Hard, wear resistant coatings deposited on tool materials

Daniel Pakuła

Institute of Engineering Materials and Biomaterials,
Silesian University of Technology,
Gliwice, Poland

Aim of the work

The aim of this work is to investigate the structure and properties of multilayer coatings type of TiC, Ti(C,N), Al_2O_3, TiN obtained in the CVD and PVD processes and manufactured in the PVD process complex multi-component coatings of TiN+TiAlSiN+TiN, TiN+multiTiAlSiN+TiN and TiN+ TiAlSiN+AlSiTiN onto silicon nitride (Si_3N_4) ceramics tool and compare them with commercial tool materials, coated in the CVD processes by multilayer coatings of Al_2O_3+TiN wear resistantce.

Thesis work

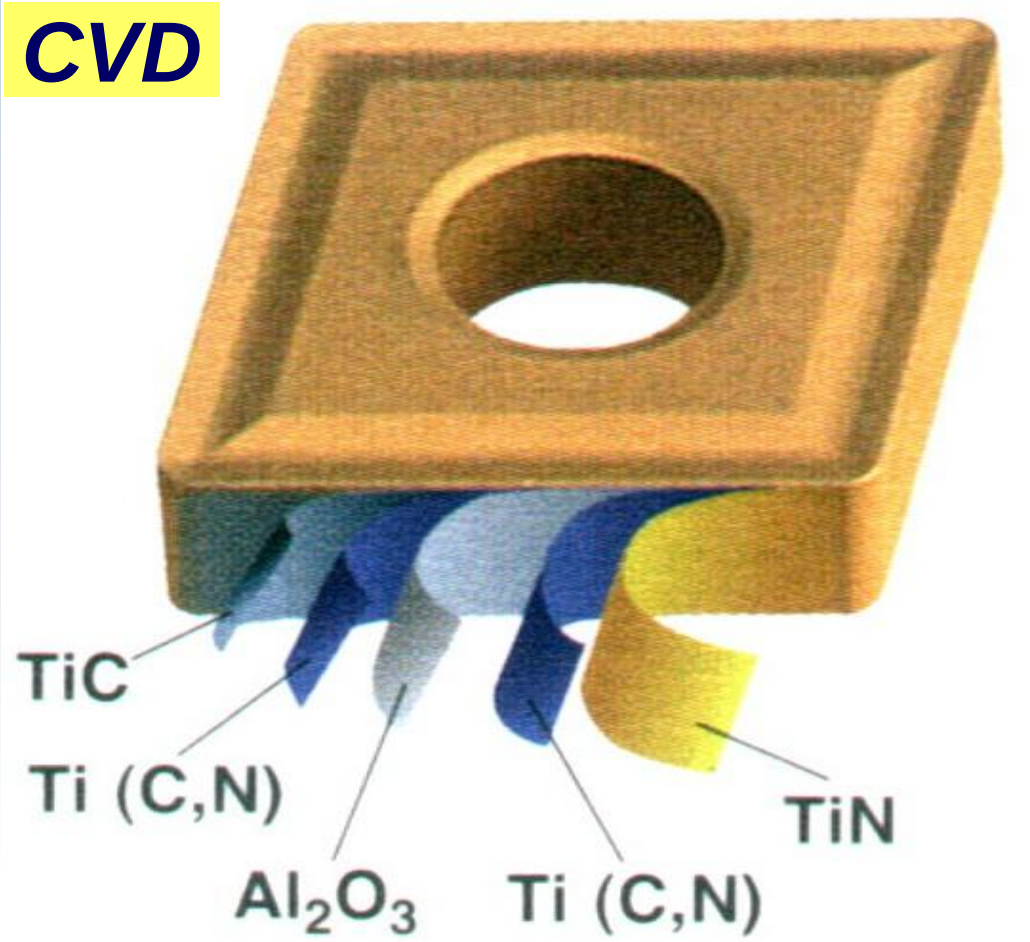
Producing of multi-layer coatings type of Al_2O_3+TiN and TiN+Al_2O_3 in the CVD processes onto silicon nitride (Si_3N_4) ceramics can increase utility properties of cutting tools coated by them machining tools in comparison with multilayer coatings with an intermediate of TiC and Ti (C,N) are produced in the CVD process and the multi-component coatings type of TiAlSiN obtained in the PVD process, especially destined for the implementation of modern machining technologies, including high-speed machining with high speeds, precision machining and dry cutting without employment of any cutting fluids.

Materials

Substrate	Coatings	Coating thickness, μm	Process type
Si_3N_4 nitride tool ceramics	TiN	0.8	PVD
	TiN+multiTiAlSiN+TiN	4.0	PVD
	TiN+TiAlSiN+TiN	2.0	PVD
	TiN+TiAlSiN+AlSiTiN	2.5	PVD
	Ti(C,N)+TiN	4.2	CVD
	Ti(C,N)+Al_2O_3+TiN	9.5	CVD
	TiC+TiN	5.4	CVD
	TiC+Ti(C,N)+Al_2O_3+TiN	7.8	CVD
	TiN+Al_2O_3	10.0	CVD
	TiN+Al_2O_3+TiN	3.8	CVD (1)*
	Al_2O_3+TiN	2.6	CVD (2)*
	Al_2O_3+TiN	1.7	CVD (3)*
	TiN+Al_2O_3+TiN+Al_2O_3+TiN	4.5	CVD (4)*

*(1) to (4) commercially available inserts from various manufacturers

Chemical Vapour Deposition (CVD)



based on Sandvik Baildonit

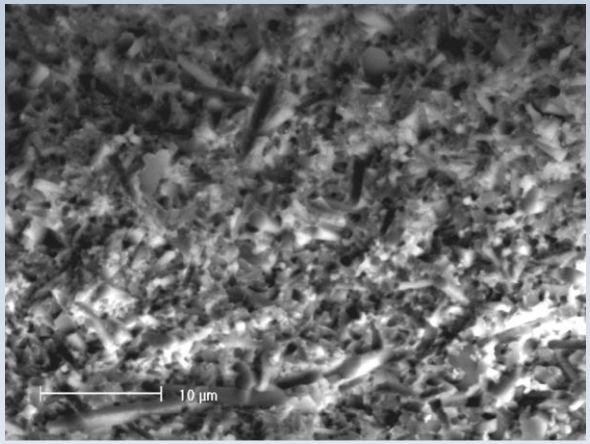
Methodology of researches

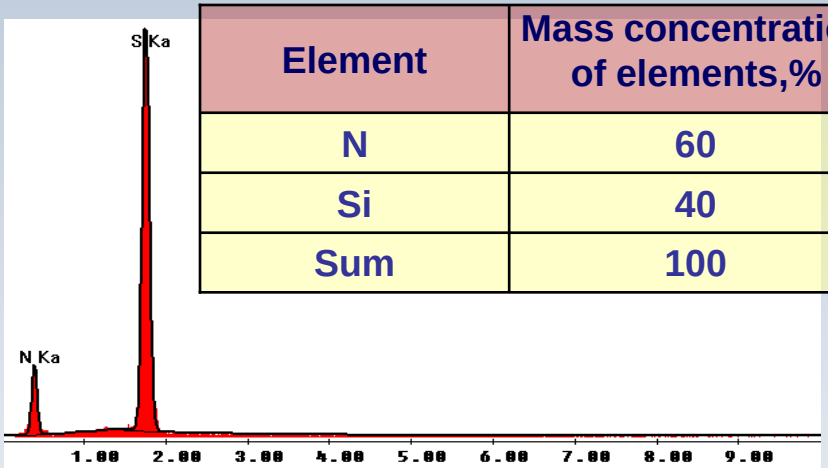
- **Examinations of the structure:**
  - ✓The Scanning Electron Microscopy (SEM);
  - ✓The Transmission Electron Microscopy (TEM).
- **The study of chemical composition and phase:**
  - ✓X-ray of qualitative and quantitative microanalysis;
  - ✓Optical emission spectrometry (GDOS);
  - ✓X-ray qualitative phase analysis;
  - ✓Texture analysis;

Methodology of researches

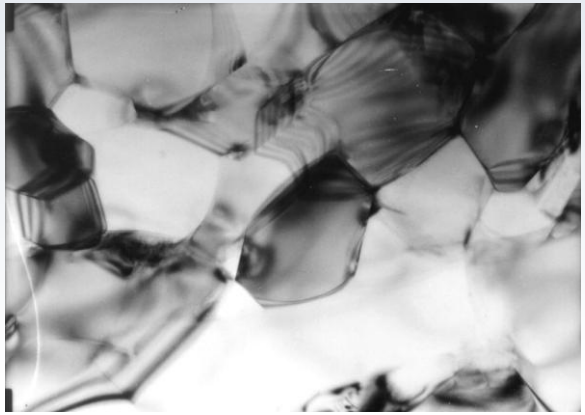
- **Research of the mechanical properties:**
  - ✓Roughness;
  - ✓Dynamic hardness;
  - ✓Internal stresses;
  - ✓Adhesion - „scratch test”;
- **Research of the exploitative properties :**
  - ✓Wear resistance – „pin-on-disc”;
  - ✓Try cutting cast iron and nickel alloy

Structure of nitride ceramics tool Si_3N_4

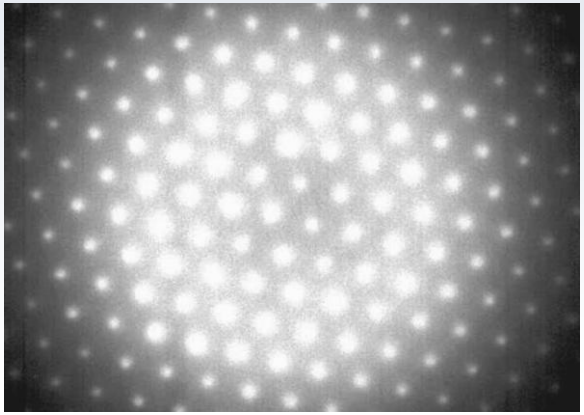


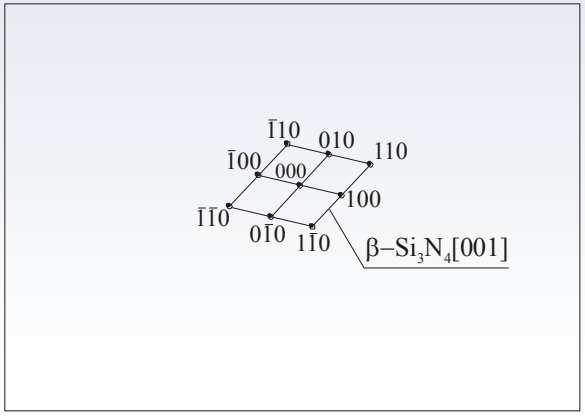


Element	Mass concentration of elements,%	Atomic concentration of elements, %
N	60	57.04
Si	40	42.96
Sum	100	100

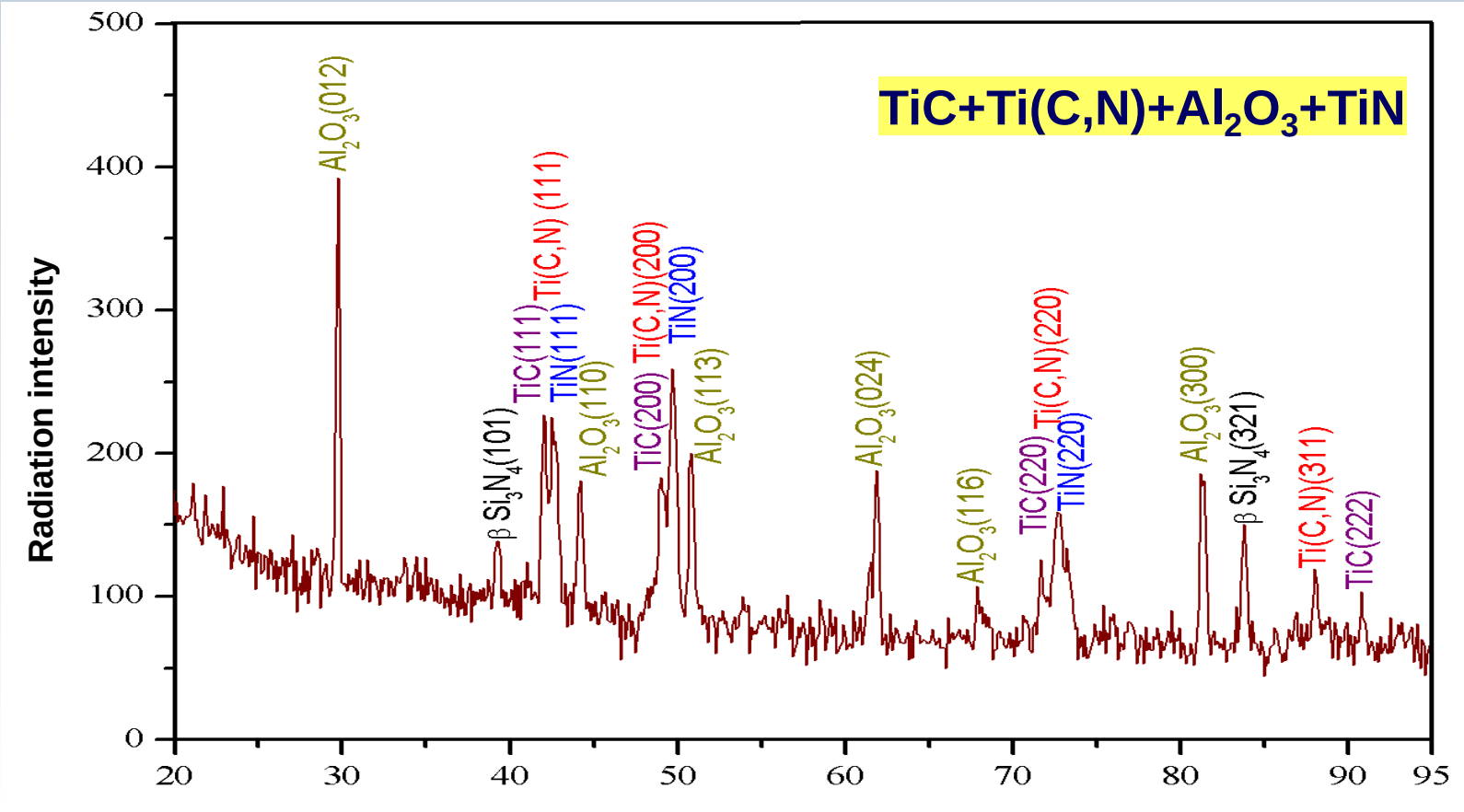


200 nm



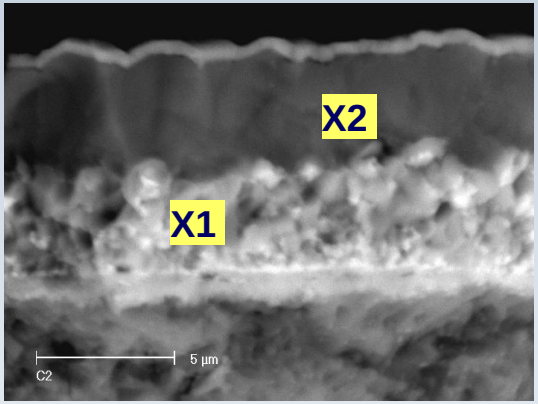


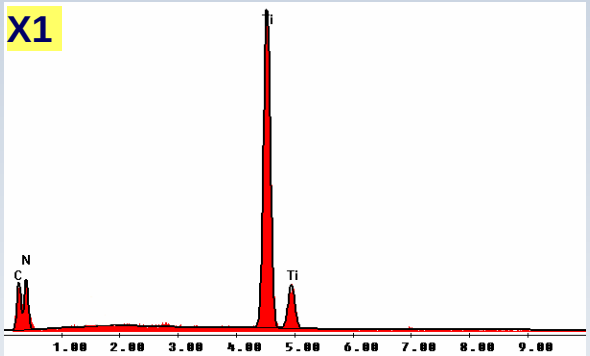
X-ray qualitative phase analysis

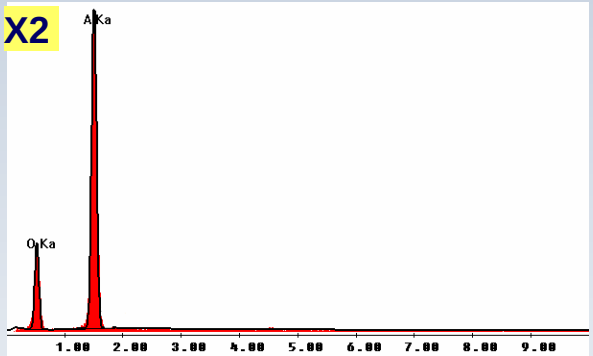


The chemical composition of the coatings

$Ti(C,N)+Al_2O_3+TiN$







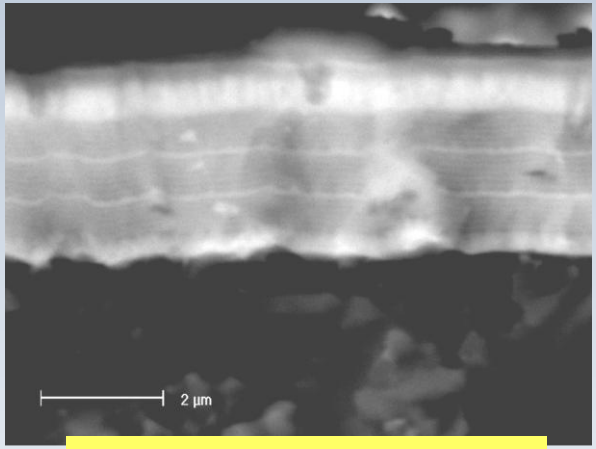
area X1

Element	Mass concentration of elements,%	Atomic concentration of elements, %
C	9.72	20.21
N	22.03	40.29
Ti	68.25	39.50
Sum	100	100

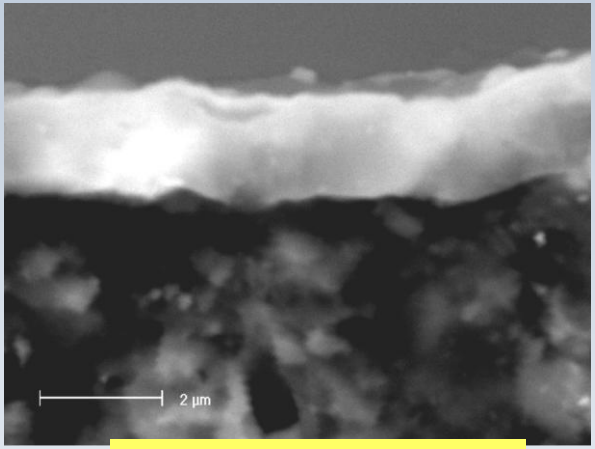
area X2

Element	Mass concentration of elements,%	Atomic concentration of elements, %
O	42.86	55.89
Al	57.14	44.11
Sum	100	100

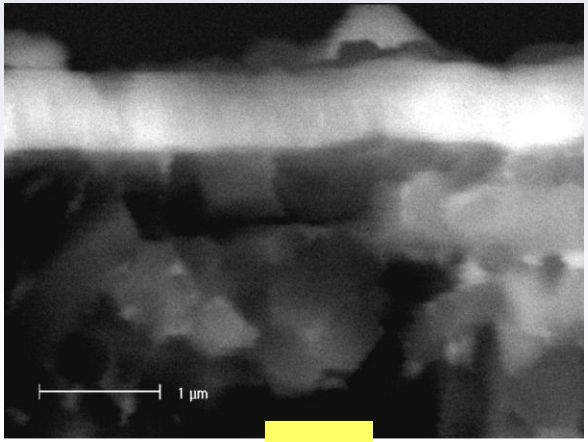
Structure of PVD coatings



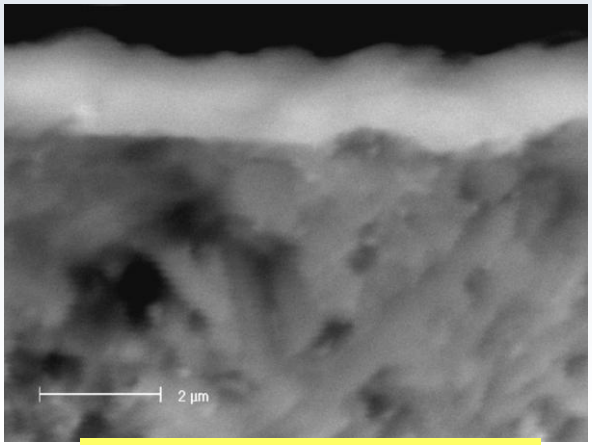
TiN+multiTiAlSiN+TiN



TiN+TiAlSiTiN+TiN

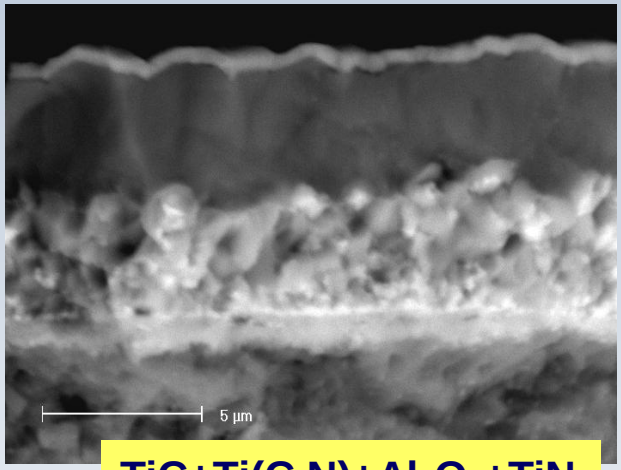


TiN

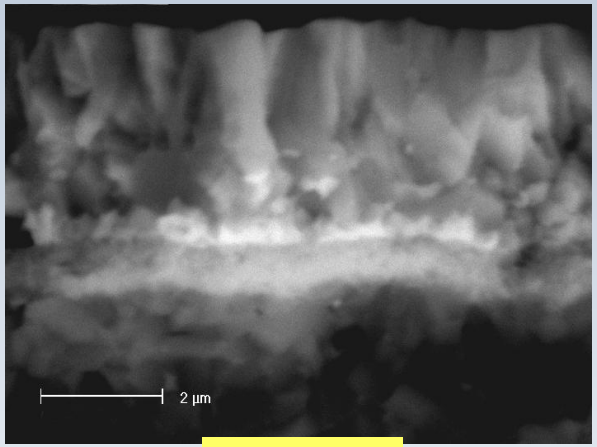


TiN+TiAlSiN+AlSiTiN

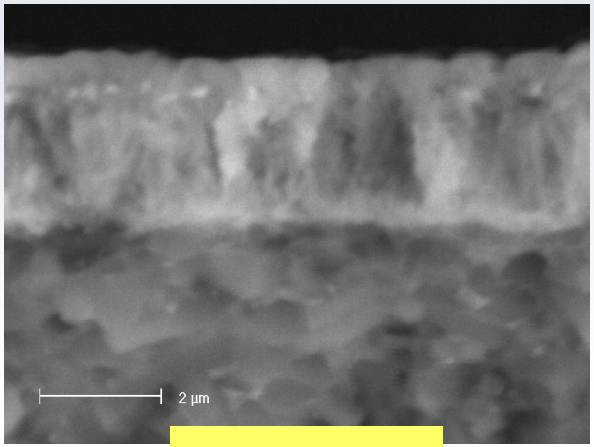
Structure of CVD coatings



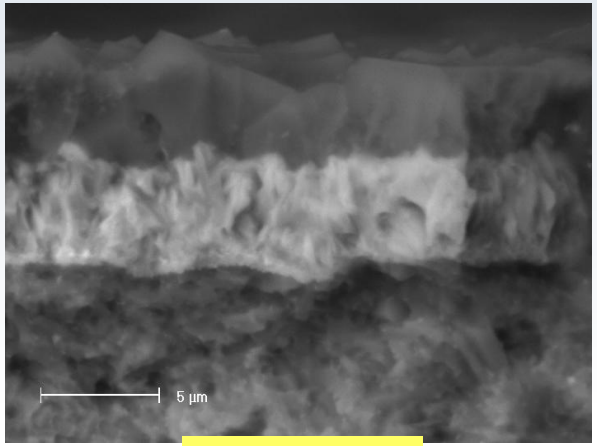
TiC+Ti(C,N)+Al_2O_3+TiN



TiC+TiN

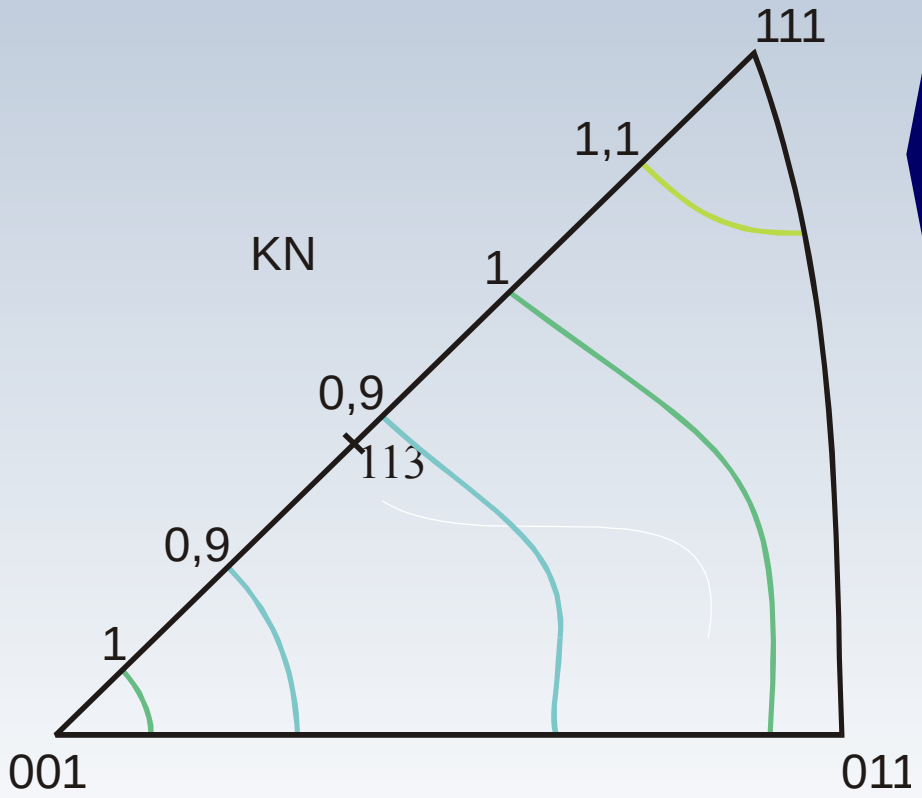


Ti(C,N)+TiN

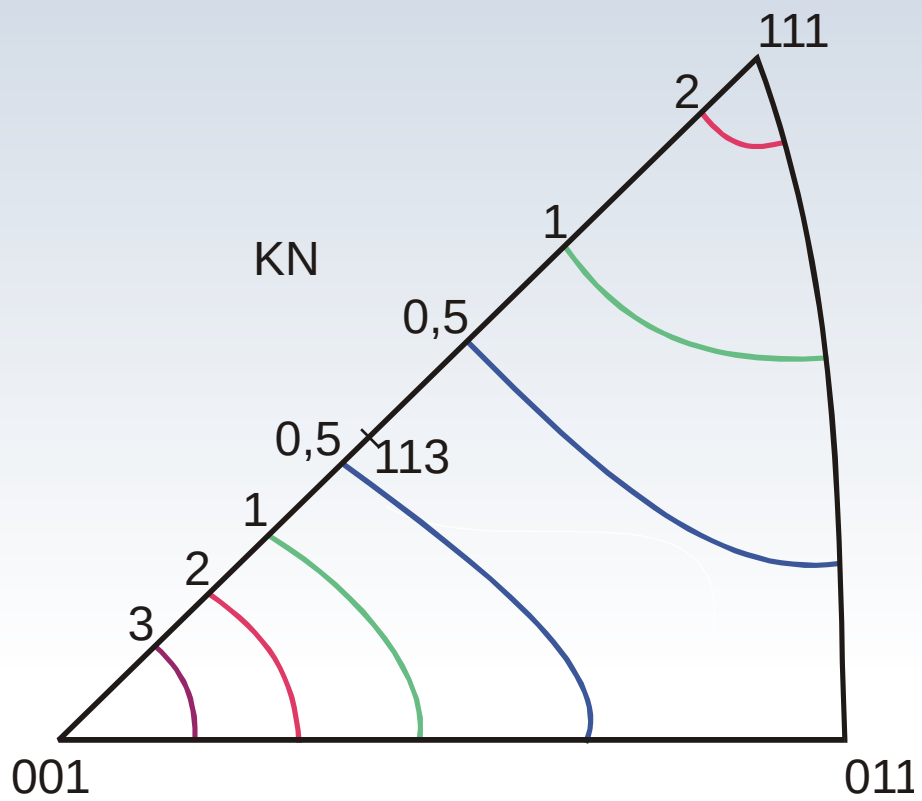


TiN+Al_2O_3

Texture of coatings



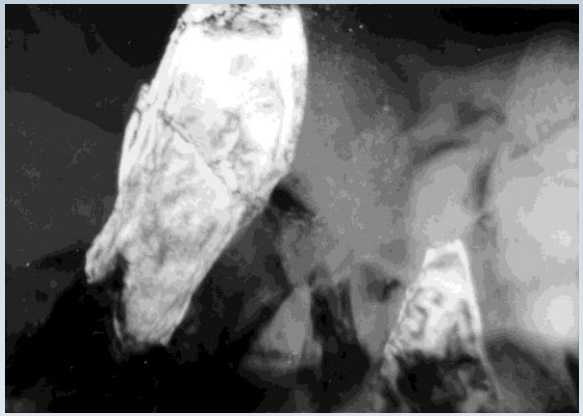
Exemplary inverse for TiN layer representing the distribu-tion of normal to the TiN+Al_2O_3+TiN+-Al_2O_3+TiN coating surface in the (001)-(011)-(111) base triangle (KN - normal direction)



Exemplary inverse for TiN layer representing the distribu-tion of normal to the TiN+TiAlSiN+TiN coating surface in the (001)-(011)-(111) base triangle (KN - normal direction)

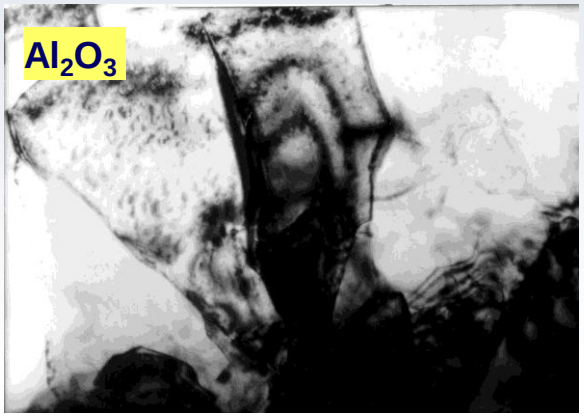
Structure of the TiN+Al_2O_3+TiN+Al_2O_3+TiN coating

100 nm

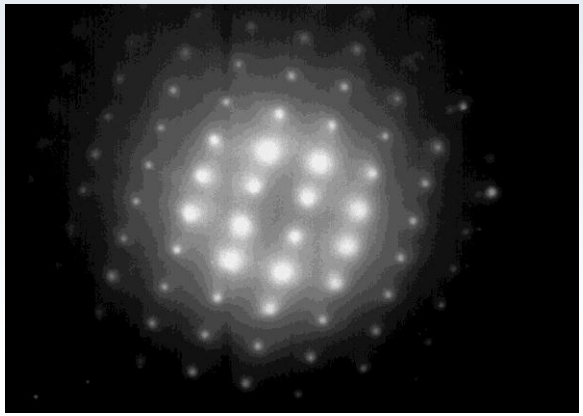


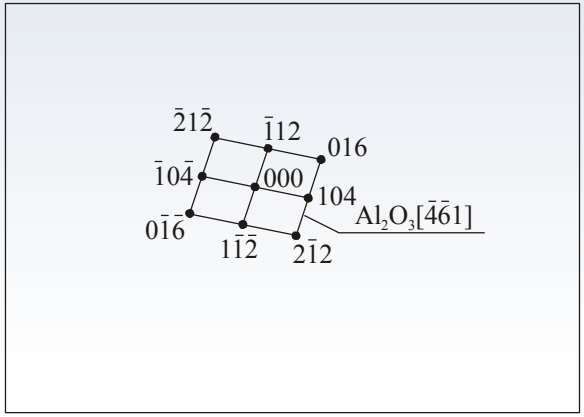
100 nm

Cross-section perpendicular to a layer surface



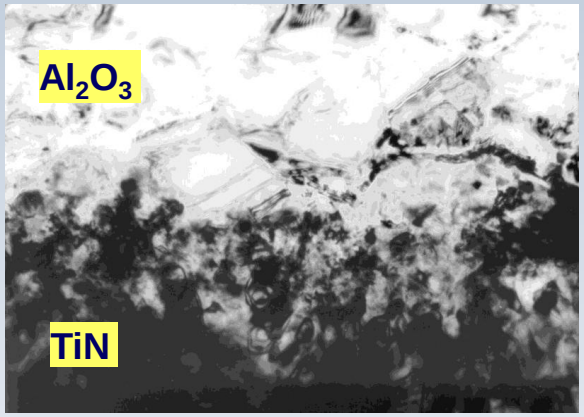
100 nm



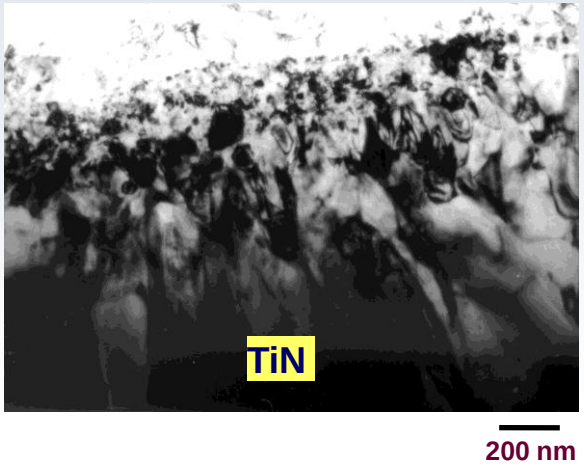


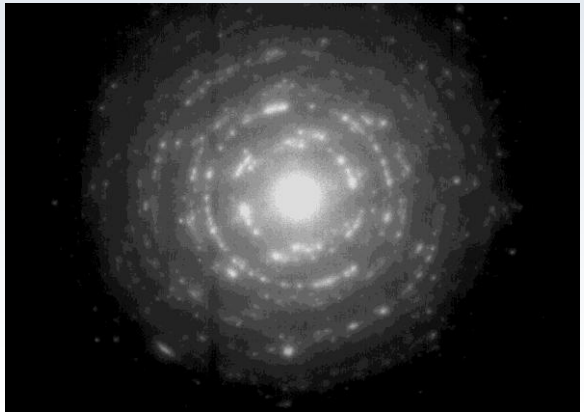
Structure of the TiN+Al_2O_3 coating

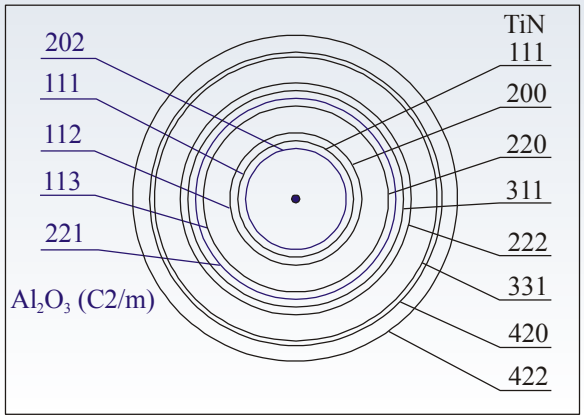
The transition zone



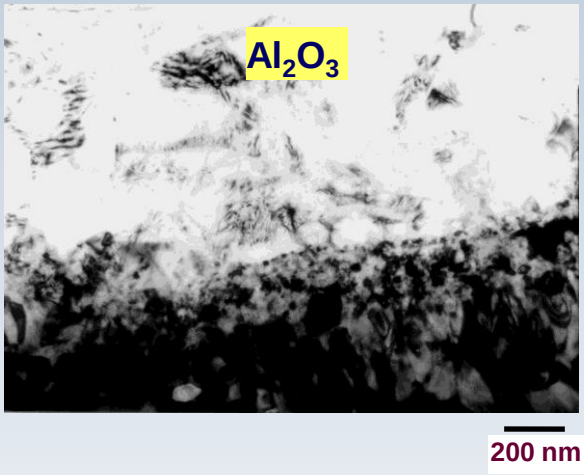
Cross-section perpendicular to a layer surface

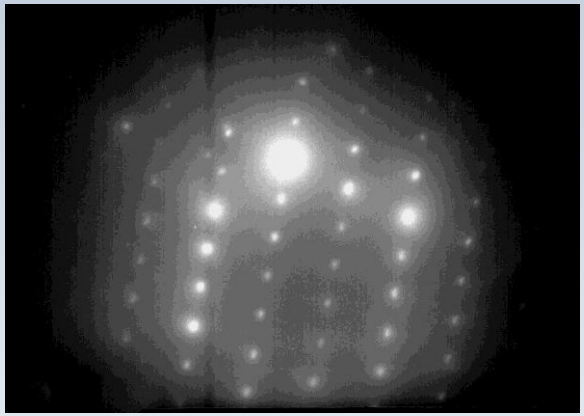




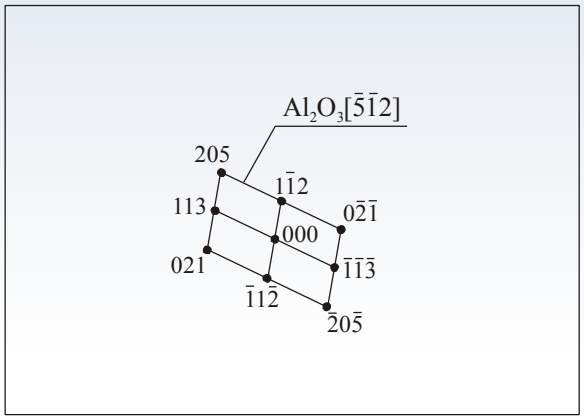


Structure of the TiN+Al_2O_3 coating



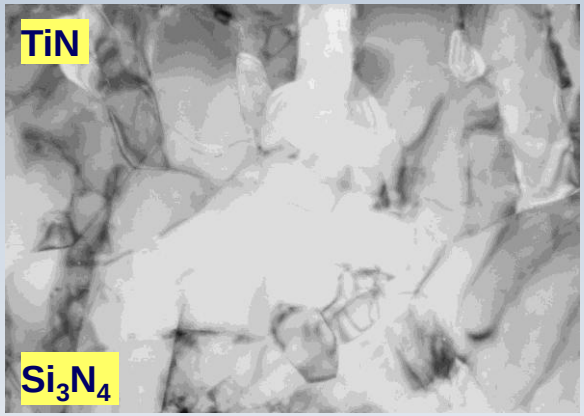


Cross-section perpendicular to a layer surface

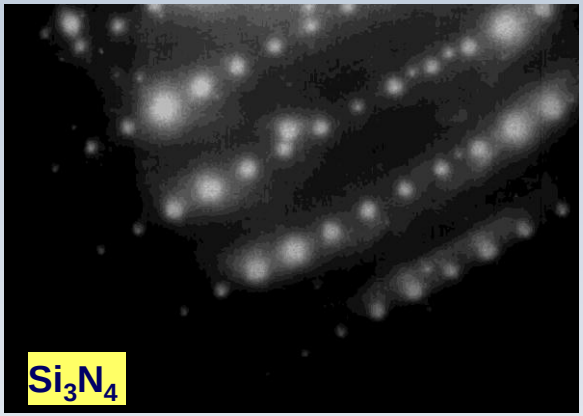


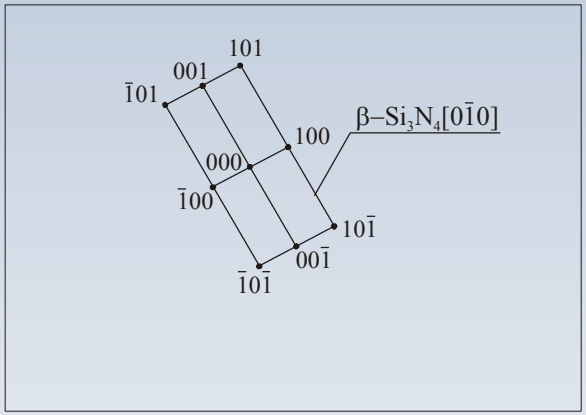
Dark field of reflexes (113) Al_2O_3

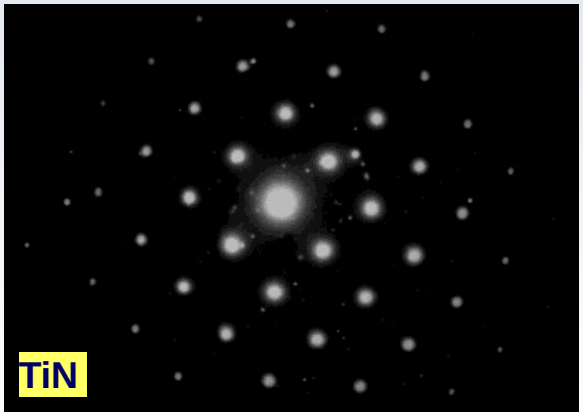
Structure of the TiN+Al_2O_3+TiN+Al_2O_3+TiN coating

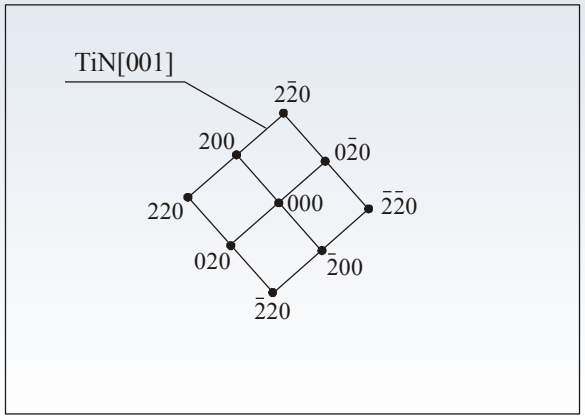


200 nm



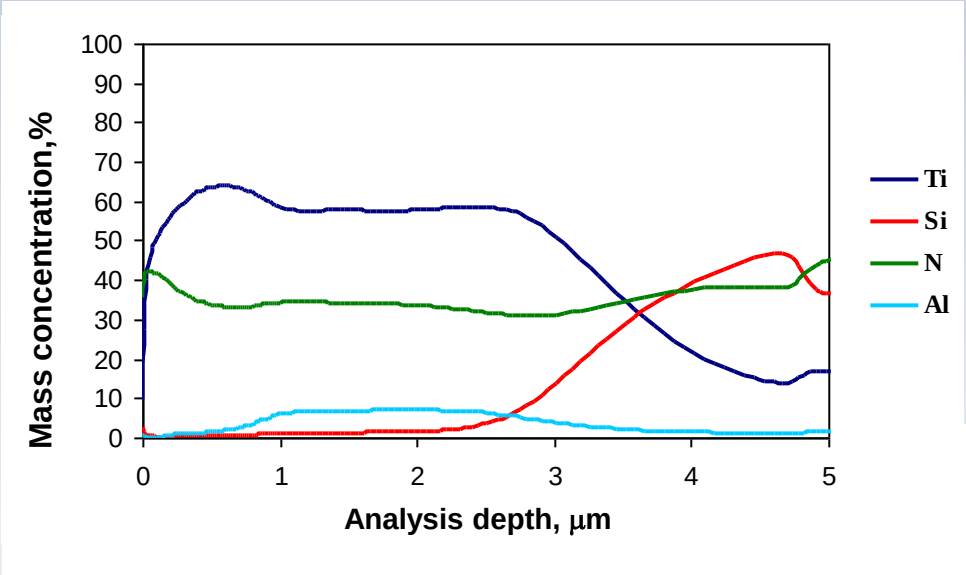






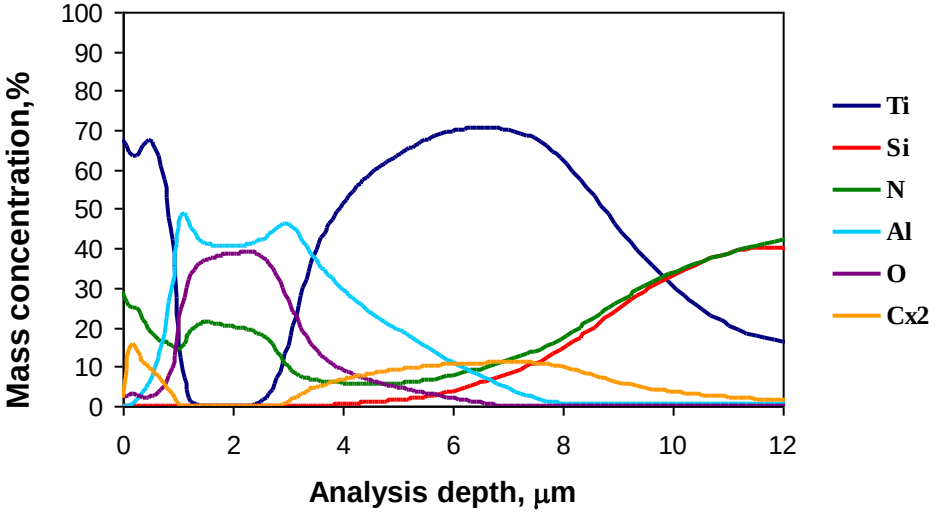
Cross-section perpendicular to a layer surface

The chemical composition of coatings

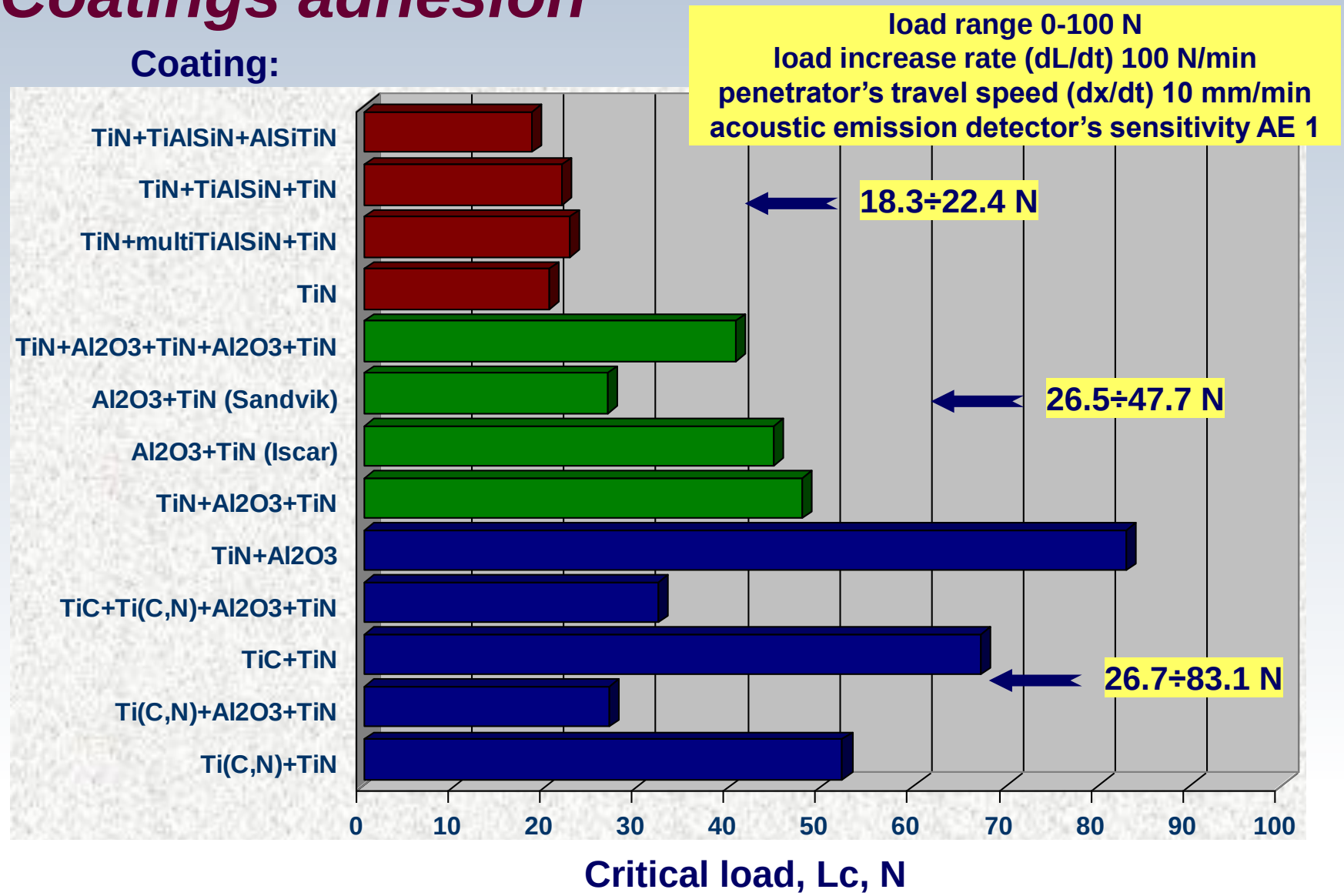


TiN+multiTiAlSiN+TiN

TiC+Ti(C,N)+Al_2O_3+TiN

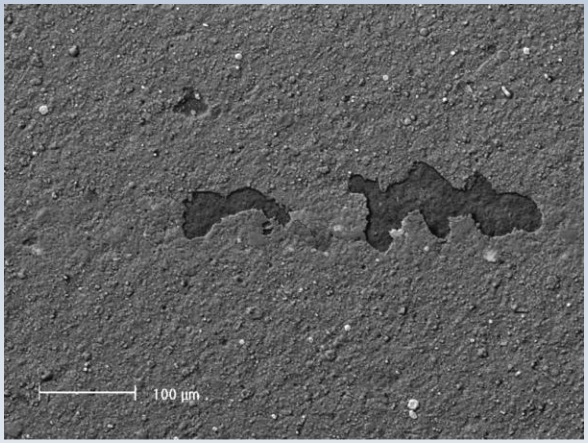


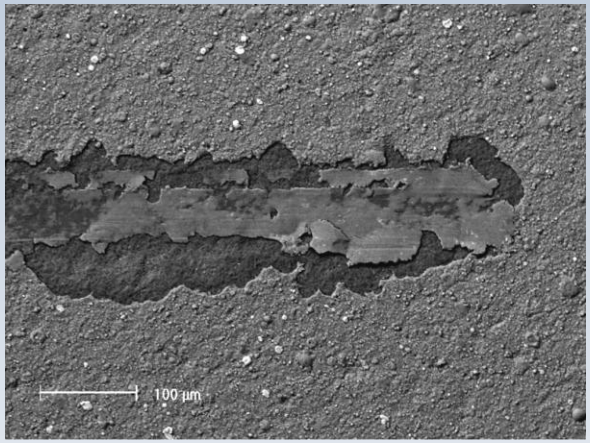
Coatings adhesion

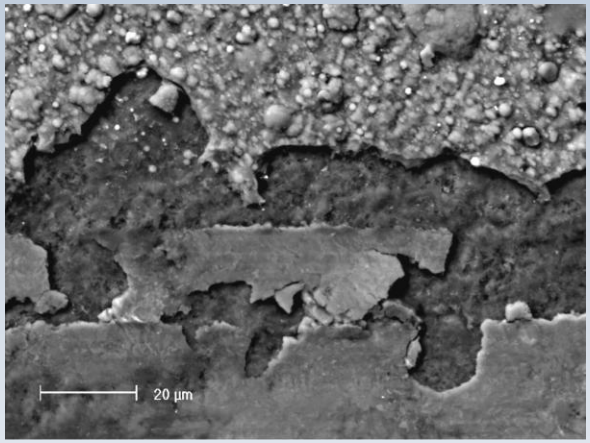


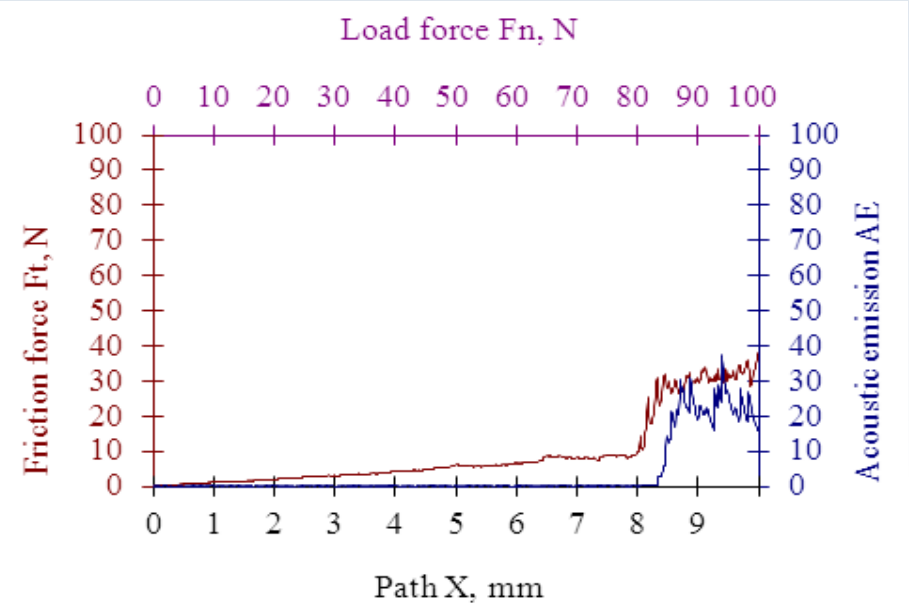
Coatings adhesion

$TiN+Al_2O_3$

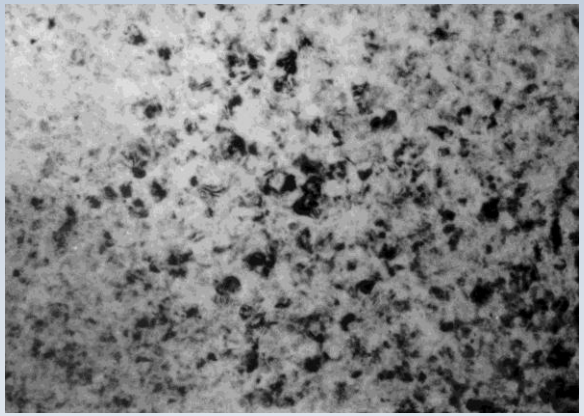




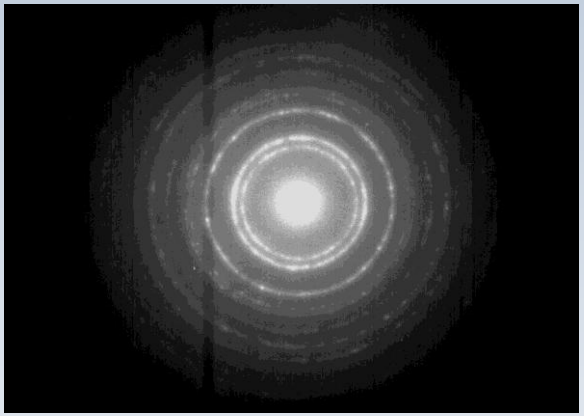




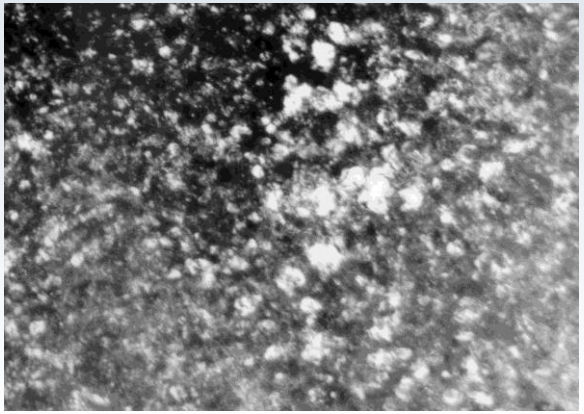
Structure of the TiN+multiTiAlSiN+TiN coating



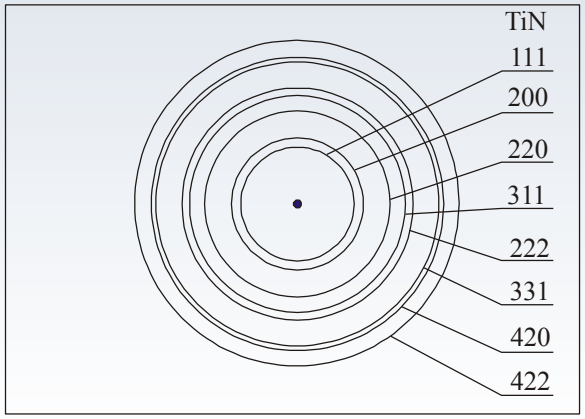
50 nm



Cross-section parallel to a layer surface

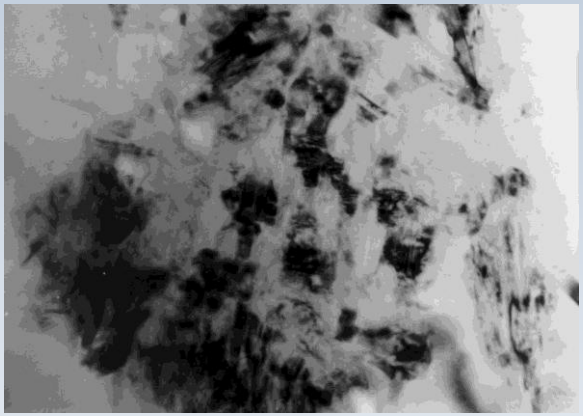


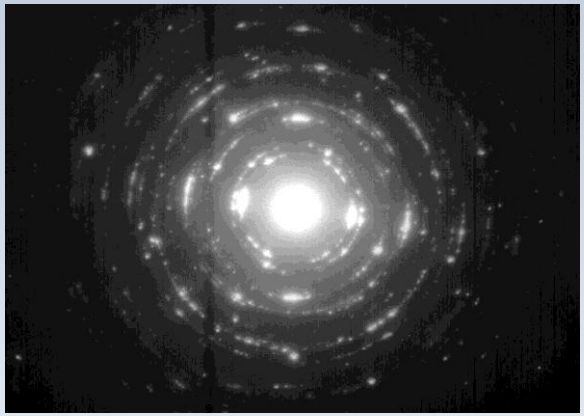
50 nm



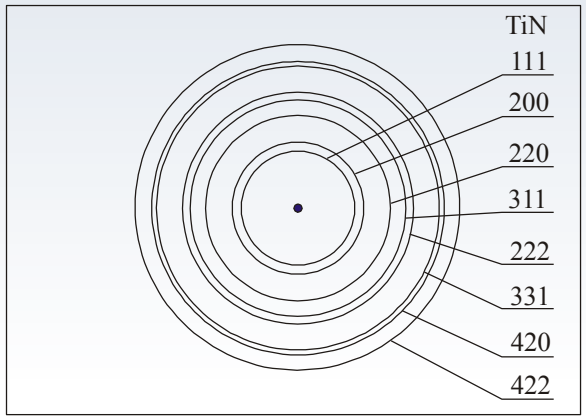
Dark field of reflexes (111) TiN

Structure of the TiN+Al_2O_3 coating



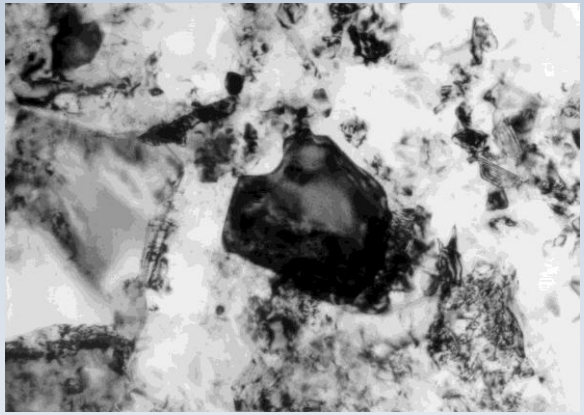


Cross-section parallel to a layer surface

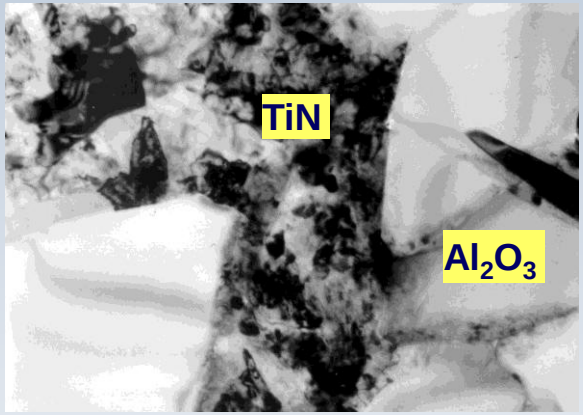


Dark field of reflexes (111) TiN

Structure of the TiN+Al_2O_3+TiN+Al_2O_3+TiN coating

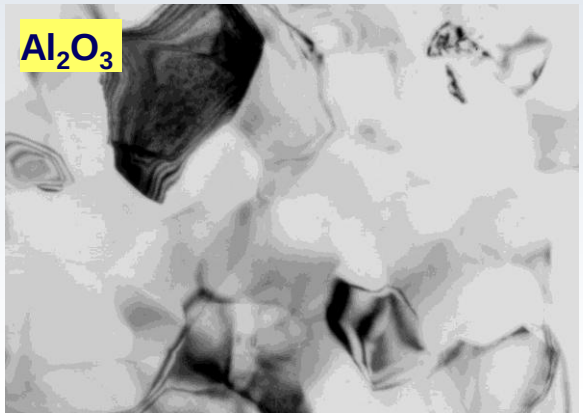


200 nm

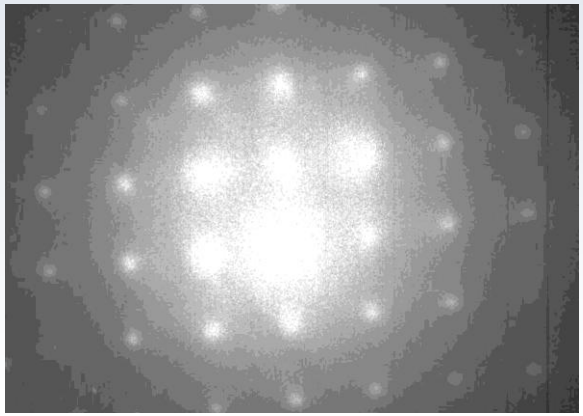


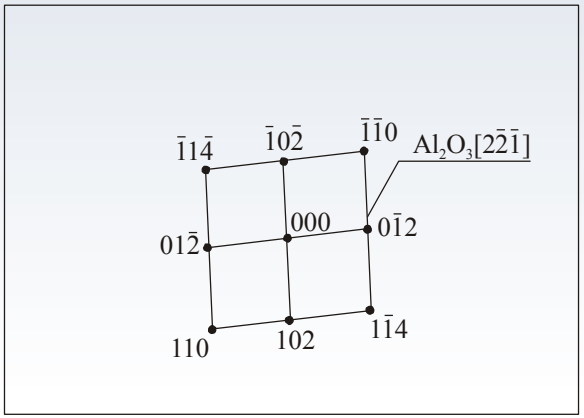
200 nm

Cross-section parallel to a layer surface

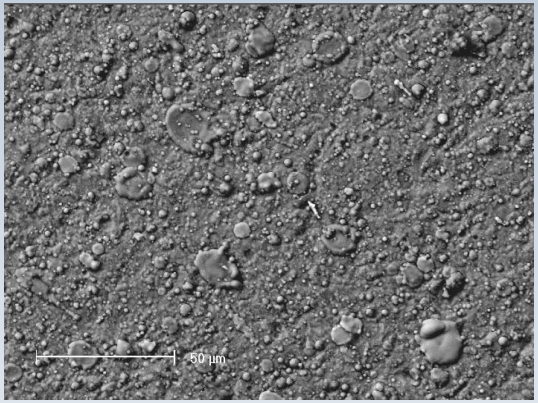


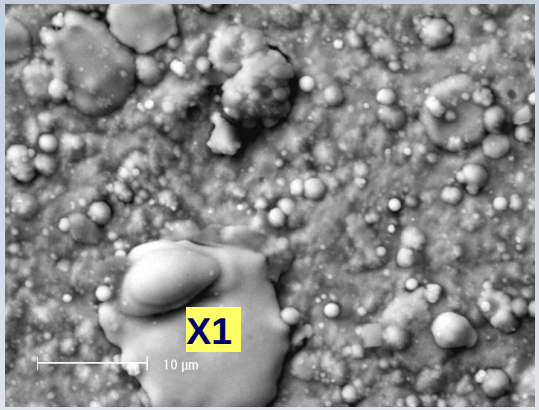
200 nm

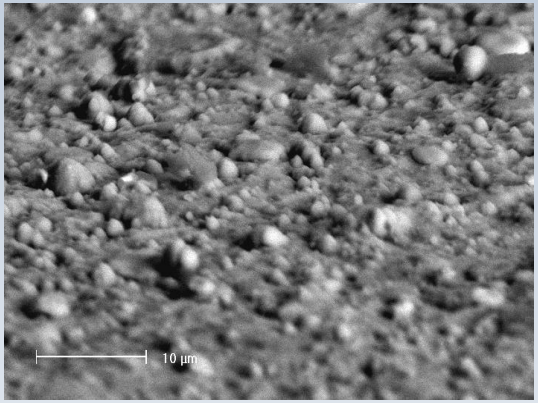




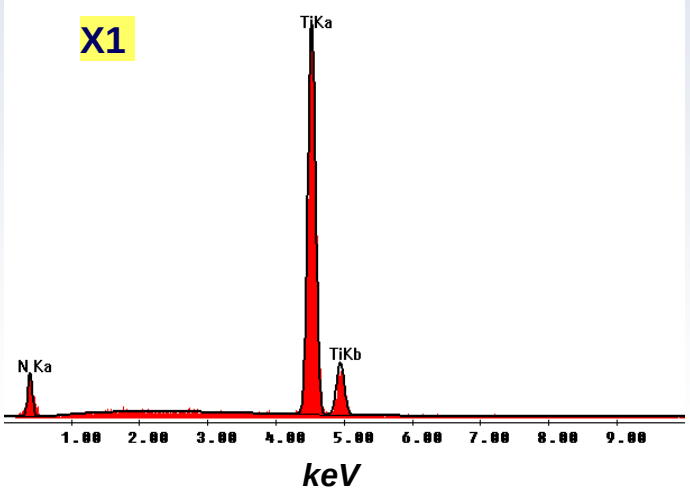
Surface topography of PVD coatings







TiN+multiTiAlSiN+TiN

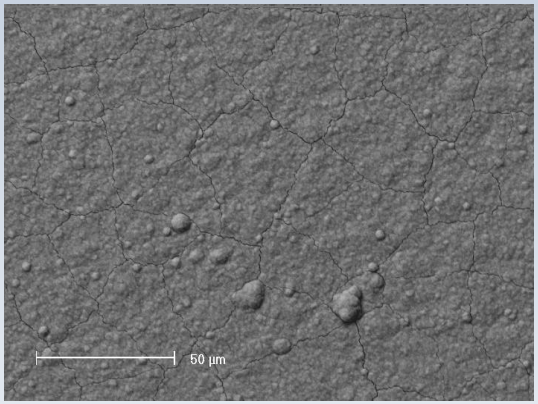


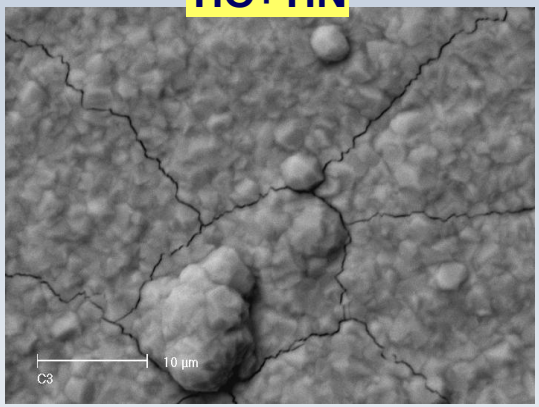
area X1

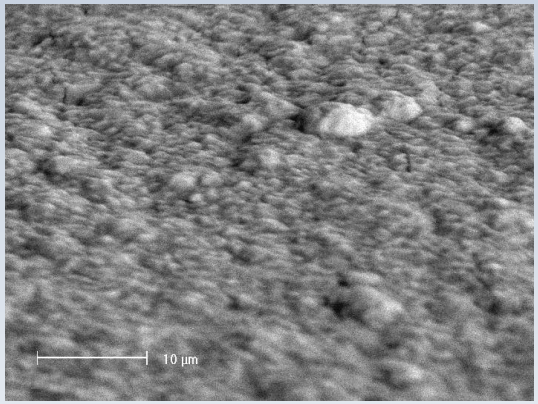
Element	Mass concentration of elements,%	Atomic concentration of elements, %
N	16.24	39.86
Ti	83.76	60.14
Sum	100	100

Surface topography of CVD coatings

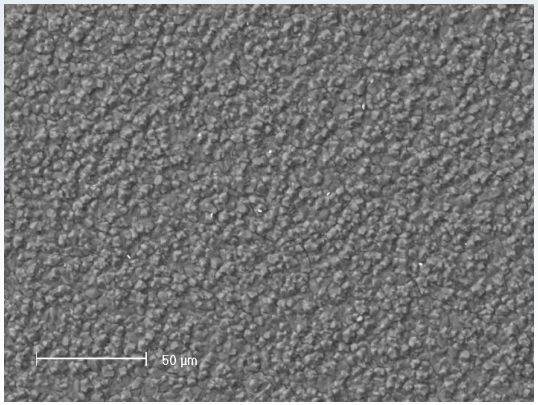
TiC+TiN

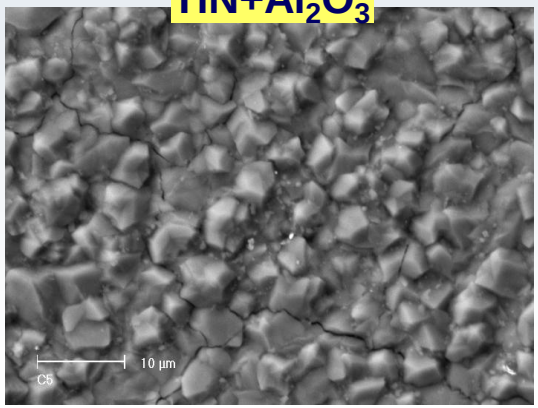


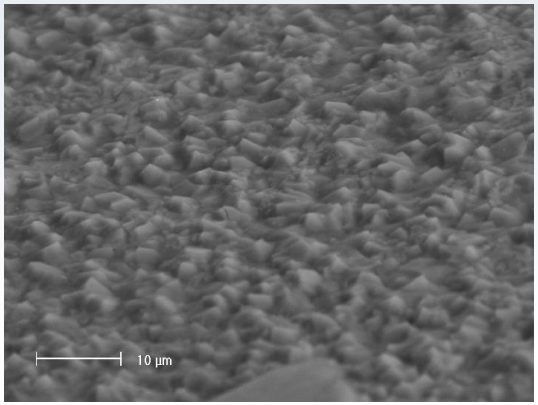




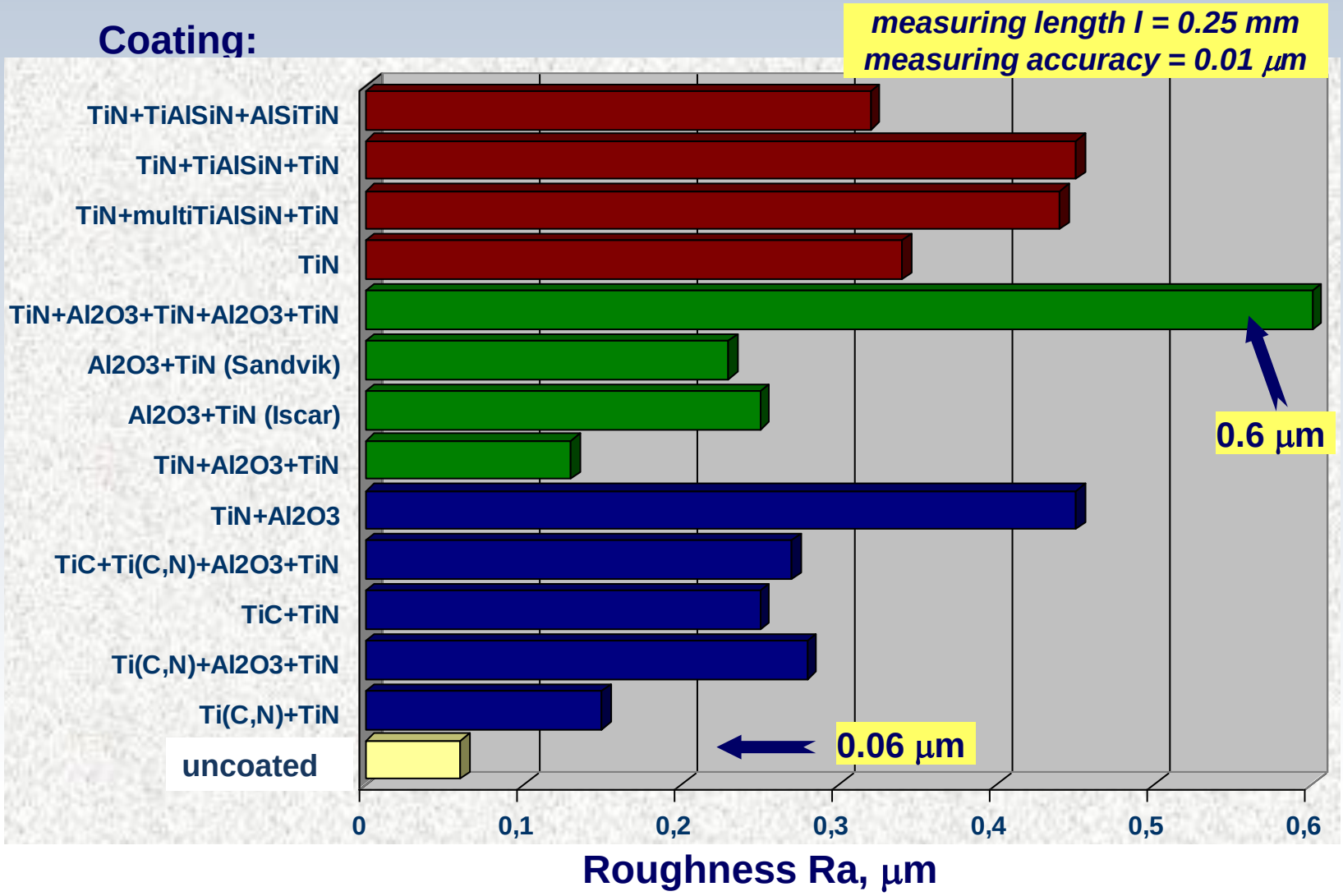
TiN+Al_2O_3





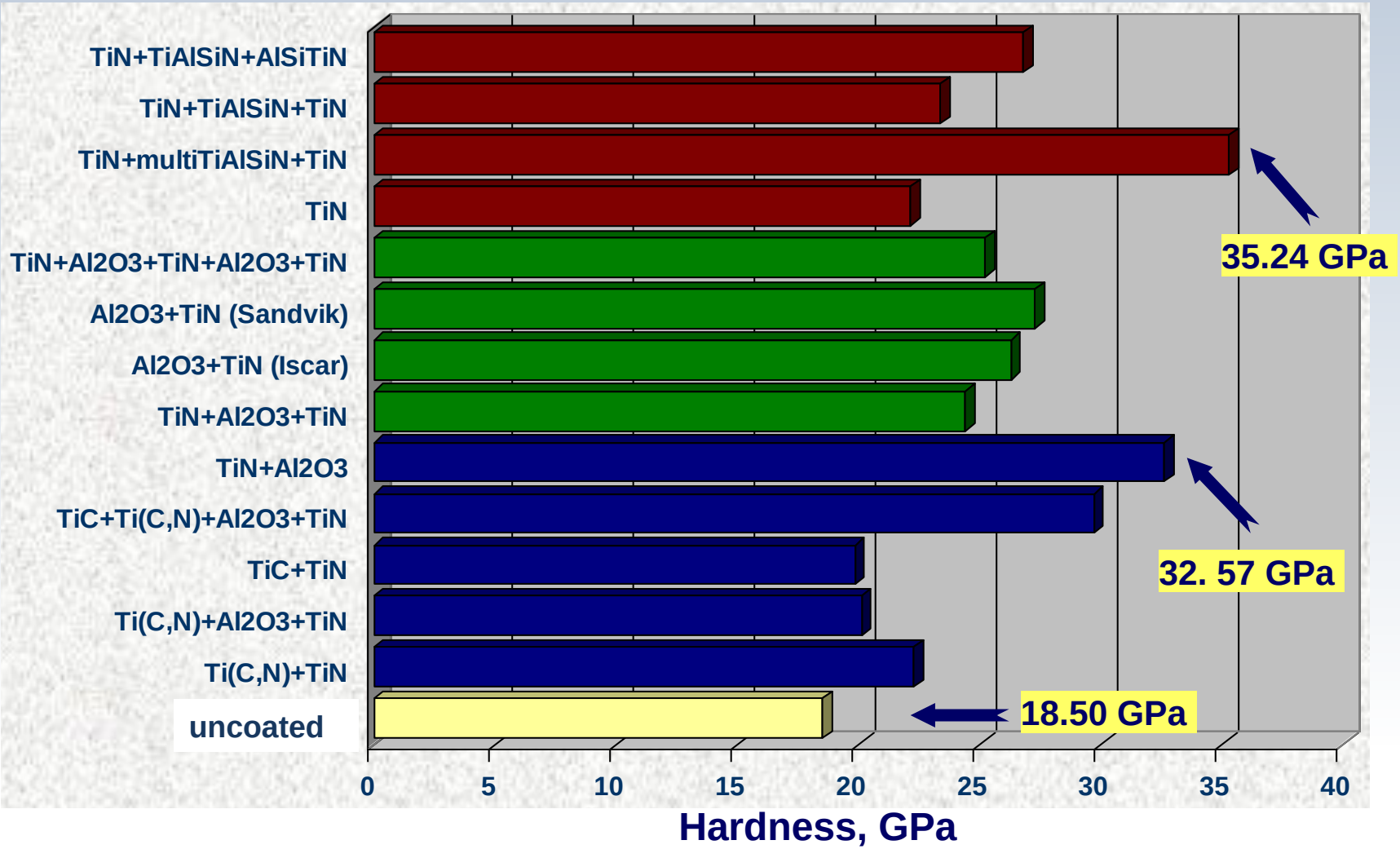


Coatings roughness

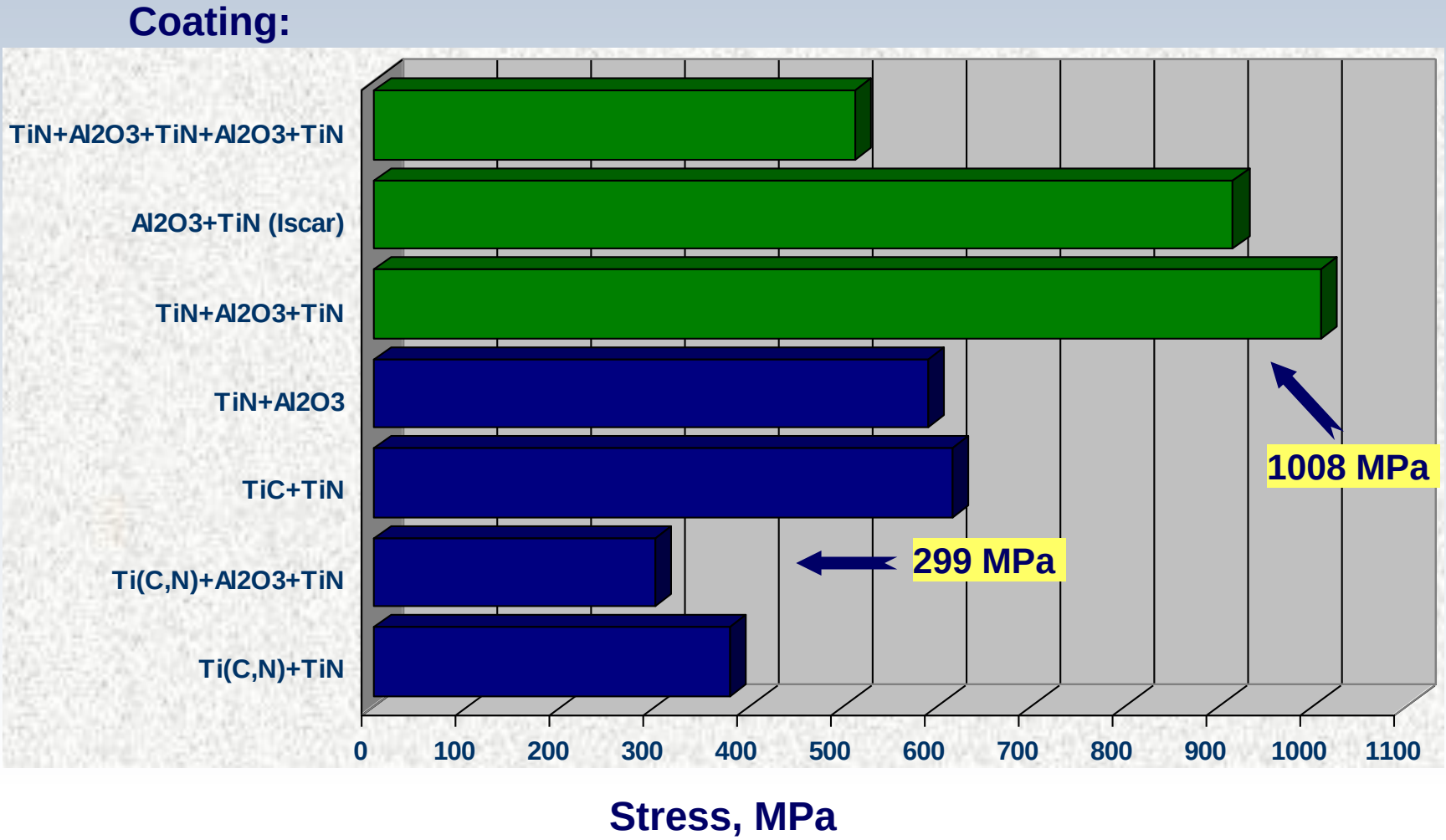


Coatings hardness

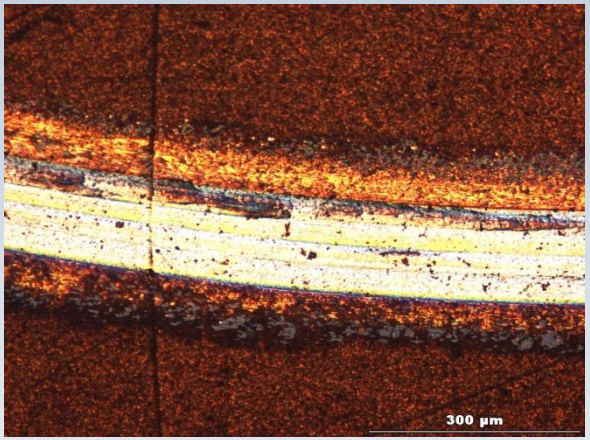
load, F = 70 mN

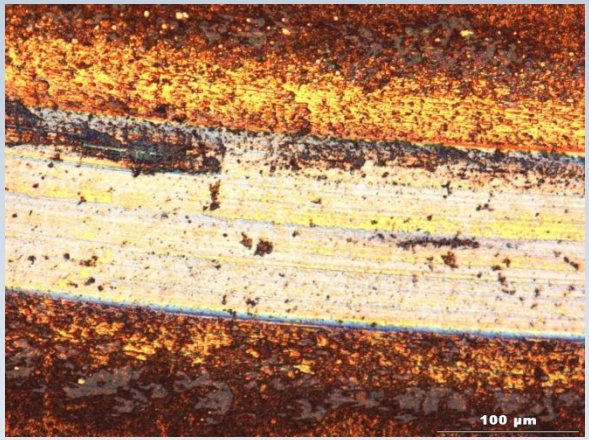


Coatings stresses

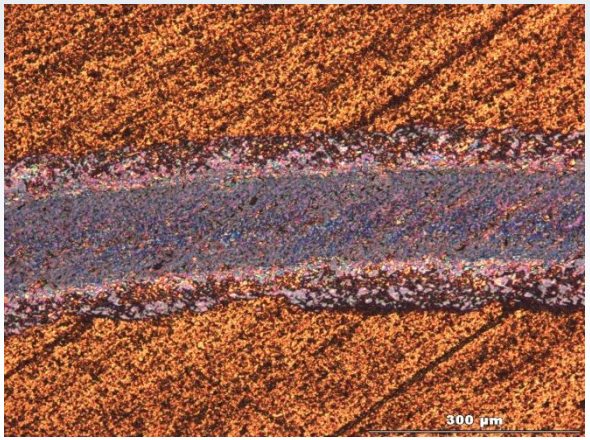


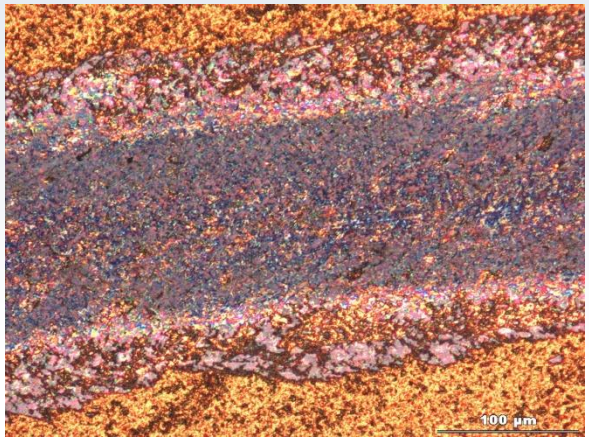
Coatings wear resistance





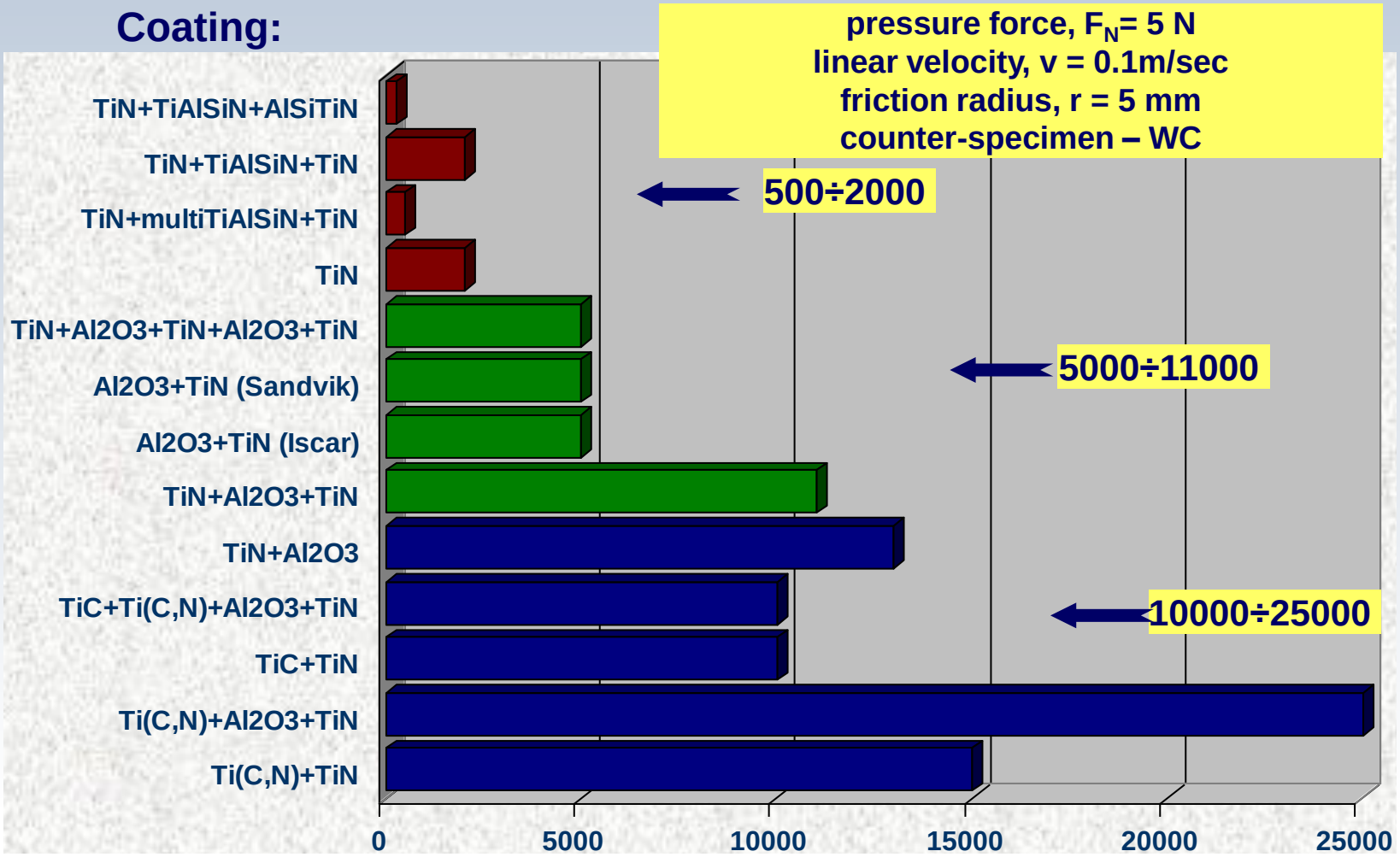
Ti(C,N)+TiN
number of cycles
15000



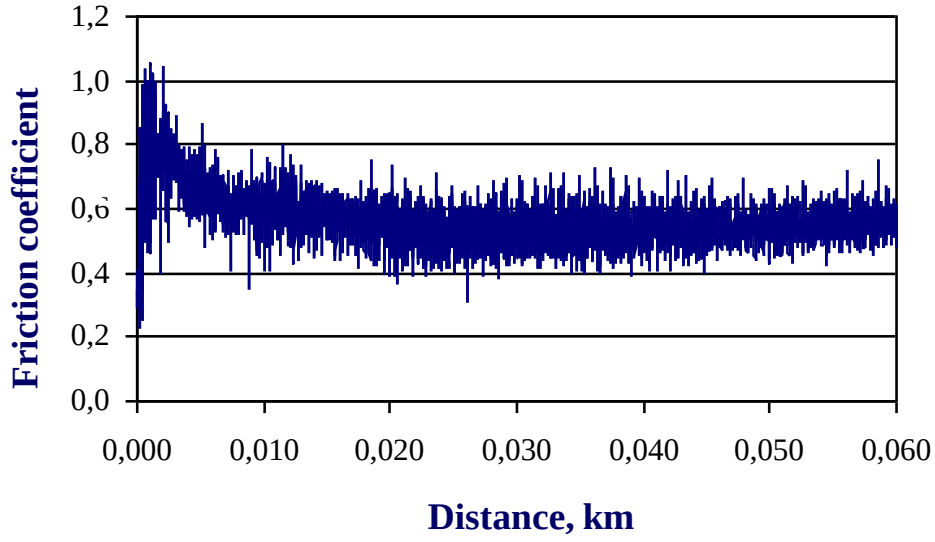


TiN+Al_2O_3+TiN
number of cycles
11000

Coatings wear resistance

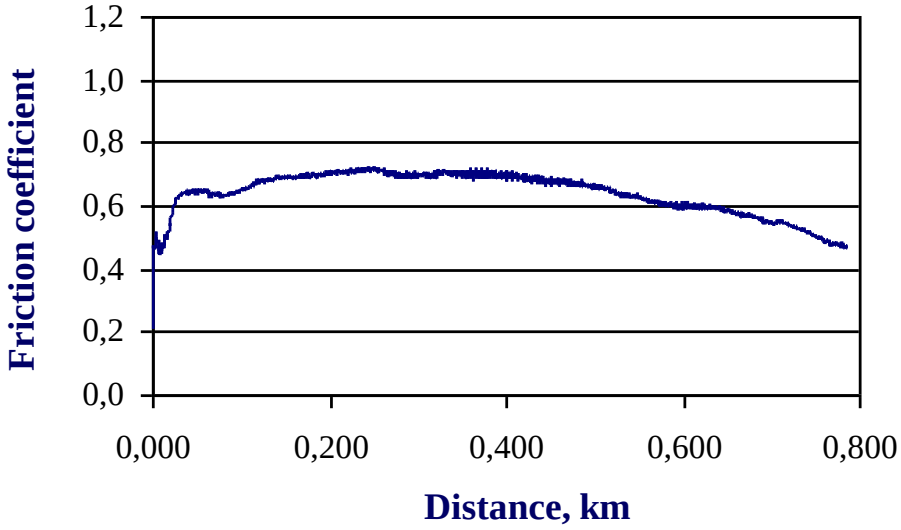


Coatings wear resistance

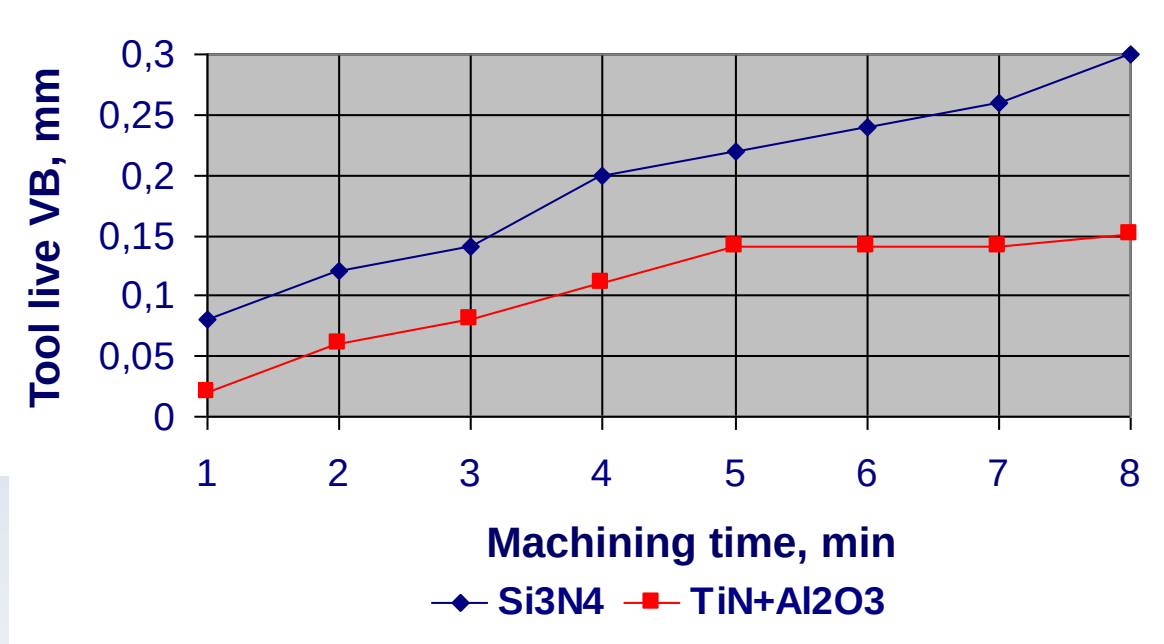


TiN
number of cycles
2000

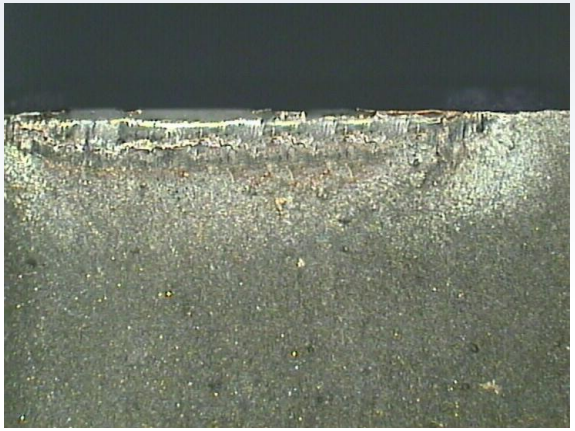
Ti(C,N)+Al_2O_3+TiN
number of cycles
25000

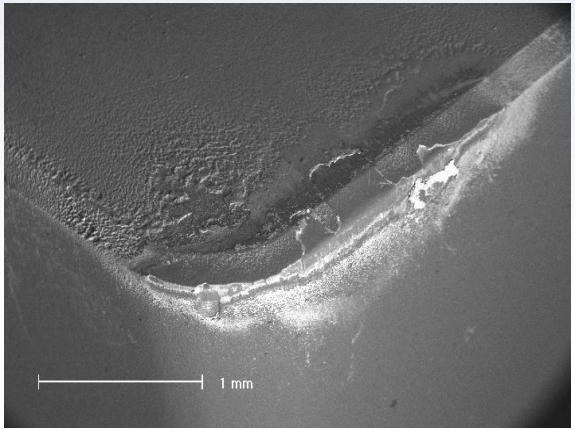


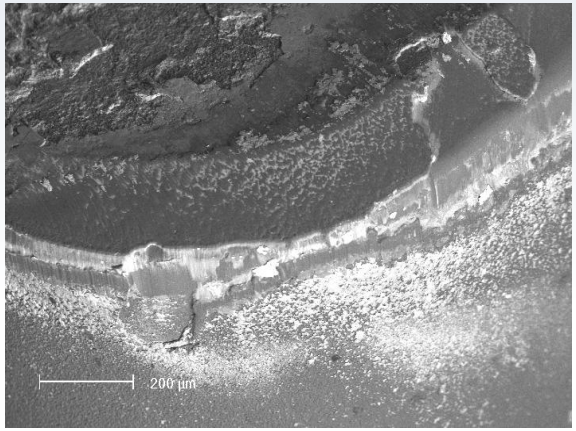
Cutting properties



$TiN+Al_2O_3$
machining time t = 8 min
VB = 0.15 mm

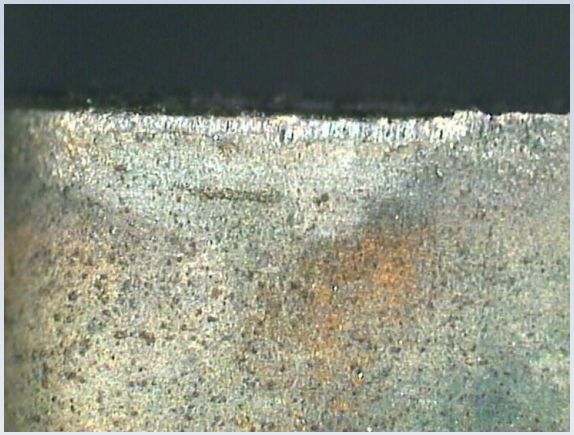


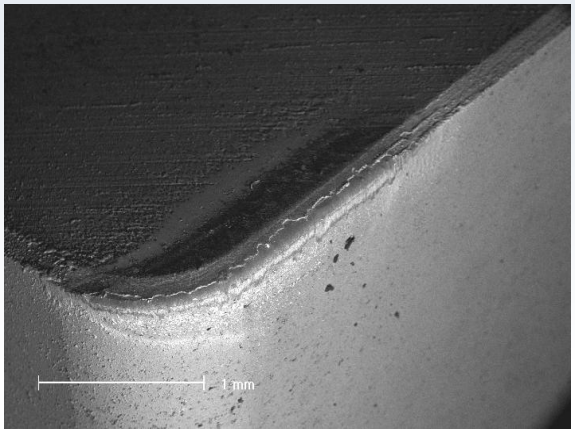




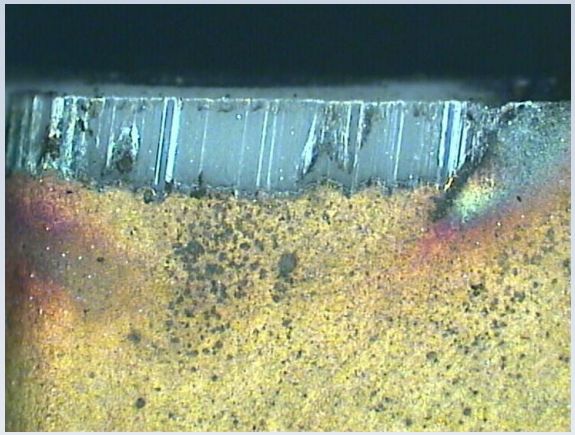
Cutting properties

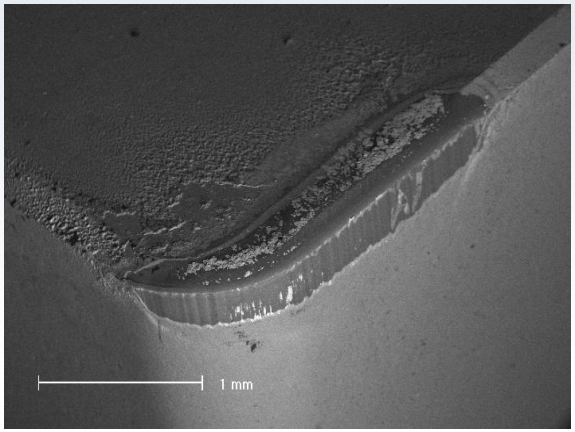
$TiN+Al_2O_3+TiN+Al_2O_3+TiN$



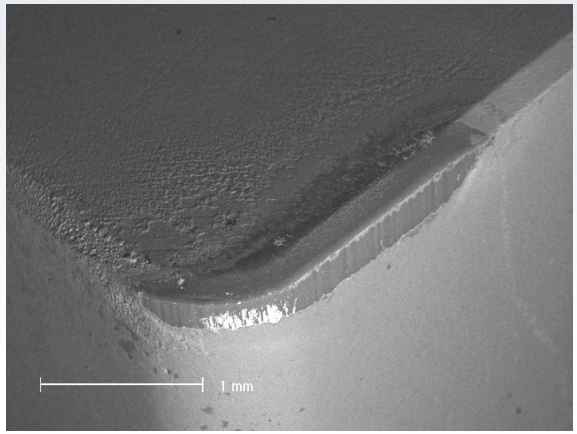


Ti(C,N)+TiN

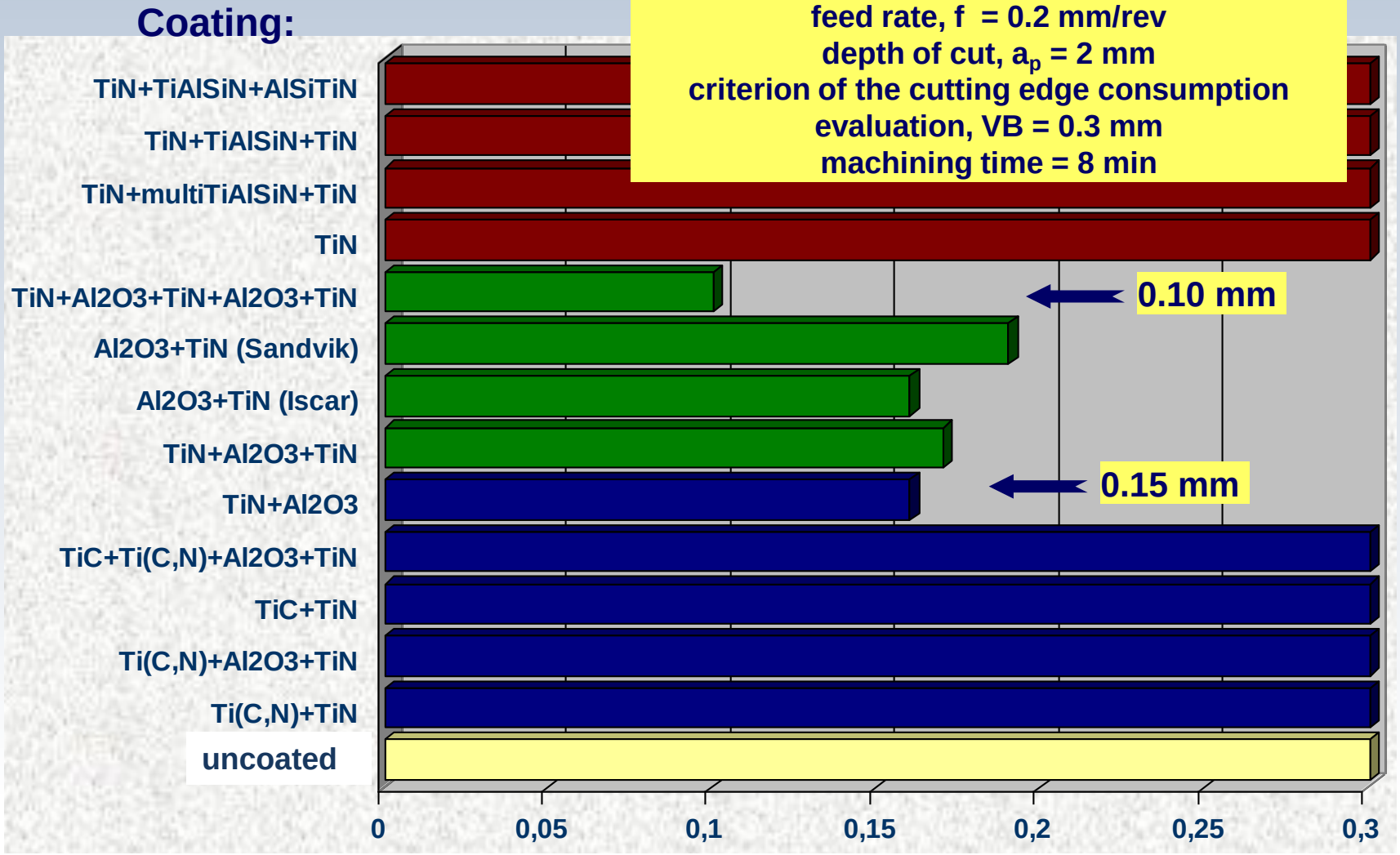




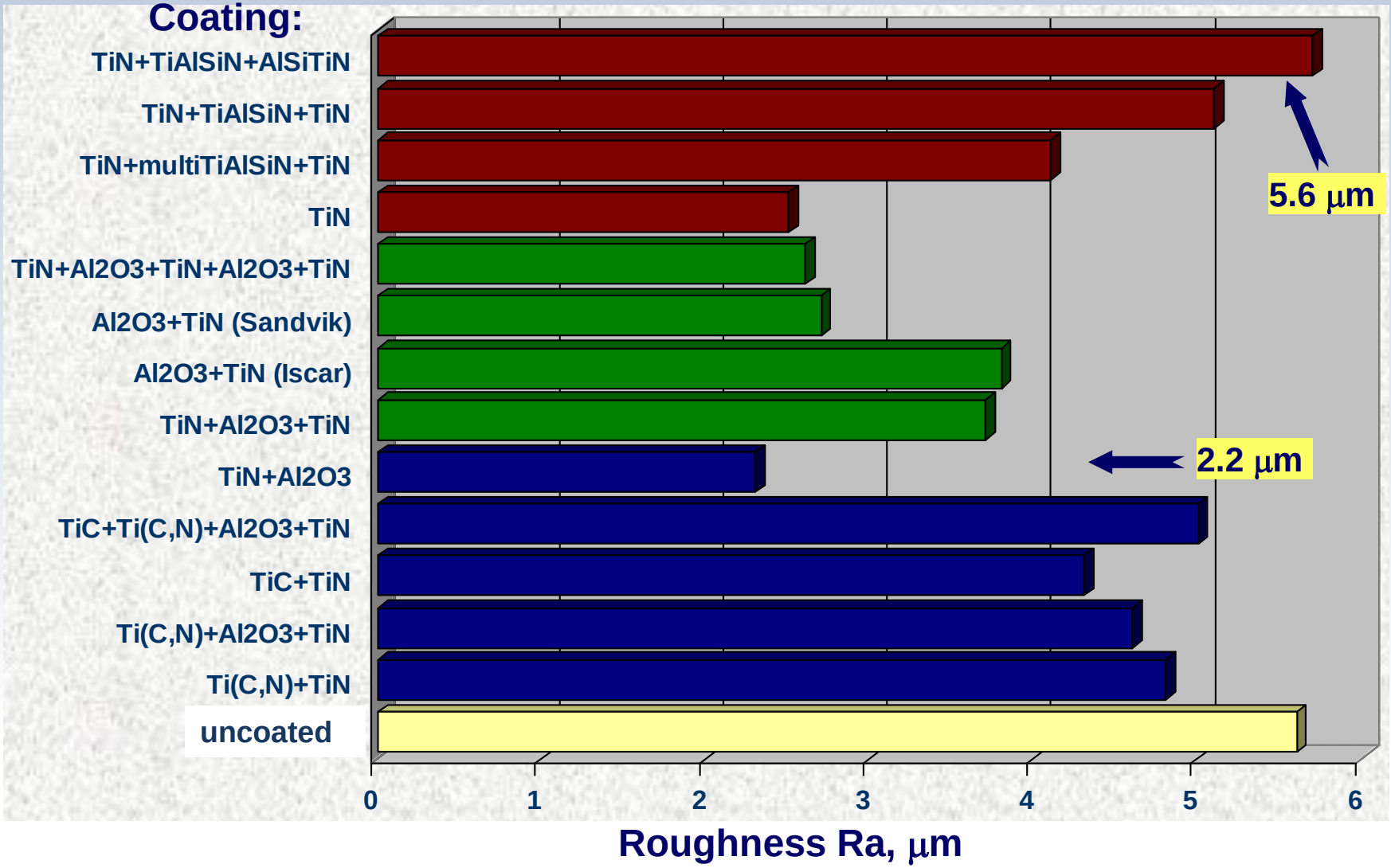
TiN+multiTiAlSiN+TiN



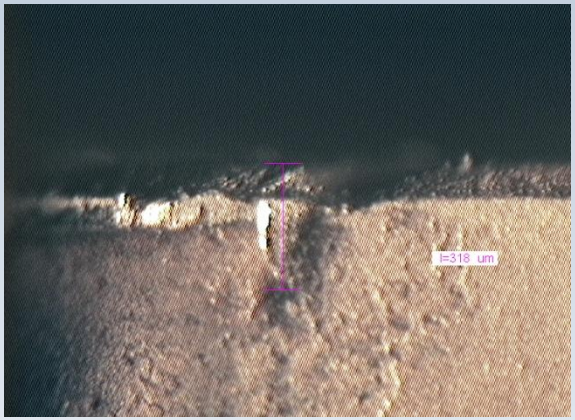
Cutting properties

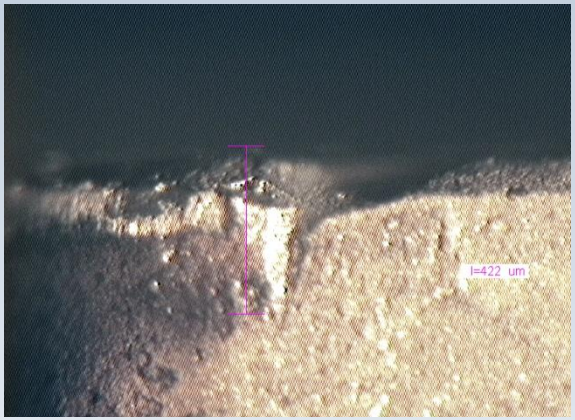


Cutting properties

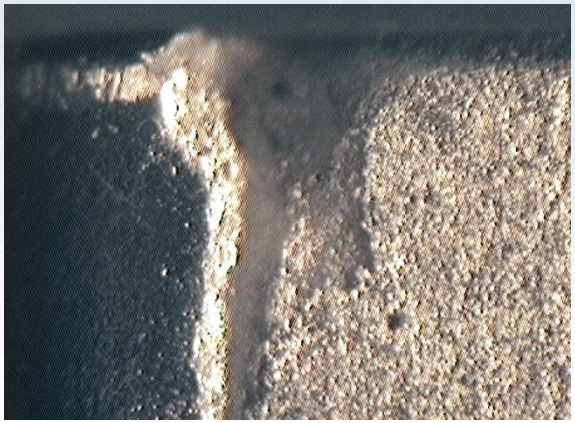


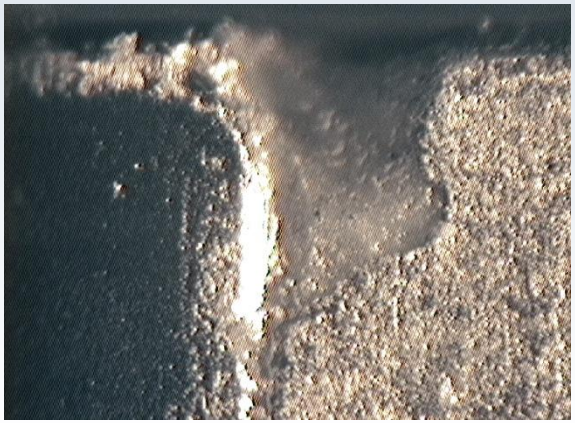
Cutting properties





TiN+multiTiAlSiN+TiN
machining time = 1.5 min
VB = 0.42 mm





TiN+Al_2O_3
machining time = 0.5 min
VB = 0.98 mm

Conclusions

1 **It has been proven stated thesis of the work pointing out that: Producing of multi-layer coatings type of Al_2O_3+TiN and TiN+Al_2O_3 in the CVD processes onto silicon nitride (Si_3N_4) ceramics can increase utility properties of cutting tools coated by them machining tools in comparison with multilayer coatings with an intermediate of TiC and Ti (C,N) are produced in the CVD process and the multi-component coatings type of TiAlSiN obtained in the PVD process, especially destined for the implementation of modern machining technologies, including high-speed machining with high speeds, precision machining and dry cutting without coolants.**

Conclusions

2 **All PVD and CVD coatings deposited onto the nitride tool ceramics are characterized by a structure without pores and discontinuities and by tight adherence to themselves and of the entire multilayer coating to the substrate. The comprehensive examinations on the transmission electron microscope (thin foil perpendicular to the layer surface) make it possible to reveal the columnar structure for the TiN layer included in the TiN+Al_2O_3.**

Conclusions

3 **These examinations have revealed also that there is an interface between the TiN and Al_2O_3 layers in case of the TiN+Al_2O_3 coating, where the fine grains of these phases are found. Occurrences of the scarce fine-grained Al_2O_3 grains with the monoclinic structure were revealed in this zone, unlike the typical structure of the Al_2O_3 phase with the trigonal lattice, which occurs outside of this border area over the entire layer width. The observed interface zone contributes to good adhesion between these layers, which is also confirmed by high abrasion wear resistance of this coating.**

Conclusions

4 **Evaluating differences of textures of the TiN layers obtained with the PVD and CVD methods one can state that – in the most general understanding – the method of physical deposition from the gaseous phase favours development of the relatively strong texture. It is the {111} + {001} double texture most often; however the {001} component is usually stronger.**

Conclusions

5 **Surface layer hardness increase, compared to the uncoated substrate hardness can reach even 100%. Hardness of the investigated coatings systems determines their abrasion wear resistance, which was revealed most clearly for the TiN+ Al_2O_3 coating - the hardest one from the CVD coatings, adding simultaneously to the decrease of the cutting tools edge wear intensity during machining.**

Conclusions

6 **The CVD coatings, compared to the PVD ones, are characteristic of the very good adherence to the nitride ceramics substrate, which is decided not only by adhesion, but also the diffusion mixing of elements in the interface between the substrate and the coating, and in case of the TiN+Al_2O_3 double-layer coating – mixing of phases in the interface between the particular layers, which – even at the highest load – does not cause total delamination of any coating in the adhesion tests.**

Conclusions

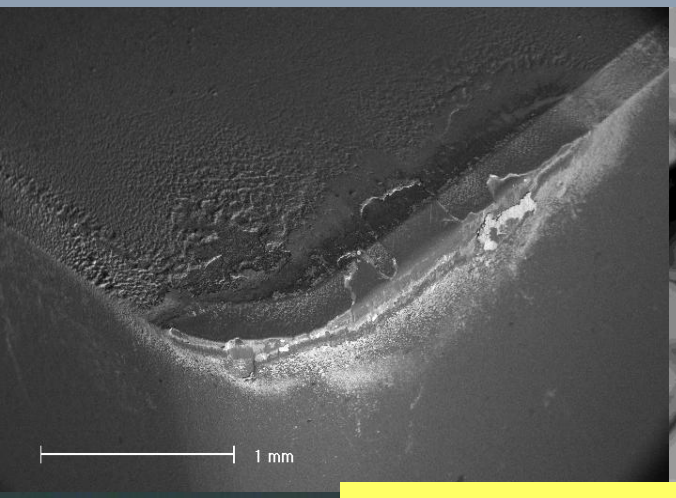
7 **The abrasive wear resistance tests made with the „pin-on-disk" method revealed that the PVD coatings have worse tribological properties compared to those put down with the CVD method. In nearly all cases damage of coatings occurs up to the Si_3N_4 nitride ceramics substrate zone. Hardness of the investigated coating systems determines their abrasion wear resistance, which was revealed most clearly for the Al_2O_3+TiN coating – the hardest among the CVD ones, contributing at the same time to decreasing the cutting tool edge wear intensity during machining.**

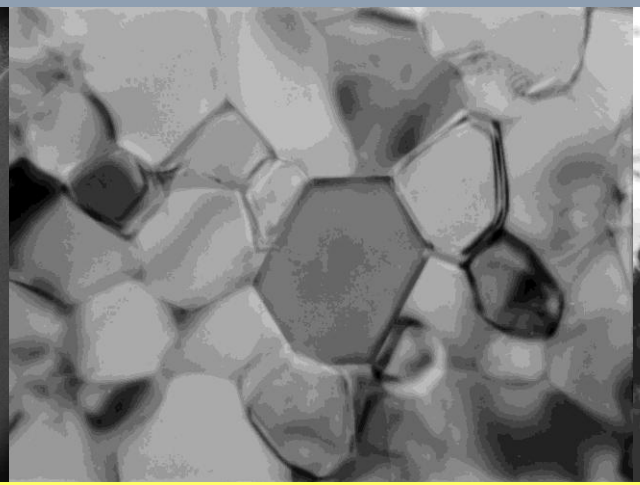
Conclusions

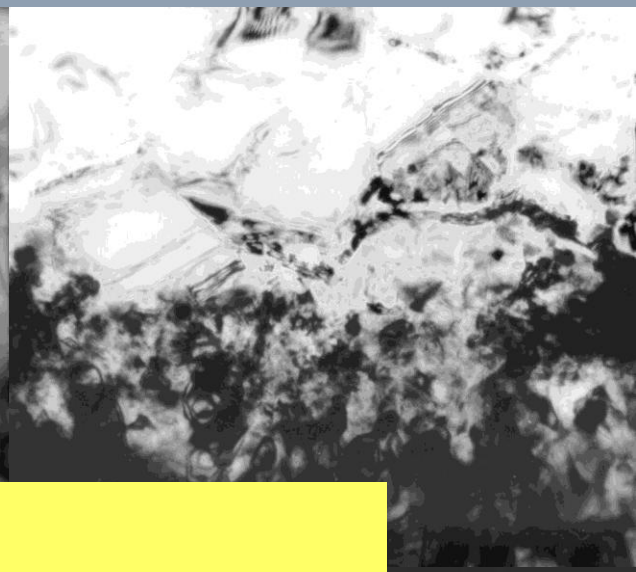
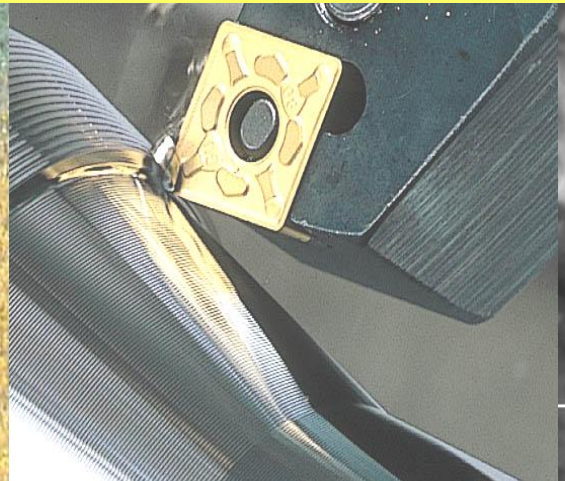
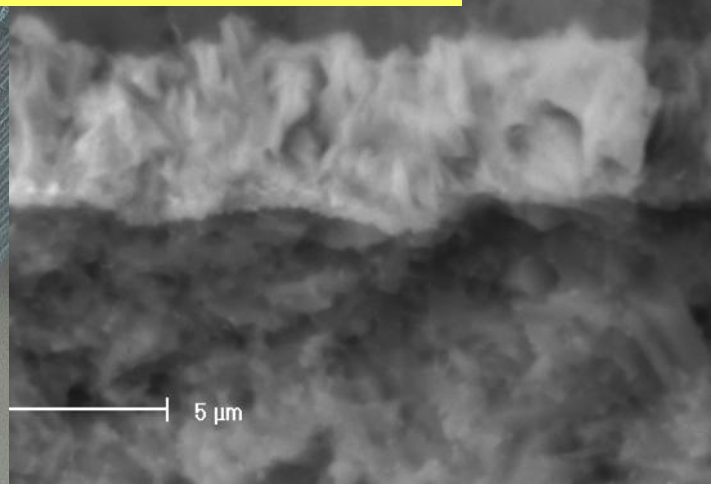
8 **High hardness, good adhesion, and very good abrasion wear resistance - especially noticeable for the nitride ceramics with the Al_2O_3+TiN combination of layers and with the TiN+Al_2O_3 coating, increase the cutting tool flank life and therefore, and also because of the possibility of their use in the pro-ecological dry-cutting processes, without employment of any cutting fluids, make these coatings suitable for many industrial applications on cutting tools.**

Acknowledgements

The research was carried out partially in cooperation with Doc. Dr Ing. Antonin Kriz from University of West Bohemia, Plzen and M. Sima from SHM-Šumperk (Czech Republic).







Thank you for your kind attention!