional properties of the most currently used in industry TiN vacuum arc coating in this paper we used plasma-based ion implantation with deposition (PBIID) method. In this method a high pulse negative potential is applied to a surface immersed in plasma which provides the necessary conditions for significant atom restructuring in the area of collision and therefore initial stresses relaxation in coating.

Such stresses relaxation (and associated deformed state) is necessary, because due to a large ionization degree characteristic of vacuum arc method and accordingly high flux density of accelerated particles, great compressive stresses in the coating can occur, which causes significant stretching of substrate and loss of required functional properties of the system.

Samples were obtained with the help of vacuum-arc plant "Bulat-6" extra supplied with a high-voltage pulse generator. We used a stainless steel substrates with dimensions 20*20*3 mm and a copper foil 0.2 mm thick.

Negative bias value of U_s = - 5 V (“floating” potential), 40 V and 230 V was applied on a substrate during deposition process. In some cases negative pulse potential (U_{pi}) with amplitude of 2 kV, 10 ms duration and repetition frequency of 7 kHz was applied on a substrate along with a constant bias during deposition. Evaporator arc current (I_d) was 100..110 A, nitrogen pressure was P_N = 0,53 ... 0,66 Pa.

Composition and structure were studied by X-ray diffraction on a diffractometer DRON-3M in Cu-K_α radiation using a secondary beam graphite monochromator.

Determination of residual macroscopic stresses in the TiN coatings with a cubic (NaCl structural type) crystal lattice was carried out by X-ray strain

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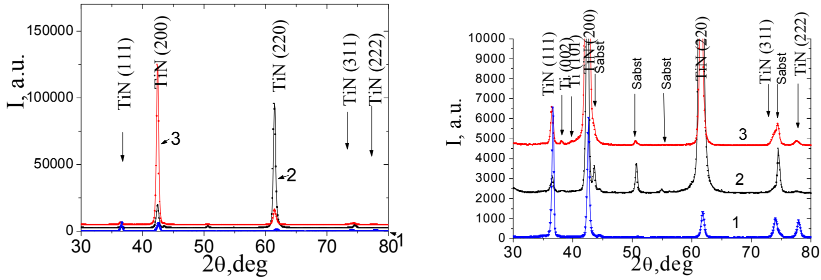
gauging ("a-sin2ψ" method) and its modification in the case of strong axial texture type.

Hardness test was performed using "Micron-Gamma" indenter with Berkovich pyramid and load up to 20 g. Wear resistance test was carried out on cutting plates from a high-speed steel with TiN coating on the front surface by turning of constructional steel at speed of 103 m/min., feed 0.15 mm/rev. and cutting depth of 3 mm.

X-ray diffraction analysis of composition and structure have shown that the diffraction spectra (*Fig. 1*, curves 2 and 3) obtained under "floating" potential bias -5 V revealed reflections from two phases. The most intense are the main phase of TiN with Bl-NaCl cubic crystal structure and significantly less intense for α-Ti phase with the relative volume content less than 5%. The crystallite size determined from the Selyakova-Scherrer ratio is 27-30 nm. X-ray diffraction spectra revealed single-phase state - TiN phase with a cubic crystal structure and average crystallite size of 20-21 nm in the case of coatings obtained under additional pulse action (*Fig. 1*, curve 1).



a) b)

Fig. 1 - Plots of the diffraction spectra of titanium nitride coatings for U_s = -5 V with high-voltage pulses (curve 1), without high-voltage pulses (curves 2 and 3), coatings thickness of 7 microns (curves 1 and 3) and 3.5 microns (curve2). General view (a) and detail of low intensity diffraction peaks (b).

The formation of oriented to the axis [110] (in the case of coating thickness 2.5 mm) and [100] (coating thickness 7 mm) crystallites mainly occurs in coatings obtained under "floating" bias without any additional effects of high-voltage pulse (*Fig. 1a*). In the case of coating deposition at "floating" bias and high-voltage pulse action preferred crystallite orientation is practically absent, which indicates a high disorienting ability of such exposure.

The tendency to formation of two-phase coating (TiN phase and α-Ti) also remains at bias increase (U_s) to -230 V and absence of high-voltage pulse (*Fig. 2*, curve 1). At the same time with an increase of U_s crystallite size decreases, accounting for U_s = - 230 V average value 24-25 nm and 15 nm for TiN and α-Ti phases respectively.

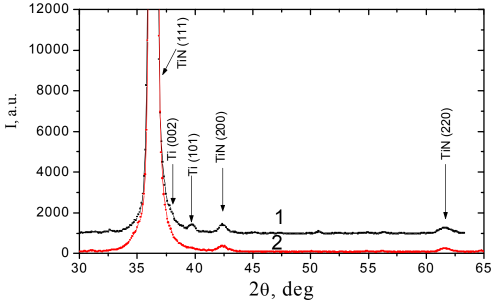


Fig. 2 - Plots of the diffraction spectra of titanium nitride coatings for U_s =- 230 without high-voltage pulses (curve 1), with high-voltage pulses (curve 2). General view (a) and detail of low intensity diffraction peaks (b)

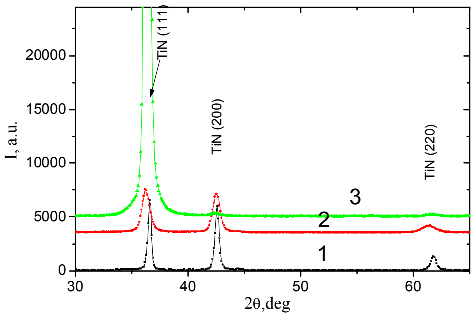


Fig. 3 - Plots of the diffraction spectra of titanium nitride coatings with high-voltage pulses and bias – 5 V (curve 1), -40 (curve 2) and -230 (curve 3)

Single-phase crystalline state of TiN coating is characterized by substantially smaller crystal size up to 12 nm when high-voltage pulses are applied.

In the case of relatively high U_s = 230 V the formation of preferred crystalline orientation with the axis of the axial texture [111] perpendicular to the plane of the growth surface is observed in spite of presence or absence of high-voltage pulses (*Fig. 2*).

Comparison of the diffraction spectra of coatings obtained by applying high-voltage pulses and different constant bias (*Fig. 3*) shows that at "floating" bias (curve 1, *Fig. 3*), and at relatively low potential U_s = - 40 V(curve 2, *Fig. 3*) polycrystalline coatings without significant preferred orientation plane of crystallite growth are formed, and only applying of relatively high U_s = - 230 V leads to preferential orientation of crystallites growth, expressed in the diffraction spectra as redistribution of peaks intensity (curve 3, *Fig. 3*).

For investigating the elastically stressed state, the X-ray tensometry technique ("α-$\sin^2\psi$" method) was used, and in the case of an axial-type strong texture a modified version of the method was used, based on the measurement of interplanar spacings from different planes at certain crystallographically preset tilt angles ψ of the sample. From the "α-$\sin^2\psi$" plot given in *fig. 4* it can be seen that with an increase in the constant bias potential on the substrate residual stresses and the titanium nitride lattice constant increase, this being apparently the result of an increased intensity of ion bombardment during deposition.

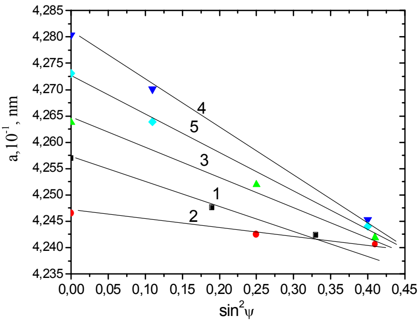


Fig. 4 - The function "α-$\sin^2\psi$" for TiN coatings: 1 – without pulses, U_s = -5 V; 2 – with pulses, U_s = -5 V; 3 – with pulses, U_s = -40 V; 4 – without pulses, U_s = -230 V; 5 – with pulses, U_s = -230 V

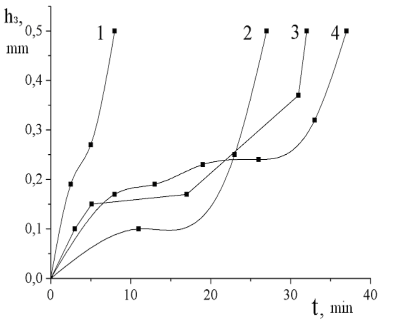


Fig. 5 - Cutting bit flank wear (h_3) versus turning time(t). 1 – uncoated bit, 2 – with coating with no HVP (U_s=-230V), 3 – with coating and with HVP(U_s=-20V), 4 - with coating and HVP (U_s=-200V).

A special feature of the effect of high-voltage pulses on the properties of the coating during its deposition is the deformation reduction of the material. Note, however, that, in this case, irrespective of the absence or presence of high-voltage pulses, the increase in the constant voltage U_s leads to the increase in elastic deformation.

The characteristic property of the coatings deposited under the action of high-voltage high-frequency pulses is the increase in their hardness from 38 … 45 GPa at floating and low (less than – 100V) bias potentials up to a superhard state (60 … 62 GPa) at a high bias potential ranging from -150V to -230V.

Another important performance parameter of TiN coatings is their wear resistance. The strength tests of TiN-coated cutting tips from high-speed steel R6M5 by turning steel 45 have demonstrated that the cutting bits having the coatings deposited under the action of high-voltage pulses (HVP) are more efficient even at a low constant potential U_s (*fig. 5*).