Interdisciplinary conference

«RECENT ADVANCES in SCIENCE and TECHNOLOGY»

The 27th of May

Tomsk Scientific Center

The mechanical properties of Ti-Ni-Ta- based surface alloys on the NiTi-substrate formed by the additive thin-film electron beam synthesis

Filipp D'yachenko[1] 2nd year graduate student

Meisner L.L.[1, 2], Atovullaeva A.A.[2]

[1]Institute of Strength Physics and Materials Science SB RAS
[2]National Research Tomsk State University
Tomsk, Russia
E-mail: frozennonetroll@mail.ru

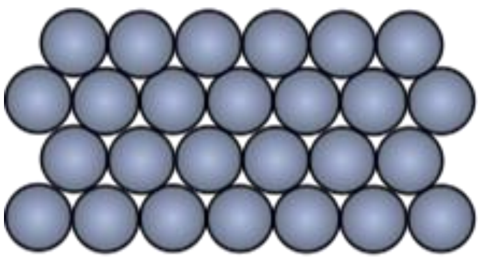
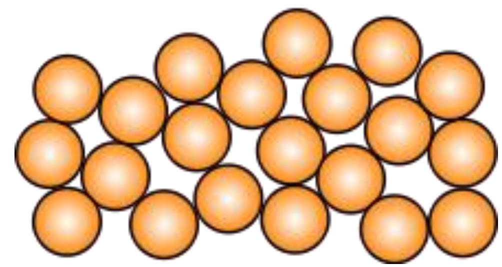
The research was carried out with support by the grant of the Russian Science Foundation No. 18-19-00198 (26.04.2018)

The structure

METALLIC GLASSES

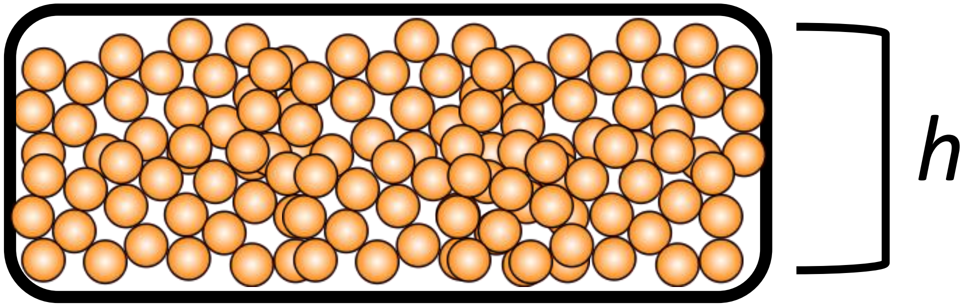
Comparative characteristics

of crystalline and amorphous state

CRYSTALLINE STRUCTURE	AMORPHOUS STATE
	
Long atomic order Translational symmetry	Near atomic order Disordered structure
Structural anisotropy	Isotropic material
High elastic and plastic properties	Low plastic properties
Strain hardening	No strain hardening

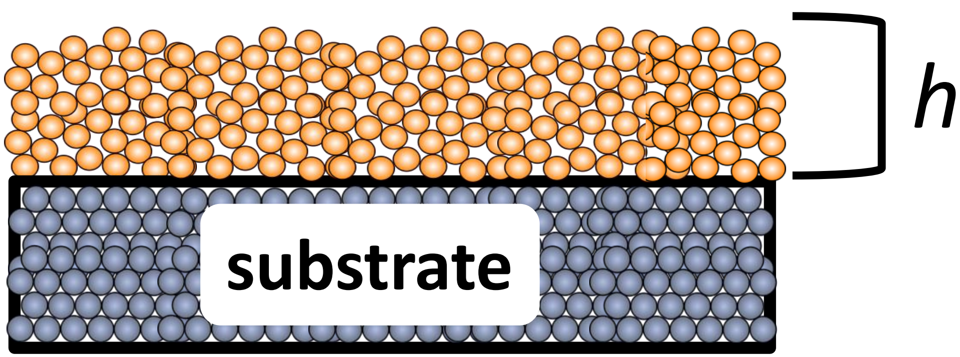
Introduction

METALLIC GLASSES



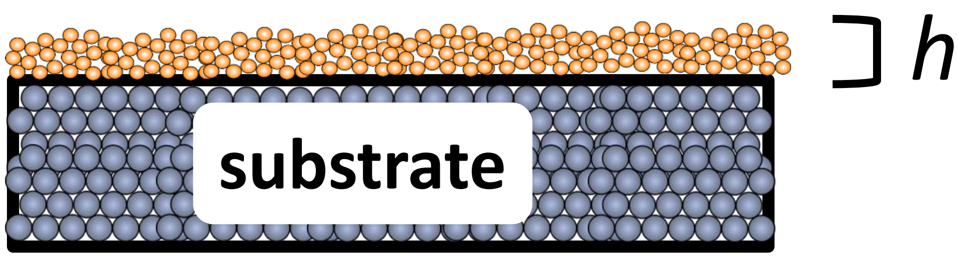
BULK METALLIC GLASSES

(BMGs) ($h \geq 10$ mm)



AMORPHOUS COATING on the metallic substrate

(10 µm $\leq h \leq 100$ µm)



THIN-FILM METALLIC GLASSES

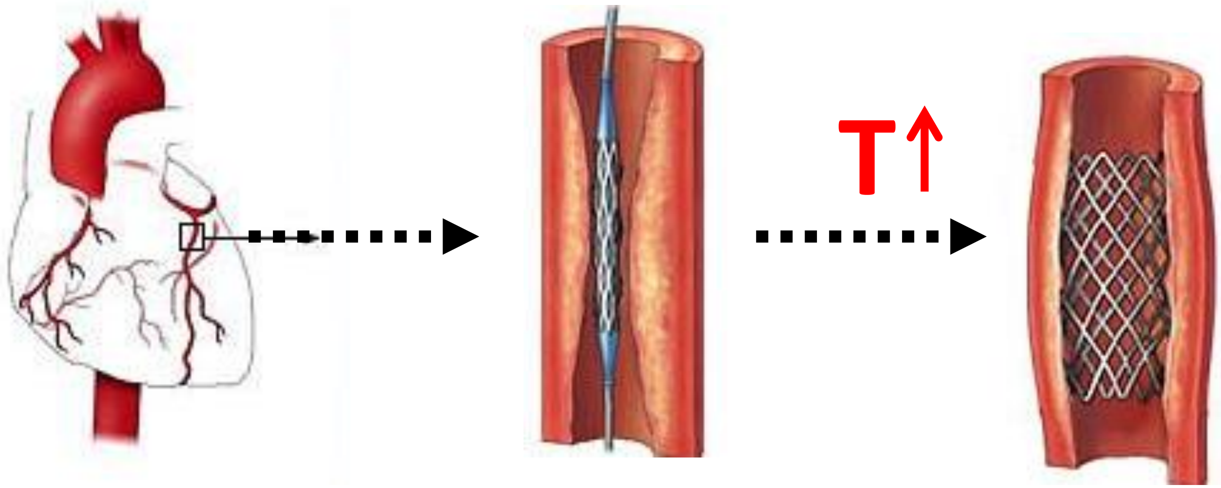
(TFMGs) ($h \leq 100$ µm)

NiTi stent

Stenosis of artery

Deformed shape

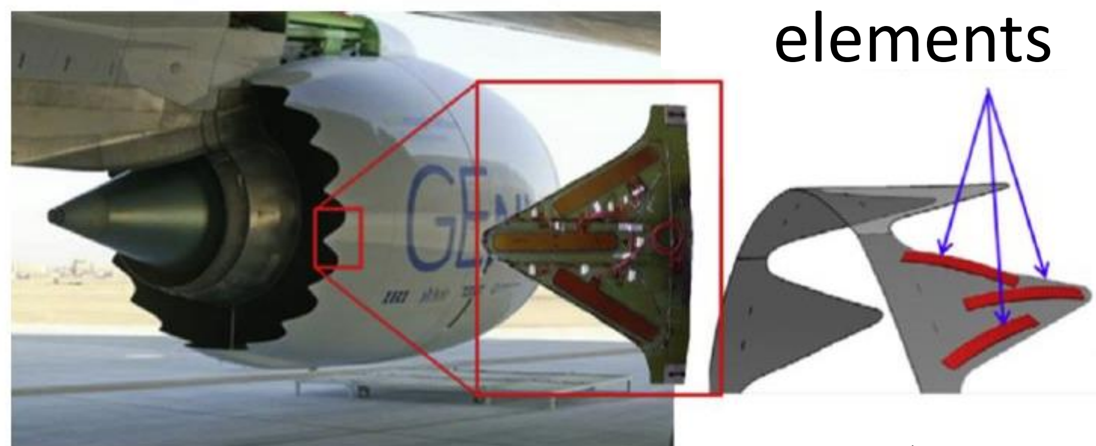
Original shape



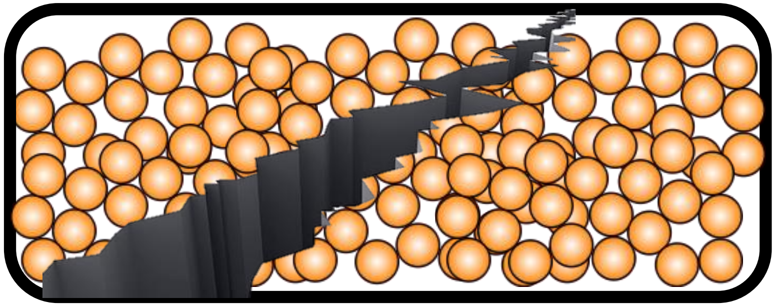
Springs / Wires

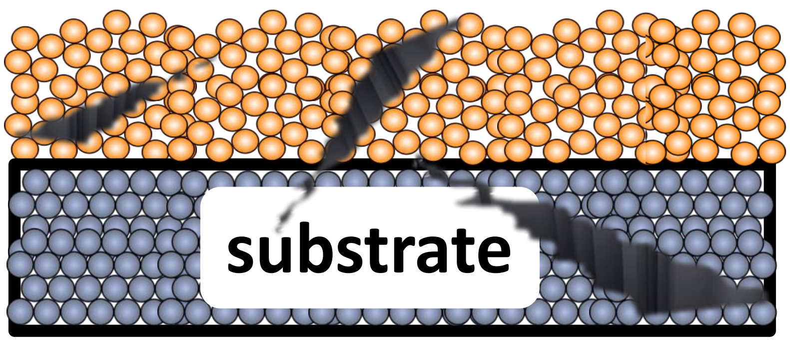
Boeing's variable geometry of nozzle

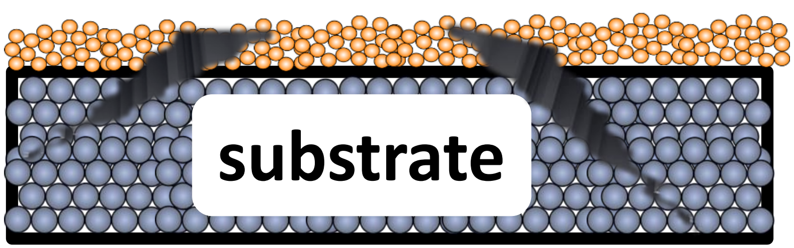
Shape memory elements



METALLIC GLASSES







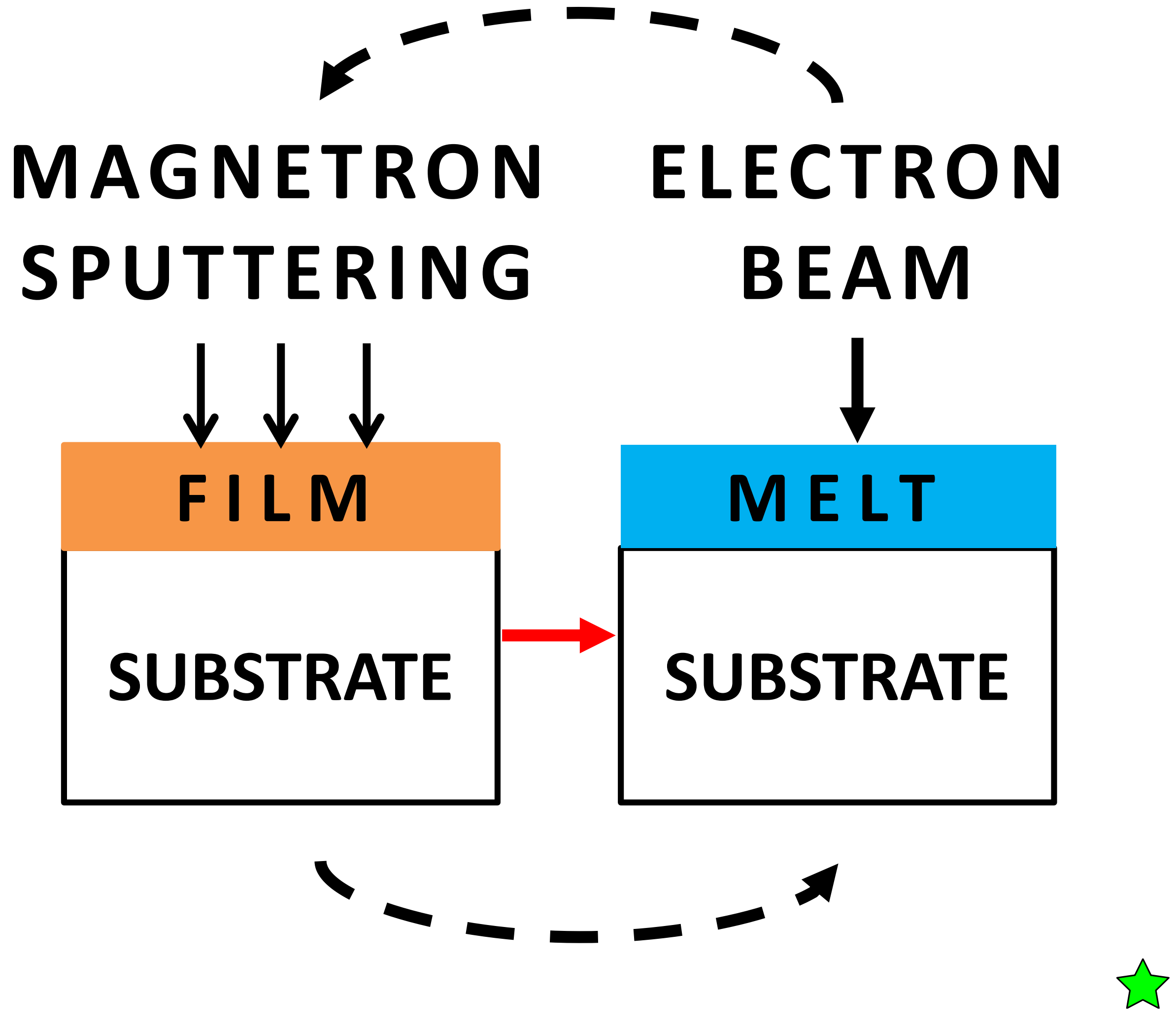
CRACK PROPAGATION

due to the

low ductility of
amorphous state

SURFACE ALLOYS

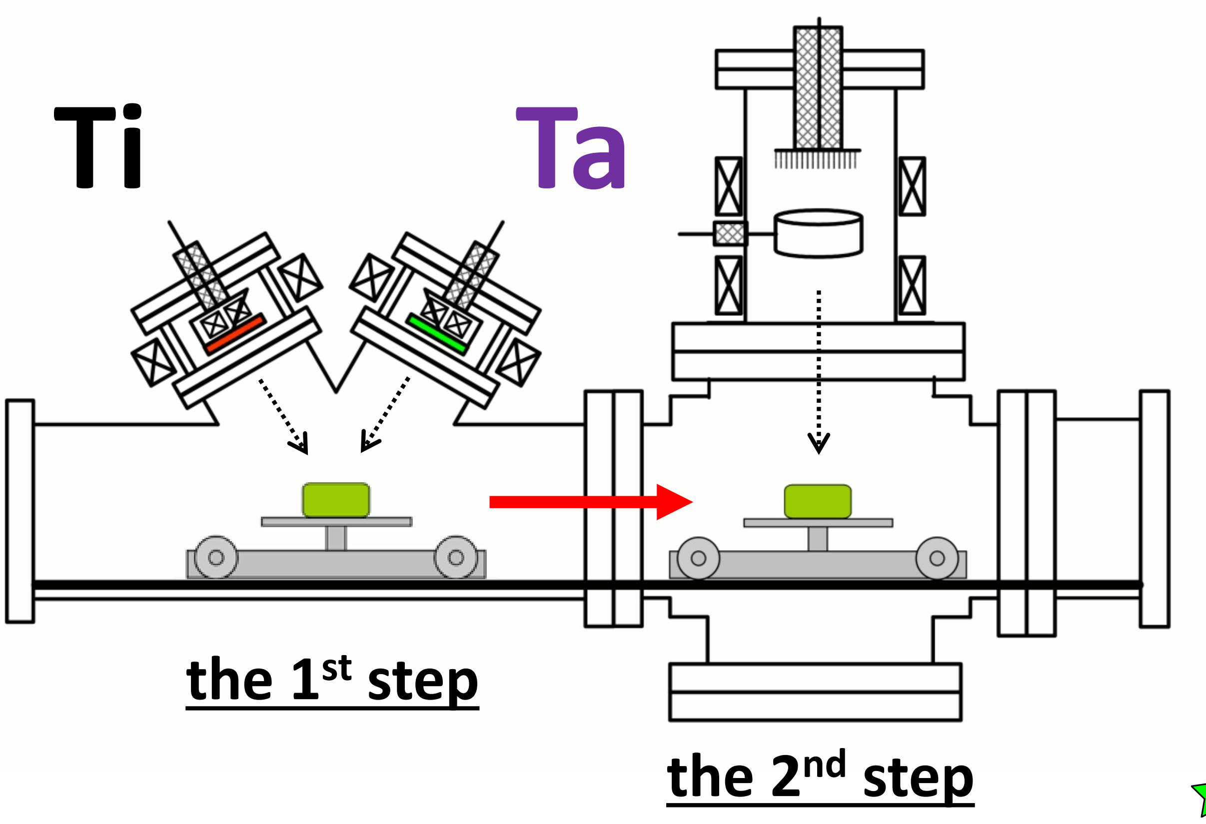
Additive thin-film electron beam synthesis



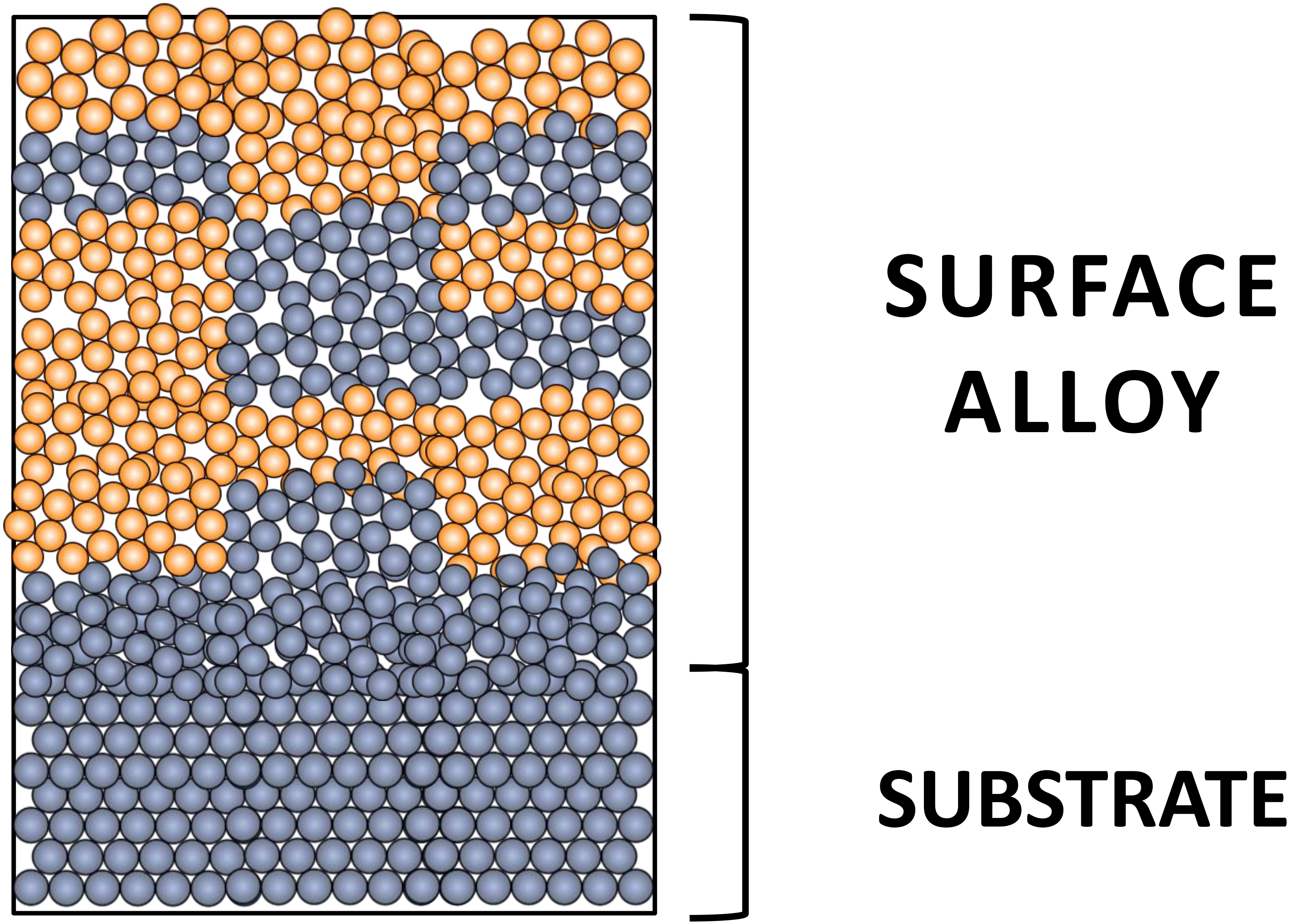
SURFACE ALLOYS

Additive thin-film electron beam synthesis

MAGNETRON SPUTTERING **ELECTRON BEAM**



SURFACE ALLOYS



The purpose

to investigate the mechanical properties of Ti-Ni-Ta-based surface alloys on the NiTi-substrate formed by the additive thin-film electron beam synthesis

The scientific and applied tasks

- to study basic principles and methods of investigations of mechanical properties of the materials on submicro- and microscale levels
- to investigate the mechanical properties of the surface layers of the NiTi samples before and after additive thin-film electron beam synthesis by method of the instrumented indentation
- to determine the values of hardness *H*, elastic modulus *E*, characteristic of plasticity δ and recovery ratio η of the indent on the synthesized layers

Materials and methods

Commercial ***NiTi alloy*** produced as rolled sheets by vacuum induction melting (MATEK-SMA, Russia)

Chemical composition:

Ti – 55.08Ni – 0.051C – 0.03O – 0.002N (wt. %)

Specimen's size – 10 x 10 x 1 mm

Preliminary surface treatment

1 Chemical etching

In acid bath
(3 p. HNO_3 + 1 p. HF)

2 Electrolytically polishing

In acid bath
(3 p. CH_3COOH + 1 p. $HClO_4$)
and ice-water mixture

3 Ultrasonic bath

Three times in distilled water

4 LEHCEB* treatment

Energy density
E_s = 3,4 J/Cm²

Pulses
n = 32 ☆

LEHCEB – low-energy high-current electron beam*

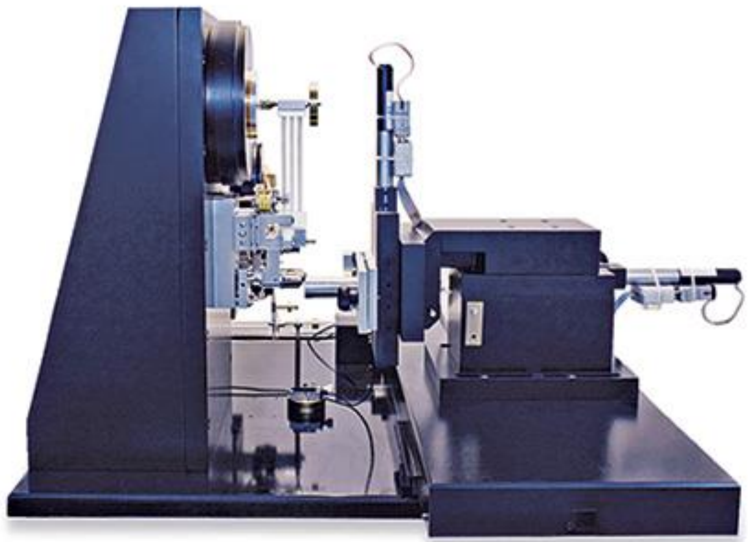
Additive thin-film electron beam synthesis

#	Magnetron sputtering	Pulsed electron beam melting of "film-substrate" system	Thickness *h*, µm
1	$Ti_{70}Ta_{30}$ 50 nm	$E_s = 2$ J/cm^2 $n = 5$	~1
	Number of cycles $N = 20$		
2	$Ti_{60}Ta_{40}$ 50 nm	$E_s = 2$ J/cm^2 $n = 5$	~1,5
	Number of cycles $N = 30$		

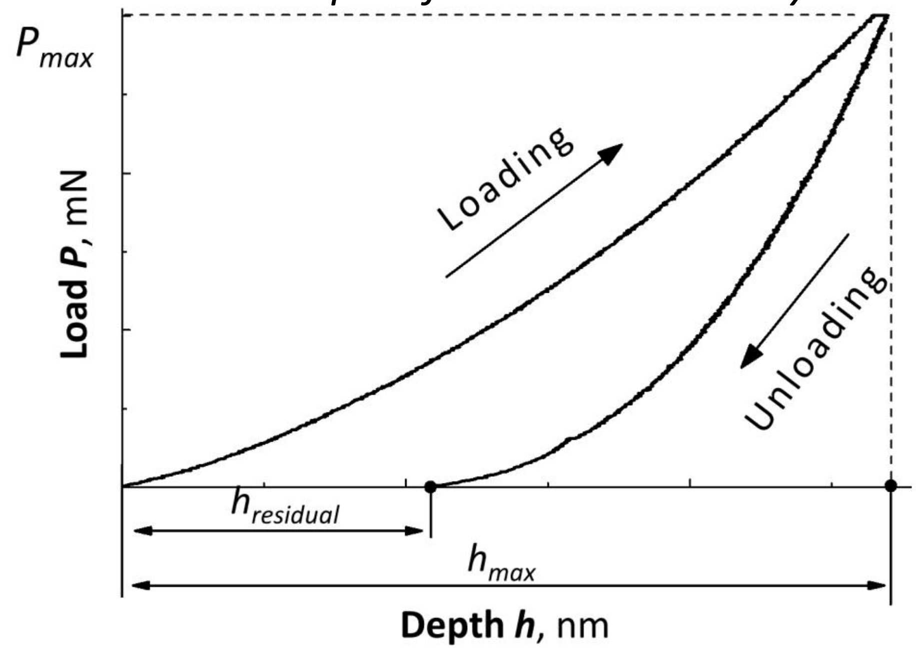
The surface modifying of NiTi specimens was performed on automatic RITM-SP facility ("Microsplav", . Russia, Tomsk)

Instrumented indentation

Nanohardness tester NanoTest 600



The example of one indentation cycle



HARDNESS

$$H = \frac{P_{max}}{A}$$

CHARACTERISTIC OF PLASTICITY

$$\delta_H = 1 - 14{,}3 \times (1 - \nu - 2\nu^2)\,\frac{HV}{E}$$

ELASTIC MODULUS

$$E = \frac{E_r^2 \times E_i^2 \times (1 - \nu^2)}{E_i^2 - E_r^2 \times (1 - \nu_i^2)}$$

RECOVERY RATIO OF THE INDENT

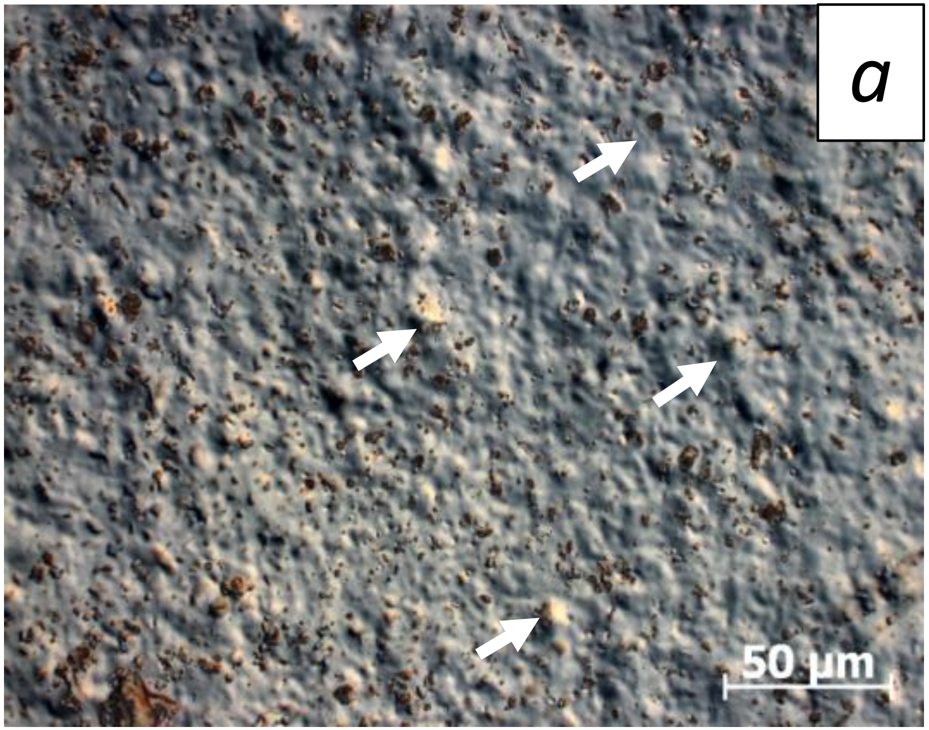
$$\eta = \frac{h_{inelastic} + h_{elastic}}{h_{max}}$$

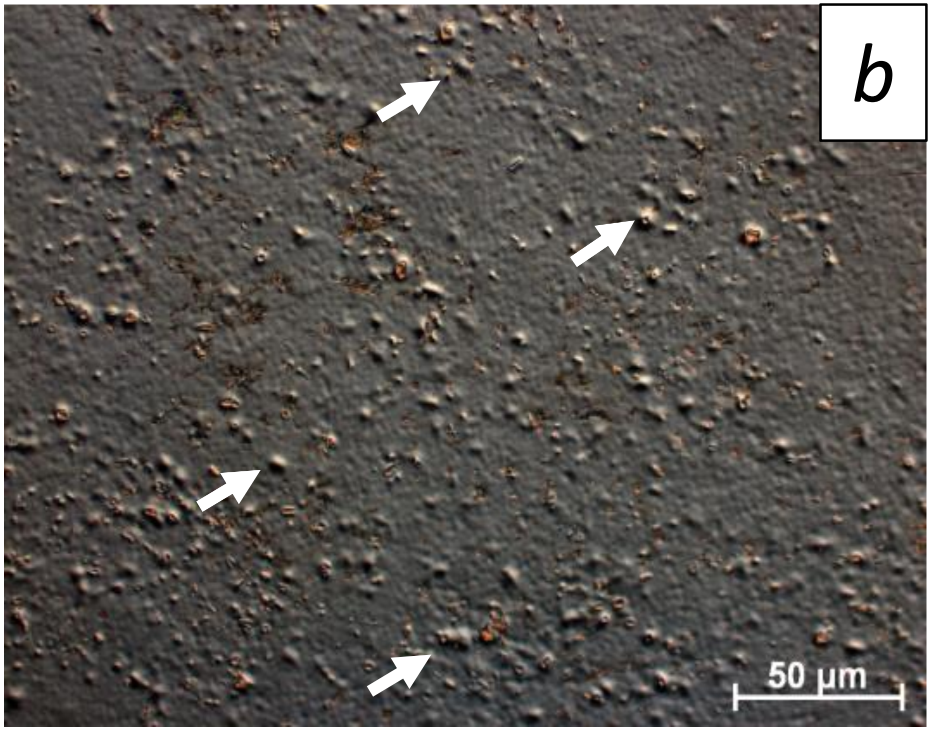
Measurement of thin film mechanical properties using nanoindentation / G. M. Pharr, W. C. Oliver // MRS Bulletin. – 1992. – Vol. 17. –P.28–33.
Plasticity characteristic obtained through hardness measurement / Yu. V. Milman, B. A. Galanov, S. I. Chugunova // Acta Met.Mater. – 1993. –Vol. 41. – P. 2523–2531.
Shape recovery after nanoindentation of NiTi thin films / W. C. Crone, G. A. Shaw, D. S. Stone, A. D. Johnson, A. B. Ellis // Carlotte. NC. – 2003. – P. 1–6.

Results and discussion

Initial NiTi

OPTICAL METALLOGRAPHY



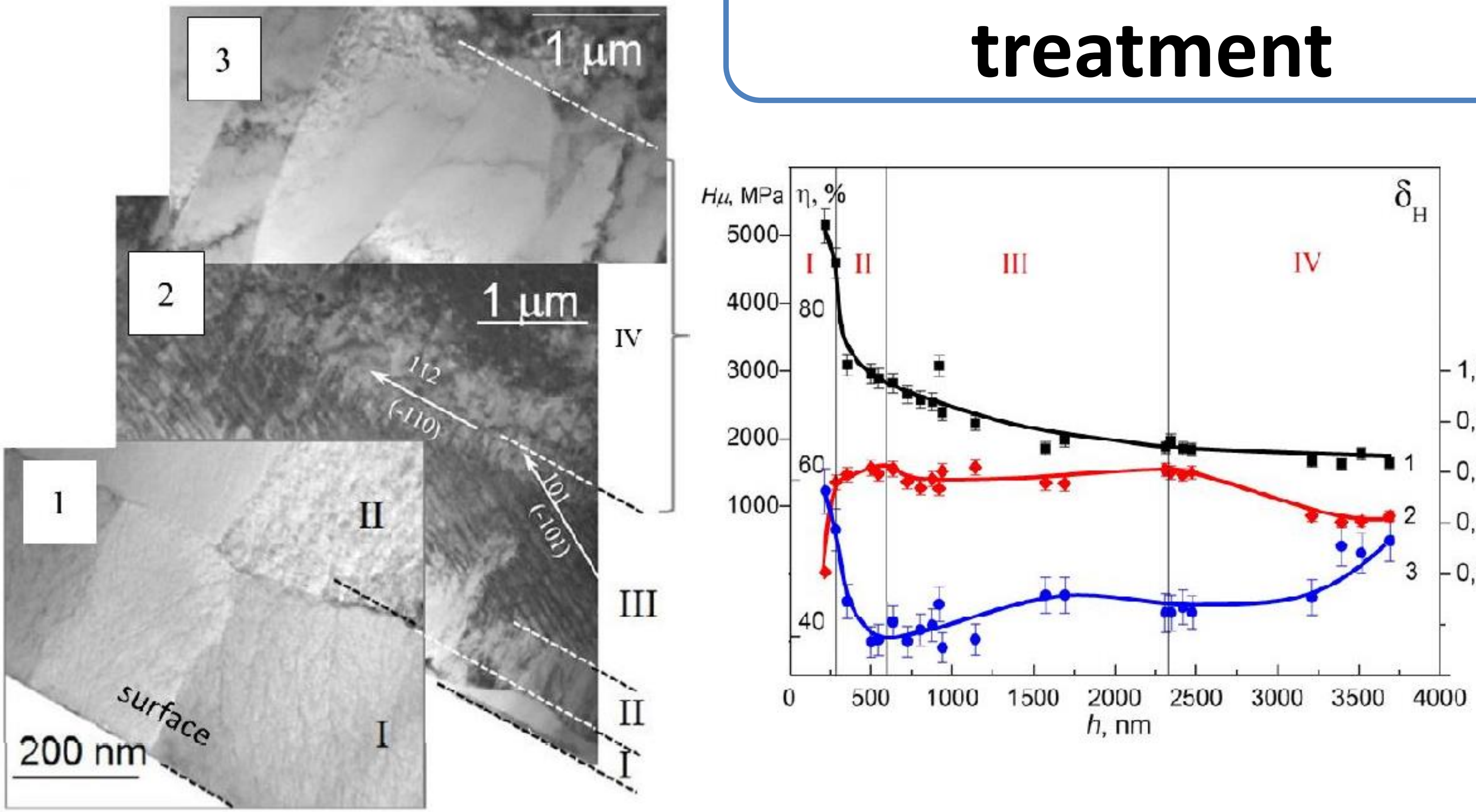


Initial NiTi

After preliminary surface treatment with out ★ electron beam irradiation

Results and discussion

Electron beam treatment

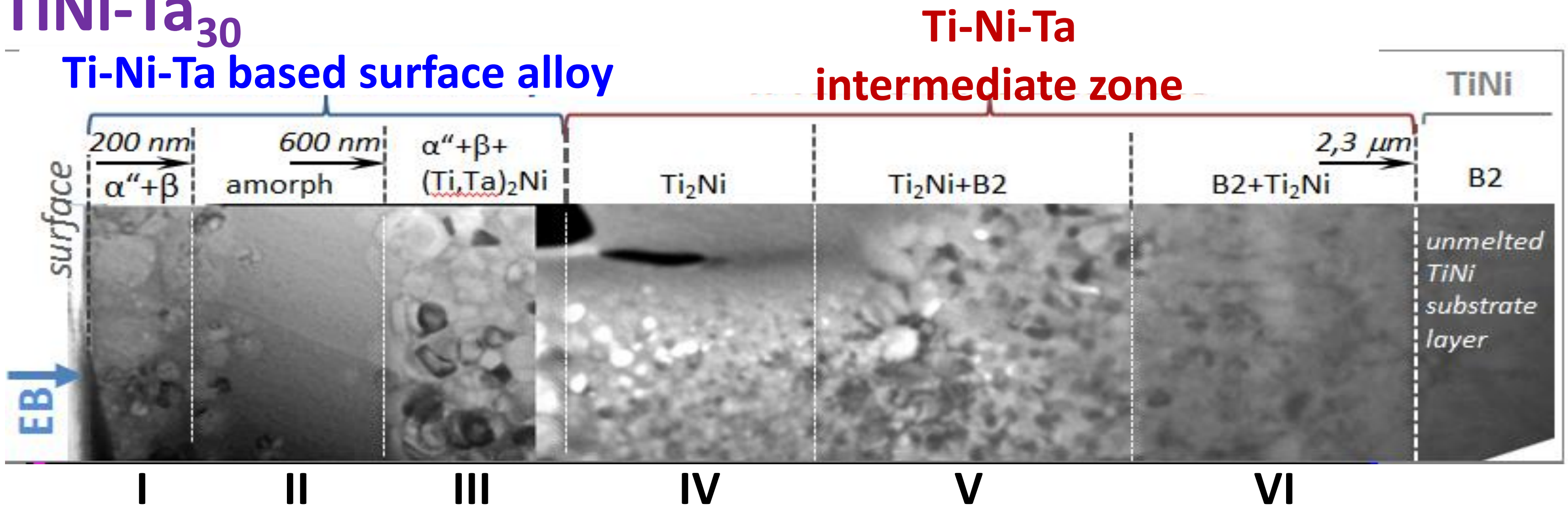


(a) (b)

FIGURE 2. Surface microstructure of e-beam treated NiTi (a): *1*, *2*, *3*—images with indication of sublayers I–IV, and dependences of H_μ (*1*), δ_H (*2*), and η (*3*) on indentation depth *h* (b)

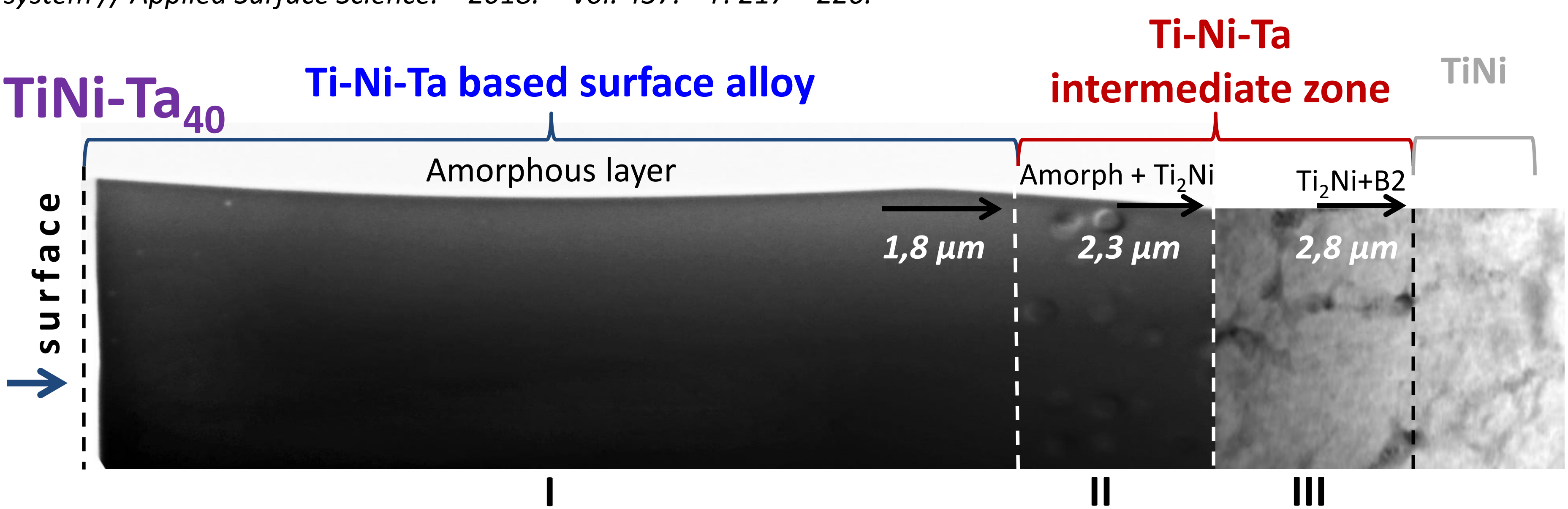
[*] Surface structure and physicomechanical properties of NiTi exposed to electron beam and ion-plasma treatment / S.N. Meisner [et al.] // AIP CP. – 2017. – Vol. 1909. – P. 020134(1-4).

TiNi-Ta$_{30}$

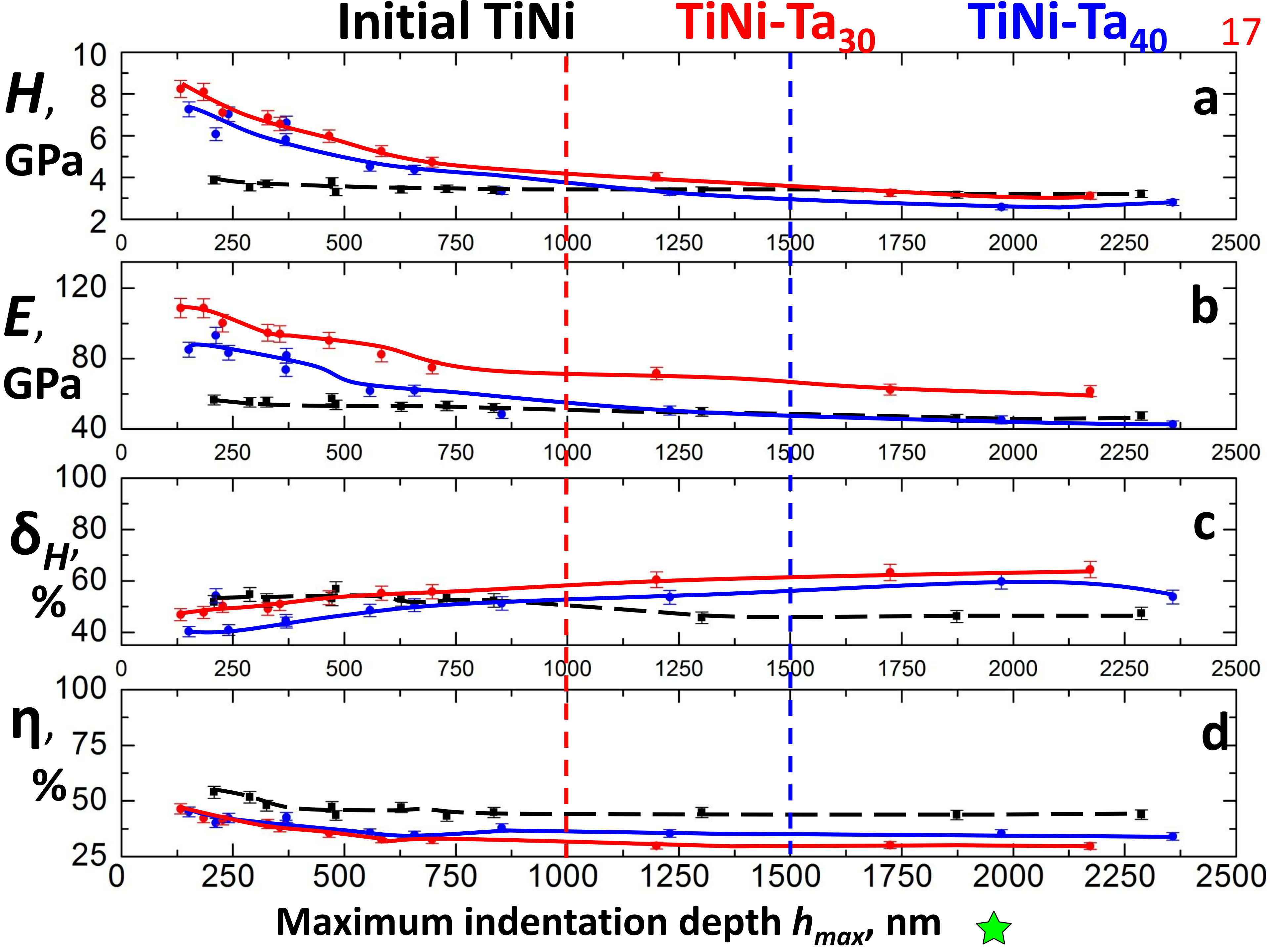


Meisner S. N., Yakovlev E. V., Semin V. O., Meisner L. L., Rotshtein V. P., Neiman A. A., D'yachenko F.A. Mechanical behavior of Ti-Ta based surface alloy fabricated on TiNi SMA by pulsed electron-beam melting of film/substrate system // Applied Surface Science. – 2018. – Vol. 437. – P. 217 – 226.

TiNi-Ta$_{40}$



Neiman A., Mukhamedova R., Semin V. Mechanical properties of the TiNi and surface alloy formed by pulsed electron beam treatment // Materials Research Proceedings. – 2018. – Vol. 9. – P. 58–62.


Initial TiNi
TiNi-Ta30
TiNi-Ta40
H, GPa
E, GPa
δH, %
η, %
a
b
c
d
Maximum indentation depth hmax, nm

Conclusion

The additive thin-film electron beam synthesis of Ti-Ni-Ta surface alloys leads to the formation of the nanocomposite structure with high strength and elastic characteristics of the surface alloys, with a good combination of plasticity properties of the intermediate zone.

References

- *Measurement of thin film mechanical properties using nanoindentation / G. M. Pharr, W. C. Oliver // MRS Bulletin. – 1992. – Vol. 17. –P.28–33.*
- *Plasticity characteristic obtained through hardness measurement / Yu. V. Milman, B. A. Galanov, S. I. Chugunova // Acta Met.Mater. – 1993. –Vol. 41. – P. 2523–2531.*
- *Shape recovery after nanoindentation of NiTi thin films / W. C. Crone, G. A. Shaw, D. S. Stone, A. D. Johnson, A. B. Ellis // Carlotte. NC. – 2003. – P. 1–6.*
- *Surface structure and physicomechanical properties of NiTi exposed to electron beam and ion-plasma treatment / S.N. Meisner [et al.] // AIP CP. – 2017. – Vol. 1909. – P. 020134(1-4).*
- *Meisner S. N., Yakovlev E. V., Semin V. O., Meisner L. L., Rotshtein V. P., Neiman A. A., D'yachenko F.A. Mechanical behavior of Ti-Ta based surface alloy fabricated on TiNi SMA by pulsed electron-beam melting of film/substrate system // Applied Surface Science. – 2018. – Vol. 437. – P. 217 – 226.*
- *Neiman A., Mukhamedova R., Semin V. Mechanical properties of the TiNi and surface alloy formed by pulsed electron beam treatment // Materials Research Proceedings. – 2018. – Vol. 9. – P. 58–62.*

Acknowledgements

The authors would like to thank

Yakovlev E.V.

Junior researcher of the IHCE SB RAS –

for work related to the additive thin-film electron beam synthesis,

Shulepov I.A.

Ph.D , Lead Engineer of the ISPMS SB RAS –

for testing mechanical properties of Ti-Ni-Ta-based surface alloys,

Semin V.O.

Ph.D , Junior researcher of the ISPMS SB RAS –

for conducting electron microscopy investigations,

This work was supported by the grant of the Russian Science Foundation
No. 18-19-00198 (26.04.2018)

Interdisciplinary conference

«RECENT ADVANCES in SCIENCE and TECHNOLOGY»

The 27th of May

Tomsk Scientific Center

THANK YOU

FOR YOUR ATTENTION

Filipp D'yachenko[1] 2nd year graduate student

Meisner L.L.[1, 2], Atovullaeva A.A.[2]

[1]Institute of Strength Physics and Materials Science SB RAS

[2]National Research Tomsk State University

Tomsk, Russia

E-mail: frozennonetroll@mail.ru

The research was carried out with support by the grant of the Russian Science Foundation No. 18-19-00198 (26.04.2018)