ÉCOLE POLYTECHNIQUE MONTRÉAL

LaRFIS

Nanocomposite hard coatings for protection against LIE

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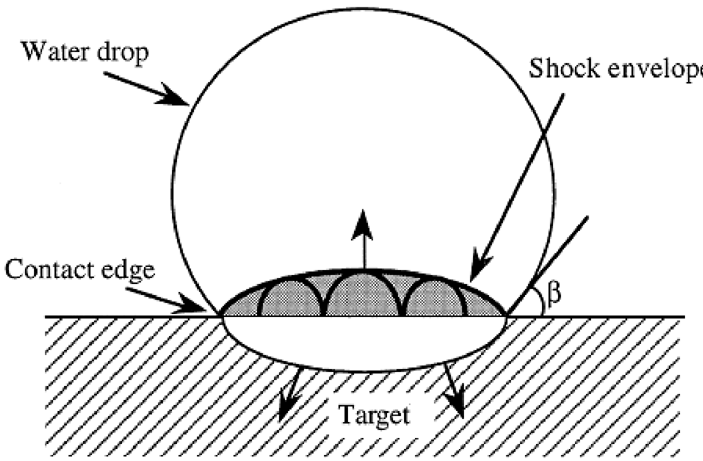
Concordia University, December 21th

Overview

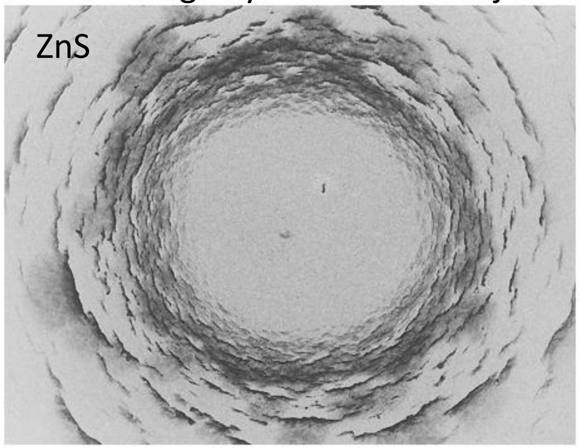
- Review of liquid impingement erosion process
- TiN and TiSiN coatings by HiPIMS
- Plasma nitriding
- Summary and outlook

Liquid impingement erosion mechanism

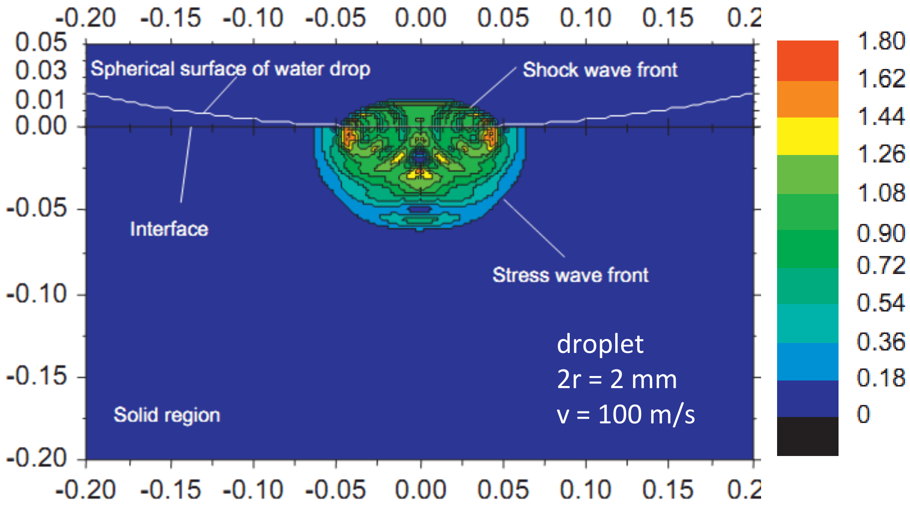
Liquid impingement causes fatigue of material through propagation of **shockwaves**



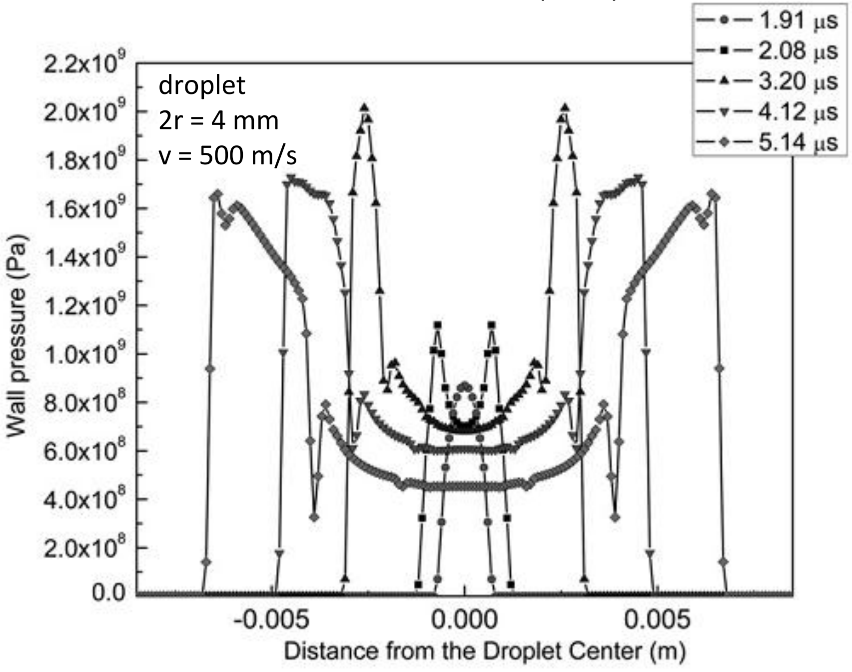
damage by discrete water jet



J.E. Field, Wear, 233-235 (1999) 1-12.

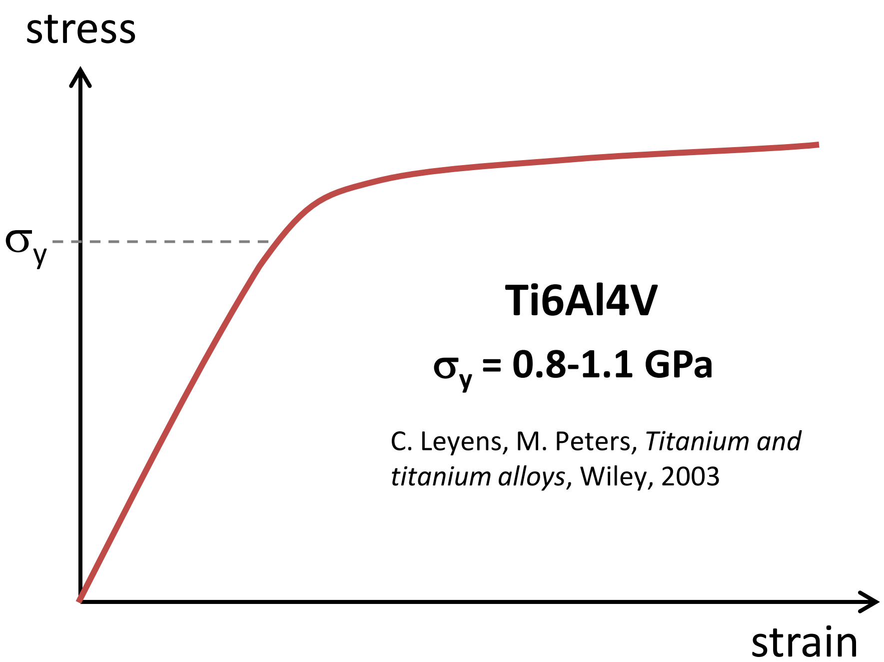


Q. Zhou, N. Li, X. Chen, T. Xu, S. Hui, D. Zhang, International Journal of Mechanical Sciences, 50 (2008) 1543



R. Li, H. Ninokata, M. Mori, Progress in Nuclear Energy, 53 (2011) 881

Approaches to protect against LIE

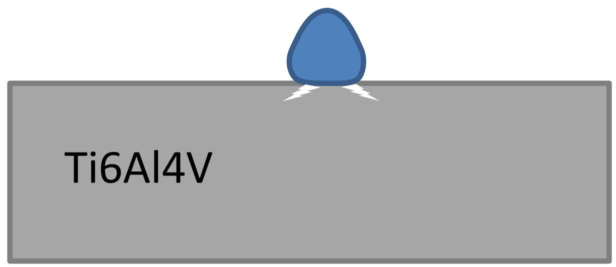


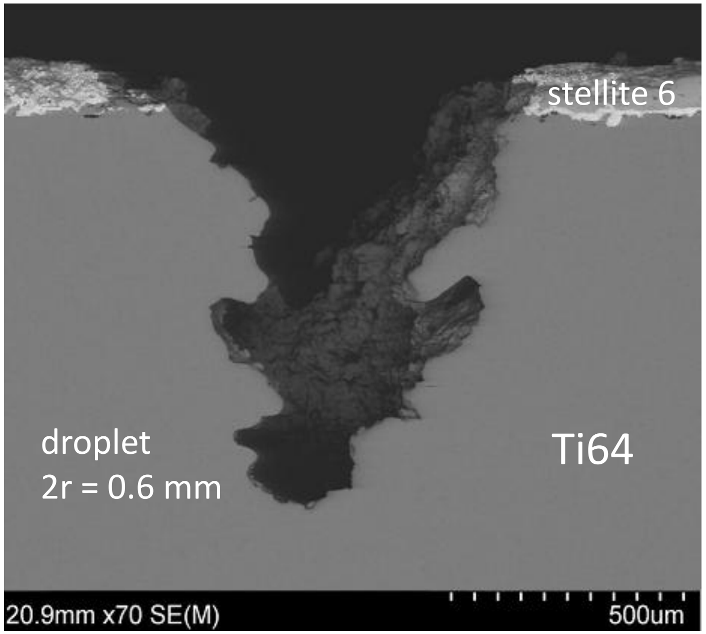
Ti6Al4V

σ_y = 0.8-1.1 GPa

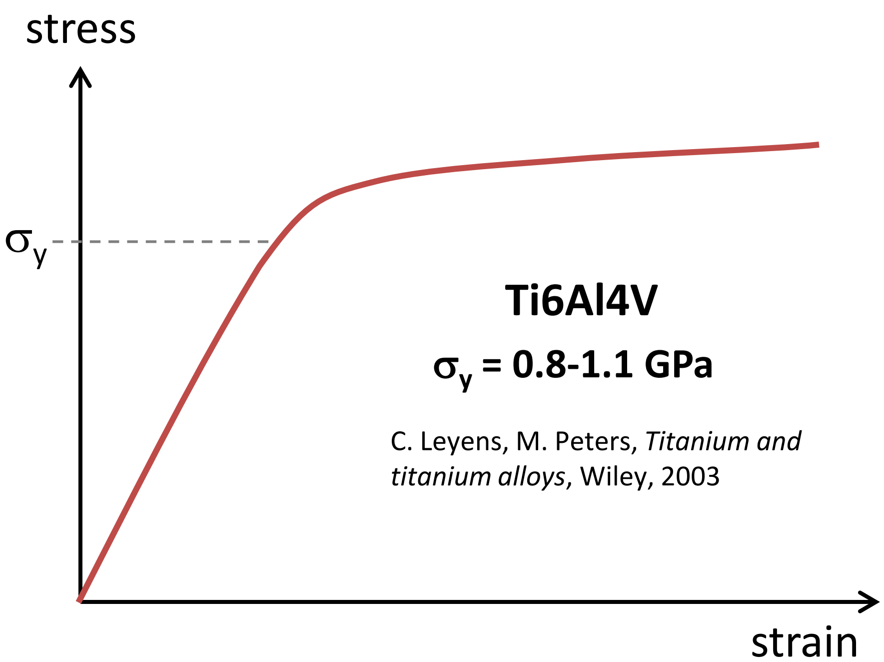
C. Leyens, M. Peters, *Titanium and titanium alloys*, Wiley, 2003

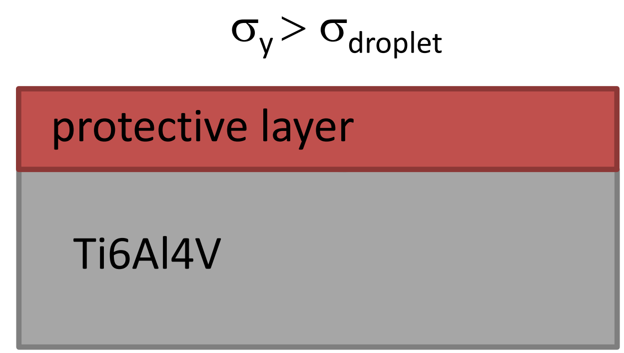
$\sigma_{droplet} > \sigma_y$





Approaches to protect against LIE





single-layer or treatment

e.g. TiN or nitriding

multilayered material

e.g. TiN/Ti

composite material

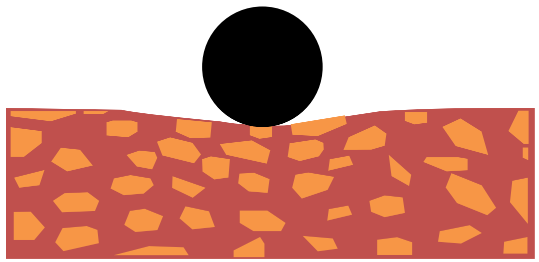
e.g. WC/Co or nc-TiN/a-SiN

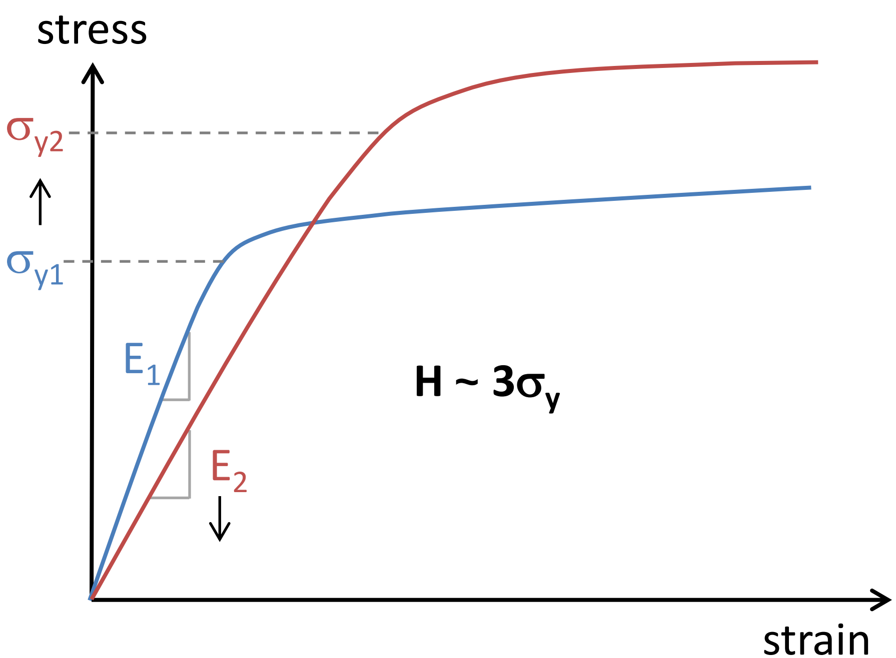
Important mechanical properties for protection against LIE

Properties of material that minimize shockwave damage :

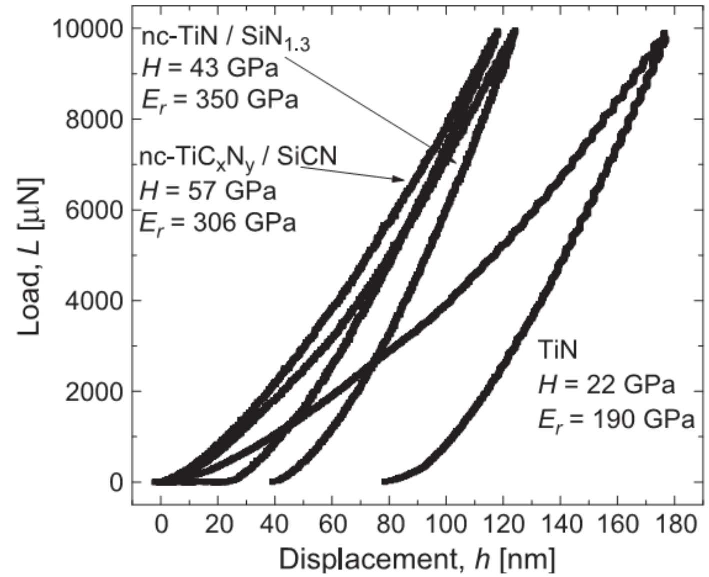
- *high hardness*
- *low elastic modulus*
- *high fracture toughness*

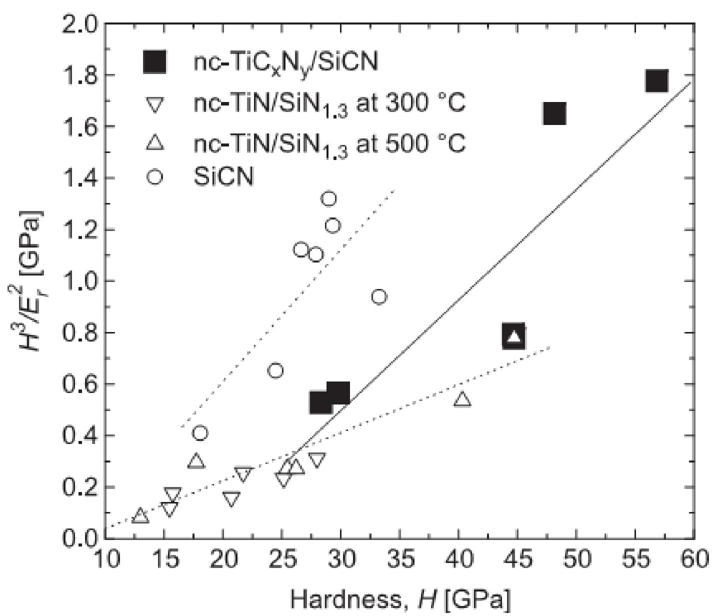
(high hardness and low elastic modulus) → *high ratio H^3/E^2*





nanocomposite coatings

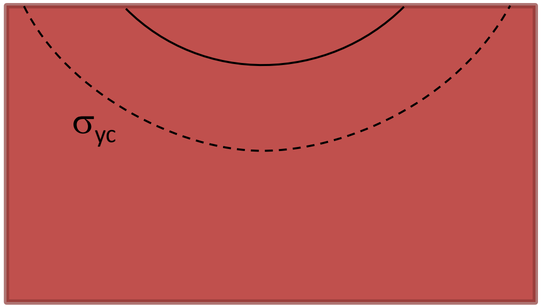




P. Jedrzejowski et al, Thin Solid Films, 466 (2004) 189

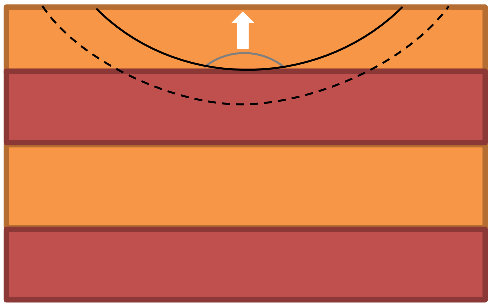
Influence of interfaces on the shockwave energy

monolithic material



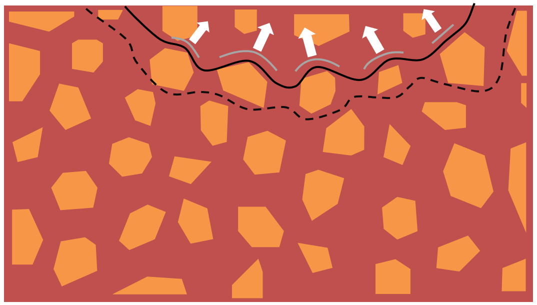
e.g. TiN or nitriding

multilayered material

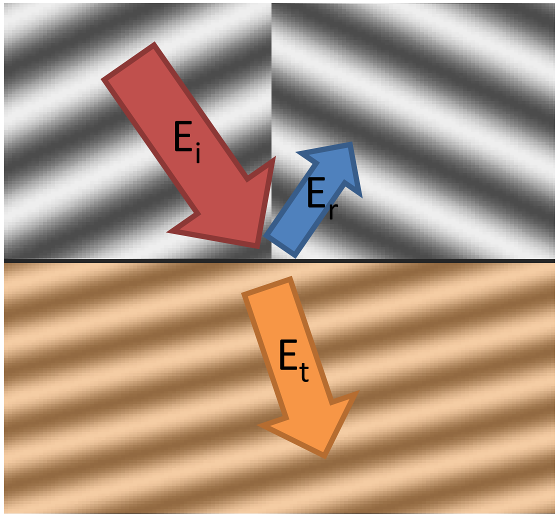


e.g. TiN/Ti

composite material



e.g. WC/Co or nc-TiN/a-SiN



Interface splits shockwave energy into reflected and transmitted wave!

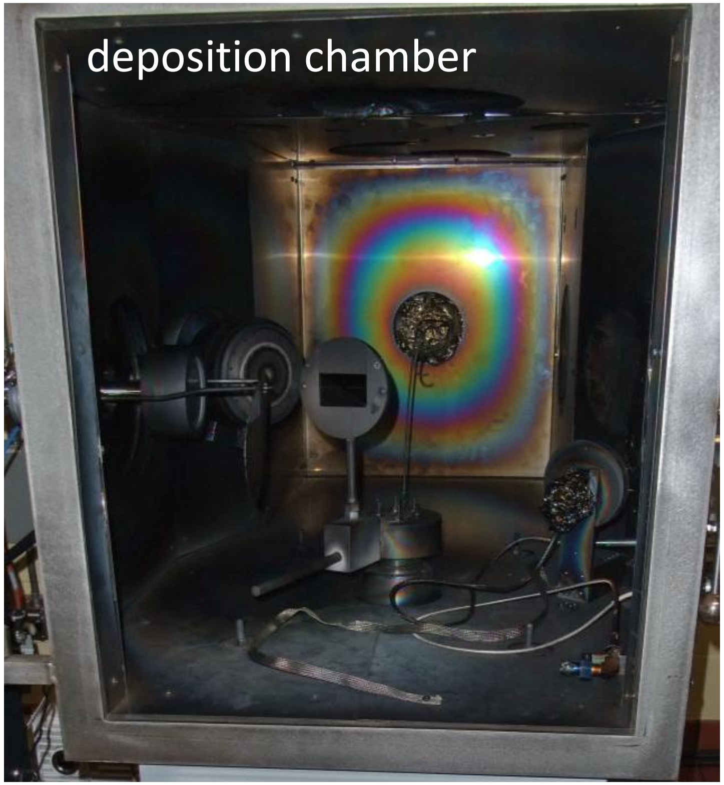
$$E_i = E_t + E_r$$

- Interfaces confine damage to smaller area of material!
- Interfacial bonding has to be strong enough to withstand high shockwave stresses!

Coatings deposited by HiPIMS

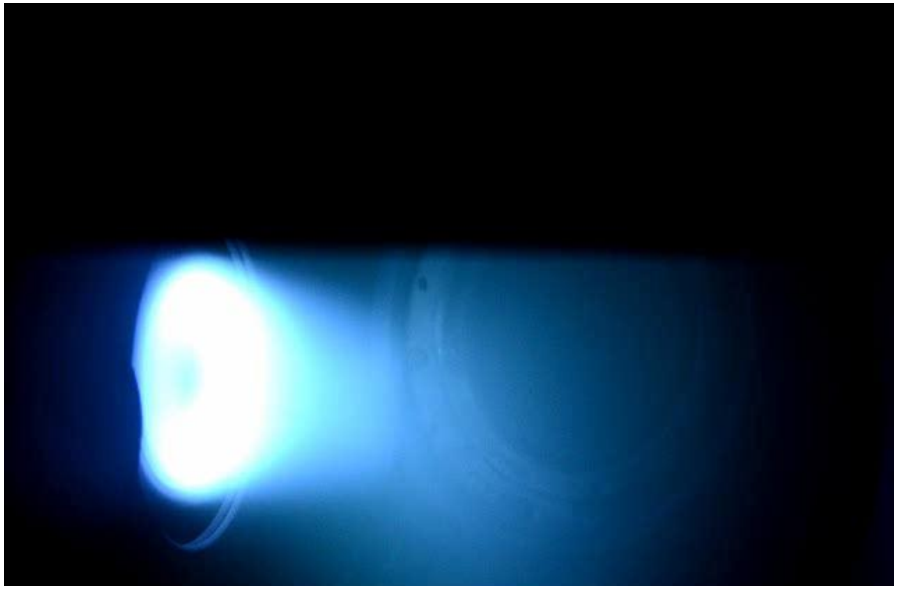
deposition system at FCSEL

HiPIMS power supplies

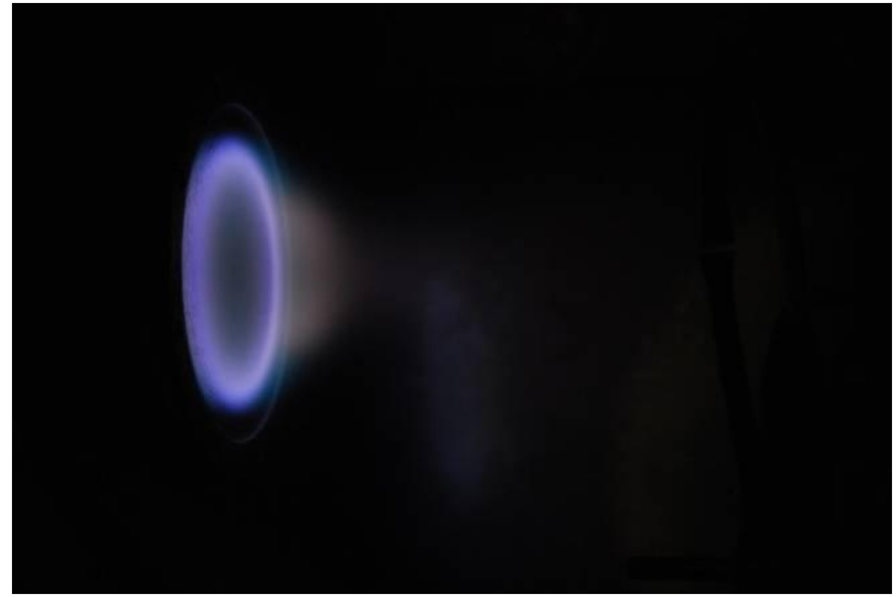


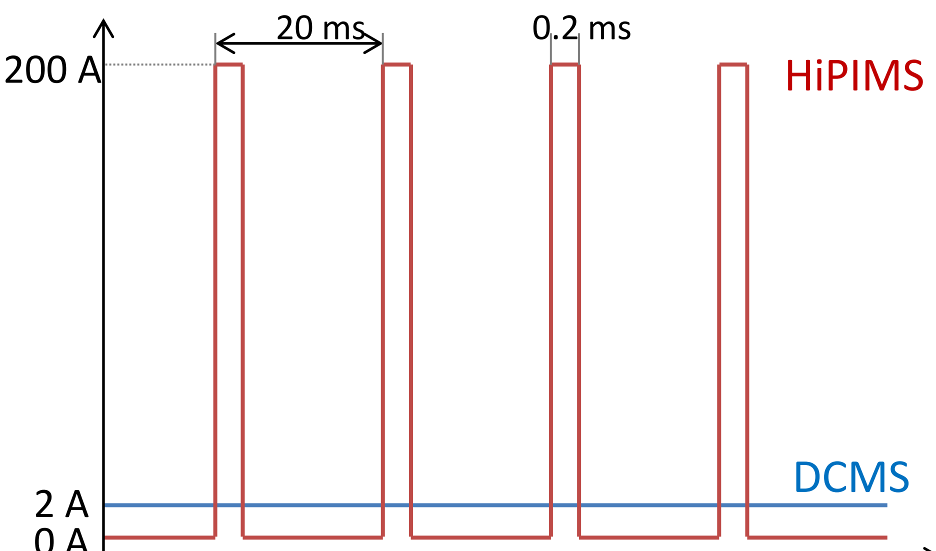
High Power Impulse Magnetron Sputtering Discharge

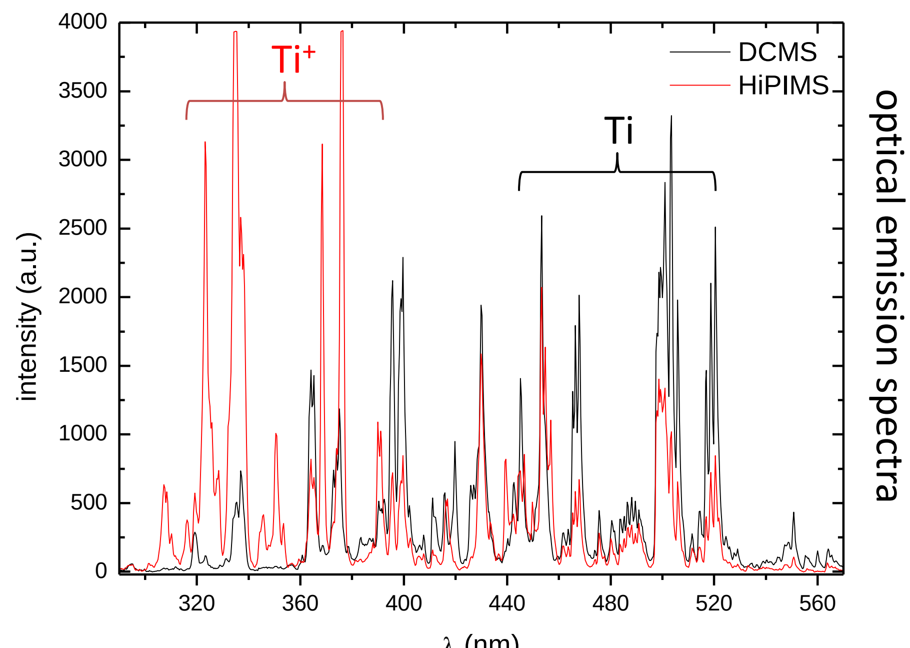
HiPIMS discharge



DCMS discharge

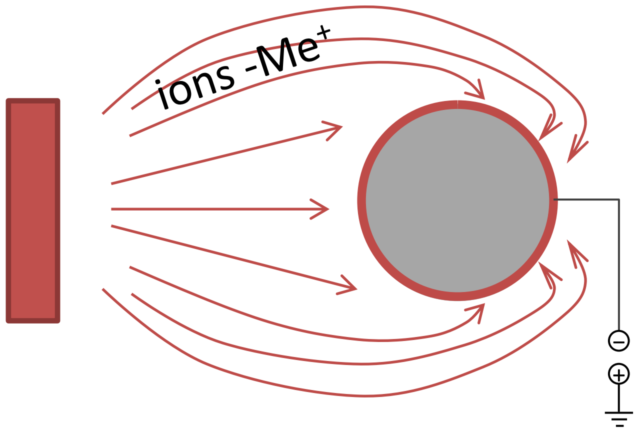




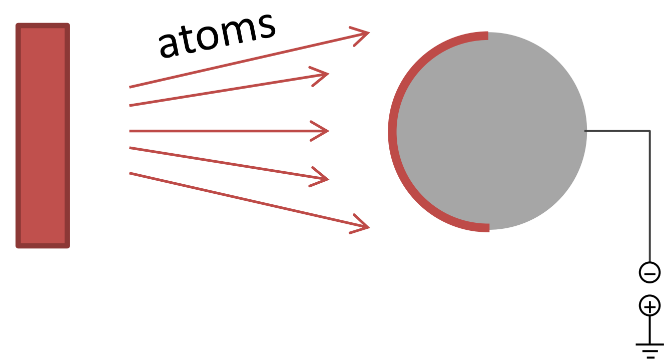


Advantages of High Power Impulse Magnetron sputtering

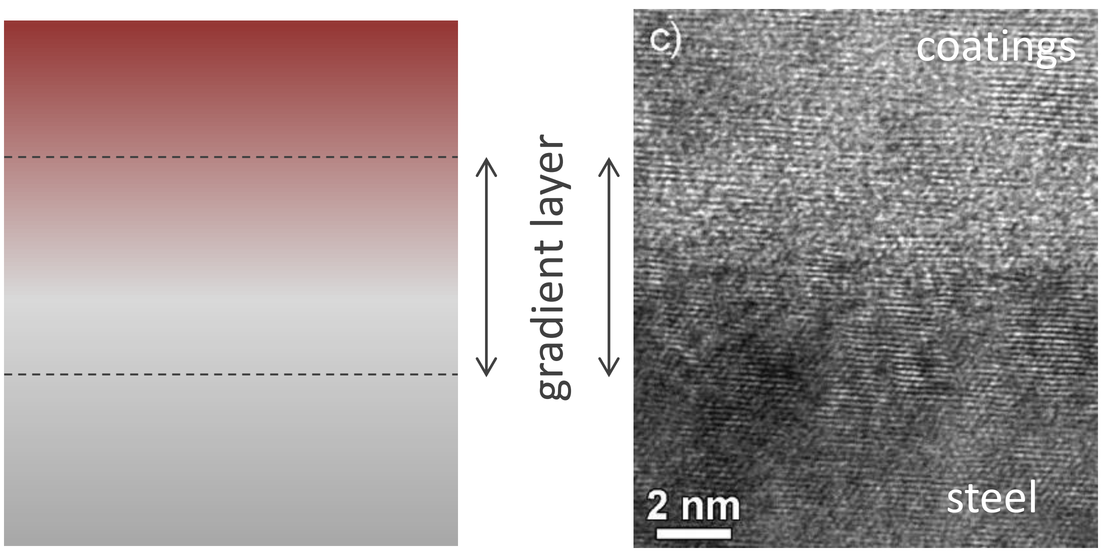
1. control of ion energy and direction

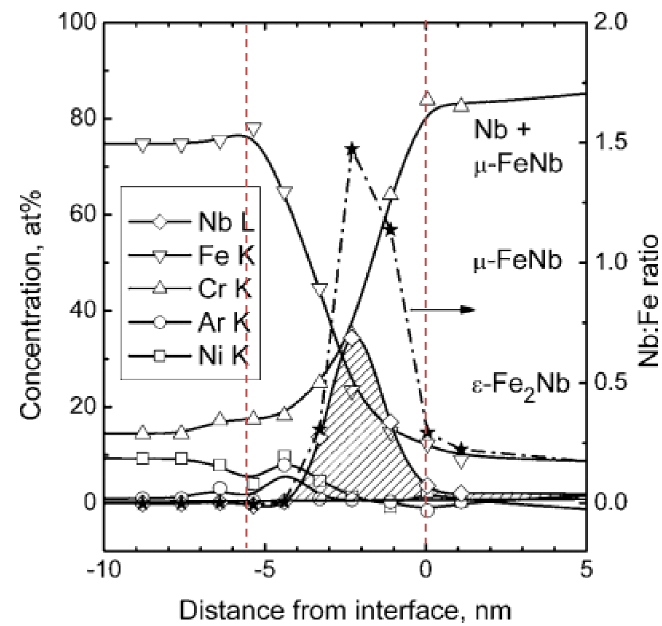


DCMS – line-of-sight deposition



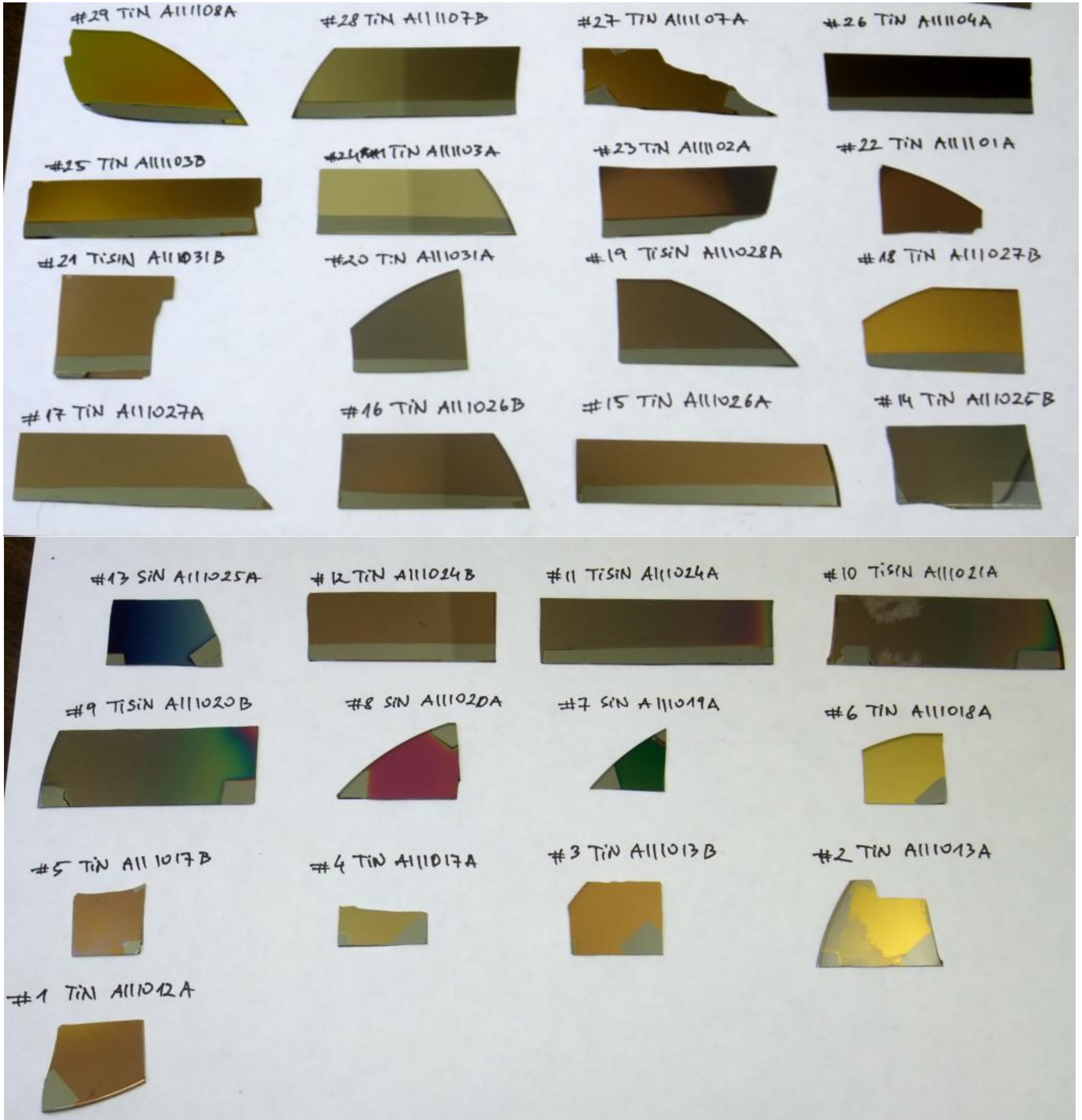
2. Improved adhesion of coatings

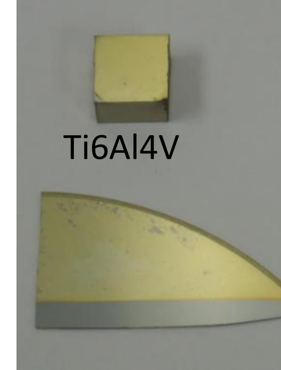


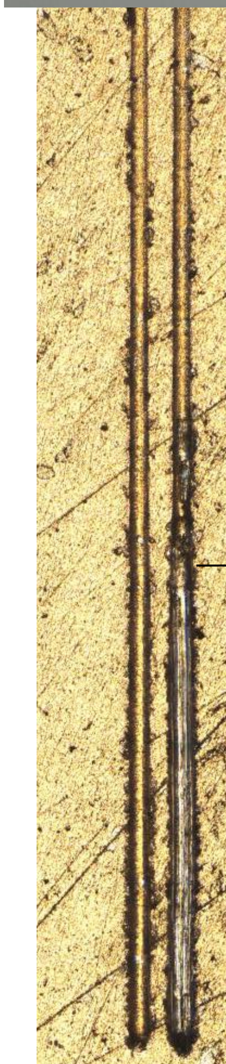


A.P. Ehiasarian, J.G. Wen, I. Petrov, Journal of Applied Physics, 101 (2007) 054301

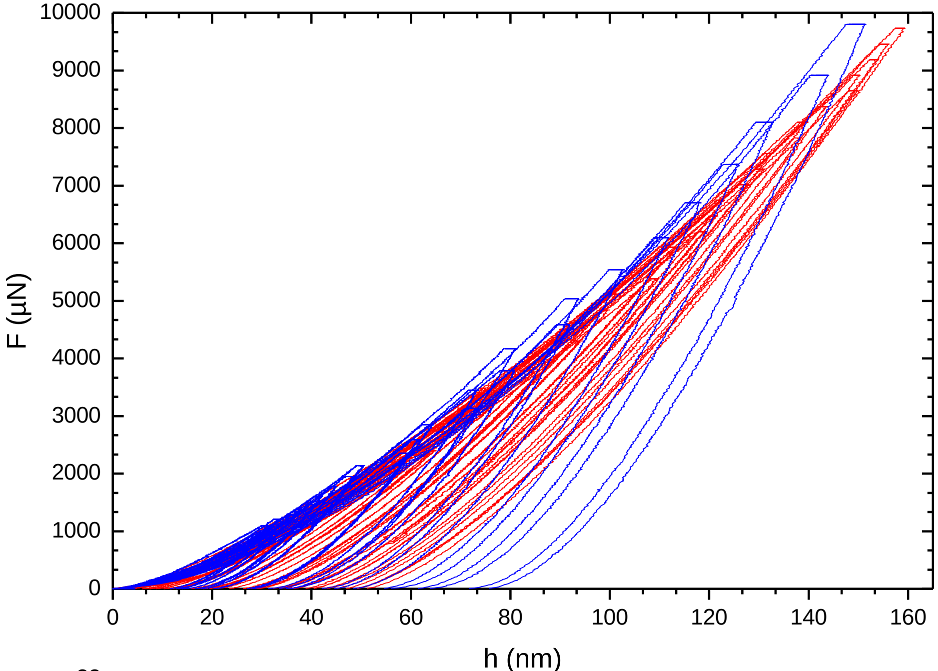
Depositions of hard coatings by HiPIMS







Indentation measurements of TiN deposited by HiPIMS and DCMS

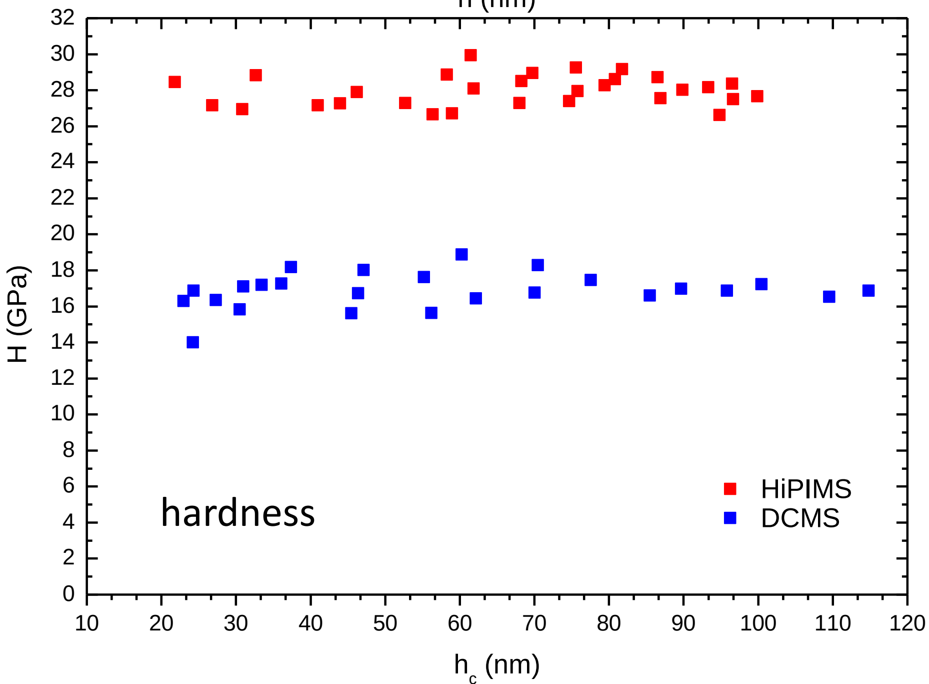


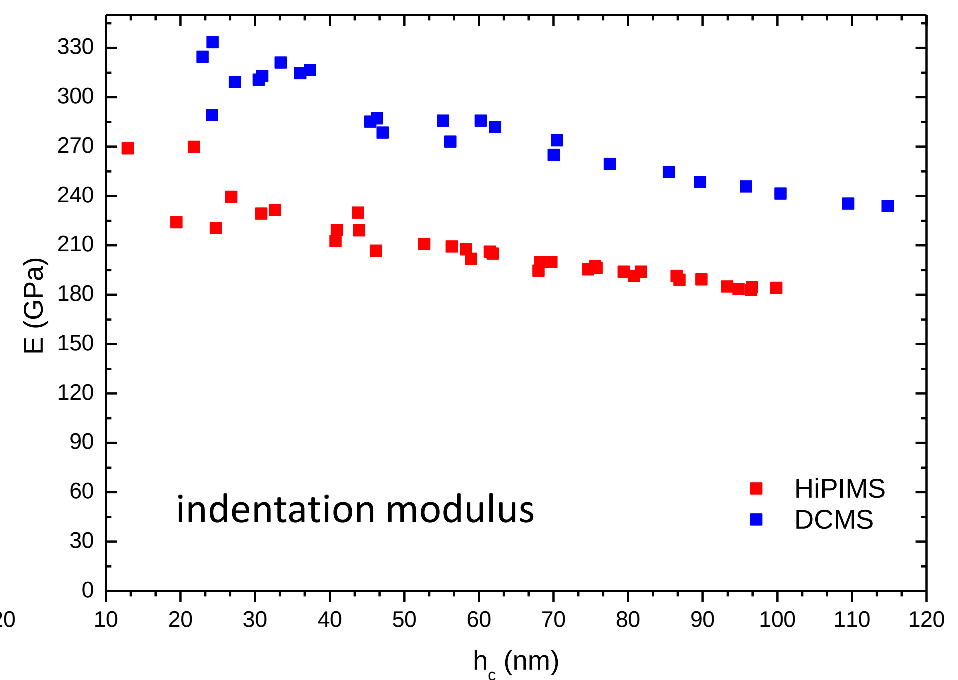
DCMS

H (GP)	E_r (GPa)	H^3/E^2 (GPa)
17	340	0.04

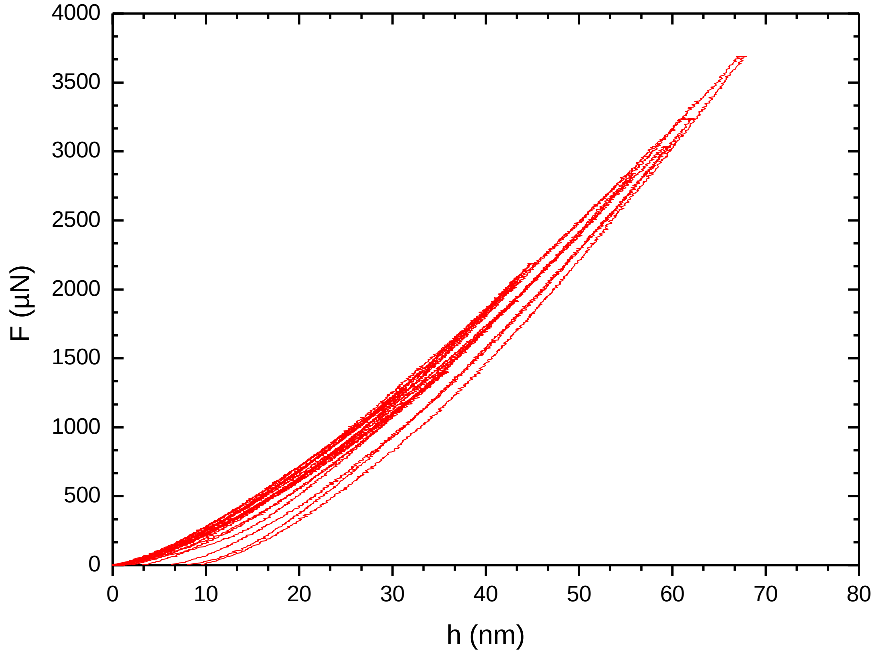
HiPIMS

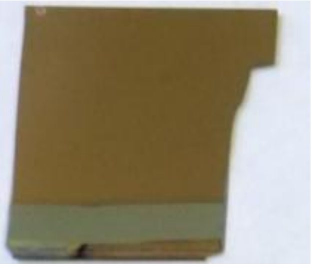
H (GP)	E_r (GPa)	H^3/E^2 (GPa)
28	250	0.35



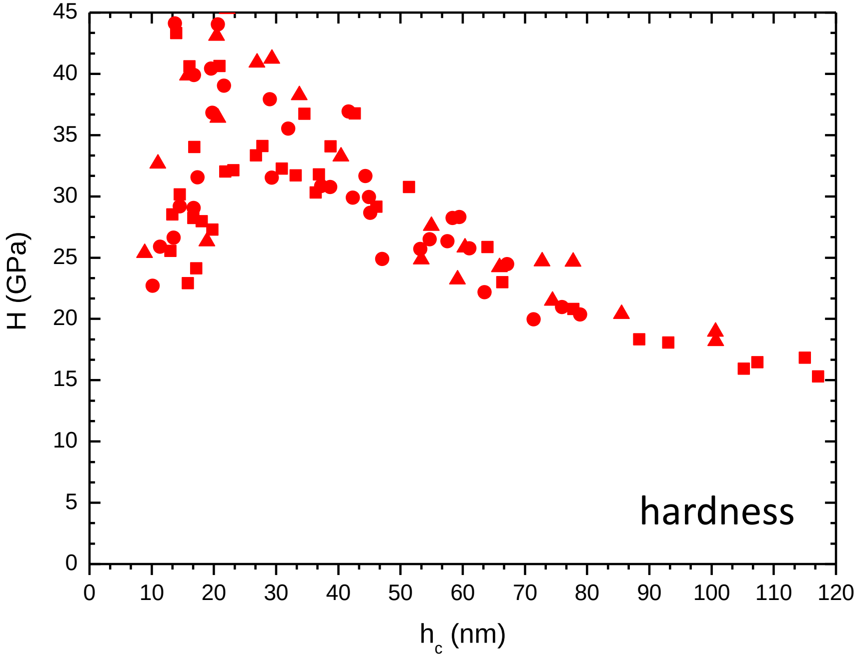


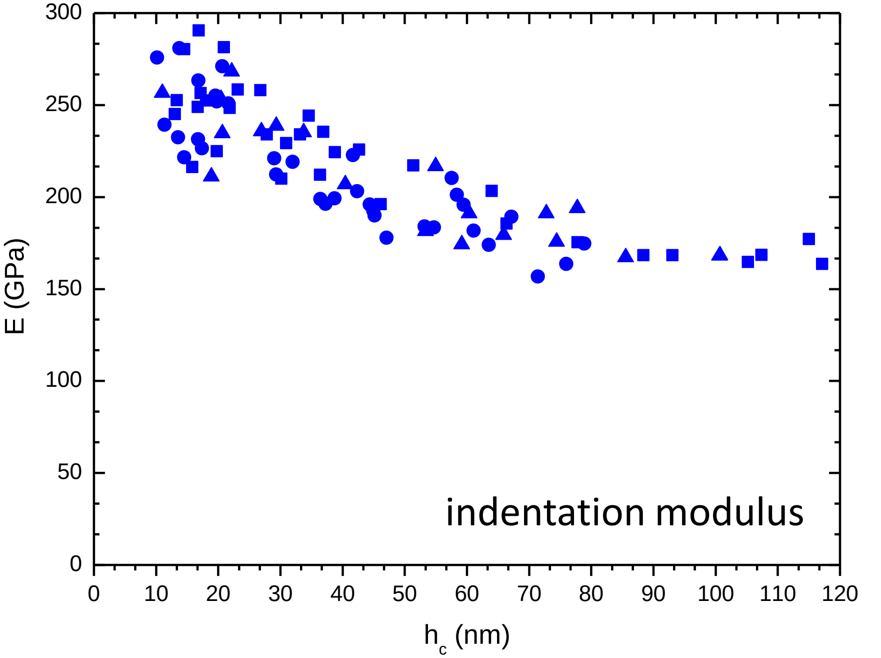
Indentation measurements of TiSiN deposited by HiPIMS



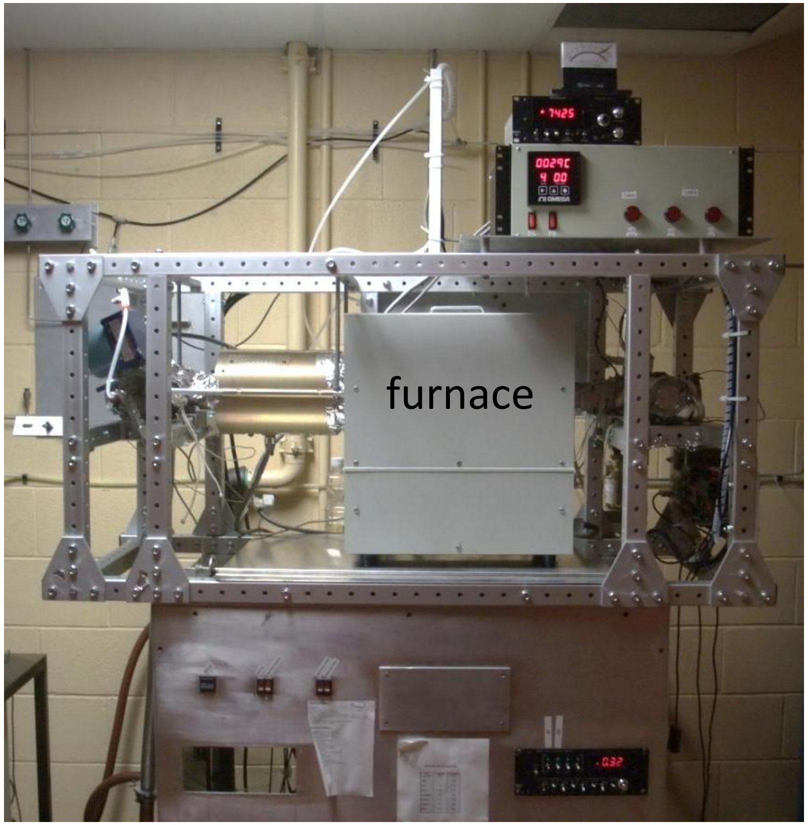


H (GP)	E_r (GPa)	H^3/E^2 (GPa)
38	250	0.87

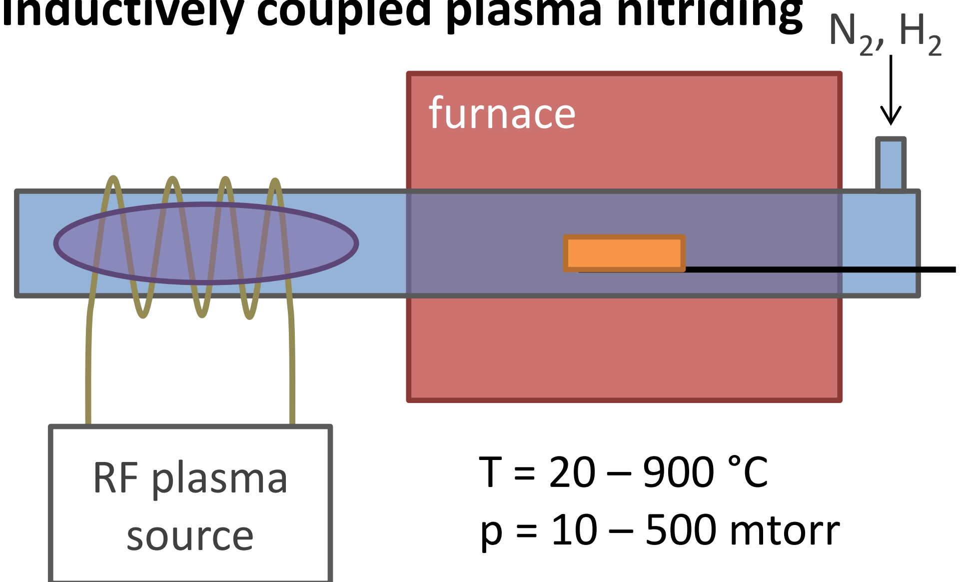




Plasma nitriding

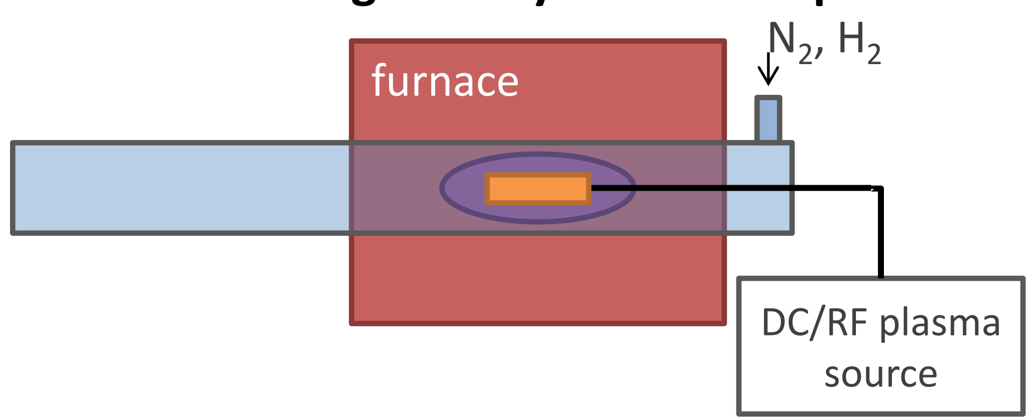


Inductively coupled plasma nitriding

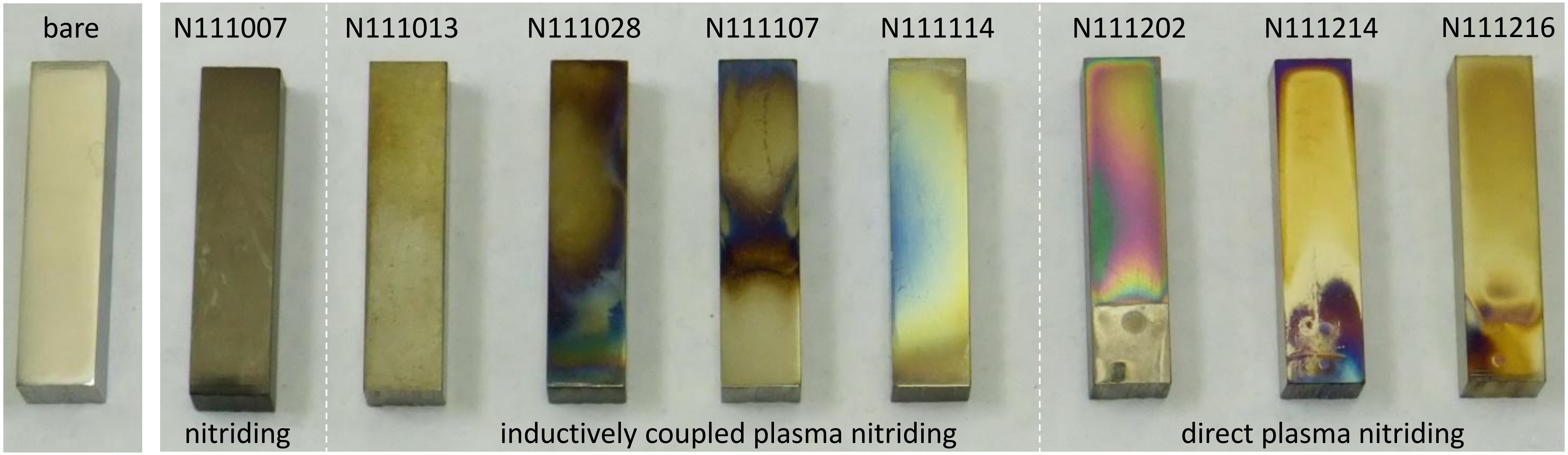


T = 20 – 900 °C
p = 10 – 500 mtorr
gas: N_2, H_2

Plasma nitriding directly on the sample

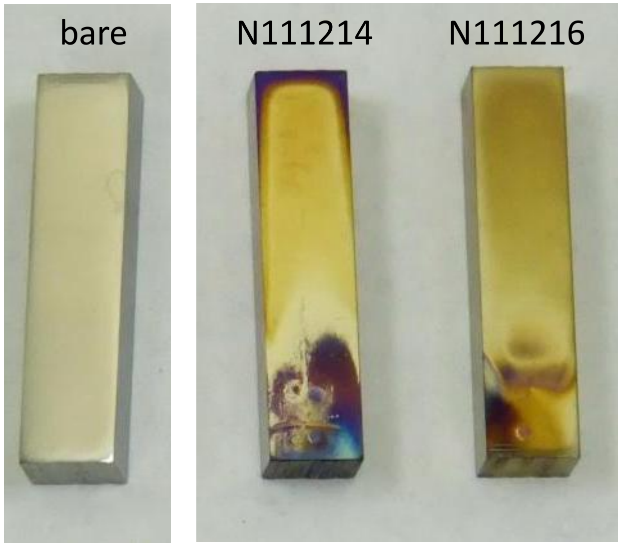


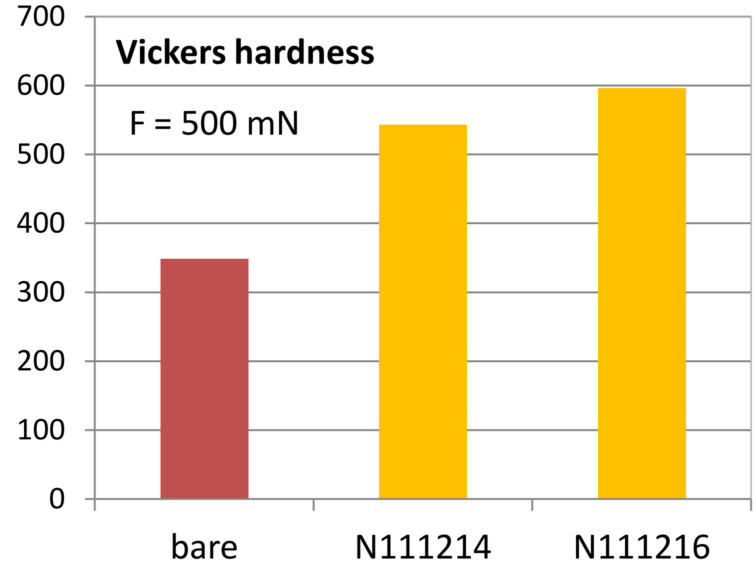
Nitriding and plasma nitriding experiments



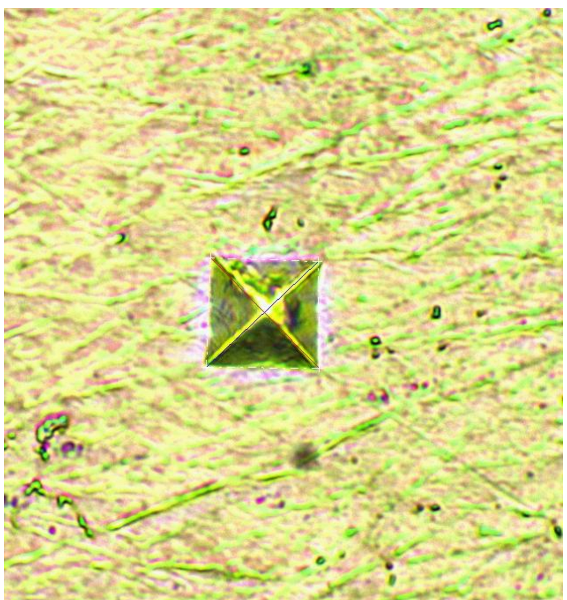
sample	N111007	N111013	N111028	N111107	N111114	N111202	N111214	N111216
temp [°C]	600	600	700	700	600	700	700	700
p [mtorr]	250	500	400	540	530	500	510	270
ϕ_{N2} [sccm]	50	77	46	77	77	70	70	9
ϕ_{H2} [sccm]	0	0	0	14	14	20	14	2
time [h]	5	5	5	5	5	2	3	3
type of nitriding	*nitriding*	*plasma*	*plasma*	*plasma*	*plasma*	*plasma*	*plasma*	*plasma*
power supply		inductively coupled RF	inductively coupled RF	inductively coupled RF	inductively coupled RF	direct DC	direct RF	direct RF
power [W]	/	100	100	100	200	50	60	130

Hardness of nitrided layer



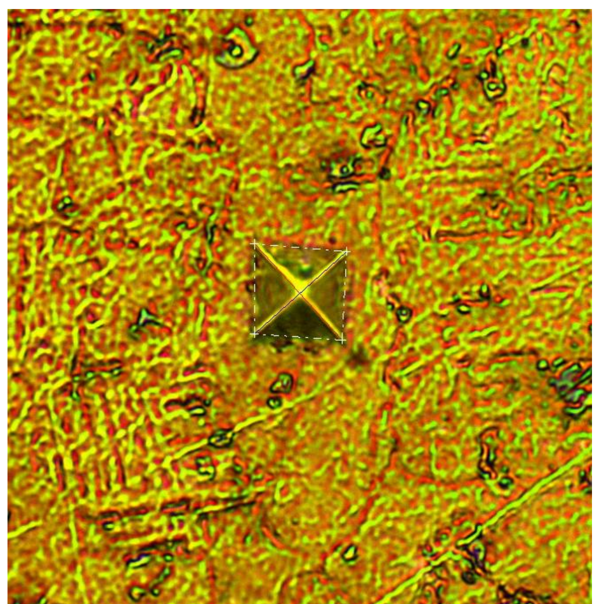


bare



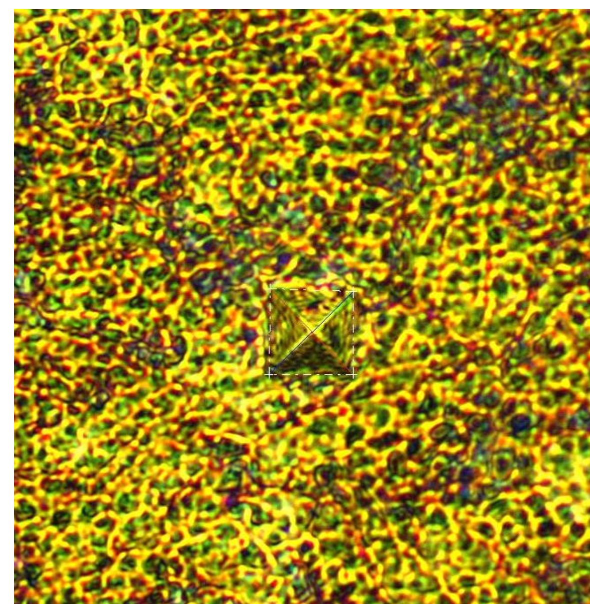
HV 340 ± 10

N111214



HV 530 ± 20

N111216



HV 600 ± 30

Summary

- Protection against liquid impingement erosion is possible with materials that are hard, elastic and tough
- Nanocomposite TiSiN deposited by HiPIMS show promising elasto-plastic properties (H= 38 GPa, E= 250 GPa)
- Inductively coupled plasma nitriding produced thin and non-uniform nitrided layer, while direct plasma nitriding produced more uniform nitrided layer

Outlook

- Improve elasto-plastic properties of nanocomposite coatings by precisely controlling coating stoichiometry
- Add other elements to the coating (e.g. carbon, aluminum) to further improve tribological properties of the coatings
- Modify parameters for plasma nitriding to achieve thick and uniform nitrided layer