Thin film growth and properties of nanostructured thermal barrier coatings

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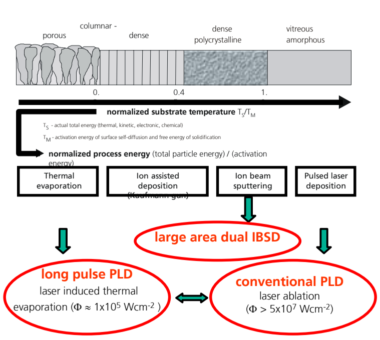
Introduction

Typical demands on thermal barrier coatings (TBC's) are low thermal conductivity and exceptional thermal stability at the operating temperatures they are designed for. Nanostructured materials can improve the thermal as well as the mechanical properties of a TBC in comparison to standard single layer coatings. We show two applications of tailored thermal barriers introducing a laminated micro- and nanostructure.

- A combined Pulsed-Laser-Deposition (PLD) technique is used to prepare columnar-lamellar ZrO_2 coatings that can sustain thermal heat flows as high as 100 MW/m² typical for rocket jet engines and that are specially adapted to the loading profile in the engine.
- Nanolaminates of W/Al_2O_3 were produced by Ion Beam Sputter Deposition (IBSD). This laminates with individual layers of only a few nanometers and total thicknesses of up to 2,5 µm show a low thermal conductivity and a excellent mechanical stability and adhesion. Therefore coatings on flexible metal foils could be realized.

Structure zone model of thin film growth

Extended structure zone model of thin film growth:
(based on K.H. Guenther, SPIE Vol.1324, 1990)

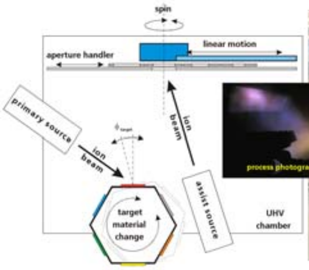


tailored film properties:

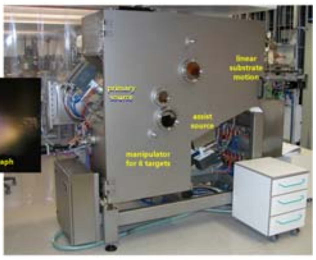
- wide range of layer thickness possible: d = 1 nm...100 µm
- microstructure can be influenced by process energy (e.g. laser parameters, ion energies)
  => amorphous as well as columnar-porous films can be deposited
- nanometer layered structures with ultra high precision
- wide material choice (e.g. metal/non-metal combinations)

Fabrication of nanostructured TBC's

Large-area dual IBSD



Schematic view of the arrangement for the large-area IBSD



Photograph of the IBSD machine

Technical data:

Ion beam sources:
- primary for sputtering
- secondary for assisting and etching
- excitation principle: ECR = electron cyclotron resonance
- grid size: 400 x 200 mm²
- ion energies: E = 50 - 2000 eV

Vacuum:
- process chamber: $p < 2\cdot10^{-8}$ mbar
- load lock: $p < 5\cdot10^{-7}$ mbar

Targets:
- number: 6 pieces
- size: 400 x 200 mm²

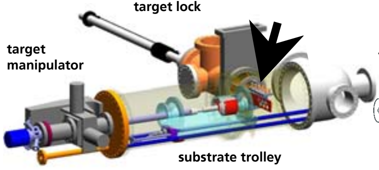
Substrates:
- round, up to ∅ = 200 mm
- rectangular, up to L = 500 mm (without spin)

Apertures:
- for beam shaping and film thickness homogenization
- 4 pieces, automatically changeable

Internal coating by hybrid PLD

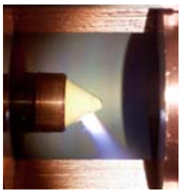
Technical data:

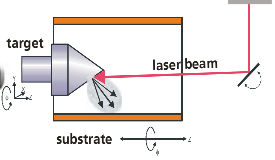
- **Lasers**: ablation: q-switched Nd:YAG; λ = 1064/355 nm;
  f = 10 Hz; E_{puls} = 50..1200 mJ; τ = 8 ns
  evaporation: 1 kW cw-Nd:YAG; λ = 1064 nm;
  f = 1..1000 Hz; E_{puls} = 0,5..4 J;
  τ = 0,5..10 ms
- **Vacuum**: UHV - $p \approx 10^{-6}$ mbar
- **Targets**: cone shaped or foils
- **Substrates**: $\varnothing_i$ = 7..120 mm; cylindrical or shaped
  l_{max} = 60 cm



UHV-chamber for internal coating by PLD

Photo of the internal coating process in a model cylinder (cross section)

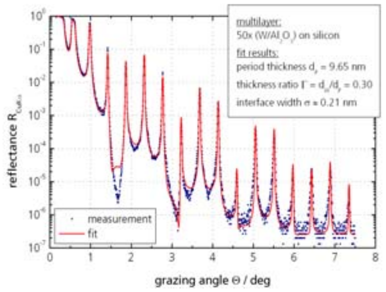




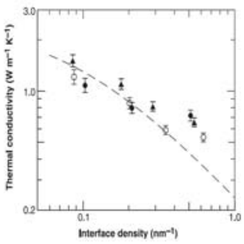
Scheme of the internal PLD process

Applications

W/Al_2O_3 Nanolaminates



Cu-Kα reflectometry of a typical W/Al_2O_3 multilayer with high regularity and a period thickness of d_P = 9.65 nm (interface density $1/\delta$ = 0.21 nm^{-1}). The red curve shows the best fit calculation with an interface width σ ≈ 0.21 nm. These sharp transitions between metal and non-metal material act as additional thermal barriers and therefore reduce the thermal conductivity of the nanolaminate.

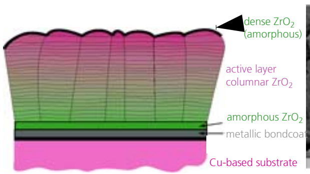


Room temperature thermal conductivity of W/Al_2O_3 nanolaminates as a function of interface density $1/\delta$; δ is the distance between interfaces. Different symbols represent various deposition techniques (from [1]).

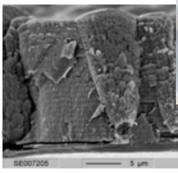
[1]: R.M. Costescu et al.: "Ultra-low thermal conductivity in W/Al_2O_3 nanolaminates", Science 303 (2004) 989

ZrO_2-coatings for rocket combustion chambers

Coating design:

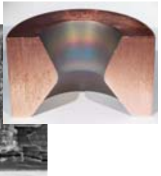


Schematic view of PLD-TBC's



SEM cross section of a PLD-TBC

Laval-nozzle coated by PLD



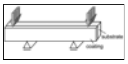
Experimental results:

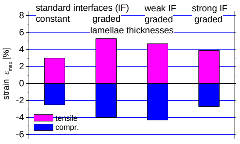
Hot Gas Tests

- tests in model thrust chambers at near working conditions
- LH_2 cooled subscale runs show effective heat load reduction and excellent adhesion of the TBC

DLR test facility P8, Lampoldshausen

Adhesion studies by bending tests





- improved strain resistance with graded and tailored interfaces

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