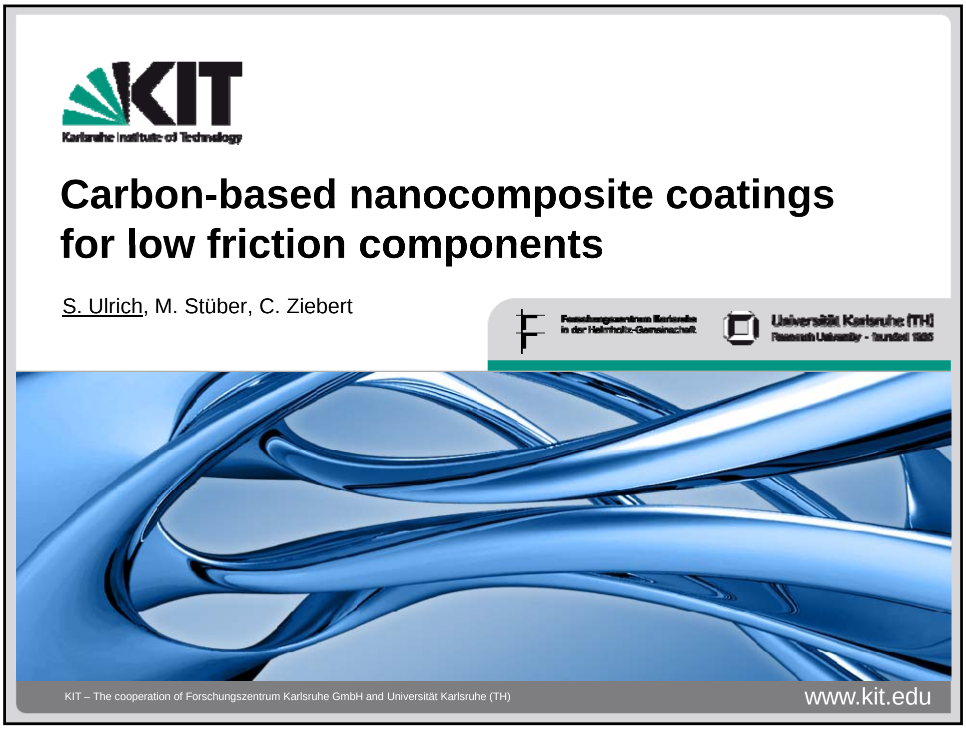
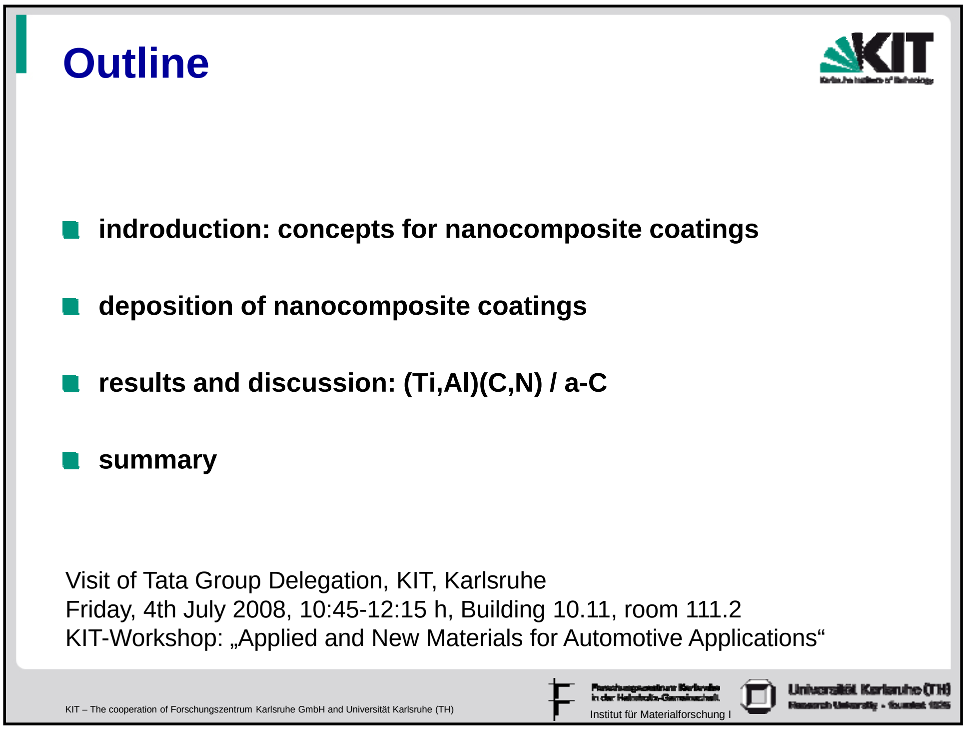


Carbon-based nanocomposite coatings for low friction components

S. Ulrich, M. Stüber, C. Ziebert

KIT – The cooperation of Forschungszentrum Karlsruhe GmbH and Universität Karlsruhe (TH)

www.kit.edu



Outline

- **indroduction: concepts for nanocomposite coatings**
- **deposition of nanocomposite coatings**
- **results and discussion: (Ti,Al)(C,N) / a-C**
- **summary**

Visit of Tata Group Delegation, KIT, Karlsruhe
Friday, 4th July 2008, 10:45-12:15 h, Building 10.11, room 111.2
KIT-Workshop: „Applied and New Materials for Automotive Applications“

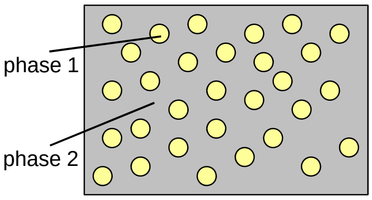
KIT – The cooperation of Forschungszentrum Karlsruhe GmbH and Universität Karlsruhe (TH)

Institut für Materialforschung I

Concepts for multifunctional wear-resistant thin film nanocomposites

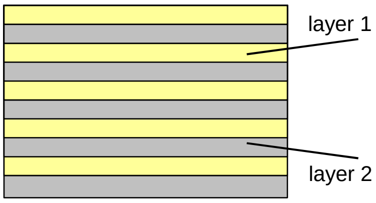
Basic characteristics: multiphase structure, at least one phase has dimensions in the nm-range

multiphase single-layer coatings



phase 1: nanocrystalline
phase 2: nanocrystalline or amorphous
matrix phase + dispersed phase or
percolated network

nanoscale multilayer coatings



layer 1: single- or multiphase
layer 2: single- or multiphase, but different
multilayers, superlattices, nanostabilisation
or nanolaminated composites

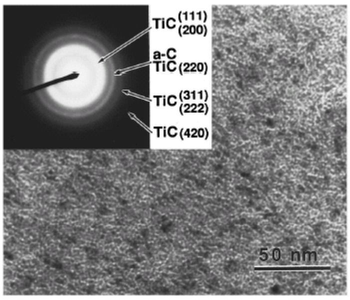
Synthesis of materials with new properties by engineering design of their nanoscale microstructure

---

Nanocomposite coatings with amorphous carbon and nanocrystalline hard phases

Objective: to design wear-resistant and lubricious coatings with tailored hardness and toughness

Example: TiC/a-C coatings



A.A. Voevodin, S.V. Prasad, J.S. Zabinski,
J. Appl. Phys. 82 (2) (1997) 855.

Concepts for carbon-based nanocomposite coatings

binary carbide phase + a-C: WC/a-C, TiC/a-C
Dimigen, Klages, Benndorf, Grischke, Sjöström,
Sundgren, Voevodin, Monteiro, Hogmark, Wiklund,
Patscheider, Wänstrand, Park, Pauleau, Gulbinski,
Pei, De Hosson et al.

binary non-carbide hard phase + a-C: TiB_2/a-C
Gilmore, Gissler, Mitterer, IMF I,
only a few reports available

metastable hard phase + a-C: (Ti,Al)(N,C)/a-C
(Ti,Cr)(N,C)/a-C
Shieh & Hon [2002/2005, CVD], Zhang [2002],
Lackner [2004], IMF I [2005],
emerging new class of material ?

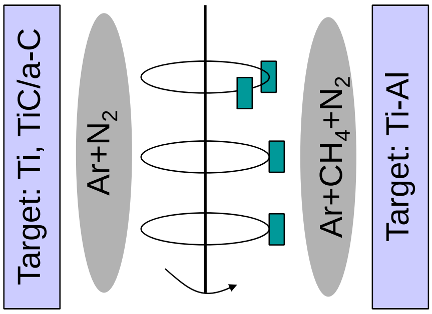
hard phase + lubricious phase + a-C: WS_2/WC/a-C
Voevodin, Zabinski, Cavaleiro et al.

Magnetron-sputtering of nanocomposite coatings in the system Ti-Al-N-C

equipment: Hauzer HTC 625 machine,
1 or 2 target-configuration resp.

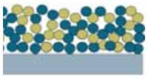
targets: commercial TiAl (Ti:Al 50/50), Ti, and TiC/a-C 30/70,
size: 400 mm x 125 mm

process parameters
Ar flow: 200 sccm
sputtering power: 3 - 6 KW
substrate bias: 80 V
N_2 flow: 0 - 32 sccm
CH_4 flow: 0 – 30 sccm
temperature: 100 - 400°C

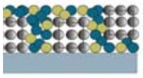


scheme of deposition

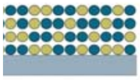
Metastable nanocrystalline fcc (V,Al)(C,N) hard coatings



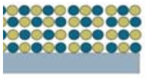
a-VCAlN
l_D = 0.5 - 1 nm



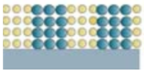
nc-fcc-VC+a-AlNVC
nc-fcc-VC+a-AlN
l_D = 4 - 6 nm



nc-disordered metastable fcc-(V,Al)(C,N)
nc-disordered metastable hex-(Al,V)(N,C)
l_D > 6 nm

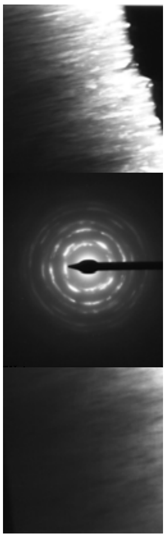


nc-ordered metastable fcc-(V,Al)(C,N)
nc-ordered metastable hex-(Al,V)(N,C)
l_D > 10 nm



nanocomposites:
nc-fcc-VC + nc-hex-AlN
l_D > 100 nm

Correlation between film constitution and diffusion length l_D



rf magnetron sputtering
VC/AlN 60:40 target
220°C, -175 V bias

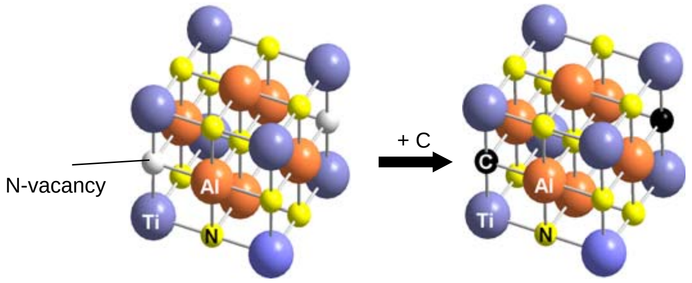
nanocrystalline, fcc
$(V_{0.3}Al_{0.2})(C_{0.3}N_{0.2})$
crystallite size
< 10 nm
a_0 = 0.4102 nm
$a_{0,\,VC}$ = 0.4159 nm

up to 3200 HV0.05
up to 520 GPa
(VC: 2300 HV0.05)
(AlN: 1200 HV0.05)

Growth model of magnetron-sputtered (Ti,Al)(N,C)/a-C nanocomposite coatings

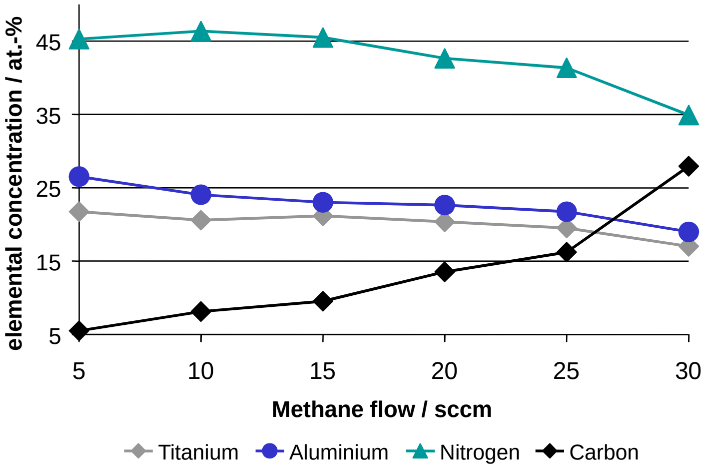
C concentration

five-step growth model of Ti-Al-N-C nanocomposite coatings:
- start from sub-stoichiometric fcc $TiAlN_{1-x}$
- fill in N-vacancies by C atoms
- substitute regularly N atoms by C atoms
- build carbon nano-clusters/agglomerates
- build continuous carbon phase

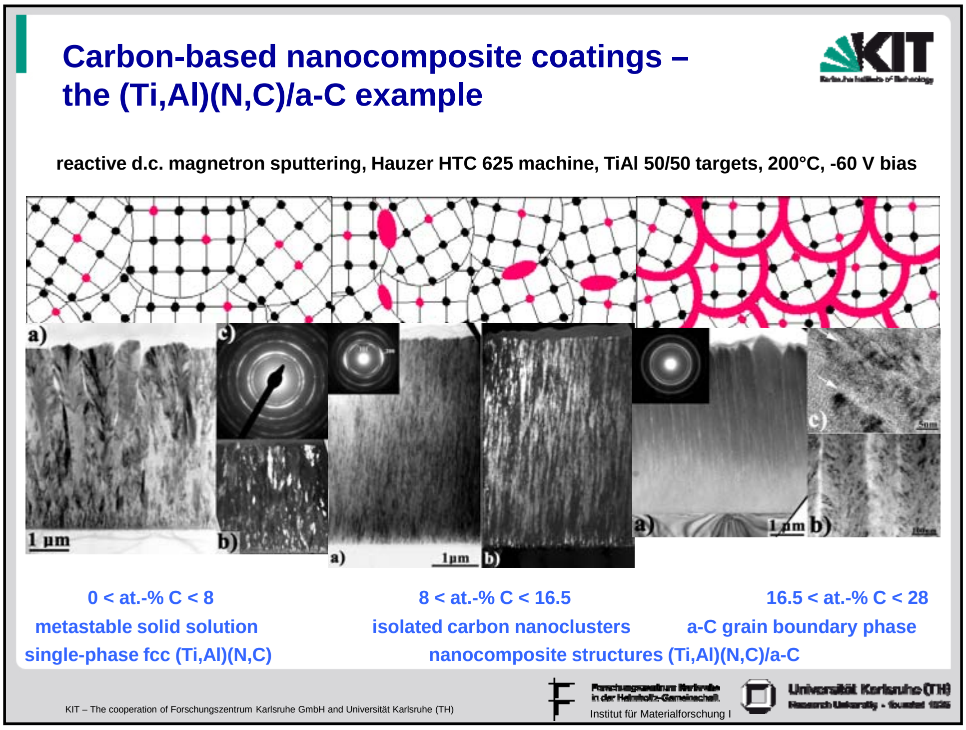


M.Stueber et al., Thin Solid Films 493 (2005) 104

Chemical composition of magnetron-sputtered Ti-Al-N-C-coatings



Characterisation method: electron probe micro analysis (Cameca microbeam system)



Carbon-based nanocomposite coatings – the (Ti,Al)(N,C)/a-C example

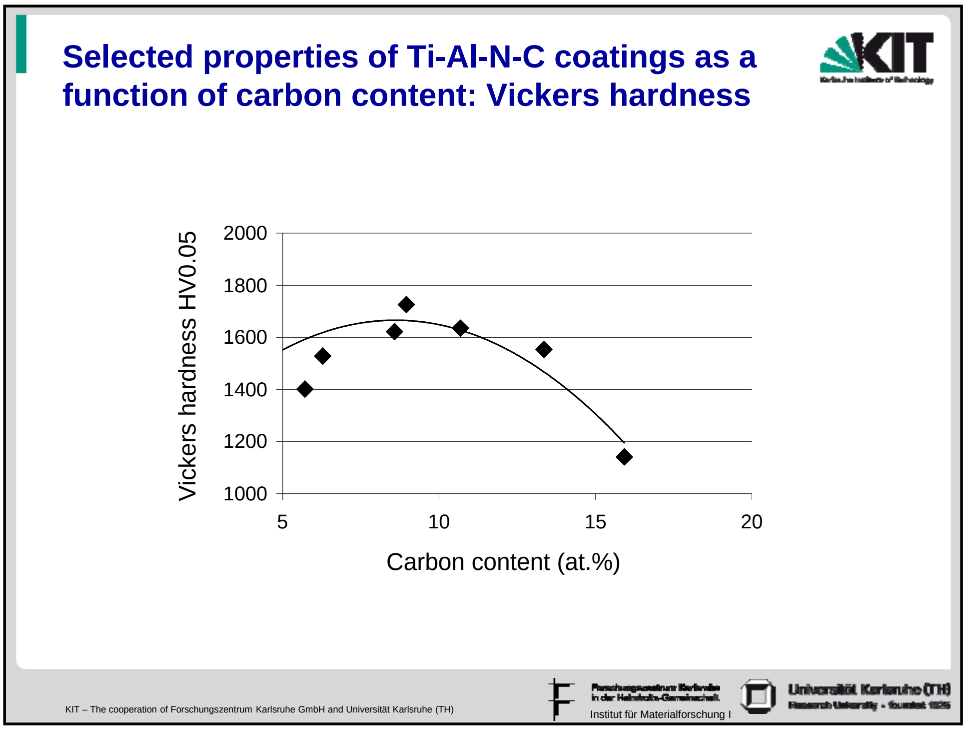
reactive d.c. magnetron sputtering, Hauzer HTC 625 machine, TiAl 50/50 targets, 200°C, -60 V bias

0 < at.-% C < 8
metastable solid solution
single-phase fcc (Ti,Al)(N,C)

8 < at.-% C < 16.5
isolated carbon nanoclusters

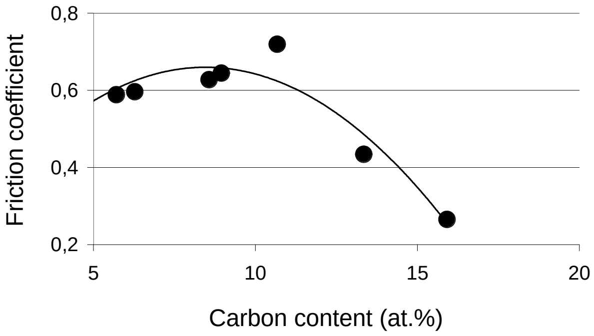
16.5 < at.-% C < 28
a-C grain boundary phase

nanocomposite structures (Ti,Al)(N,C)/a-C



Selected properties of Ti-Al-N-C coatings as a function of carbon content: Vickers hardness

Selected properties of Ti-Al-N-C coatings as a function of carbon content: friction coefficient



Pin-on-disk model testing (CSM Reve-Test)
unlubricated sliding friction against 100Cr6 ball
10 N, 1000 m, 3 cm/s

Summary

- **significant improvement of thin film properties (hardness, elastic moduli, intrinsic stress) by**

- **appropriate material selection and adjusting of kinetic and energetic conditions of PVD film growth**
- **design of specific nanoscale multilayer architectures**
- **superfine structural ordering at the nanoscale (grain boundaries + interfaces)**

- **nanocomposite formation in carbon-based systems – elastic coupling of nanograins and layers through amorphous carbon at grain boundaries, column boundaries and at interfaces**