Innovative Coatings for High Temperature Applications

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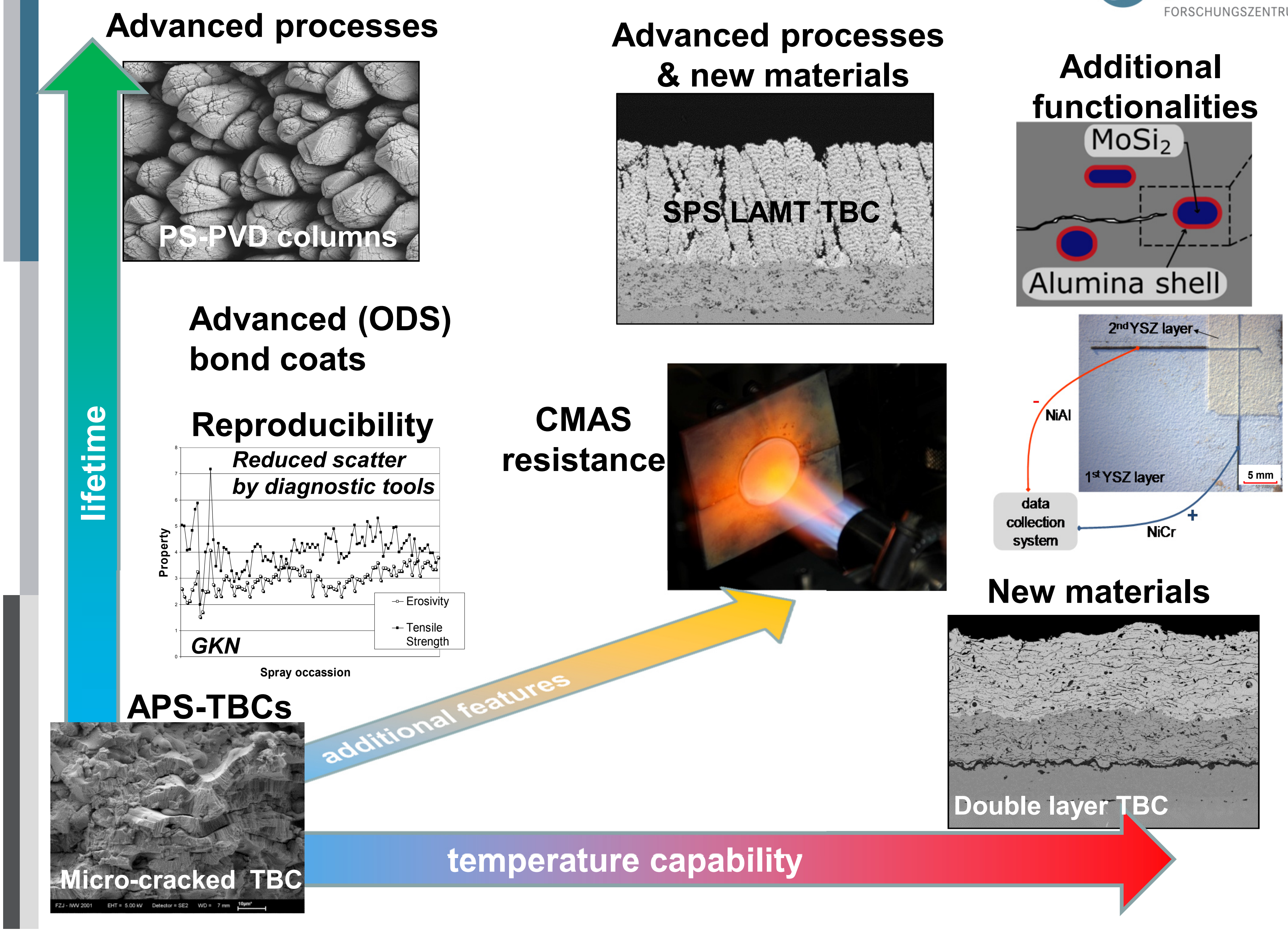
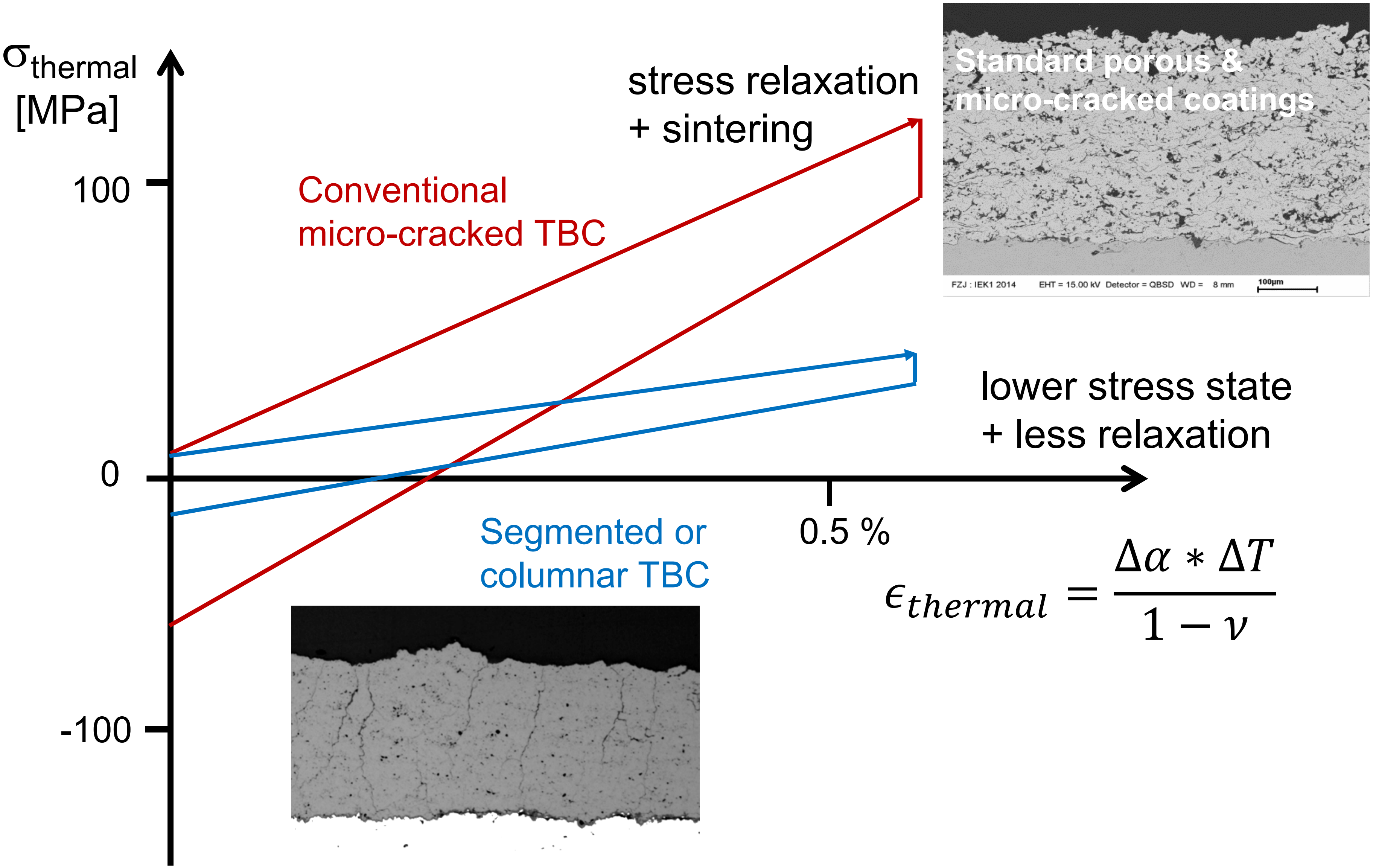
Overview

- Introduction – Thermal Barrier Coatings (TBCs)
- Segmented & columnar microstructures
    - *Why columnar structures?*
    - *Atmospheric Plasma Spraying (APS)*
    - *Suspension Plasma Spraying (SPS)*
    - *Plasma Spray – Physical Vapor Deposition (PS-PVD)*
- New Thermal Barrier Coatings (TBCs)
    - *Double layer concept*
    - *$Gd_2Zr_2O_7$ coatings by APS + PS-PVD*
    - *LAMT coatings by SPS*
- Summary

Directions of TBC development



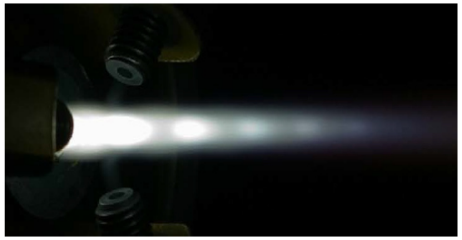
Why segmented or columnar structures?

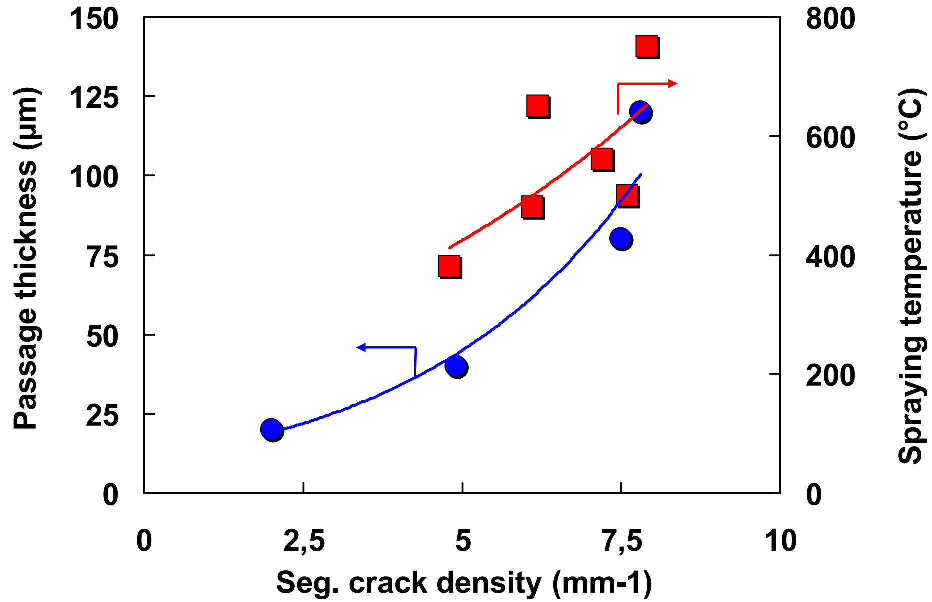


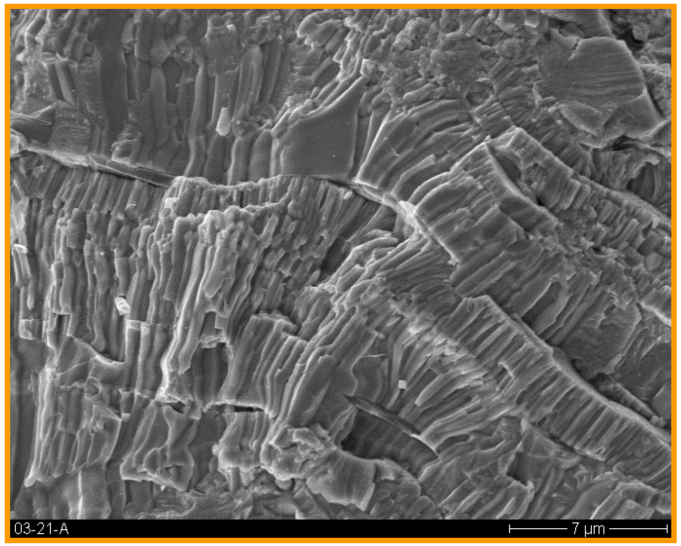
$$\epsilon_{thermal} = \frac{\Delta\alpha * \Delta T}{1 - \nu}$$

Segmented TBCs by APS

Atmospheric Plasma Spraying (APS):
Oerlikon Metco TriplexPro™-210







SEM fracture surface

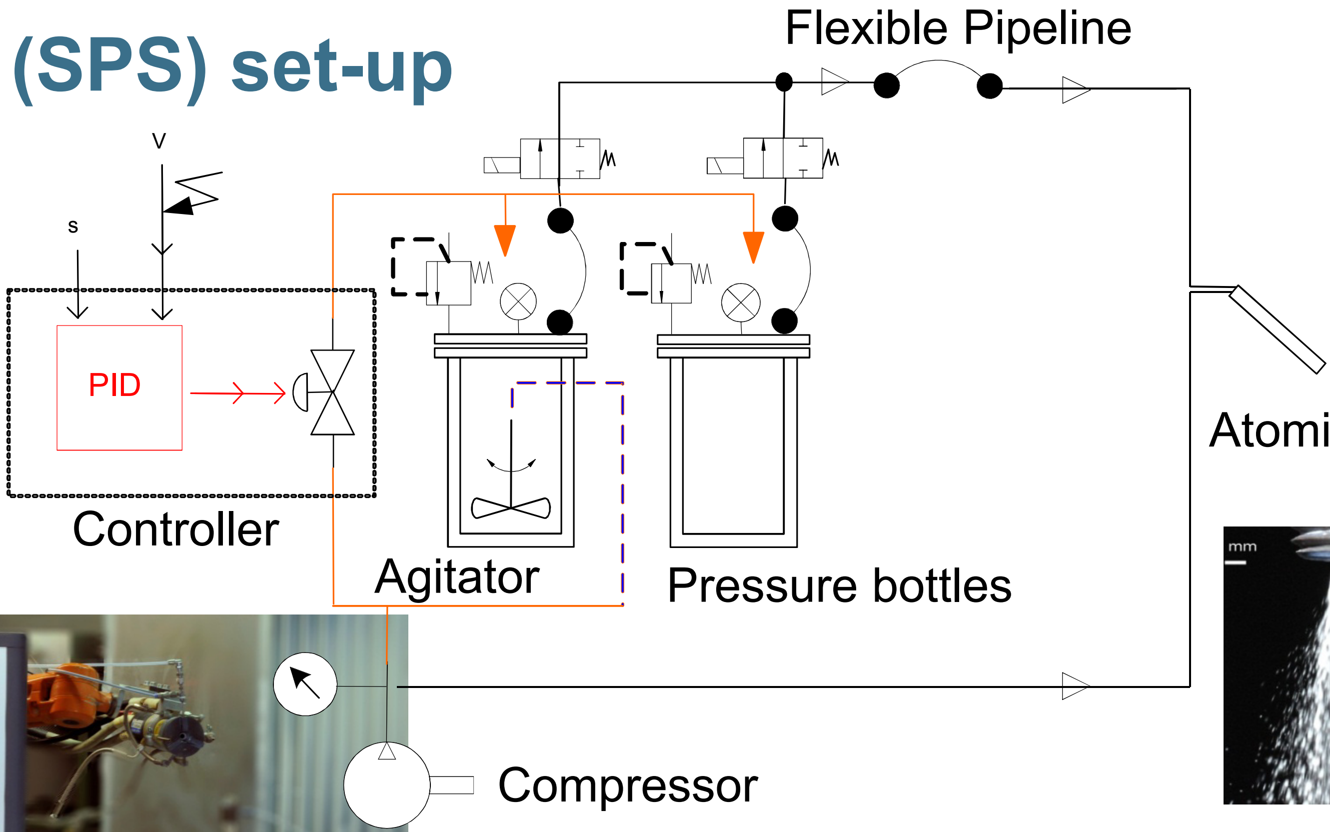
Karger,M.;Vaßen,R.;Stöver,D. *Atmospheric plasma sprayed thermal barrier coatings with high segmentation crack densities:,* Surface and Coatings Technology, Vol. 206, (2011), pp. 16-23

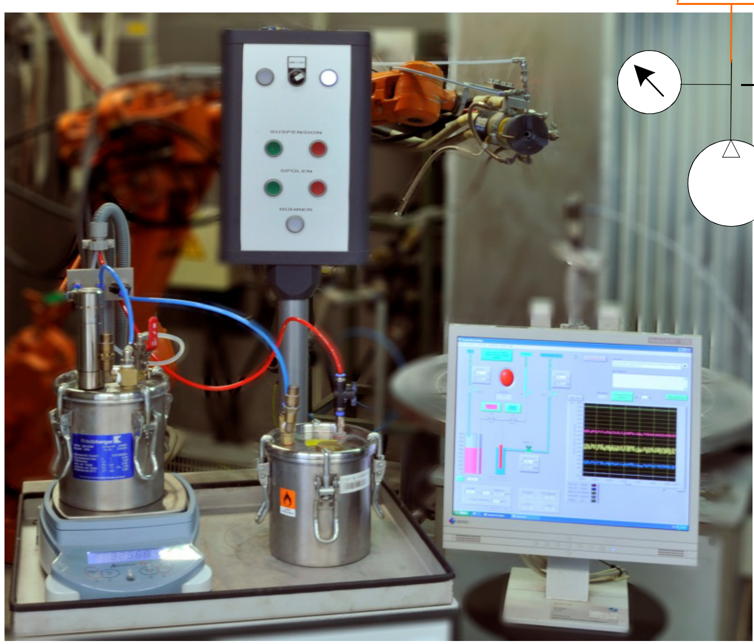
New Processes

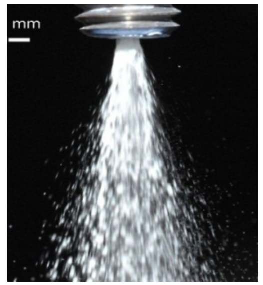
Suspension Plasma Spraying

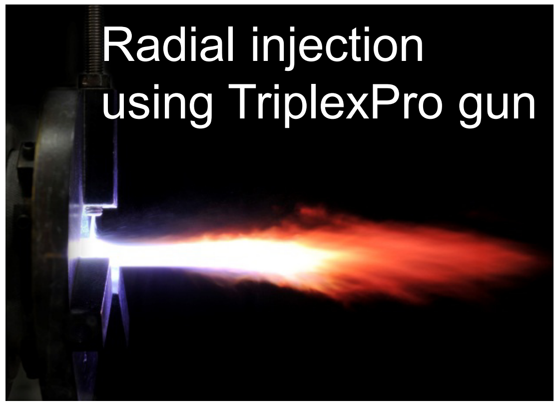
(SPS)

Suspension Plasma Spraying (SPS) set-up



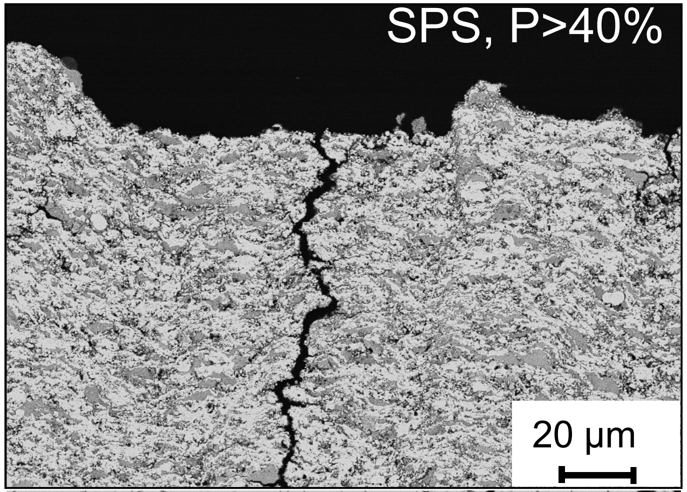


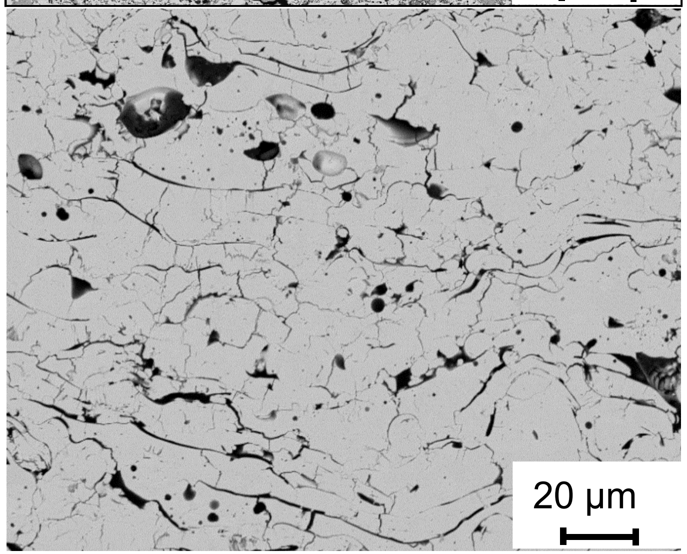


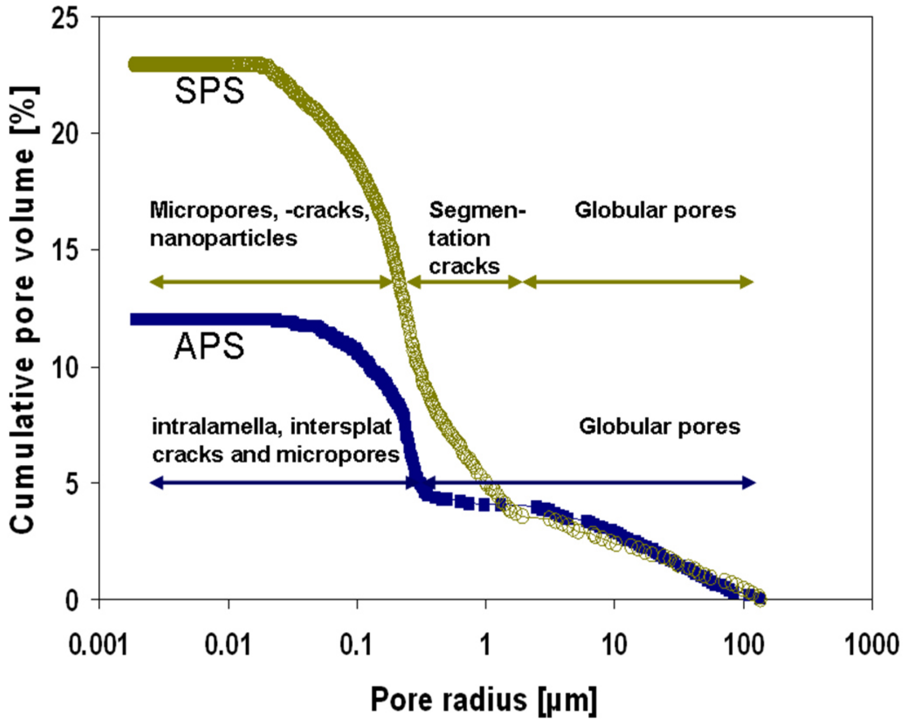


Comparison APS & SPS TBCs

Microstructure and porosity



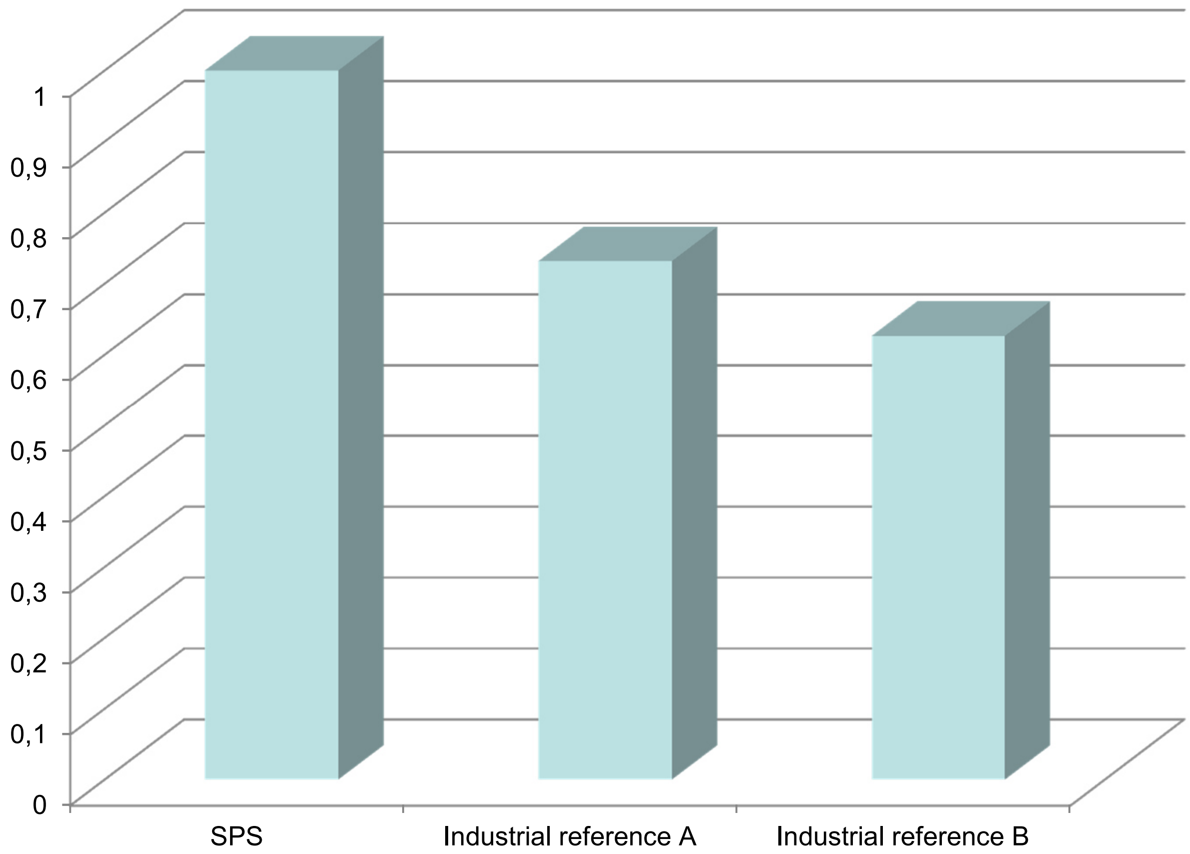




- higher porosity levels, > 40% possible
- higher amount of fine pores

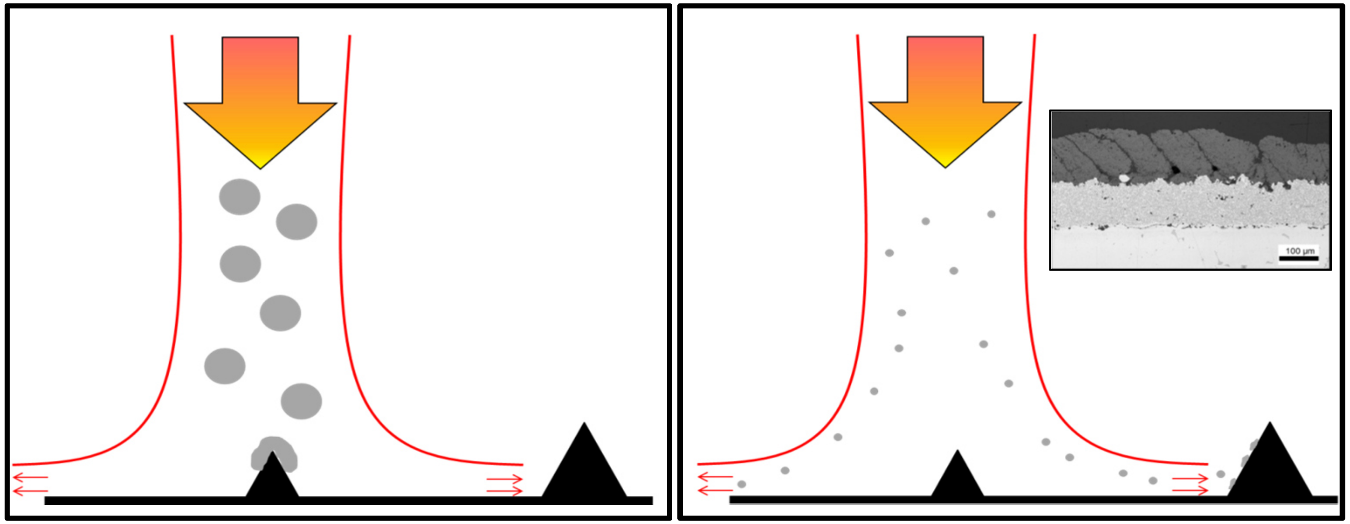
- both high porosity level + segmentation cracks possible

Furnace cycle tests @ 1000°C



obtained within the European TOPP COAT project

Mechanism of column growth:



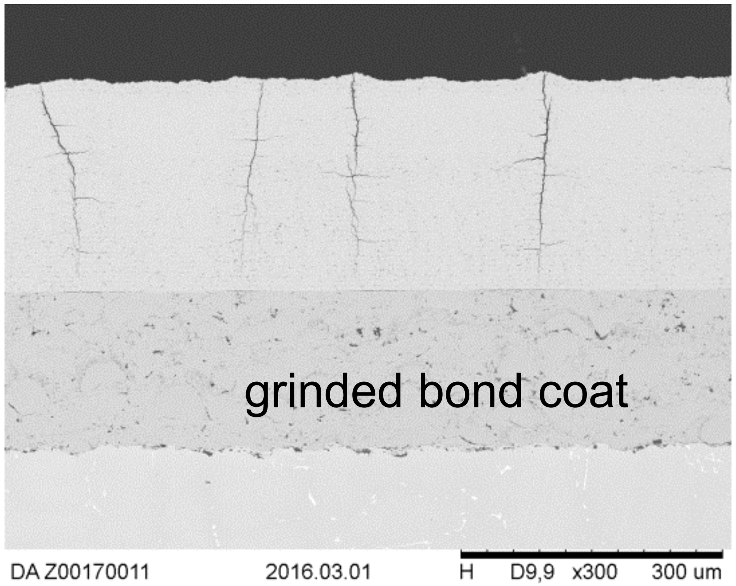
Prerequisites:

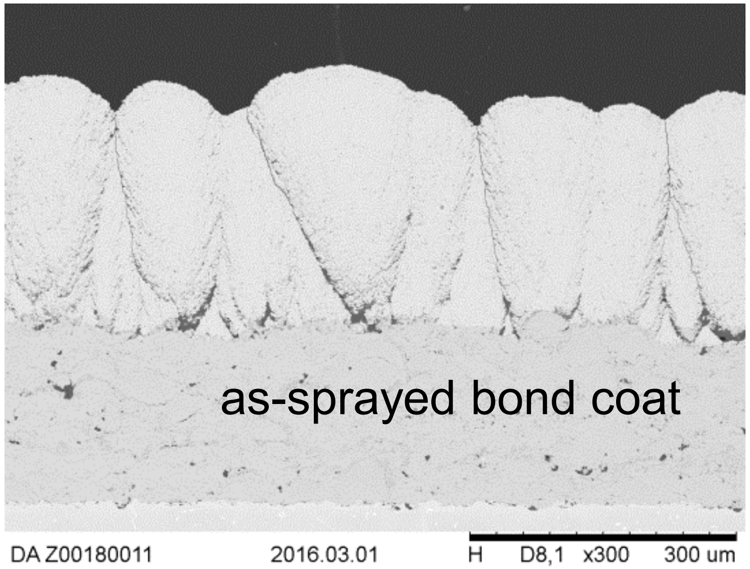
- fine droplets
- surface roughness
- some others

[VanEvery et al., 2011]

SPS with axial injection

YSZ suspensions:



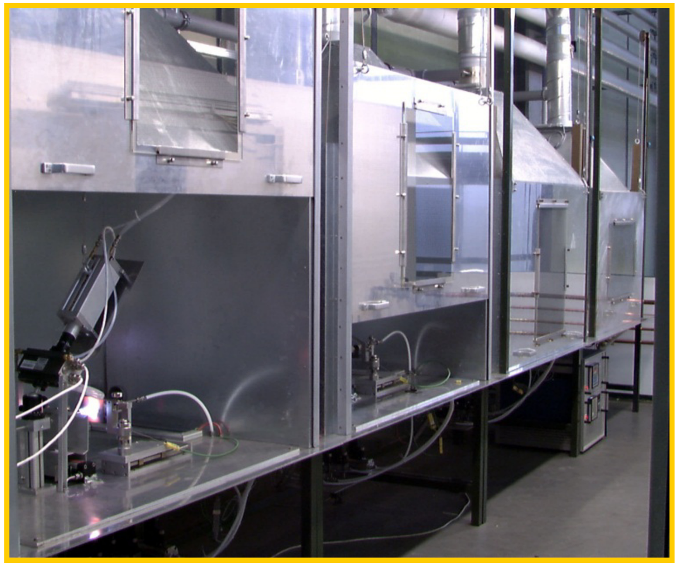


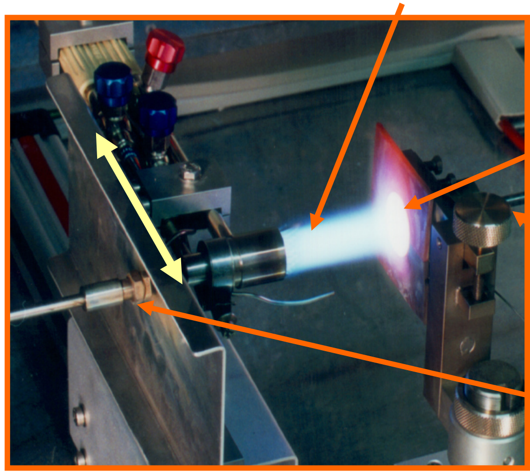
Mitglied der Helmholtz-Gemeinschaft

New Processes

Plasma Spray – Physical Vapor Deposition (PS-PVD)

Thermal cycling rigs





Independent adjustment of surface and substrate temperatures

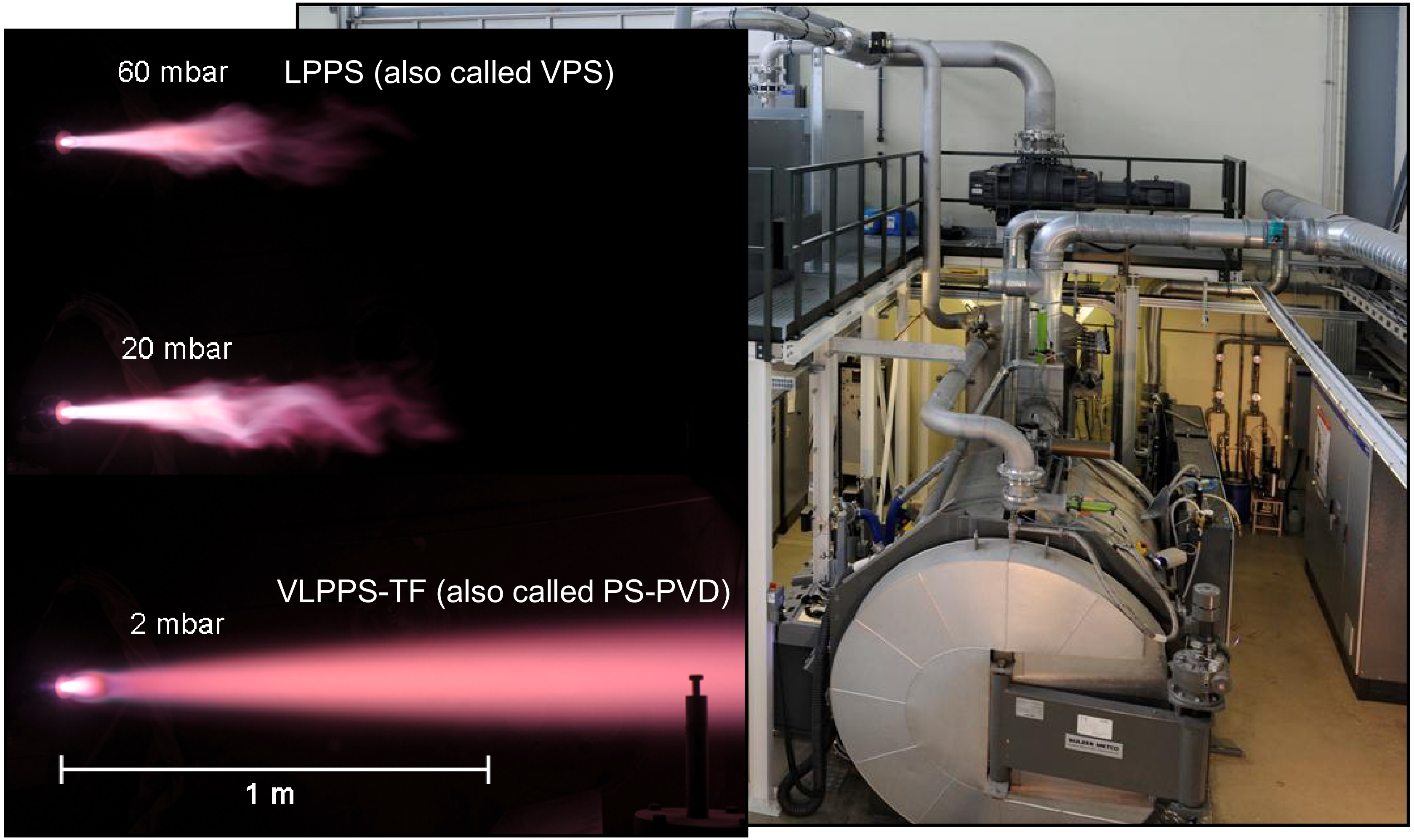
Typical test conditions:

$T_{substrate}$ 1000-1050°C,

T_{surf} 1200-1450°C

5min heating, 2 min cooling

Oerlikon Metco Multicoat Facility for VLPPS and PS-PVD



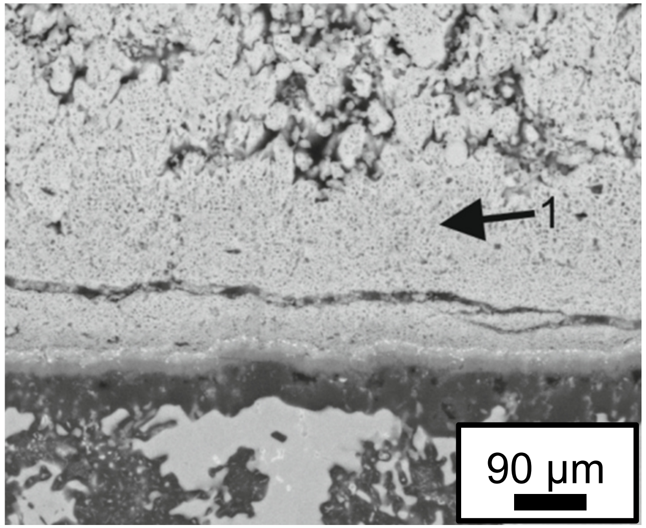
Chamber pressure: down to <u>1 mbar</u>

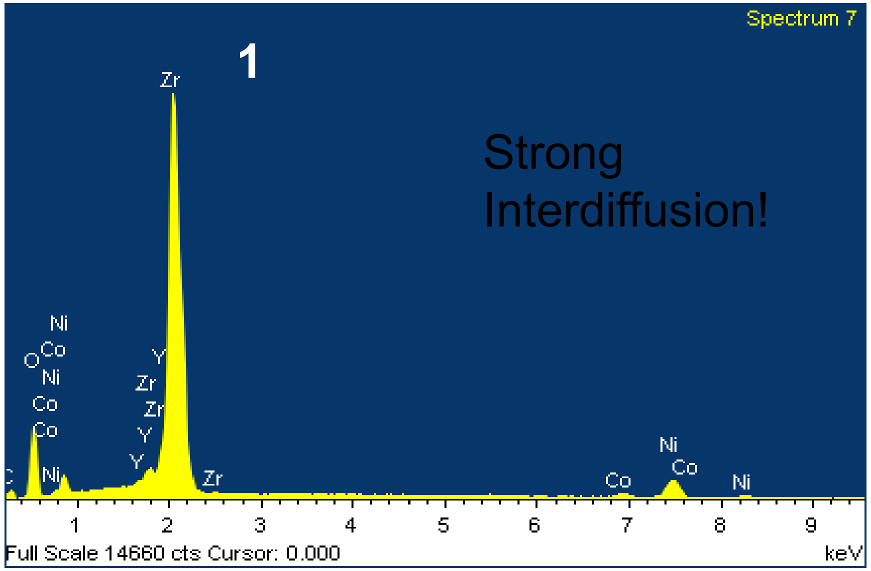
Input power: up to <u>150 kW</u>

Spraying distance: up to <u>1.5 m</u>

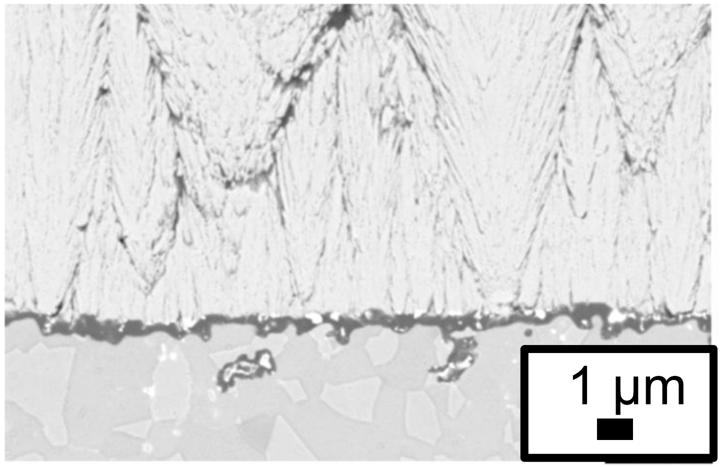
- High plasma gas velocity and laminar flow
- Flattened radial and axial flow profiles
- <u>Evaporation of powder possible</u>

Optimization of the Process



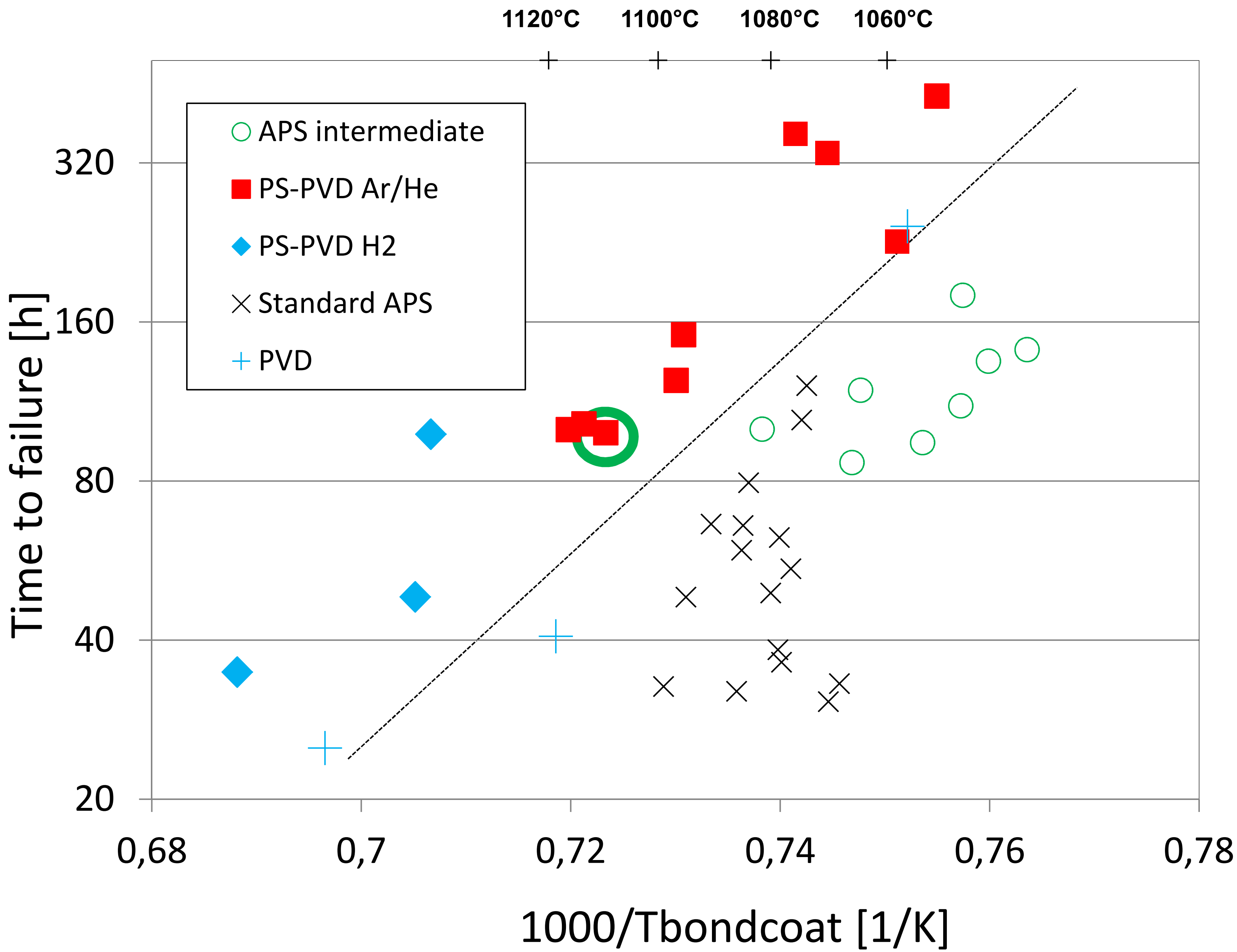


- In-situ pre-oxidation during PS-PVD process leads to TGO formation, TGO acts as diffusion barrier!



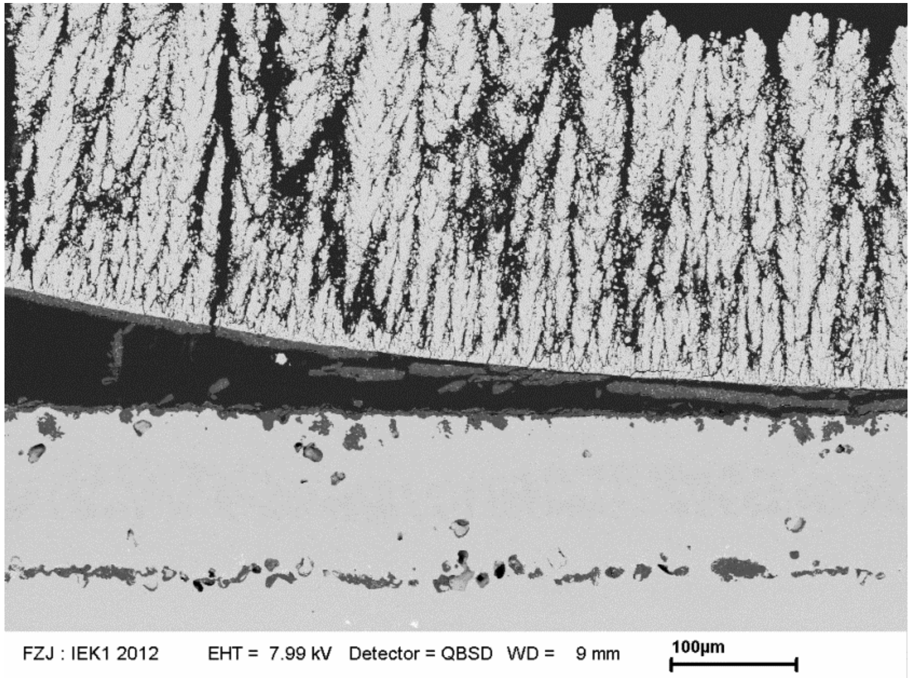
Rezanka, S.;Mauer, G.;Vaßen, R. *Improved Thermal Cycling Durability of Thermal Barrier Coatings Manufactured by PS-PVD,* Journal of Thermal Spray Technology, Vol. 23, (January 2014) Issue 1-2, pp 182-189

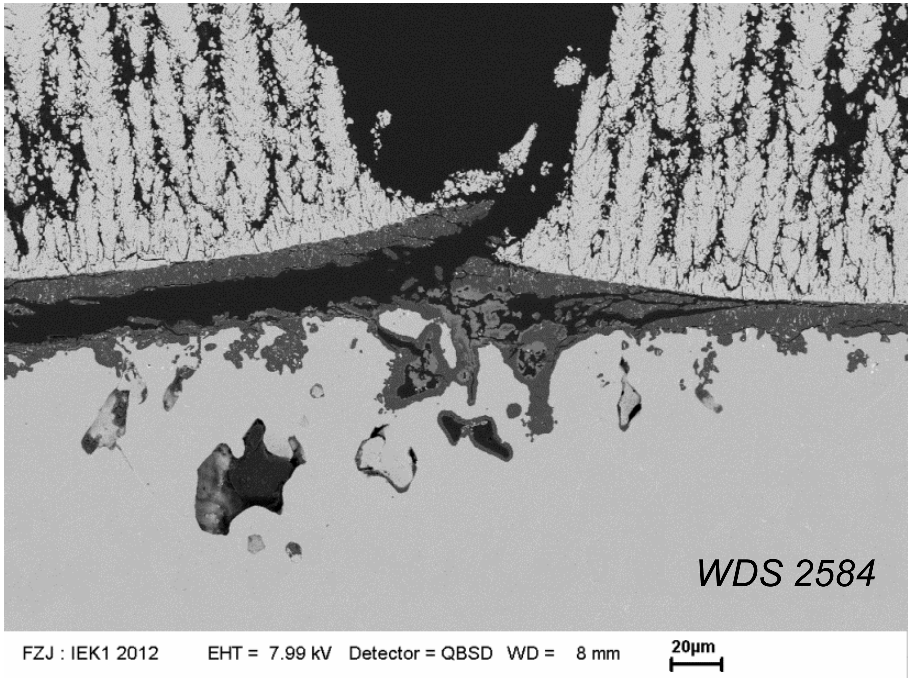
Thermal cyclic results



Failure analysis

$T_{surface}$ 1382°C, T_{BC} ~ 1113°C, cyles 1185 (≈ 99h)

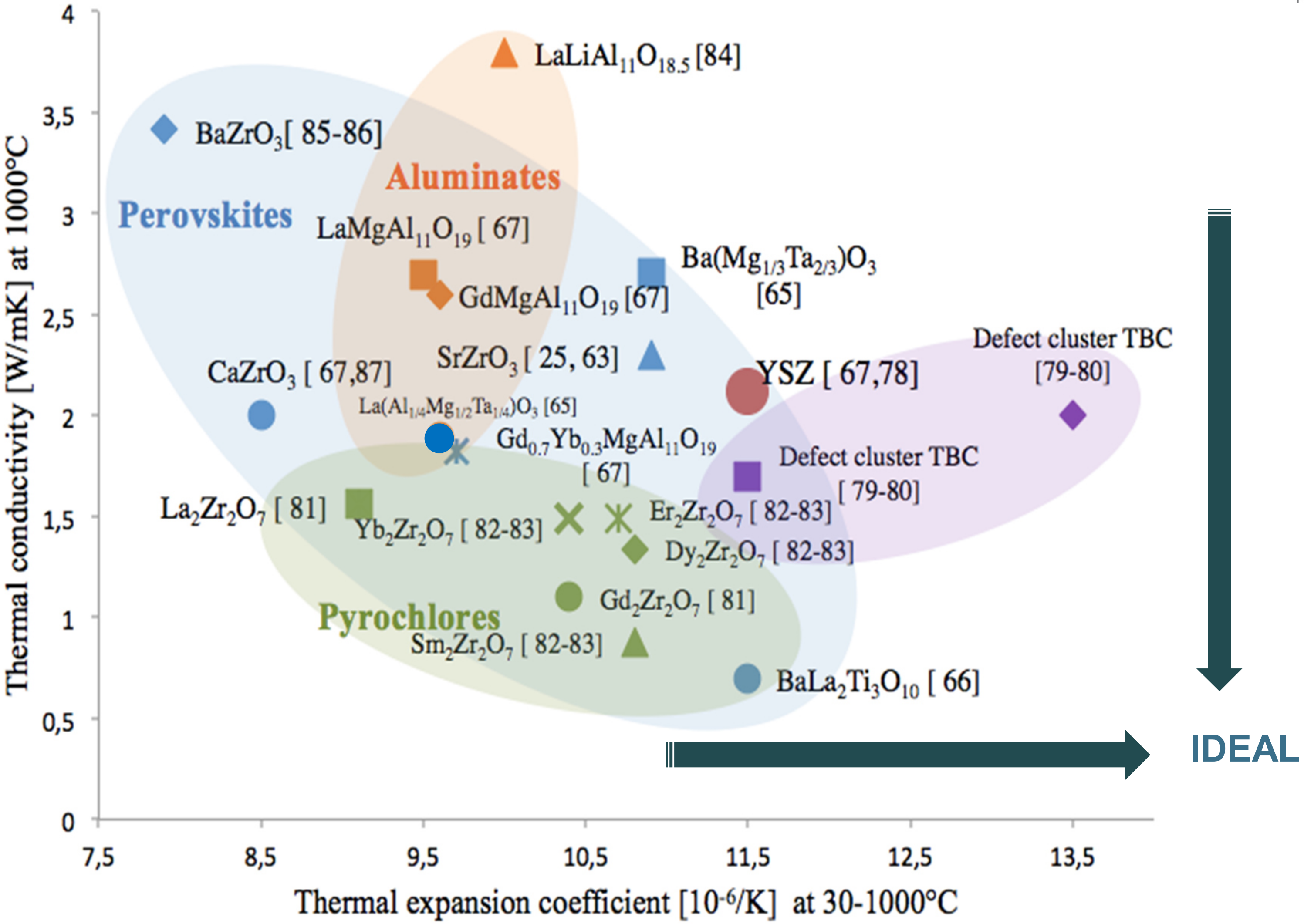




- Formation of thick Thermally Grown Oxide (TGO) layer
- Close to β-phase depletion of bond coat
- Failure mainly within TGO due to TGO cracking/ transient oxide formation
- First appearance of such failure mode in rig cycling!

New Materials

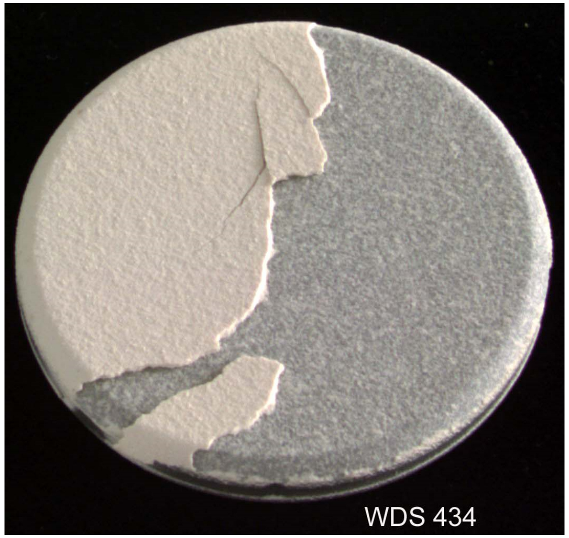
Thermal conductivity vs. TEC

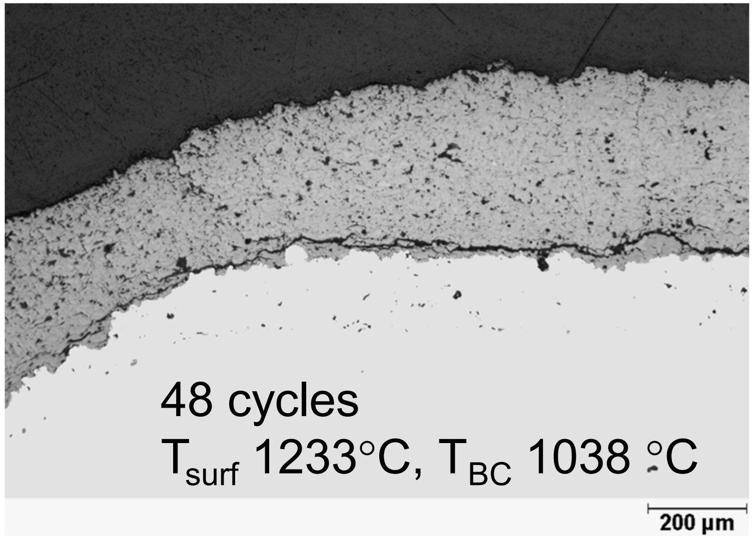


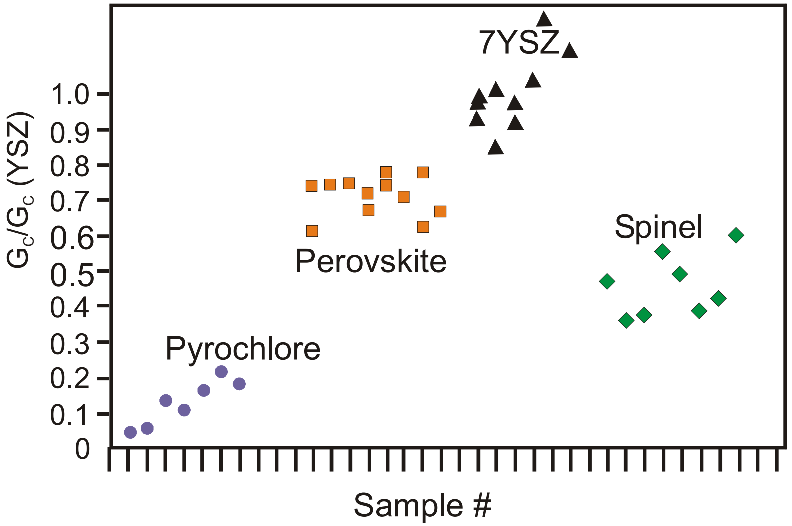
[25] Vaßen et al. J. Am. Ceram. Soc., 83 [8] (2000), [63] Ma et al. J. Eur. Ceram. Soc. 28 (2008), [65] Jarligo et al. J. Therm. Spray Technol. 18 (2009), [66] Guo et al Surf. Coat. Technol. 204 (2009), [67] Vaßen et al. Surf. Coat. Technol. 205 (2010), [78] Pan et al. Key Eng. Mater. 280-283 (2005), [79] Zhu et al. J. Therm. Spray Technol. 13 (1) (2004), [80] Gasperin et al. J. Solid State Chem. 54 (1984), [81] Vaßen et al. J. Therm. Spray Technol. 18(2)(2009), [82] Qin et al. Key Eng. Mater. Vols. 336-338 (2007), [83] Wang et al. Key Eng. Mater. Vols 280-283 (2005), [84] Pracht et al. The 30th Inter. Conf. on Adv. Cer. and Comp. (2007), [85] Lawn et al. Science 263 (1994), [86] Jarligo et al. J. Therm. Spray Technol. 19 (2010).

Double layer concept

Single layer coating made of $Gd_2Zr_2O_7$:







U. Bast et al. Cocoa Beach 2003

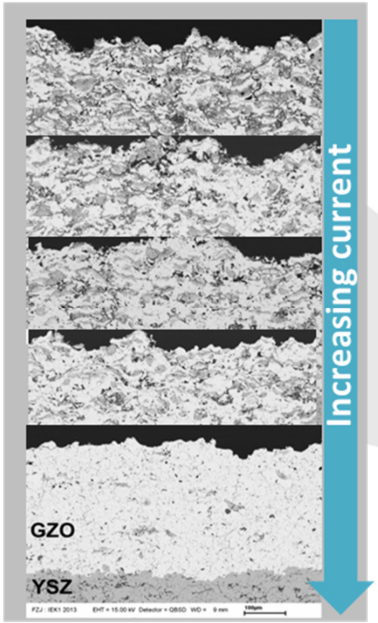
new TBCs (often) show low toughness ⇨

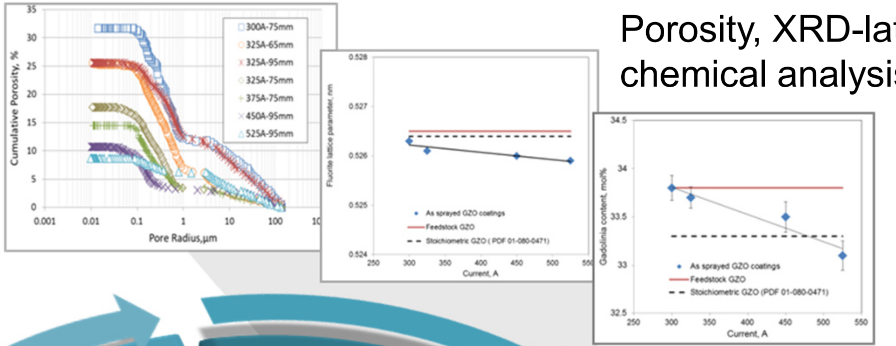
development of double layer system

i.e. tough intermediate layer of YSZ

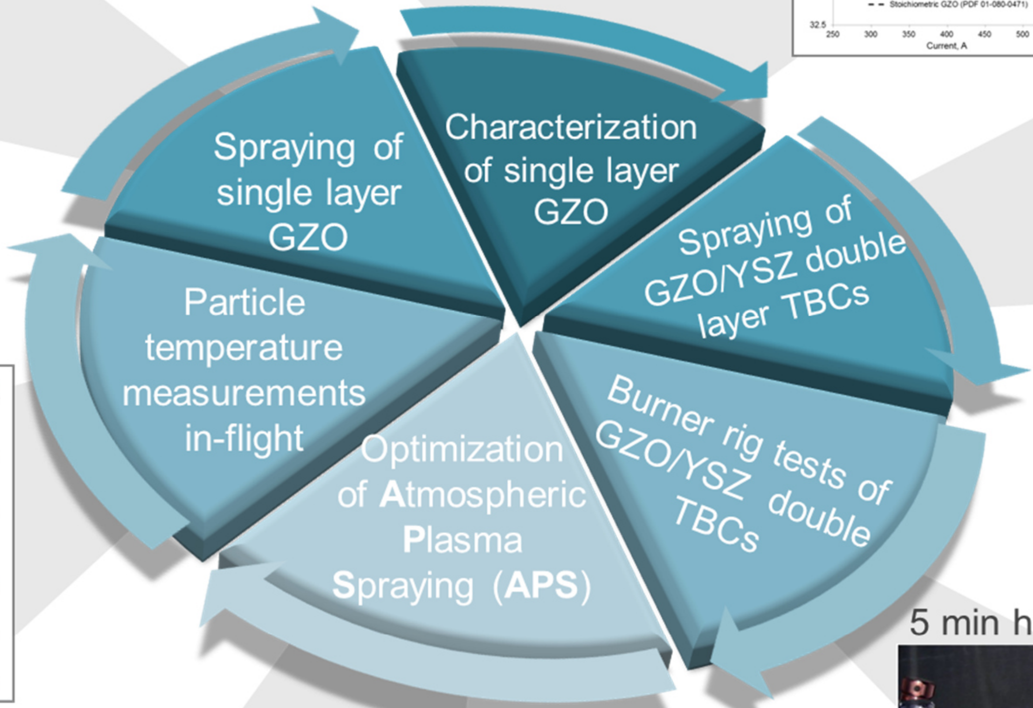
R. Vaßen, F. Traeger, D. Stöver, *New Thermal Barrier Coatings Based on Pyrochlore / YSZ Double-Layer Systems*, Int. J. of Applied Ceramic Technology 1, 4 (2004) pp. 351-61

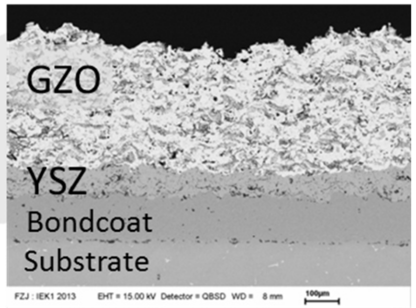
Optimisation of Double Layers

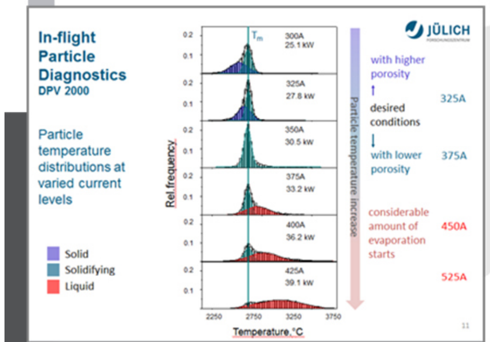




Porosity, XRD-lattice parameter, chemical analysis..



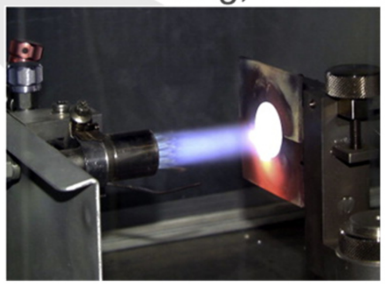




$T_{surface} \cong 1400°\ C$

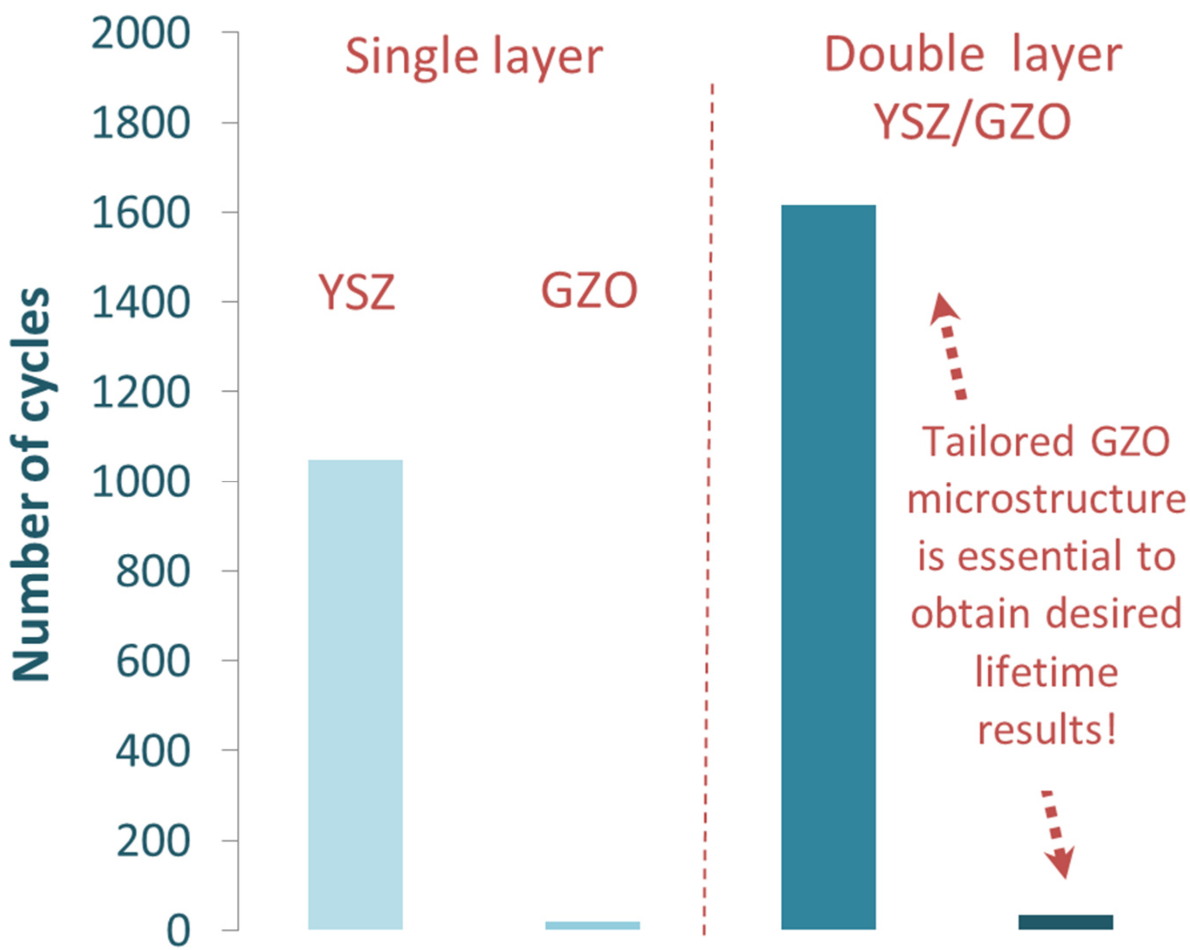
$T_{bondcoat} \cong 1070°\ C$

5 min heating, 2 min cooling



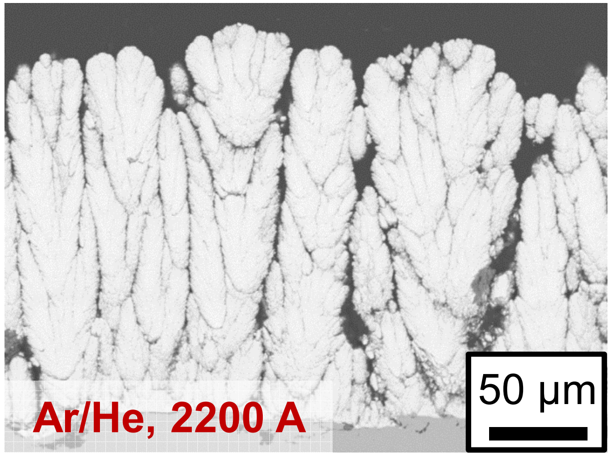
Spray current, distance, plasma gases..

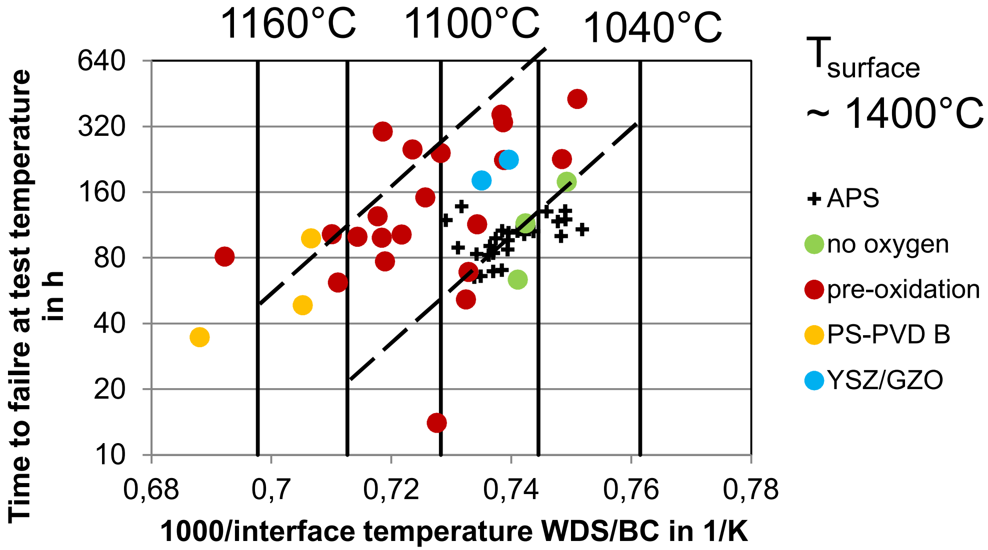
Lifetime Results at 1400⁰C

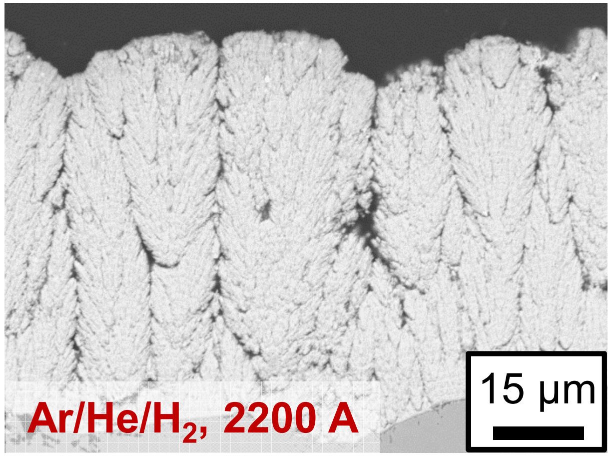


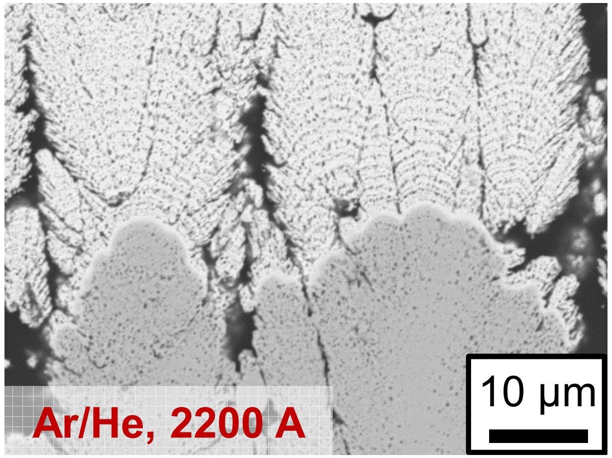
Bakan E., Mack D. E., Mauer G., Mücke, R. and Vaßen R., "Porosity-Property Relationships of Plasma-Sprayed $Gd_2Zr_2O_7$/YSZ Thermal Barrier Coatings", Journal of American Ceramic Society, 98 [8] 2647{2654

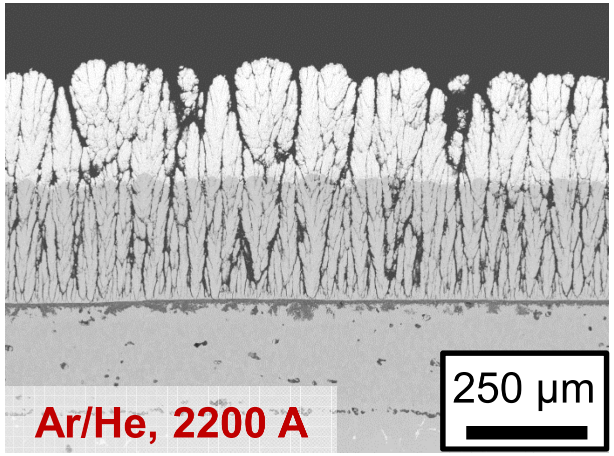
PS-PVD-$Gd_2Zr_2O_7$ (GZO)











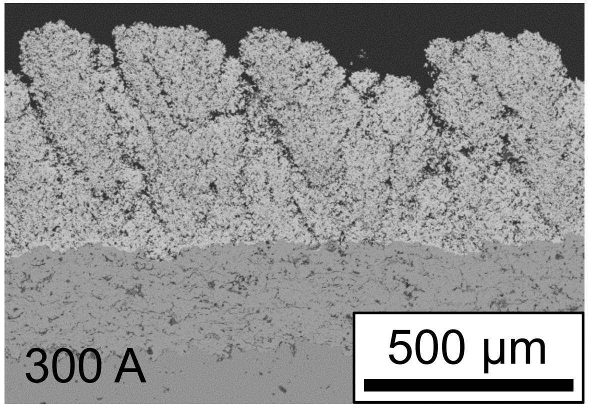
- Some deviation from stochiometry, still defect fluorite phase present

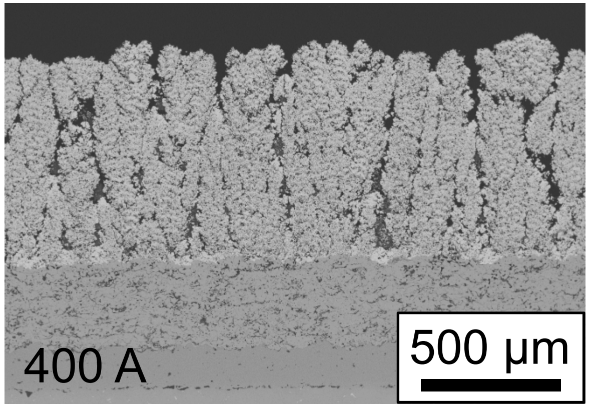
Lifetime and failure mechansim similar to YSZ

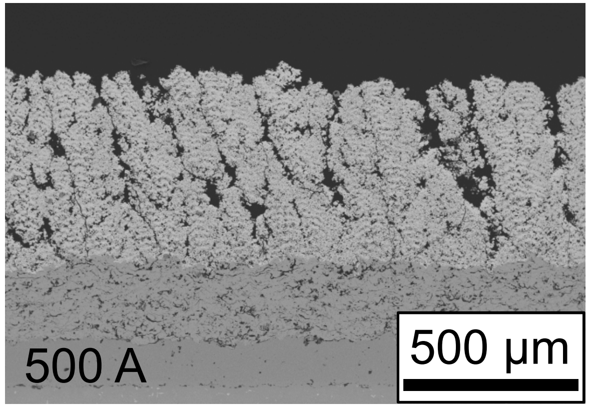
SPS LAMT-TBCs

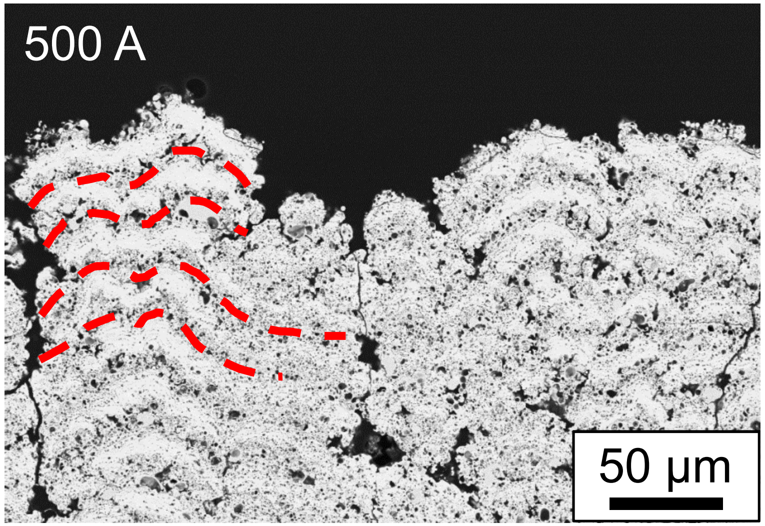
Microstructure of as-sprayed coatings – with APS YSZ bonding layer

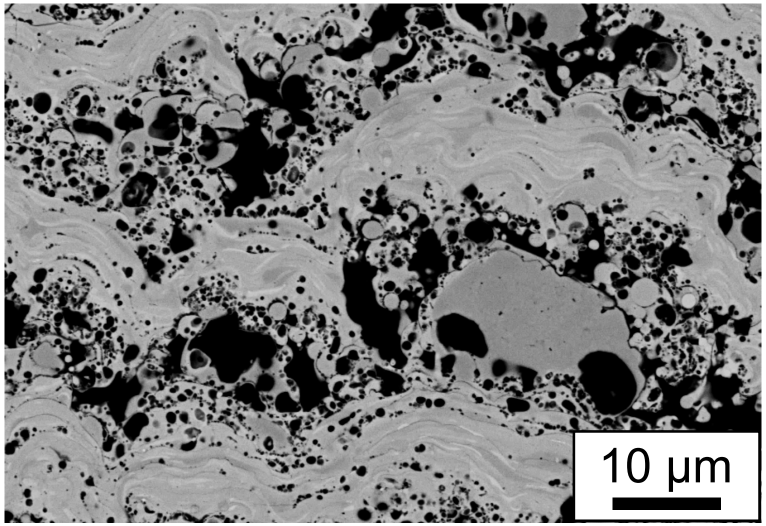
LAMT=La(Al$_{0.25}$Mg$_{0.50}$Ta$_{0.25}$)O$_3$











Parts published in: Schlegel et al., Journal of Thermal Spray Technology, 2015

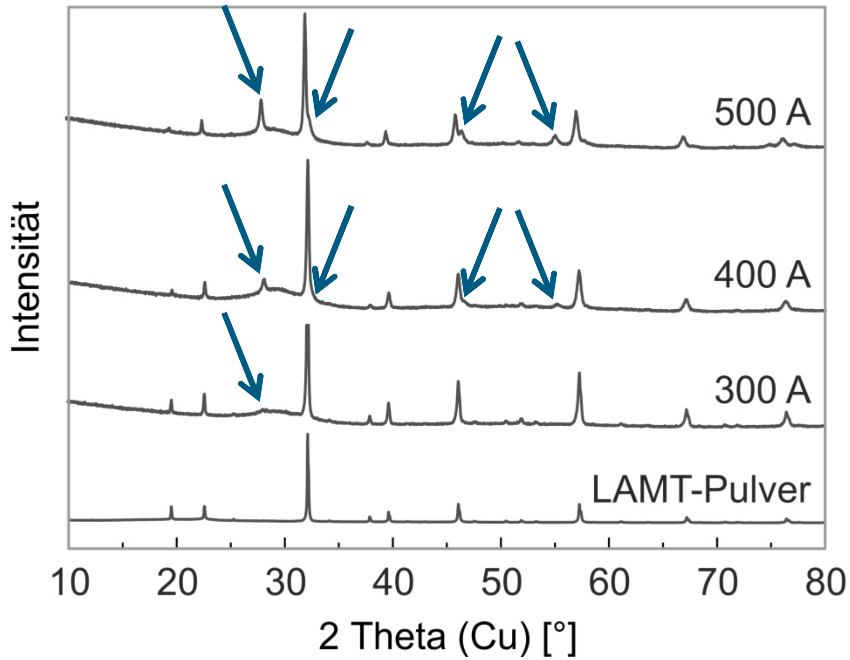
LAMT-TBCs

Coating Composition

$La\,[Al_{0.25}Mg_{0.5}Ta_{0.25}]\,O_3$

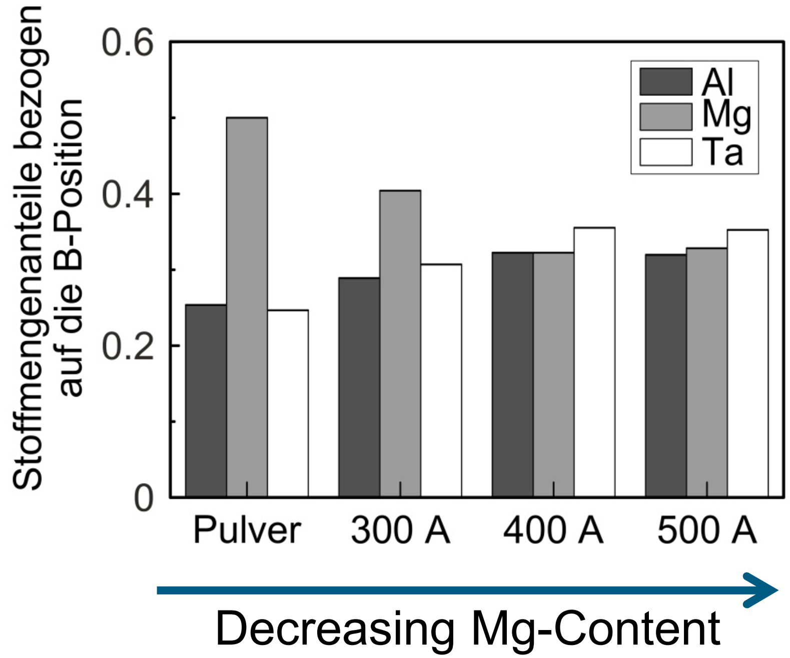
A B

Phase Analysis



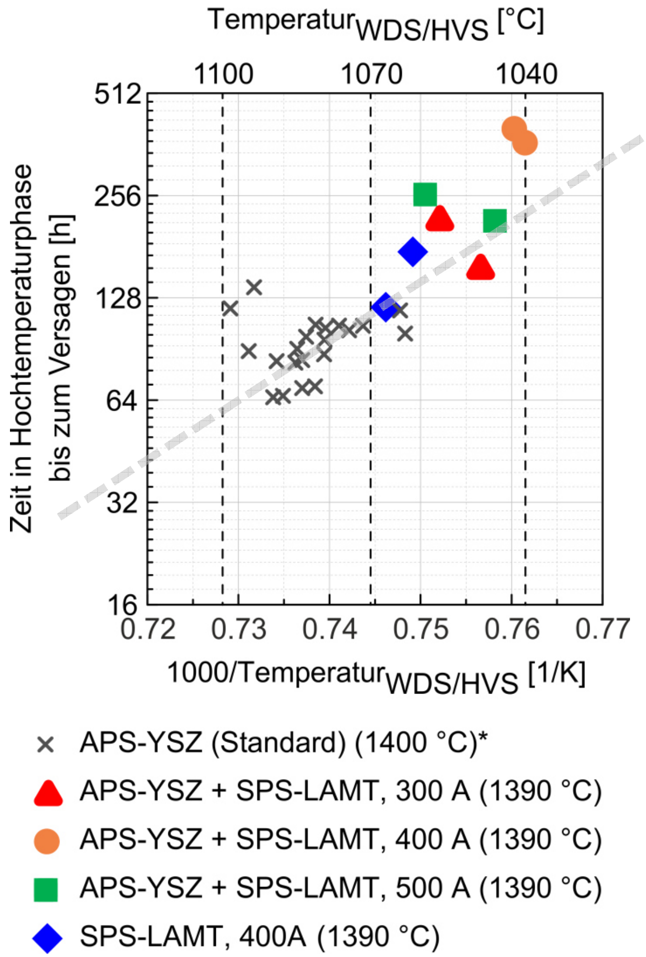
Formation of La_3TaO_7 is increasing with increased current

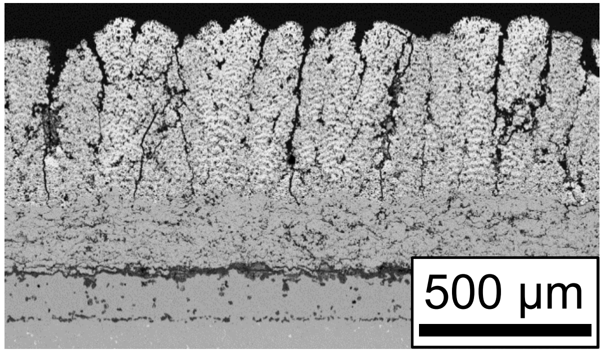
Chemical Analysis



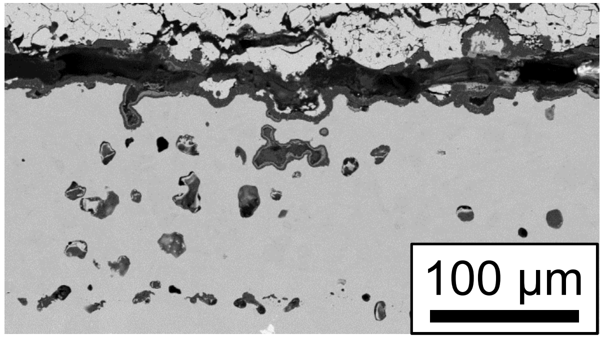
LAMT-TBCs

Arrhenius-Plot

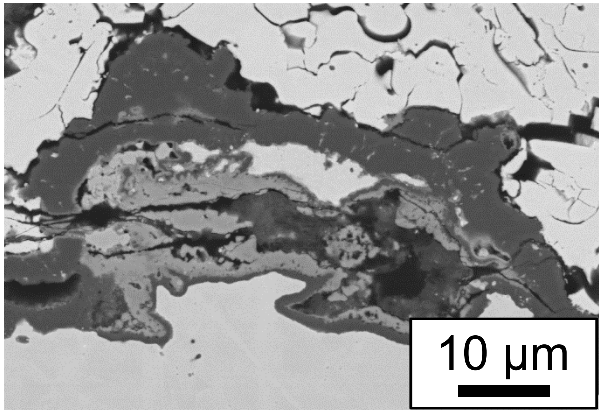




Failure at YSZ/HVS interface



Depletion of Al in BC



Formation of transient oxides

Summary

Thermal spray can manufacture different highly strain tolerant microstructures as segmented, columnar or highly porous by different techniques as APS, SPS or PS-PVD.

These technologies can also be successfully used for advanced TBC materials as perovskites (LAMT) and pyrochlores ($Gd_2Zr_2O_7$) - and also for EBC materials.

Acknowledgement:

All the supporting colleagues at IEK-1.

Thank you

for your attention!