deutsche nanoschicht

Moving towards the future of power engineering

Production of High Temperature Superconducting Tapes Enhanced by Computational Thermochemistry

GTT-Technologies Workshop, June 29th-July 1st , 2016

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outlook

- Deutsche Nanoschicht
- Superconductivity
- 2G HTS tapes
- Expanded Pilot Production Line
- Project ELSA
- summary

Deutsche Nanoschicht GmbH

- Founded November 2011 by Dr. Michael Bäcker
- Management-buy-out of former HTS wire group of insolvent Zenergy Power GmbH
- Located in Rheinbach, Germany
- Operational since January 2012
- 50 employees (chemists, physisists, enigneers, technicians, worker)
- Expertise in HTS wires, chemical solution deposition, ceramic functional layers, ink-jet-printing, epitaxial growth

Superconductors – Huge Current Carrying Capability

Breaking paradims in electro technology

Superconductors conduct electricity with no resistance – enabling 2 key properties:

- 100% Efficiency : No losses – resulting in a dramatic reduction on CO_2
- 100x Capacity : Dramatic reduction in material use

3 Energy Sectors

Sector	Application	End Products
Renewable Energy	Power Generation	Hydro, Wind
Smart Grid	Transmission & Distribution	Fault Current Limiters
Industrial Machines	Power Conversion	Induction Heater

outlook

- Deutsche Nanoschicht
- Superconductivity
  - High Temperature Superconductors (HTS)
  - Anisotropy and critical parameters
- 2G HTS tapes
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- Project ELSA
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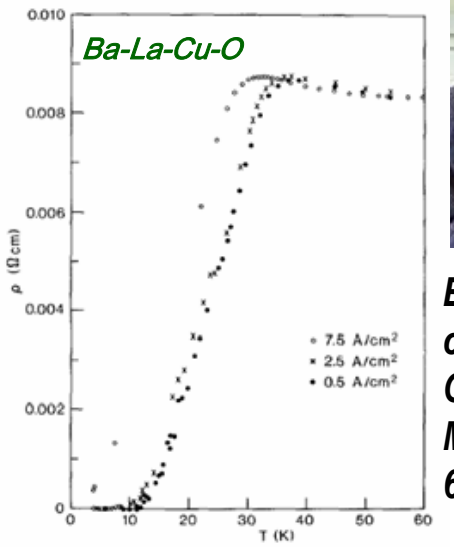
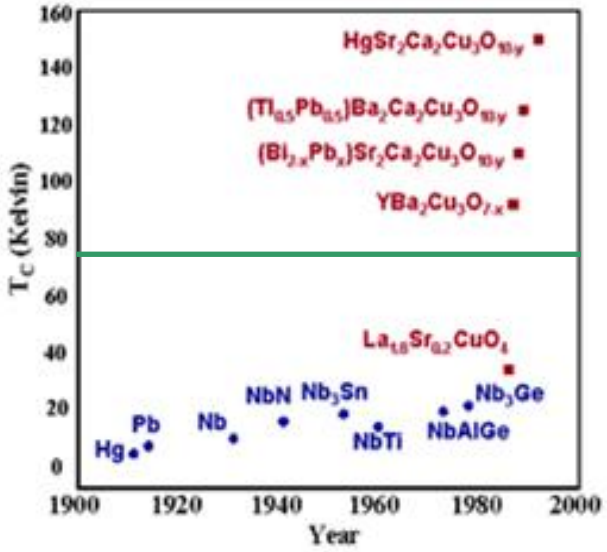
High Temperature Superconductors



Ba-La-Cu-O compound: J. G. Bednorz, K. A. Müller, Z. Physik, B 64 (1986) 189



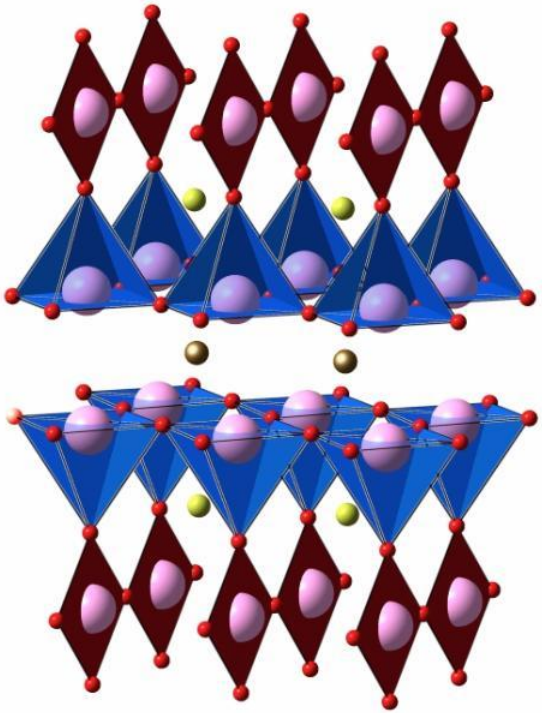
77 K

commercial potential

compound		T_C *(K)*
$YBa_2Cu_3O_{7-\delta}$	Y-123	92
$Bi_2Sr_2CaCu_2O_8$	Bi-2212	84
$Bi_2Sr_2Ca_2Cu_3O_{10}$	Bi-2223	110
$TlBa_2Ca_2Cu_3O_{10}$	Tl-1223	125
$HgBa_2Ca_2Cu_3O_{10}$	Hg-1223	133

High Temperature Superconductors

- Challenges in materials

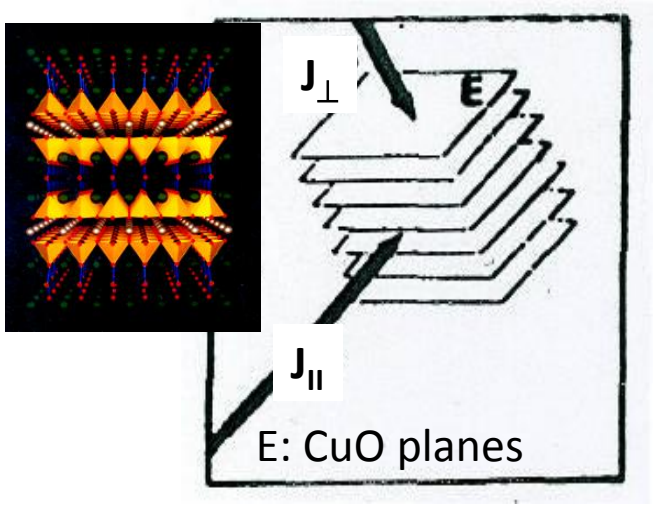


Layered microstructure similar to "graphite or mica"

- Complex ceramic oxides: $YBa_2Cu_3O_x$
- Complex layered cristalline structure
- Strong anisotropic behaviour

Superconducting current:
parallel CuO-planes >> perpendicular CuO-planes

Anisotropy in HTS materials



J_{II}: current parallel to CuO plane
$J_\perp$: current perpendicular to CuO plane

$J_{II} >> J_\perp$

$\Rightarrow$ all CuO planes have to be parallel orientated

Polycrystalline, non orientated

Second Generation (2G) HTS

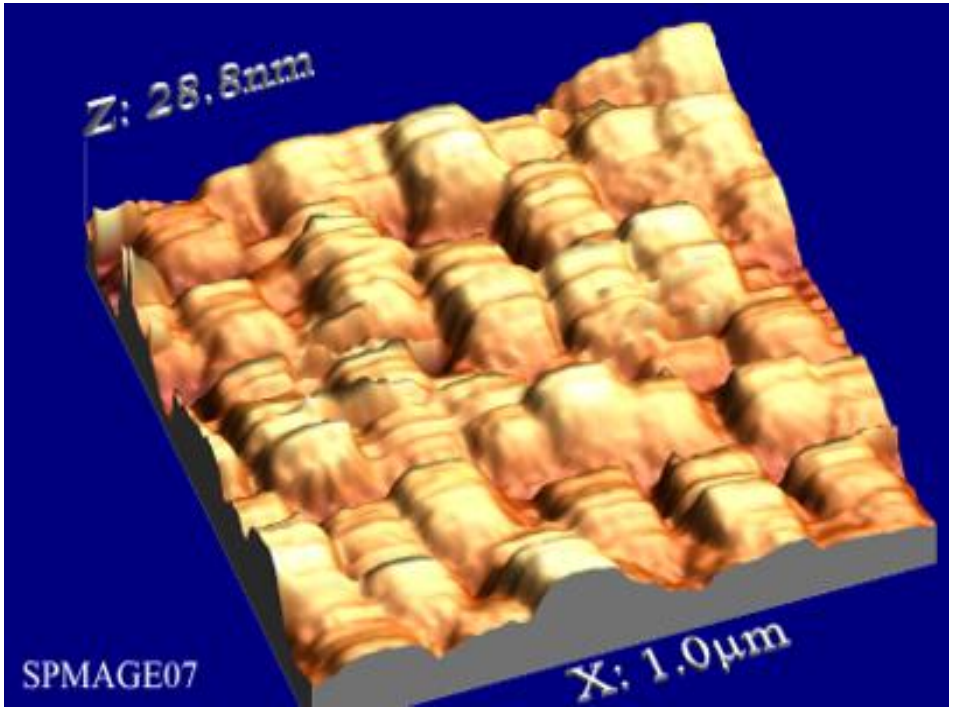
- HTS Architecture – textured epitactic crystal growth

Statistically oriented crystals

template

Zweite Generation (2G) HTS Leiter

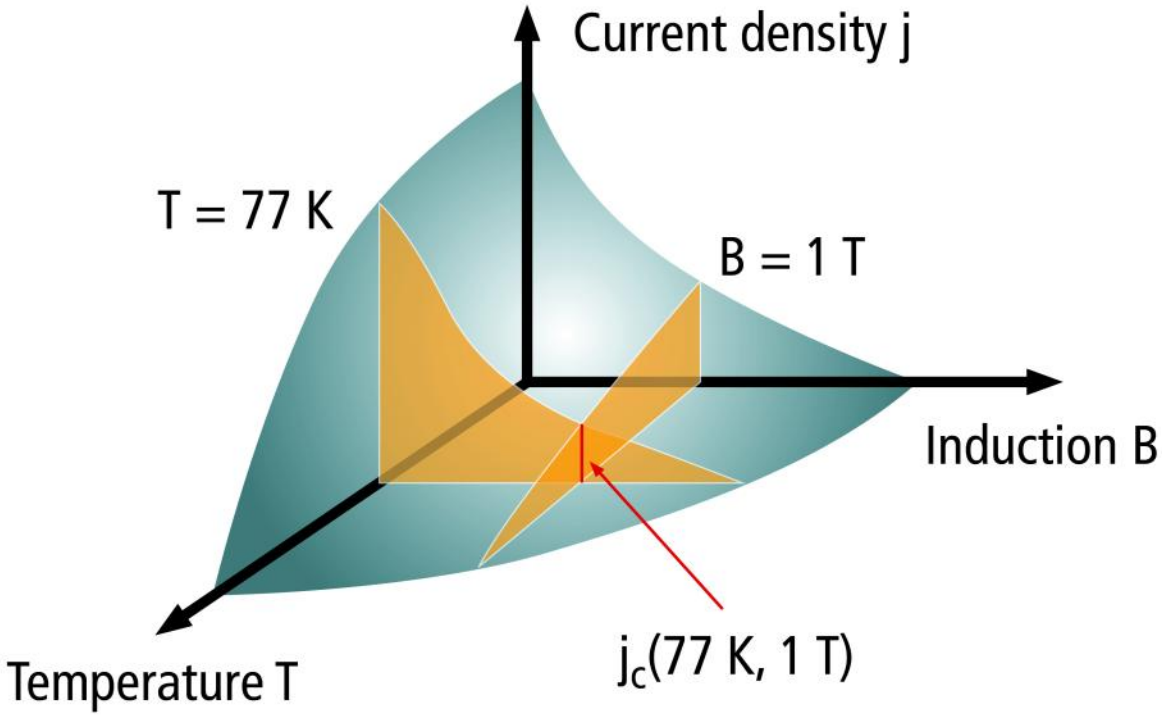
- HTS Architecture – textured epitactic crystal growth



AFM–analysrs of a Ceriumoxide buffer layer

High Temperature Superconductors

- Critical parameters



outlook

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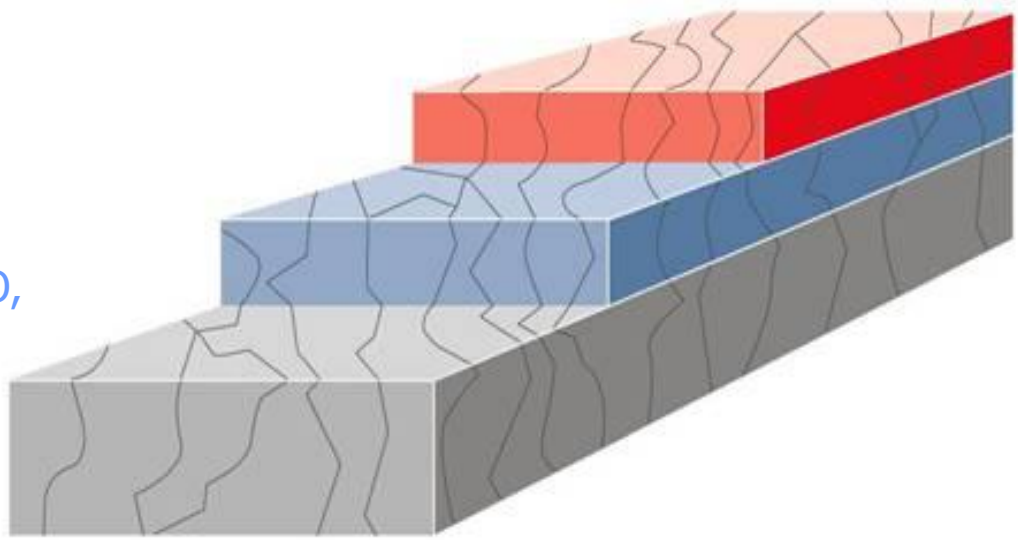
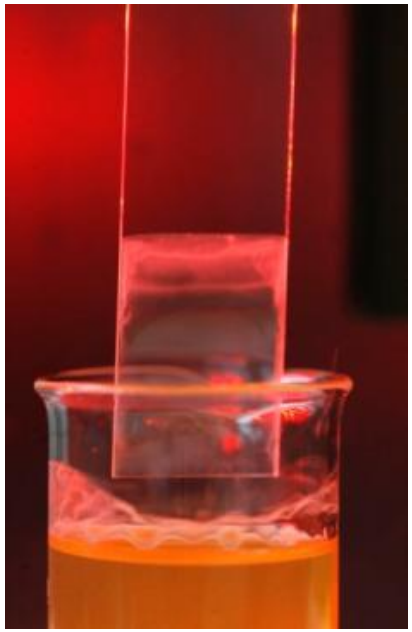
Layer architecture of (2G) HTS tape

- Protective metal layer:
  silver, gold, copper
- Superconductor layer:
  $YBa_2Cu_3O_x$,$REBa_2Cu_3O_x$
- Buffer layer:
  MgO, ZrO, GZO, YSZ, Y_2O_3, CeO_2, LZO, STO
- Metal alloy substrate:
  Hastelloy, NiCroFer, Ni-alloy

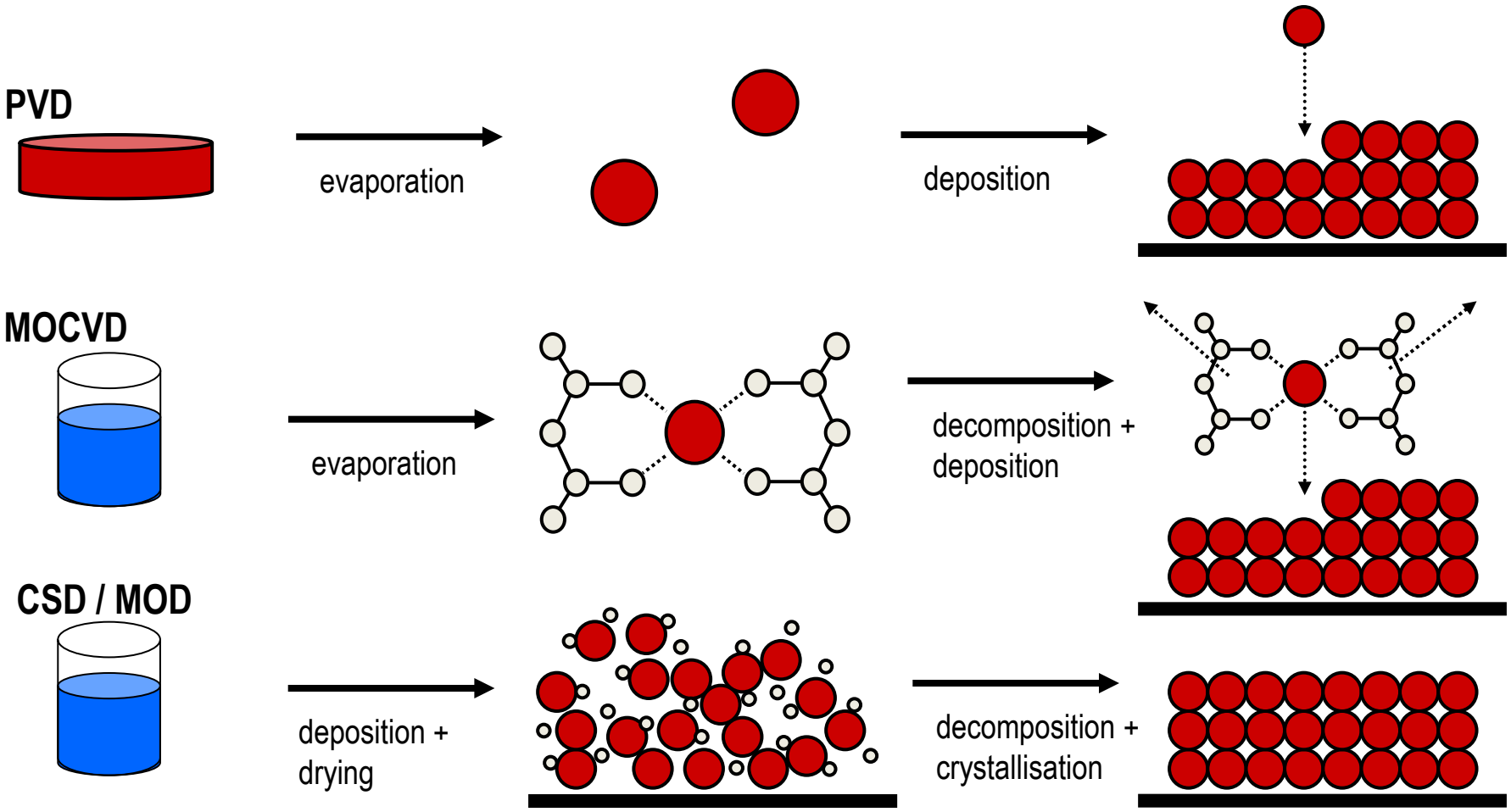


Deposition Processes

- Chemical solution deposition (CSD)
- Chemical vapour deposition (CVD)
- Physical vapour deposition (PVD)

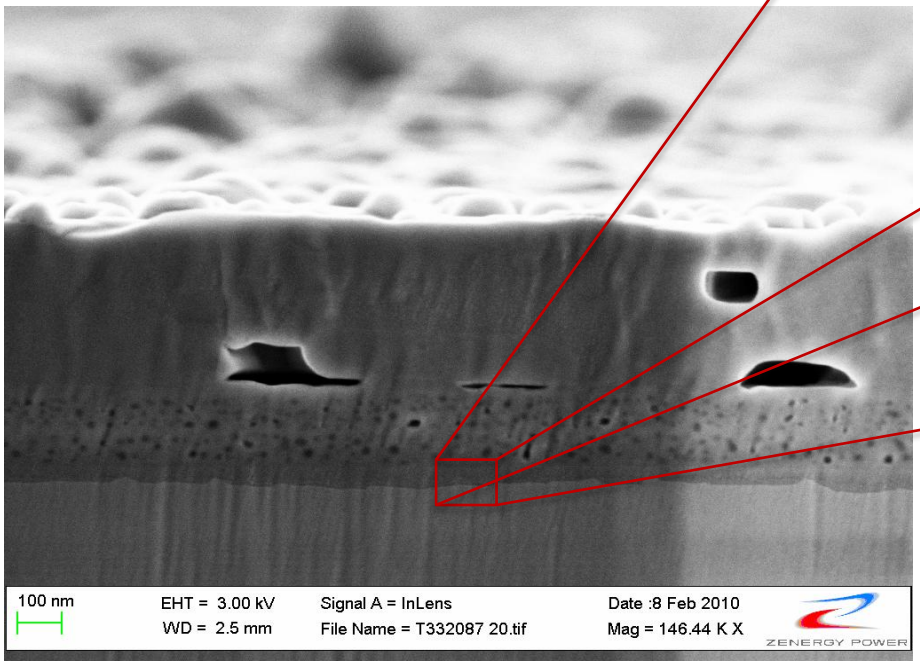


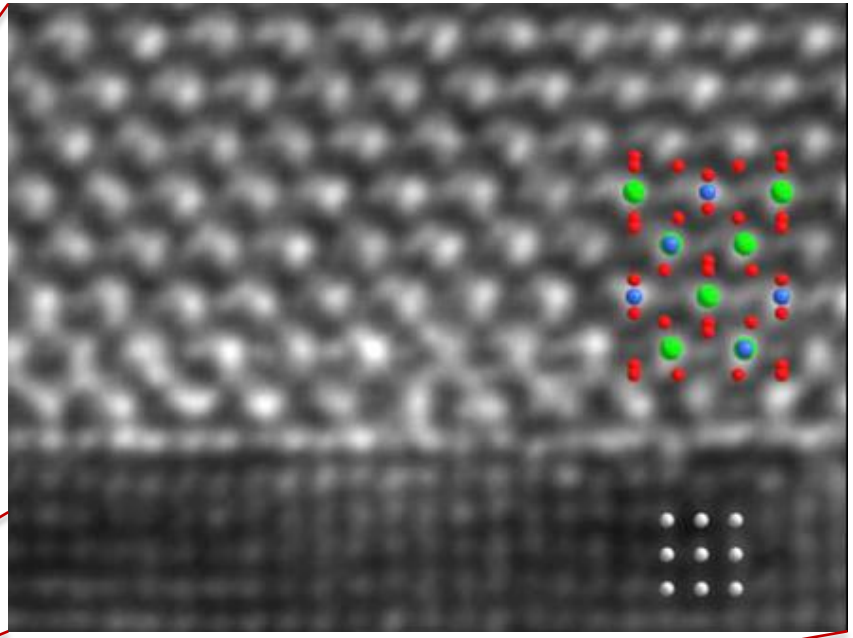
Layer architecture of (2G) HTS tape



Process Technology

- Ceramic multi-layer architecture on metallic substrate





Epitaxial (orientated) growth of ceramic functional layers on textured metallic substrate

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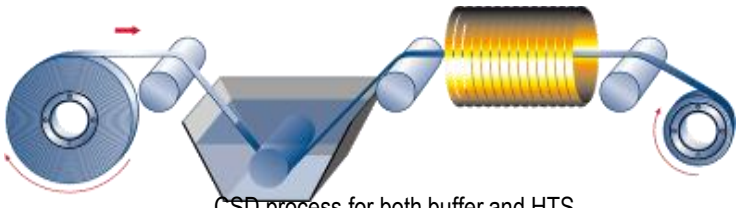
"all-solution" Coated Conductor

- Chemical solution deposition is considered to be the "most promising and most challenging process"

  - **Advantages:**
    - highest throughput (deposition rates)
    - lowest investment
    - lowest energy consumption
    - low raw material costs

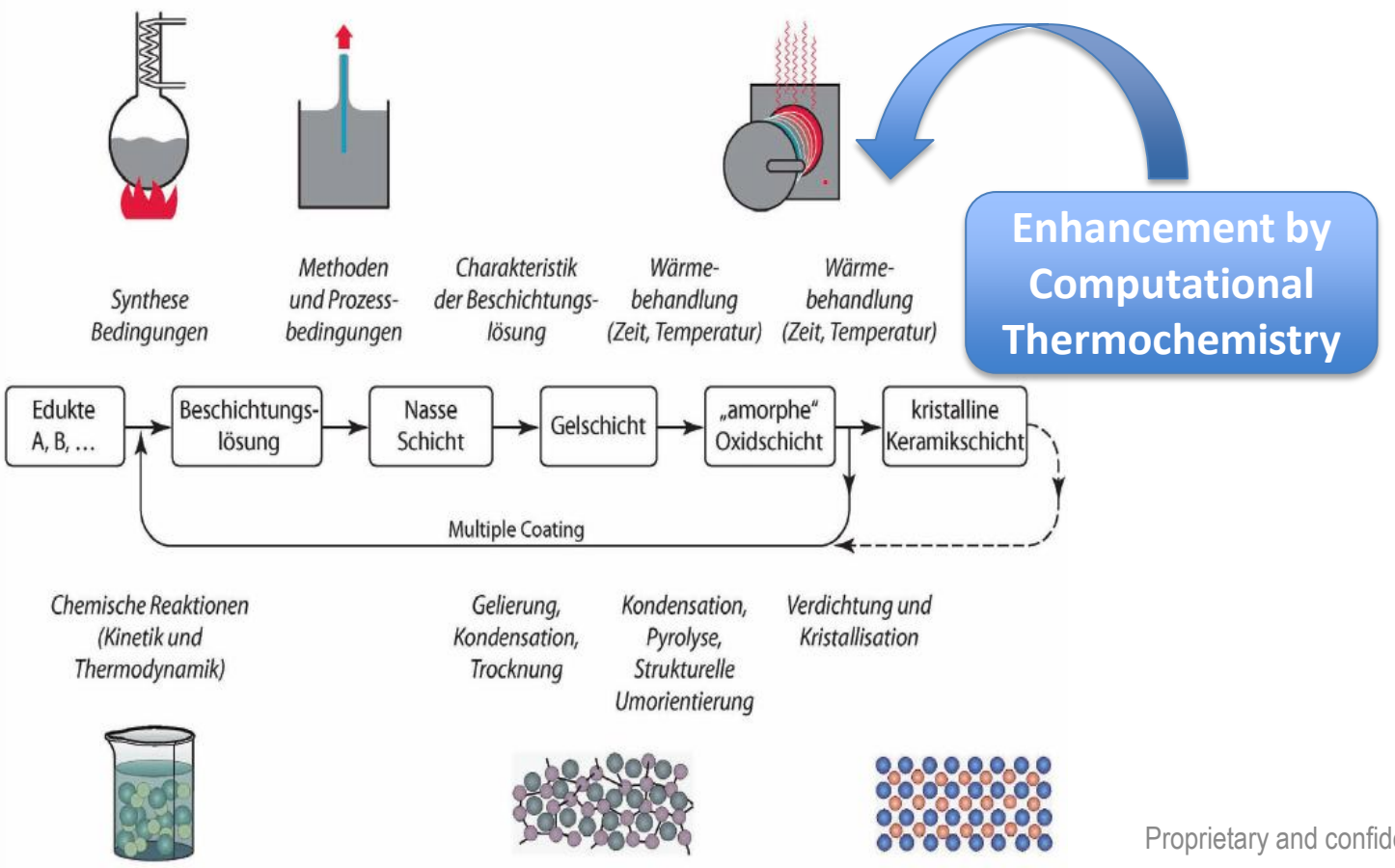
– Main disadvantage:

CSD processes only yield polycrystalline / untextured films

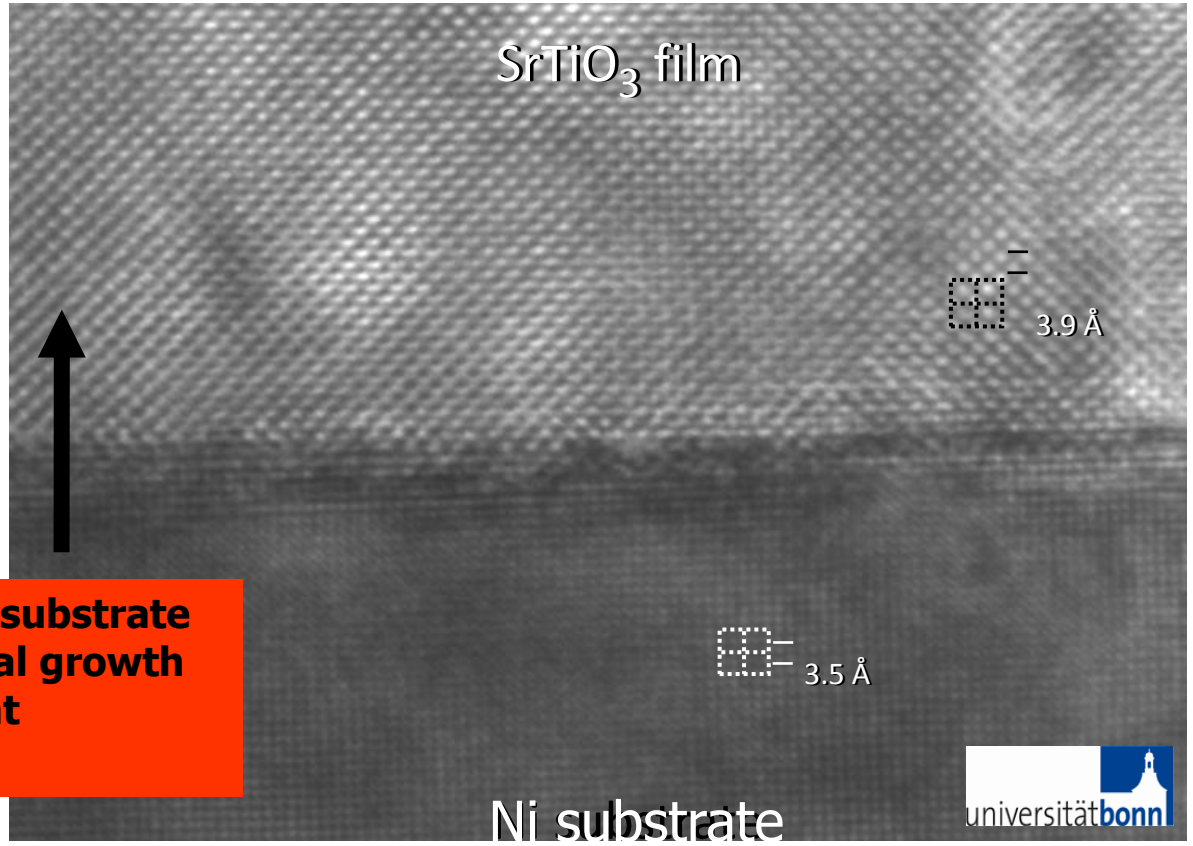


CSD process for both buffer and HTS layer

"all-solution" Coated Conductor



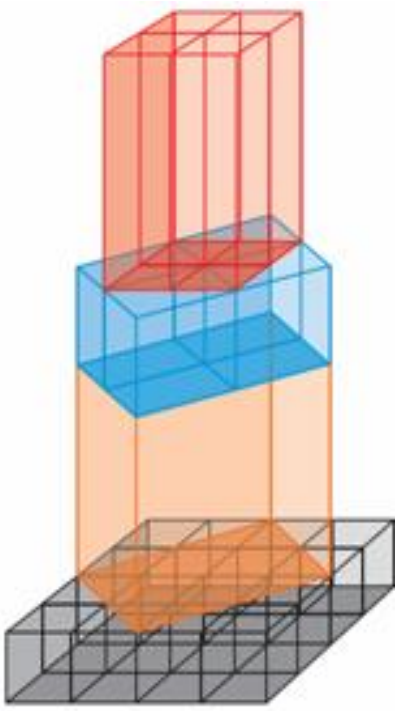
"all-solution" Coated Conductor



Biaxially aligned substrate forces an epitaxial growth of the subsequent deposited layers

"all-solution" Coated Conductor

- Standard architecture for all-solution Coated Conductor at Deutsche Nanoschicht



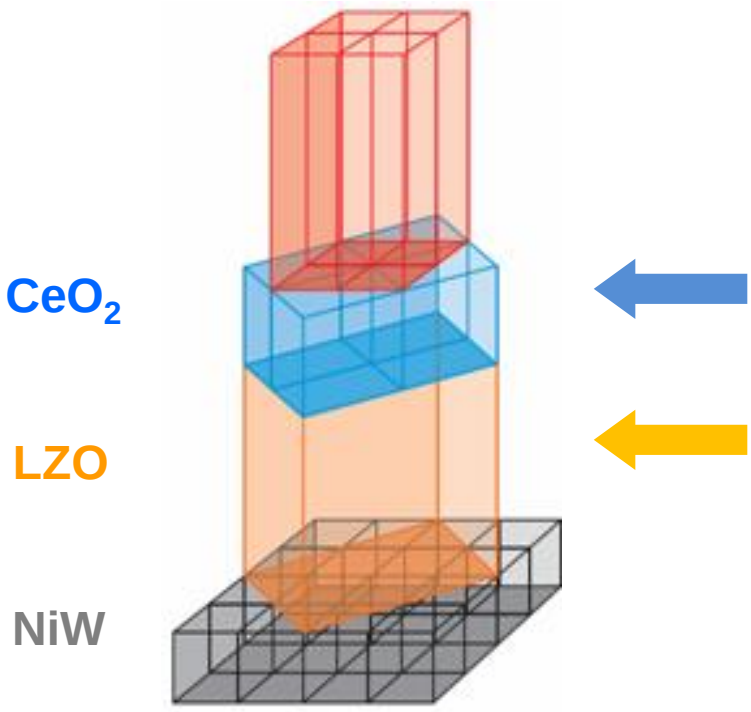
NiW

CSD processes normally result in untextured growth

⇒ biaxially textured substrate required

"all-solution" Coated Conductor

- Standard architecture for all-solution Coated Conductor at Deutsche Nanoschicht

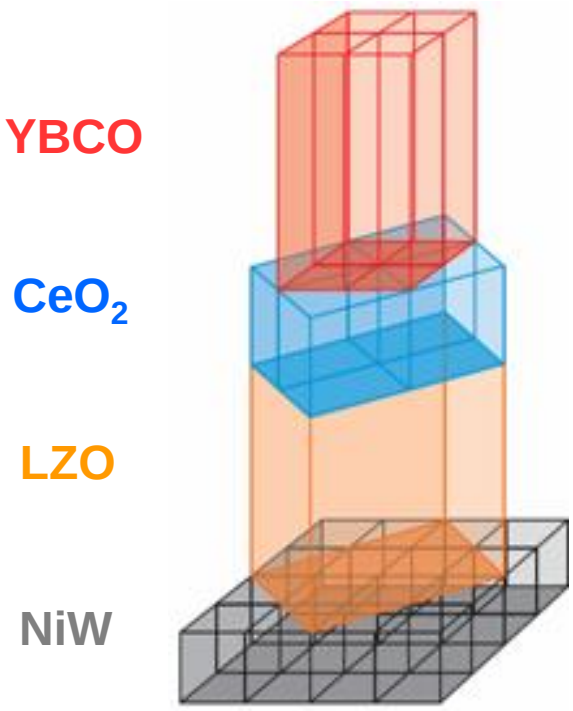


Buffer layers for
- texture transfer
- Nickel & Oxygen diffusion barrier

Special requirements for CSD processes:
- chemically inert
- low lattice mismatch

"all-solution" Coated Conductor

- Standard architecture for all-solution Coated Conductor at Deutsche Nanoschicht



HTS layer:

- TFA YBCO route
- single or multi-layer deposition

Basic processes

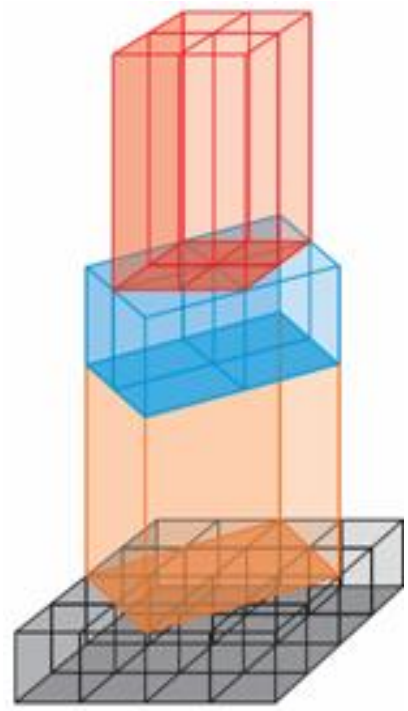
- Standard architecture for all-solution Coated Conductor

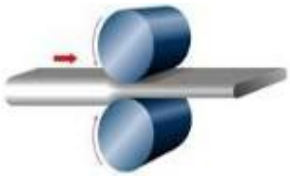
YBCO

CeO_2

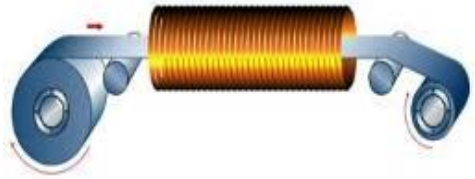
LZO

NiW





cold deformation



annealing

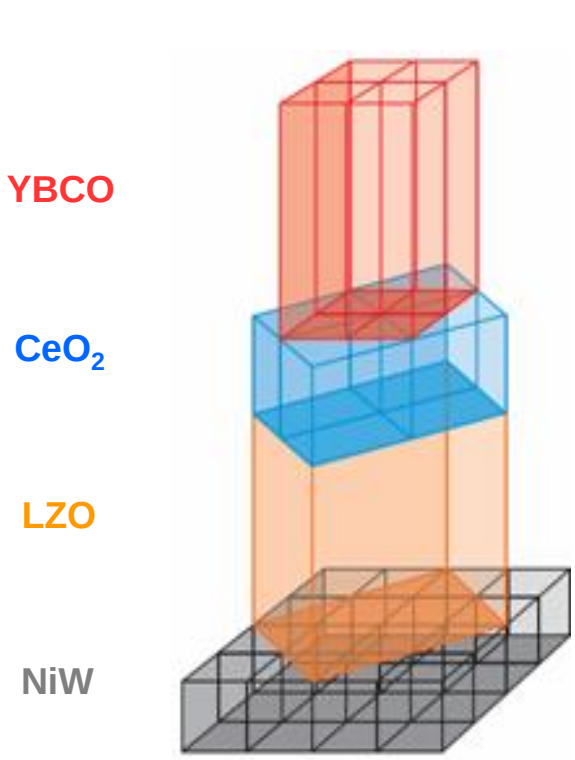
slitting

Metallic substrate

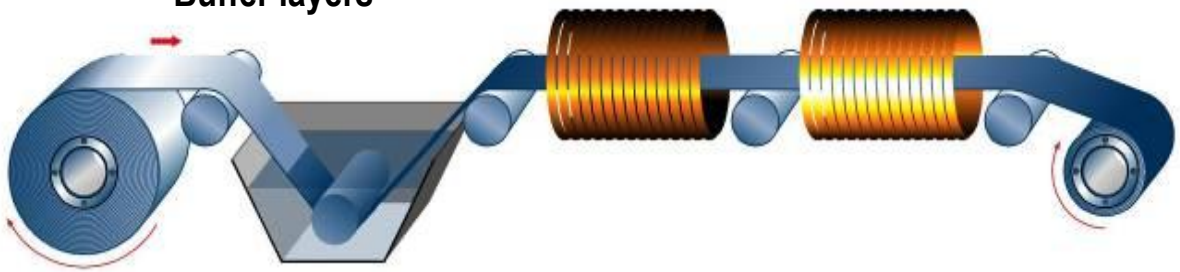
- Ni-5at%W, 0.06x10mm²
- cold deformation > 95% and subsequent annealing
- yield highly textured metal tape with average tilt angle of crystals < 5°

Basic processes

- Standard architecture for all-solution Coated Conductor



Buffer layers



Coating solution
La-, Zr-, Ce-acetylacetonates
in propionic acid

Drying
200°C, air

Crystallization
1000°C, N_2/H_2

Basic processes

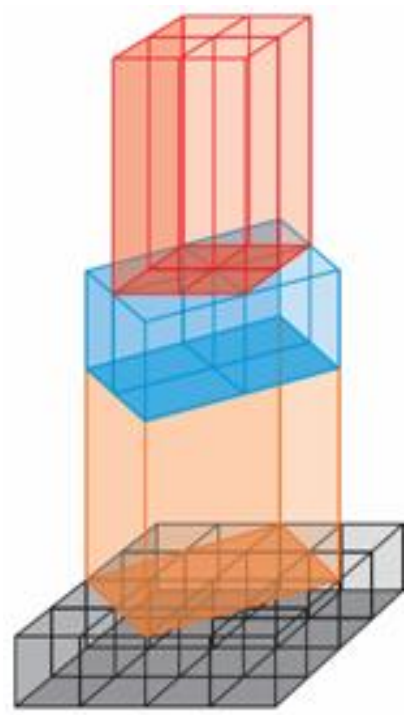
- Standard architecture for all-solution Coated Conductor

YBCO

CeO_2

LZO

NiW



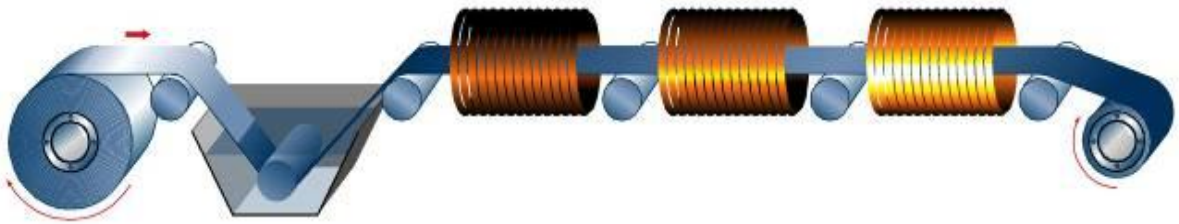
Superconducting layer

Coating solution
Y-, Ba-, Cu-trifluoroacetates
in Methanol/Triethanolamine

Drying

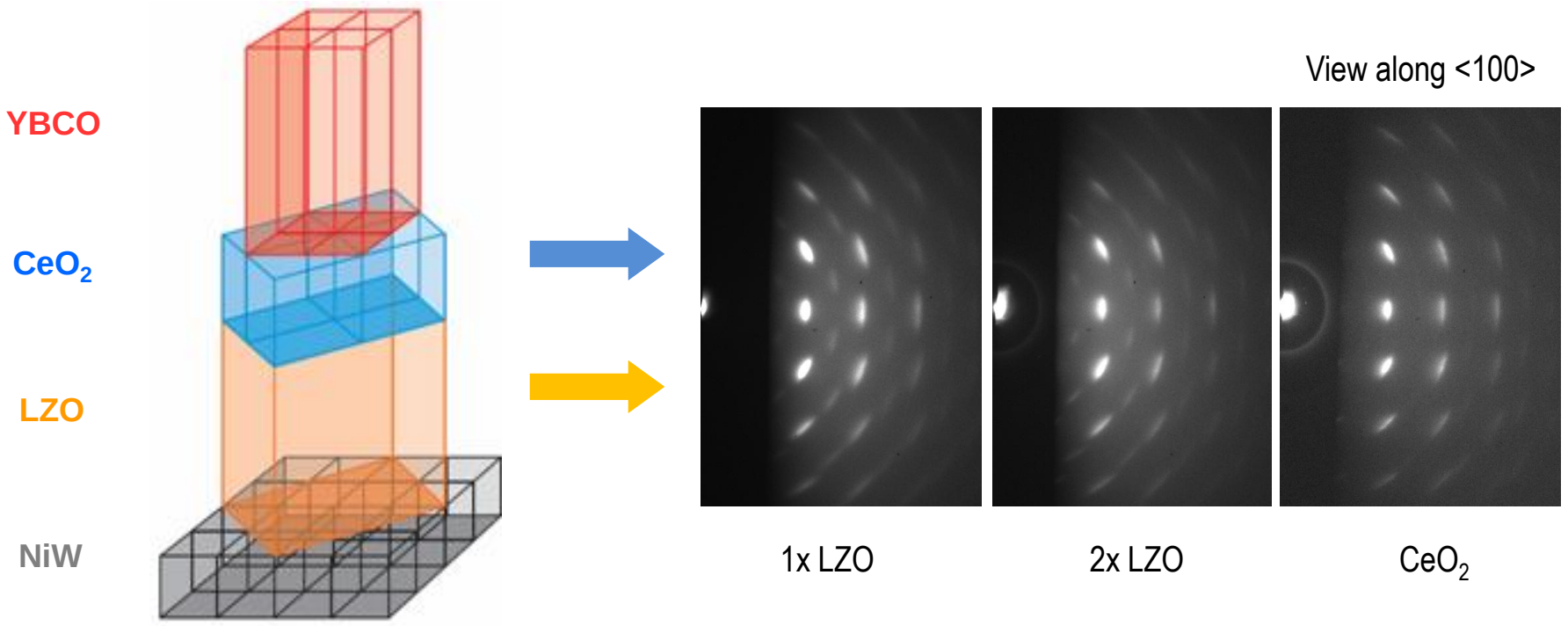
Crystallization

Oxygenation



Texture analysis: RHEED

- Standard architecture for all-solution Coated Conductor

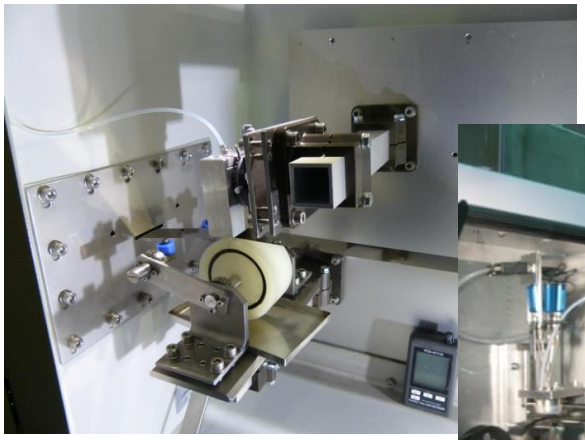


Length & Performance

Continuous processing: reel-to-reel devices

- >15 continuous processes / reel-to-reel devices
- RTR concept proven for all processes

All devices in-house designed and assembled



Slot die of coating solutions

Ink-jet printing of coating solutions

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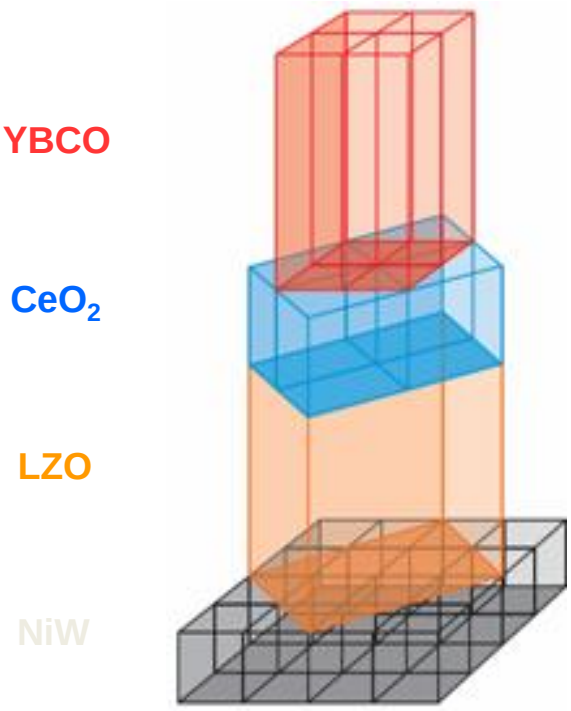
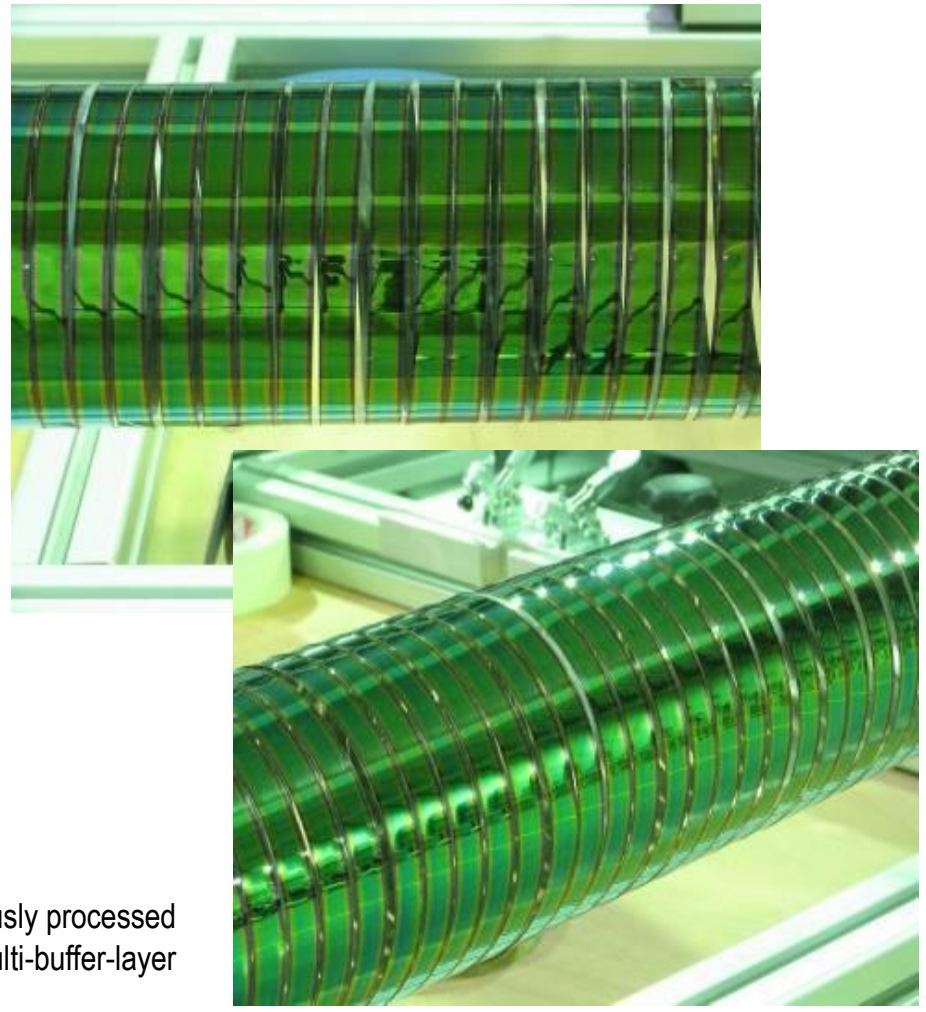
Length & Performance

- Processing of all-solution Coated Conductor





Continuously processed
multi-buffer-layer

Expanded pilot line

- EPL construction until end 2015
- Planned capacity > 200km technical HTS wire
- Start sampling for projects mid 2016

Lab processing

Expanded Pilot Line

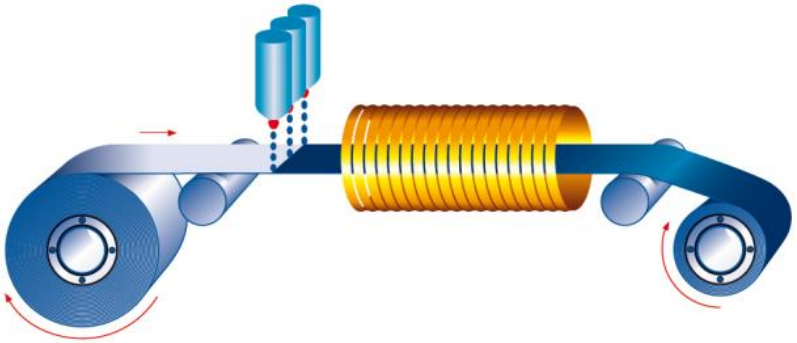
Process Technology

- Chemical solution deposition

Advantages:

- highest throughput (deposition rates)
- lowest investment
- lowest energy consumption
- low raw material costs

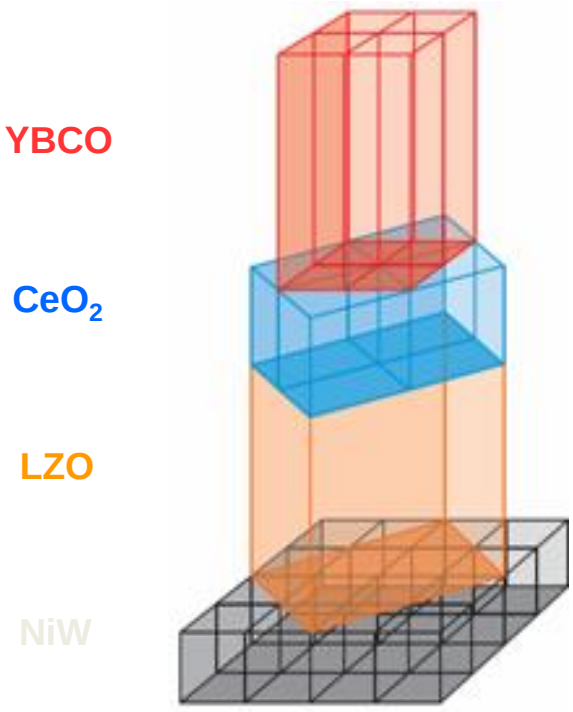
⇒ favourable for energy applications

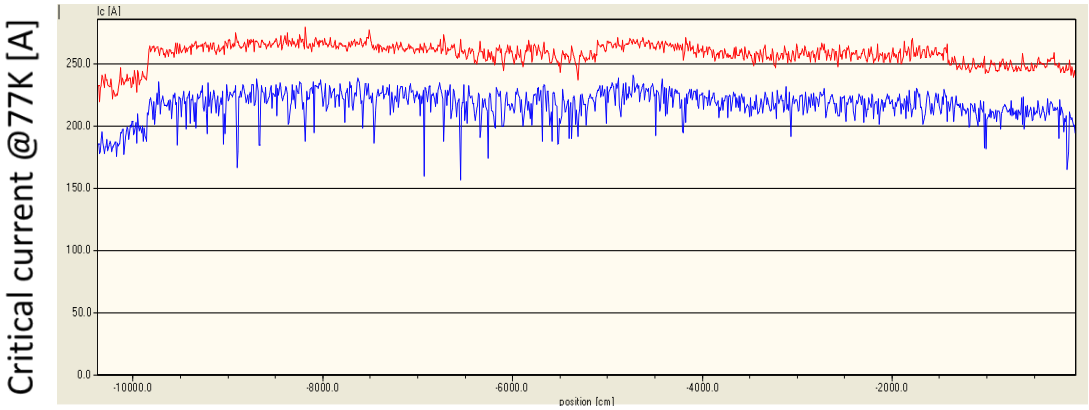


Continuous coating and annealing

Length & Performance

- Superconducting properties of all-solution Coated Conductor



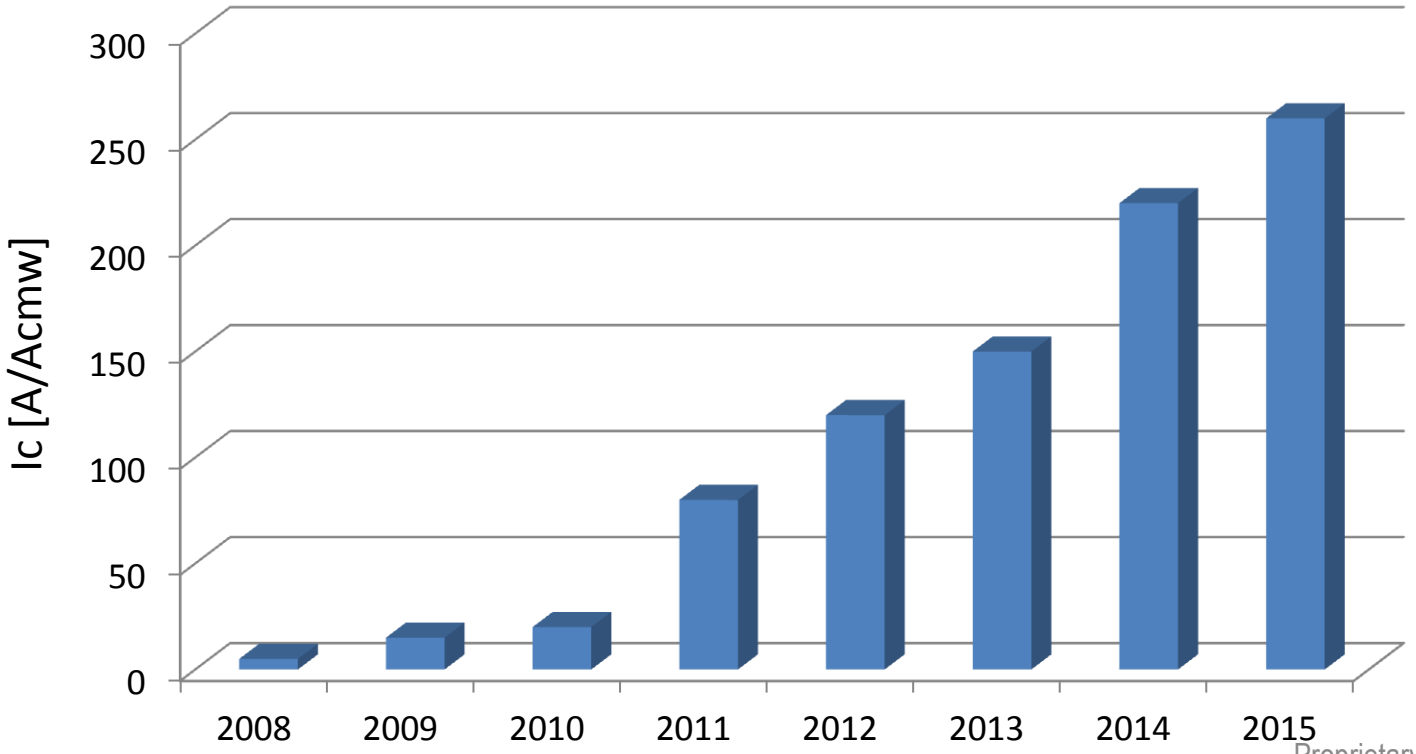


100 m tape length, 10 mm wide
Current density 1.7 MA/cm^2

Performance

VDM Metals
Honeywell
Heraeus

- Development with industrial partners over nearly 10 years
  - Sample lengths increased from 5m (2018) towards >50m (2015)



deutsche nanoschicht

Project ELSA (2006-2010)

- ELSA - "Entwicklung von SupraLeitern mit SchichtArchitektur"
  - "Development of Superconductors with Layer-Achitecture"
- Consortium

Federal Ministry of Economics and Technology

Projektträger Jülich
Forschungszentrum Jülich

This work was funded by the German Ministry of Economy (BMWi) under project number 0327433

GTT - TECHNOLOGIES

Eberhard Karls Universität Tübingen

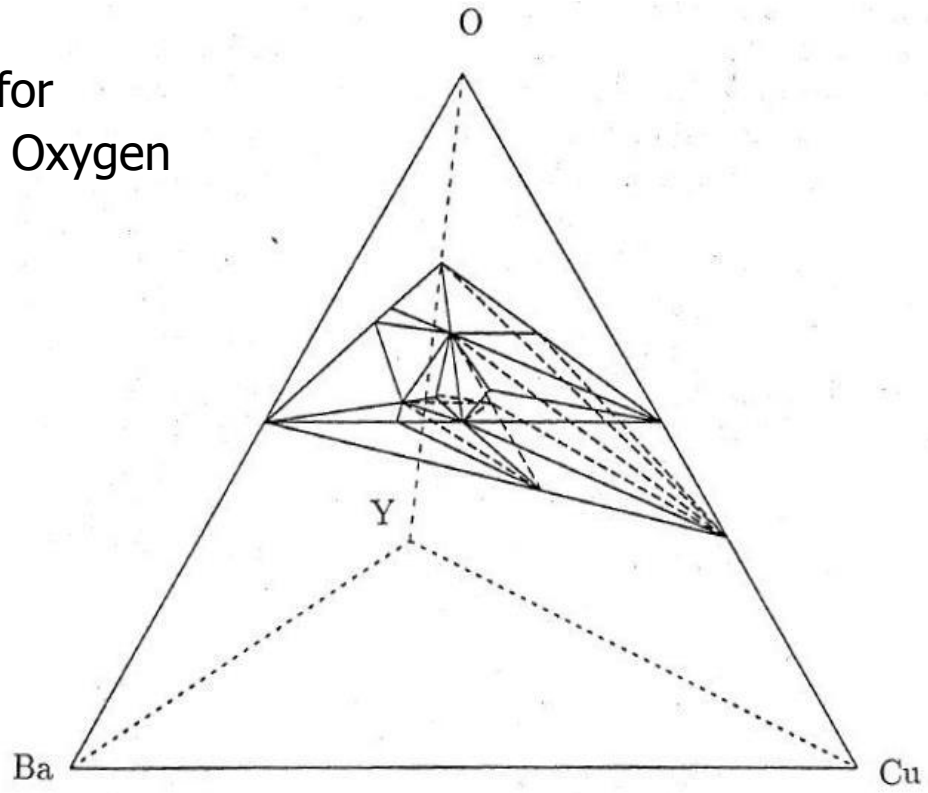
Rheinisch-Westfälische Technische Hochschule RWTH AACHEN

ZENERGY POWER

JÜLICH FORSCHUNGSZENTRUM

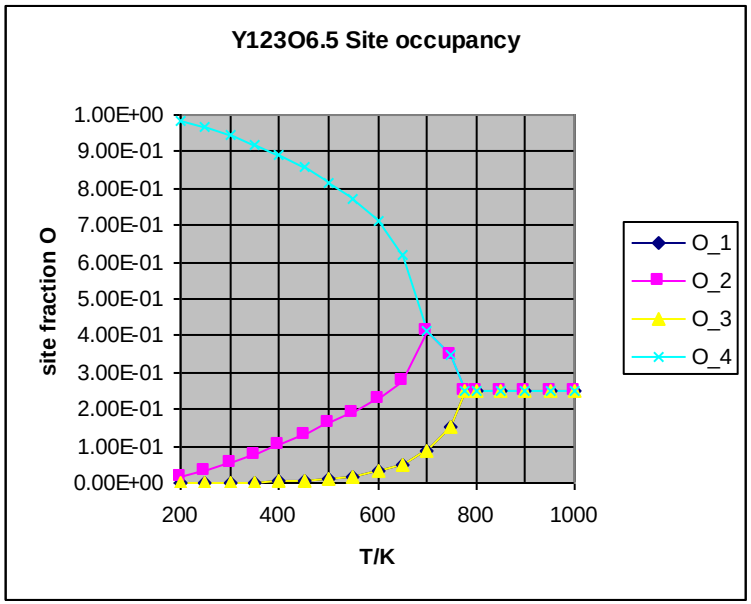
Project ELSA

- Highlights
  - Quaternary phase diagram for Yttrium - Barium - Copper - Oxygen



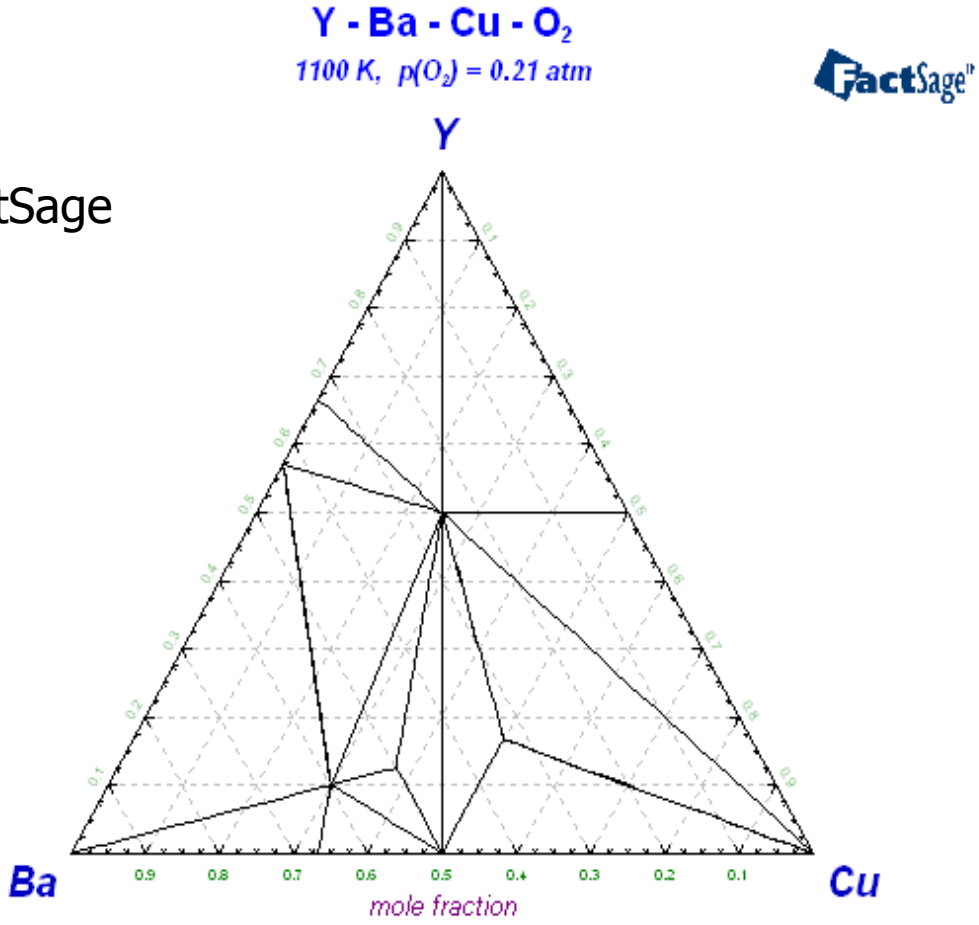
Project ELSA

- Highlights
  - Oxygen on sub-lattices in $YBa_2Cu_3O_{(6+x)}$
    - Tetragonal
    - Orthorhombic'
    - Orthorhombic''



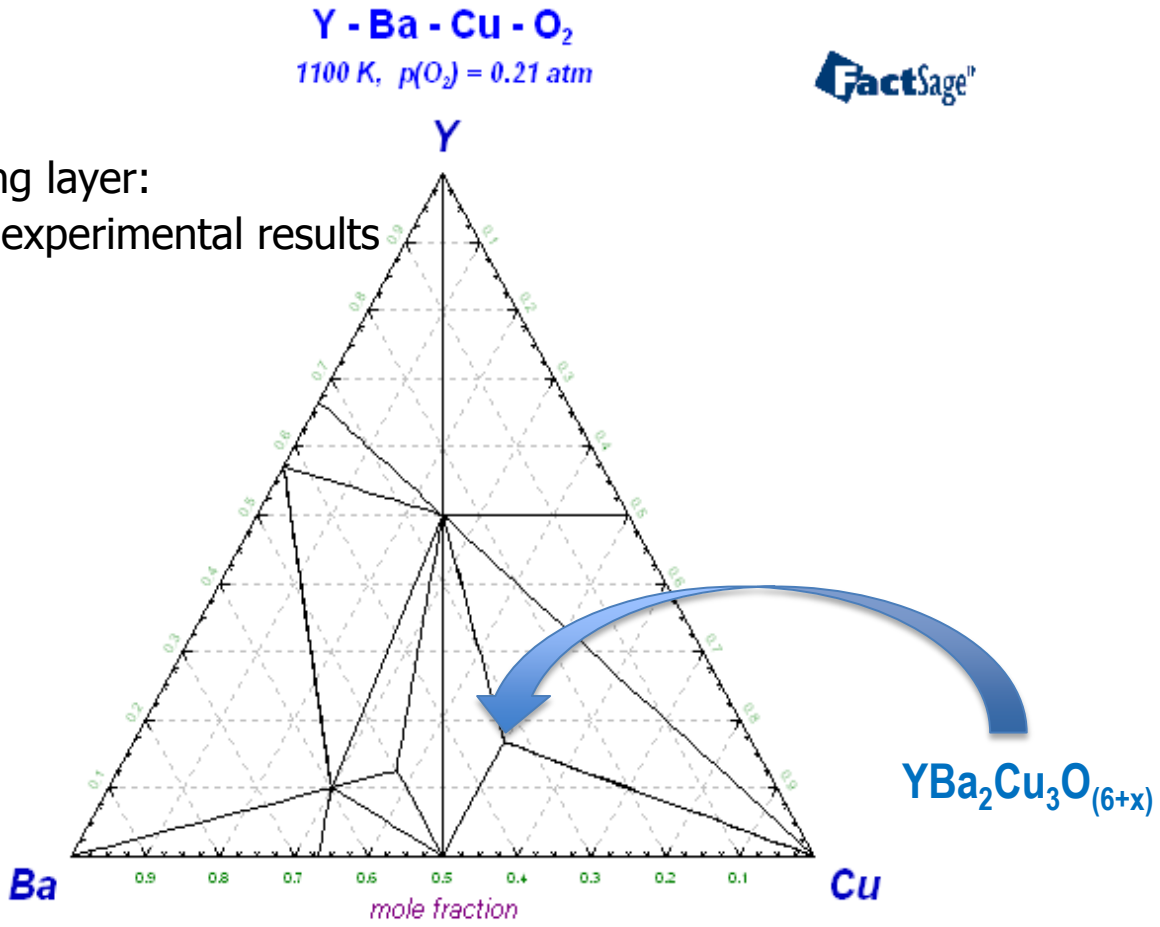
Project ELSA

- Highlights
  - Full calculation in FactSage



Project ELSA

- Highlights
  - Superconducting layer:
    Explanation of experimental results



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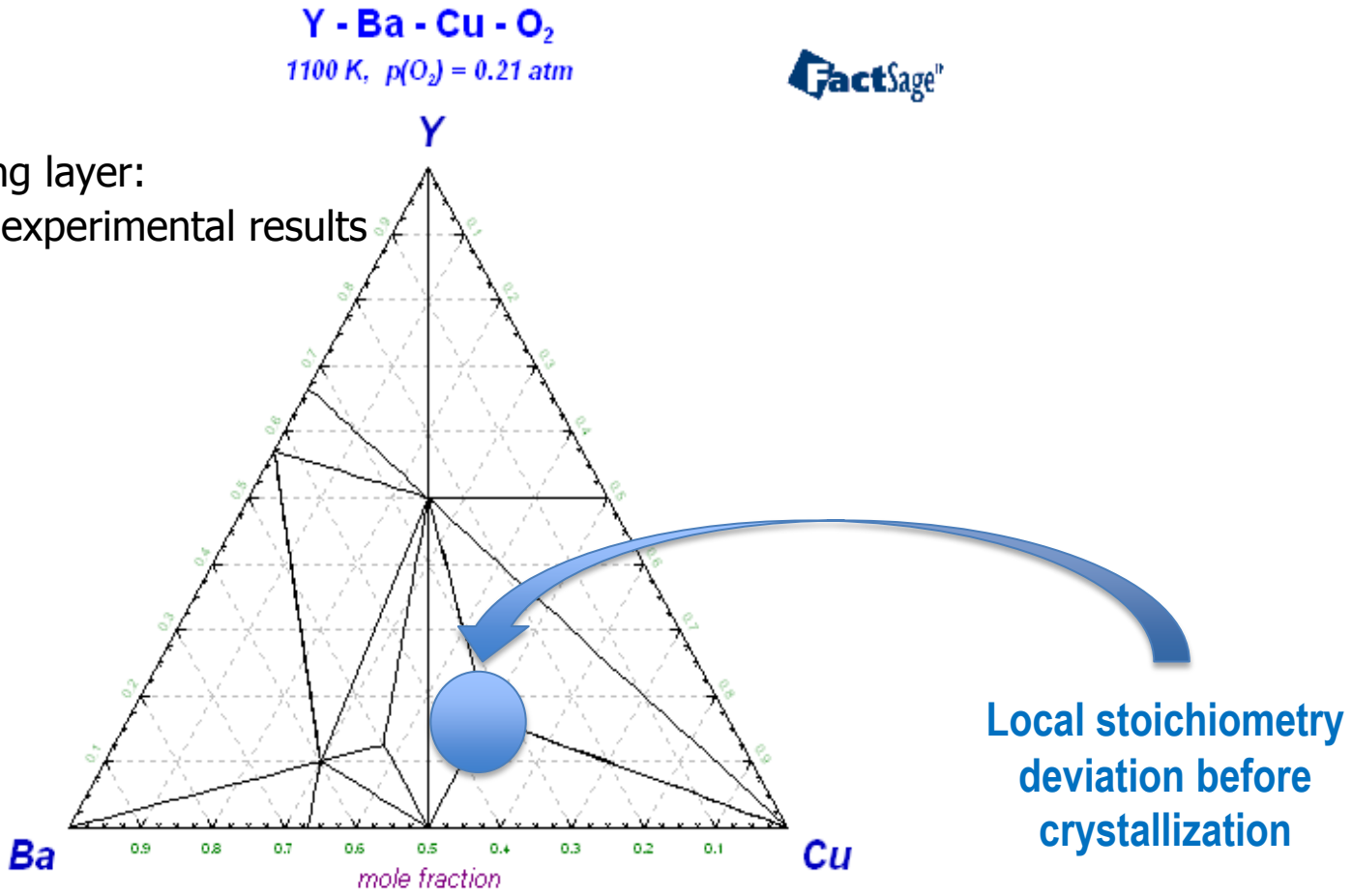

Project ELSA

- Highlights
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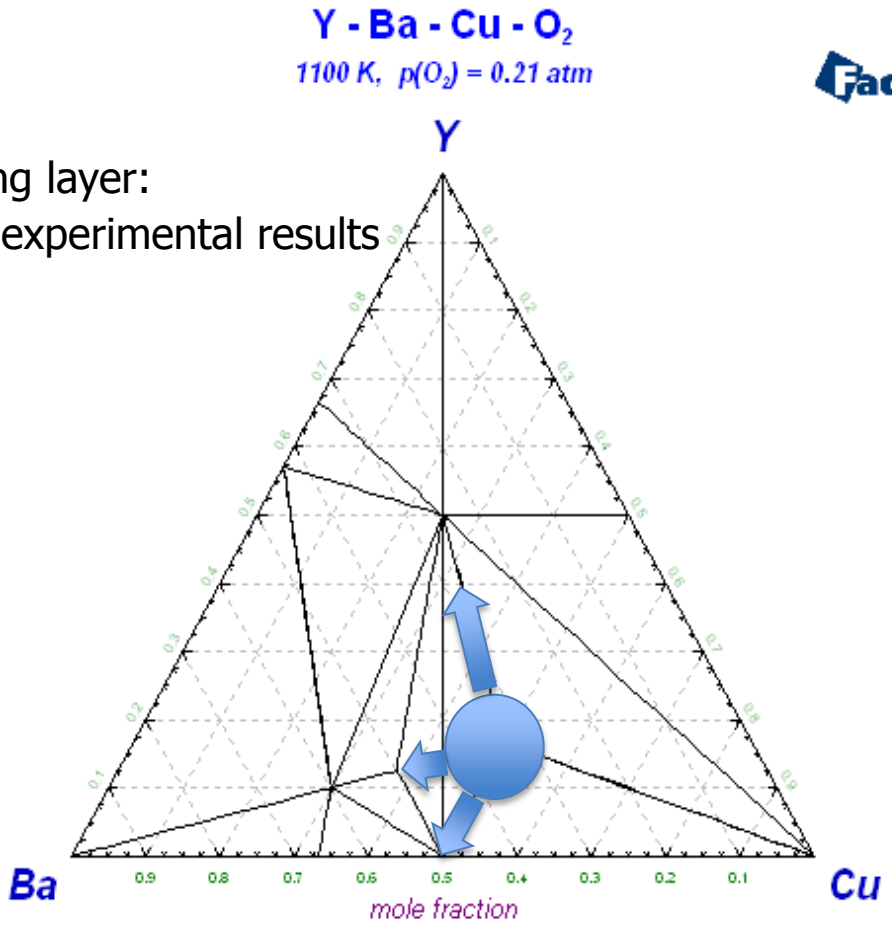
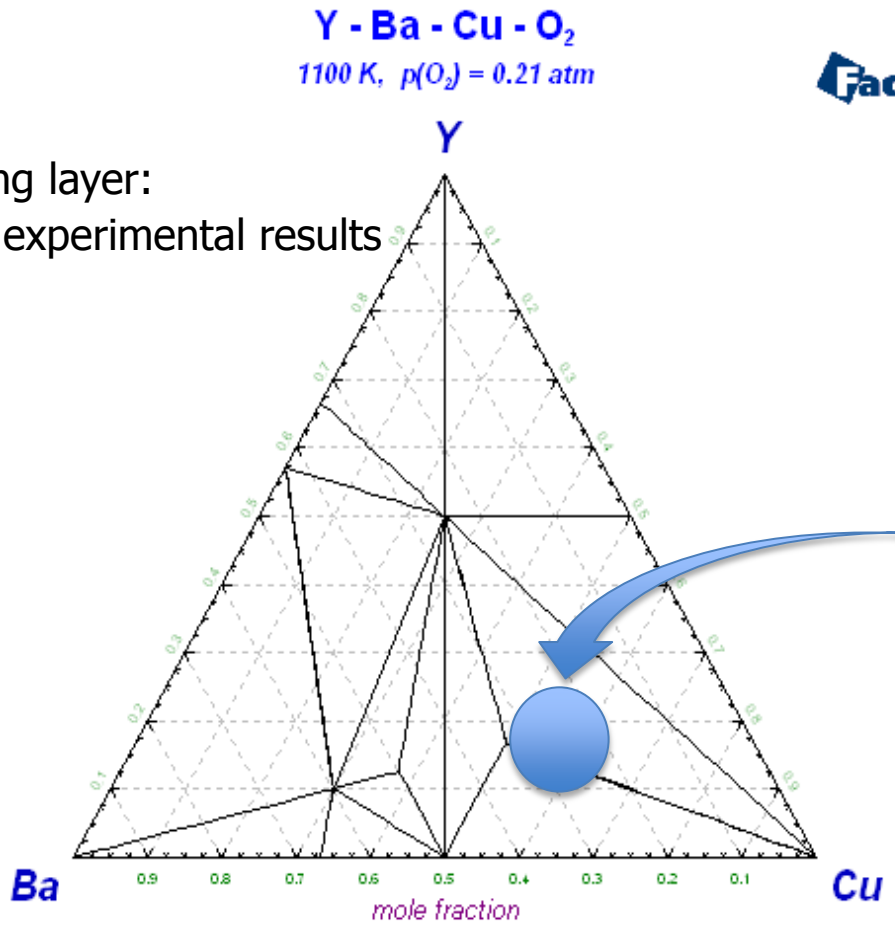


Strong tendency to secondary phases

Project ELSA

- Highlights
  - Superconducting layer:
    Explanation of experimental results



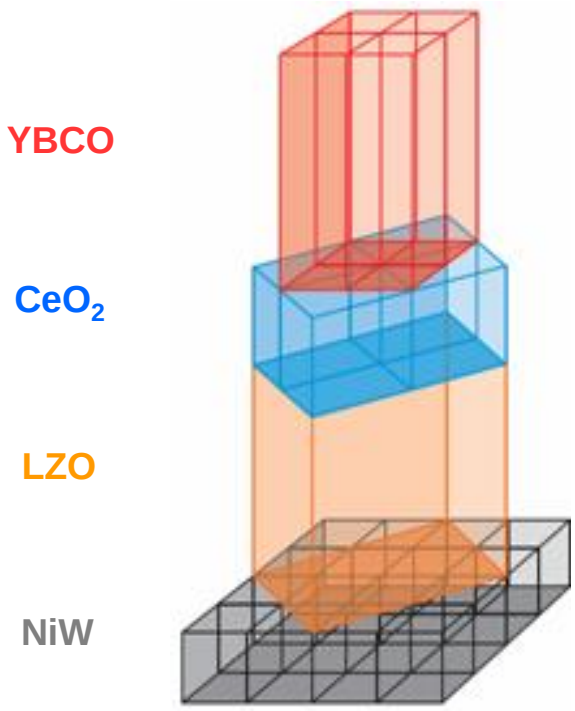
$YBa_2Cu_3O_{(6+x)}$

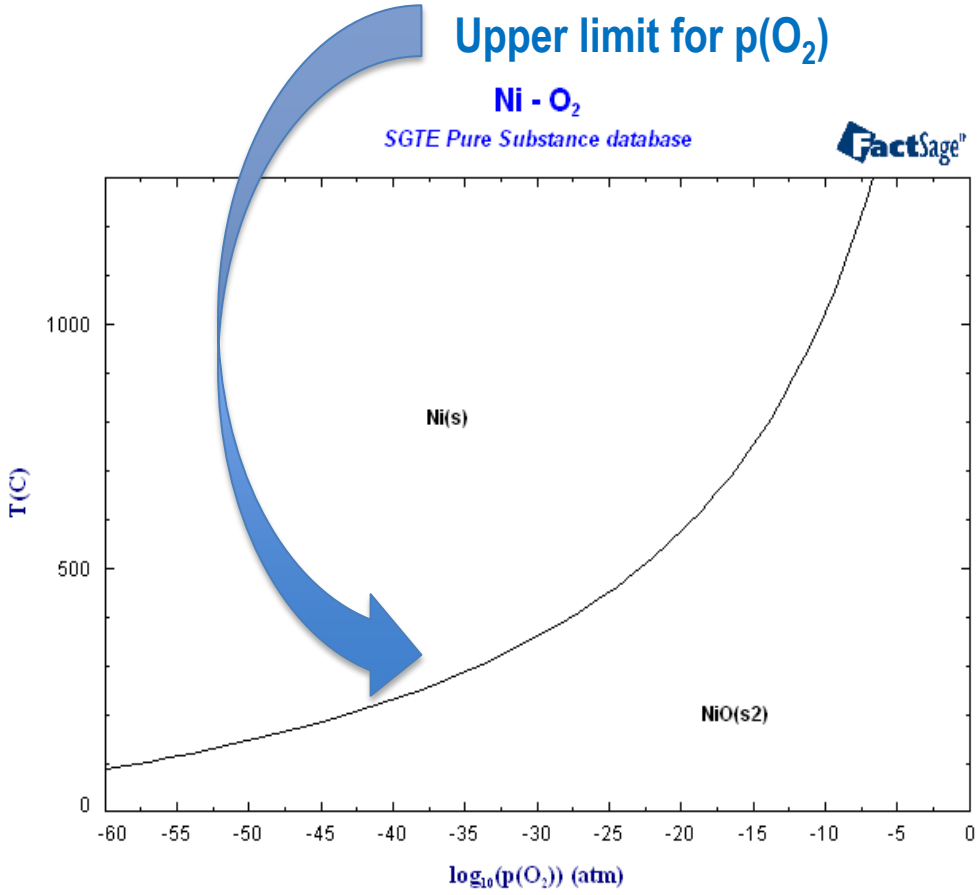
Higher phase purity by $YBa_{1.5}Cu_3O_{(6+x)}$ starting composition

Development of MOD-based Processing for Low Cost Coated Conductors; T. Izumi; CCA 2009; International Workshop on Coated Conductors for Applications; 2009 Barcelona

Project ELSA

- Highlights
  - layer interaction





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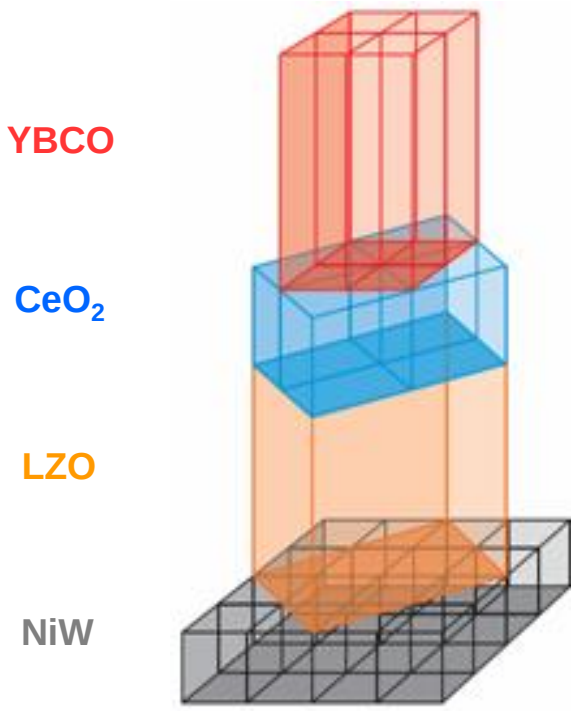
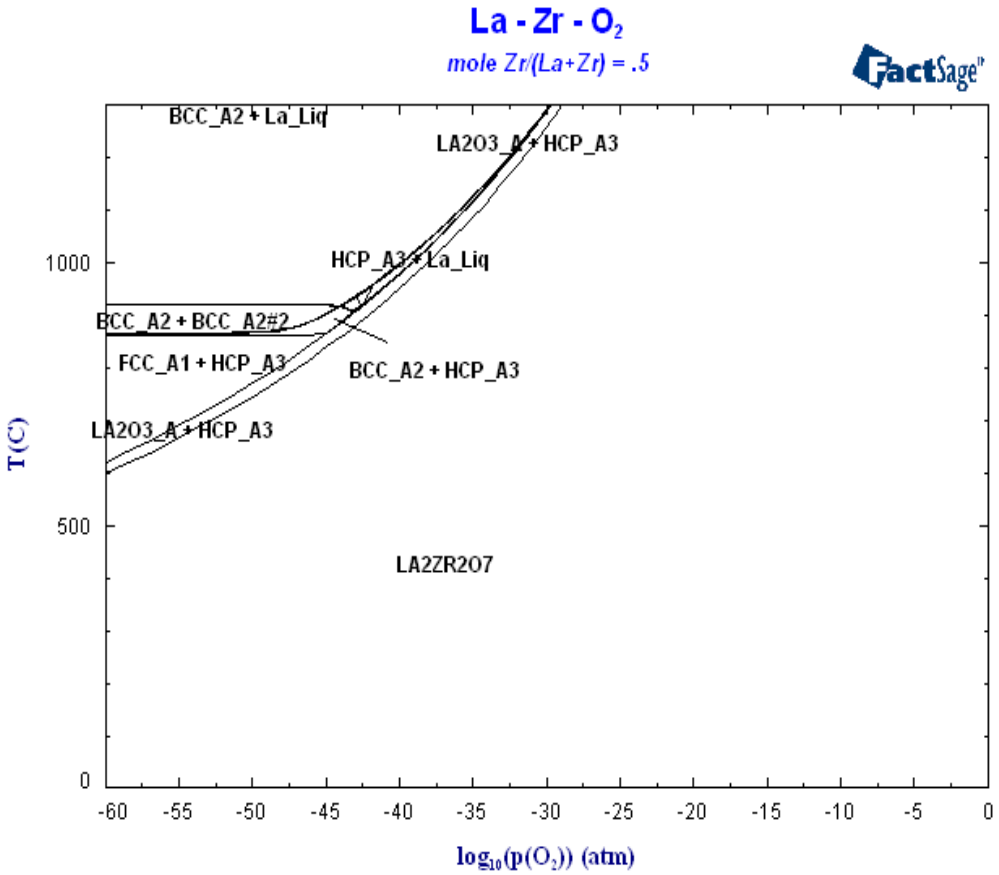
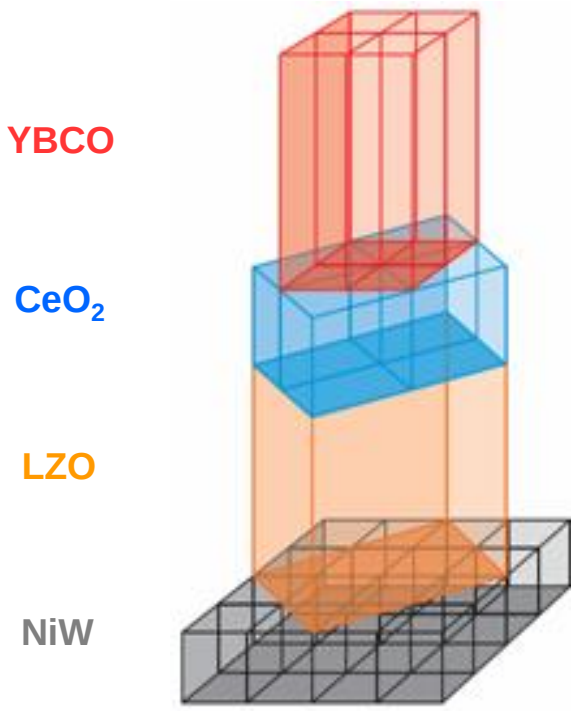
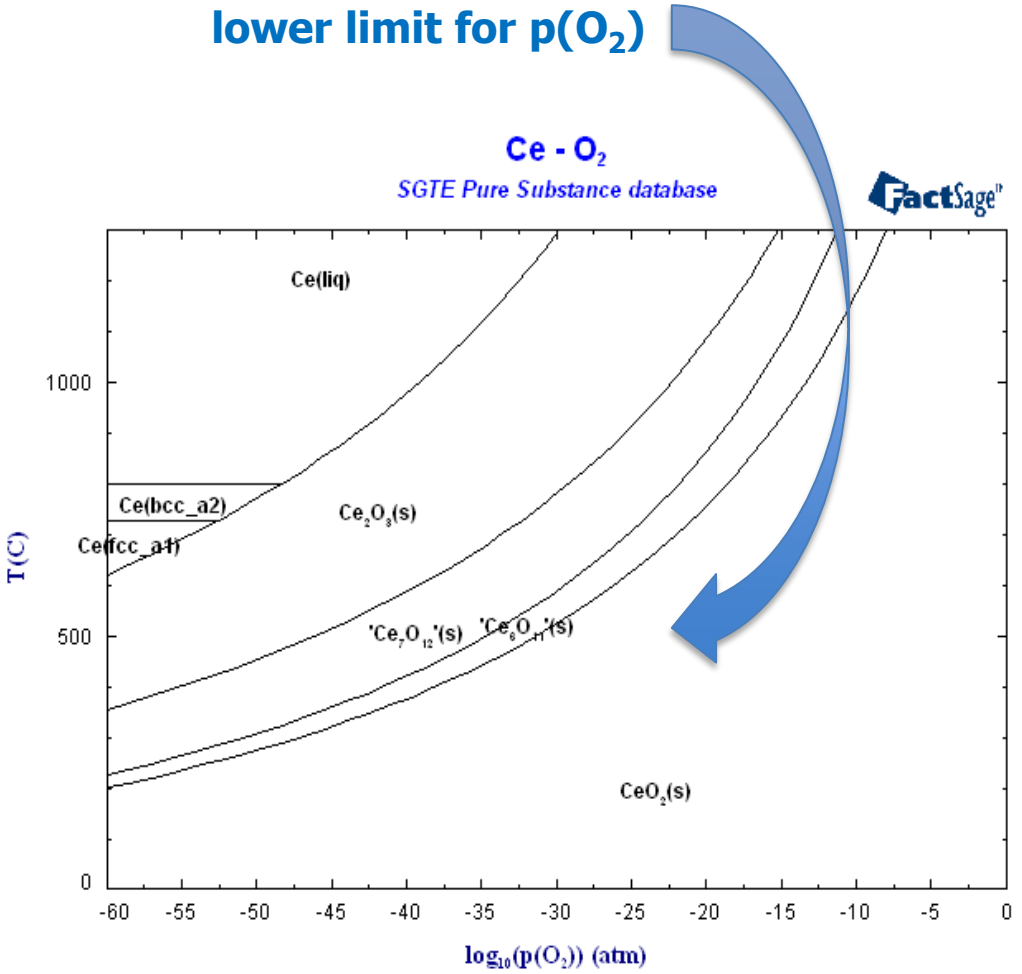




Project ELSA

- Highlights
  - layer interaction





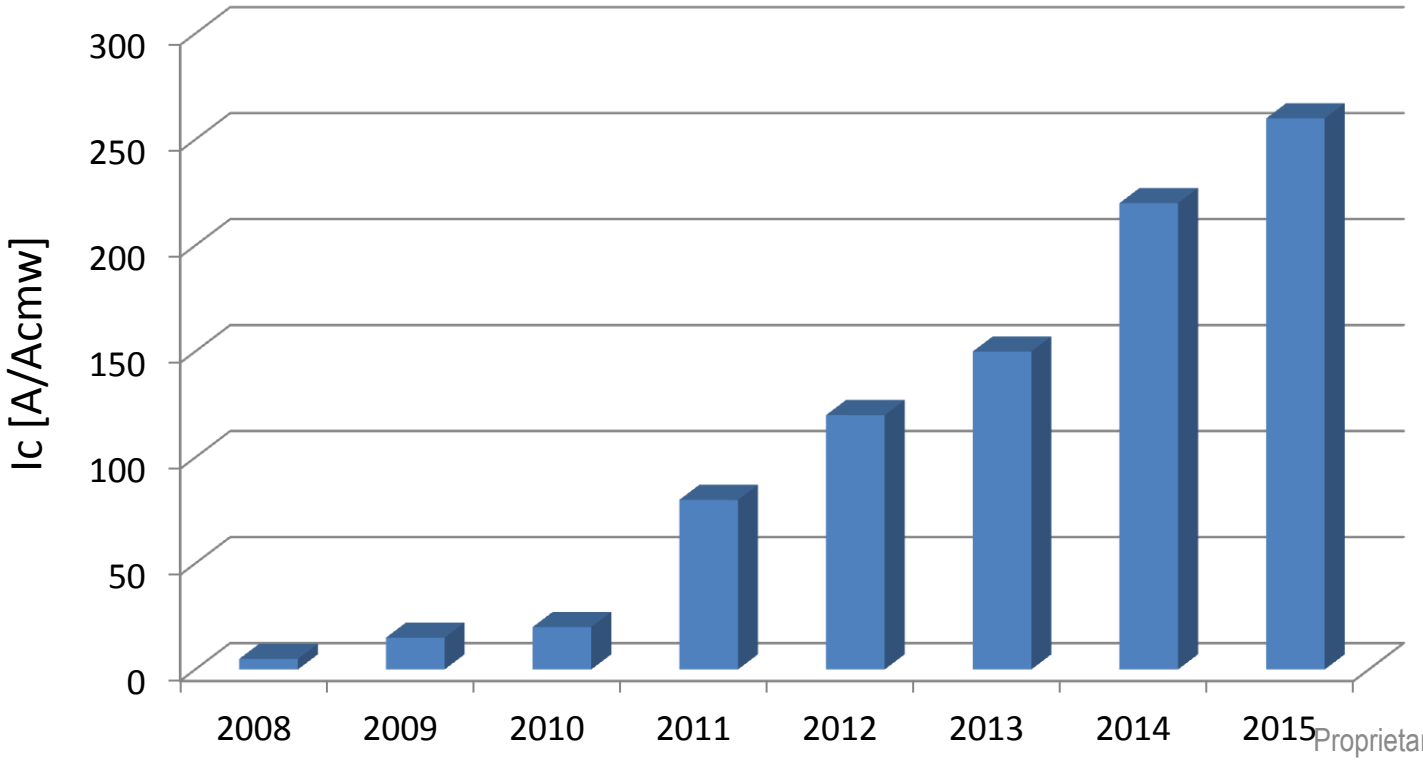
YBCO Nucleation at the Interface

```
T = 1000.00 K
P = 1.00000E+00 bar
V = 0.00000E+00 dm3

STREAM CONSTITUENTS          AMOUNT/mol
'YBa2Cu3O6.5'                1.0000E+00
CeO2                         1.0000E+00

                          EQUIL AMOUNT  MOLE FRACTION     FUGACITY
PHASE: gas_real               mol                          bar
O2_BCUY                   0.0000E+00     1.0000E+00     3.5313E-01
TOTAL:                    0.0000E+00     1.0000E+00     3.5313E-01
PHASE: DISP123                mol       MOLE FRACTION    ACTIVITY
Y:Ba:Cu:O:O               4.1667E-02     2.5000E-01     5.9800E-07
Y:Ba:Cu:O:Va              1.2500E-01     7.5000E-01     1.1922E-01
TOTAL:                    1.6667E-01     1.0000E+00     1.0000E+00
PHASE: Oxide#1                mol       MOLE FRACTION    ACTIVITY
BaO                       0.0000E+00     2.5049E-01     5.2561E-03
BaO2                      0.0000E+00     7.4951E-01     4.8305E-03
TOTAL:                    0.0000E+00     1.0000E+00     6.5027E-03
PHASE: Oxide#2                mol       MOLE FRACTION    ACTIVITY
BaO                       0.0000E+00     9.2346E-01     5.2561E-03
BaO2                      0.0000E+00     7.6543E-02     4.8305E-03
TOTAL:                    0.0000E+00     1.0000E+00     5.5248E-03
                              mol                         ACTIVITY
CuO_solid(s)              1.6667E+00                     1.0000E+00
BaCeO3_solid(s)           1.0000E+00                     1.0000E+00
Y2BaCuO5_solid(s)         3.3333E-01                     1.0000E+00
Cu2O5Y2_y2cu2o5(s)        0.0000E+00                     6.4302E-01
Y2O3_r(s2)                0.0000E+00                     3.5863E-01
```

$BaCeO_3$ is the most stable phases

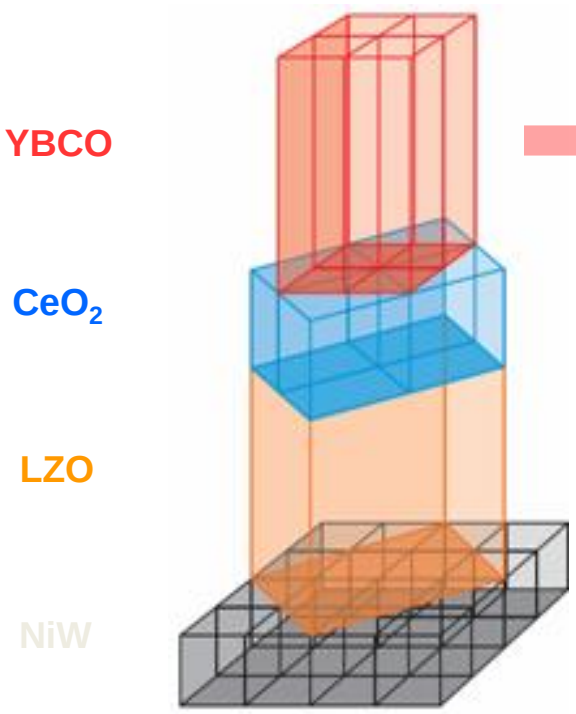
Performance

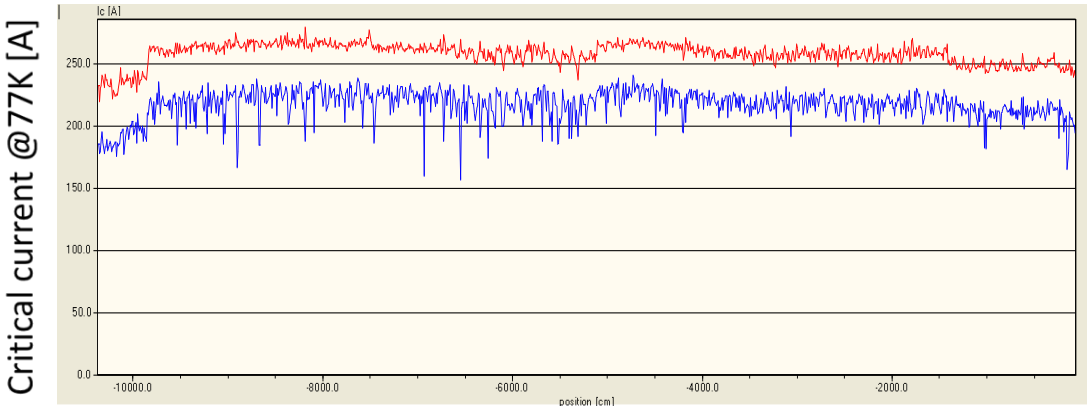
- Development with industrial partners over nearly 10 years
  - Sample lengths increased from 5m (2018) towards >50m (2015)



Length & Performance

- Superconducting properties of all-solution Coated Conductor





100 m tape length, 10 mm wide
Current density 1.7 MA/cm^2

Summary

- HTS tapes
  - HTS materials enable new and highly efficient energy applications
  - Chemical solution deposition is considered to be the "most promising and most challenging process" for HTS tapes
  - **Computational thermochemistry** for interpretation of experimental results and for lowering experimental efforts in high temperature crystallization processes

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Moving towards the future of power engineering

Thanks for your attention

Martina Falter

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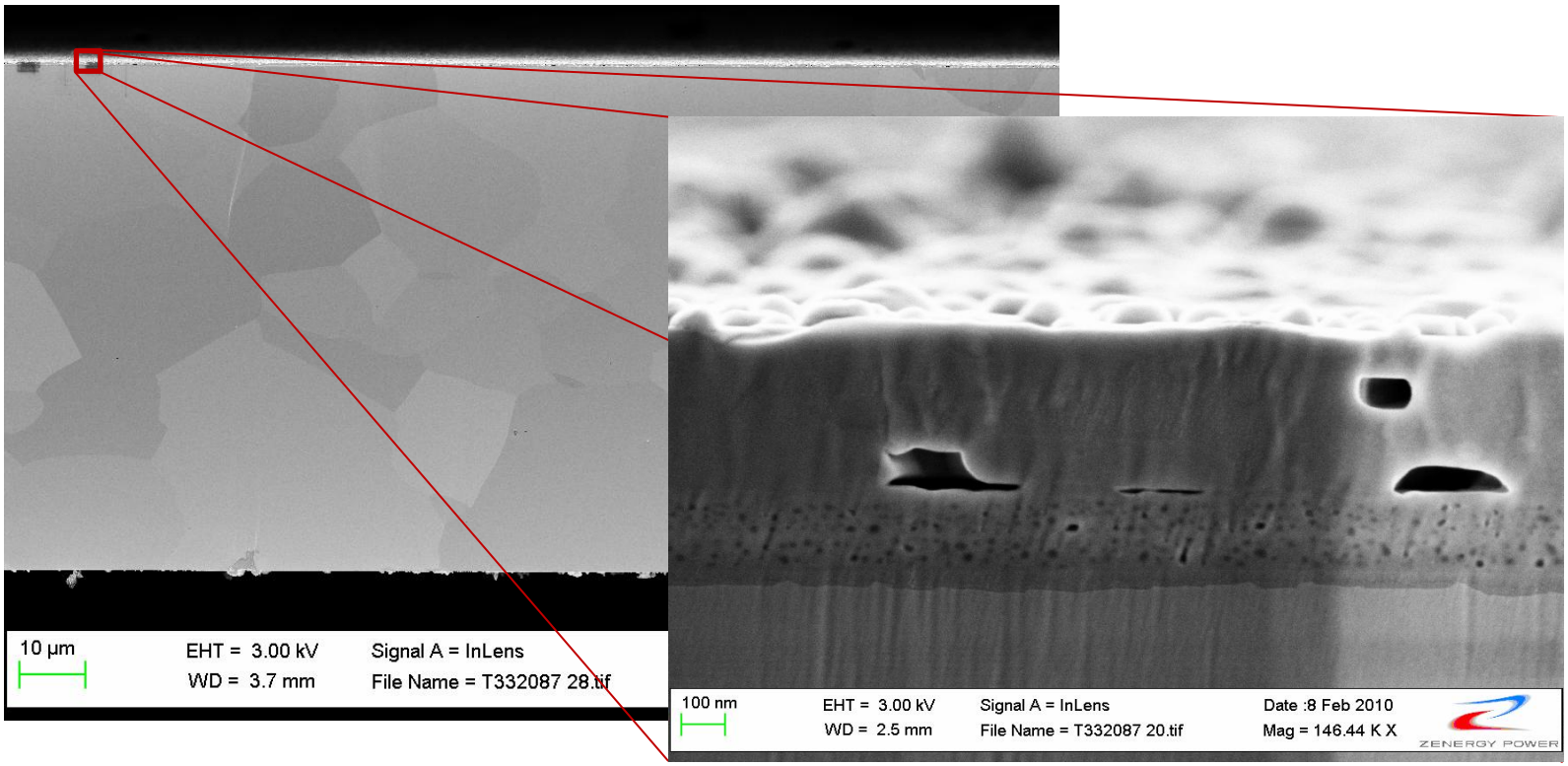
Process Technology

- Ceramic multi-layer architecture on metallic substrate



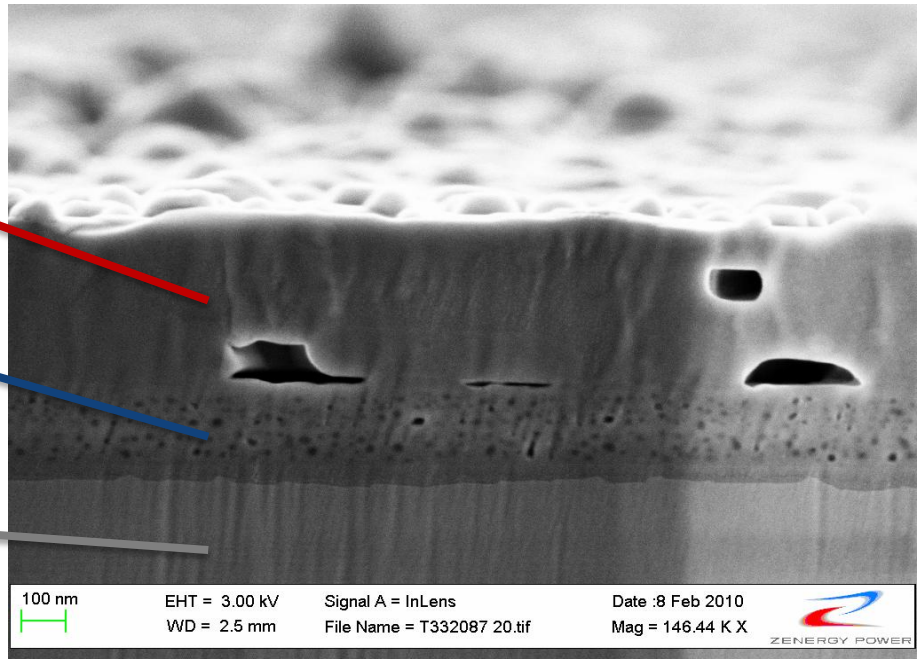
Process Technology

- Ceramic multi-layer architecture on metallic substrate

Superconducting layer
500-1000nm

Buffer layer
250nm (3 layers)

Textured metallic substrate
60µm



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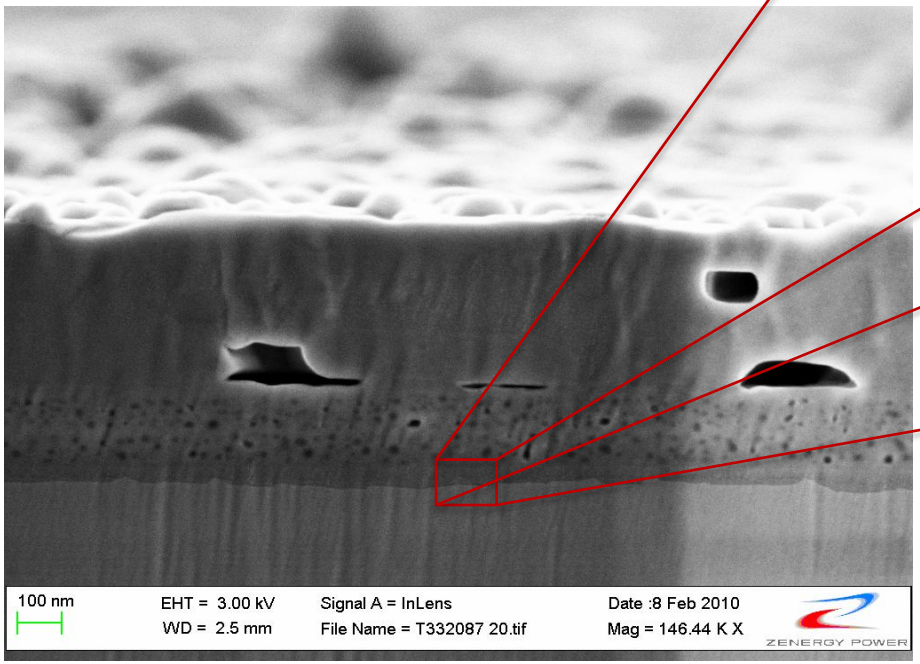
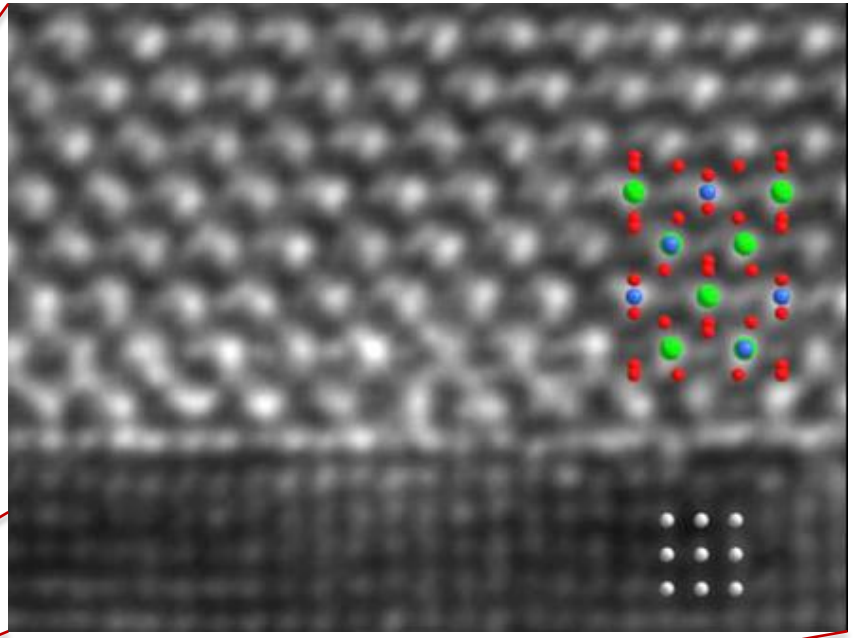
Process Technology

- Ceramic multi-layer architecture on metallic substrate

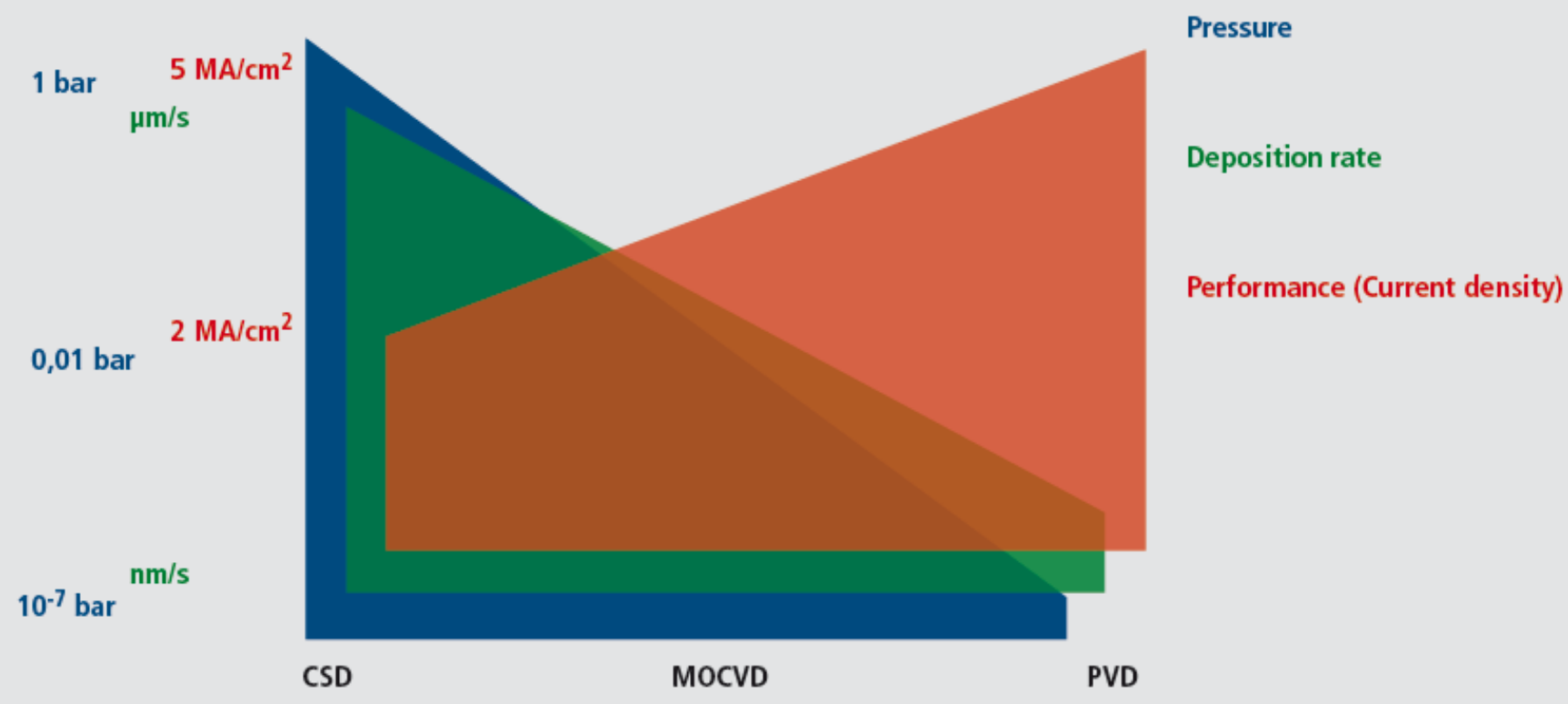




Epitaxial (orientated) growth of ceramic functional layers on textured metallic substrate

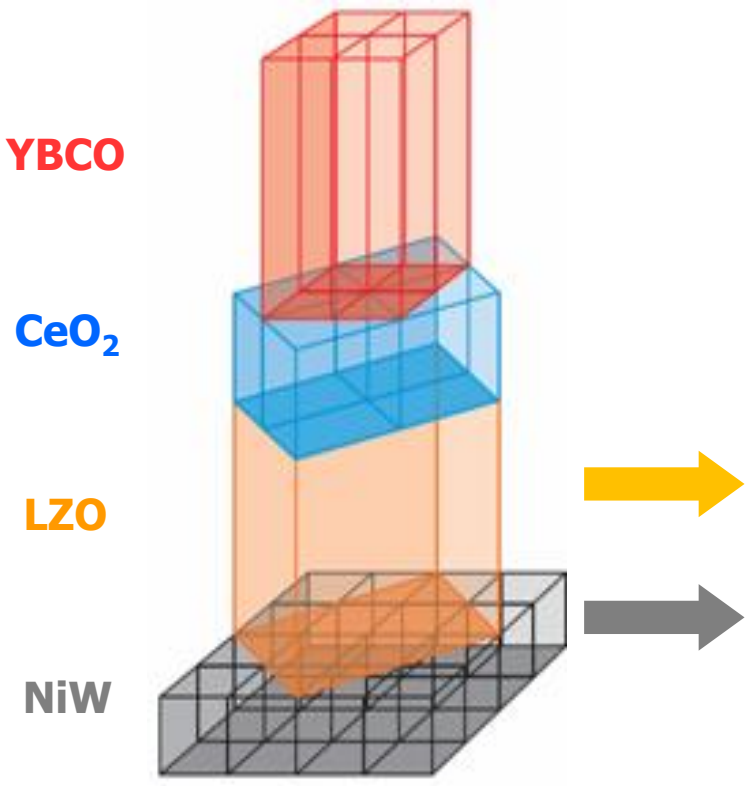
Process Technology

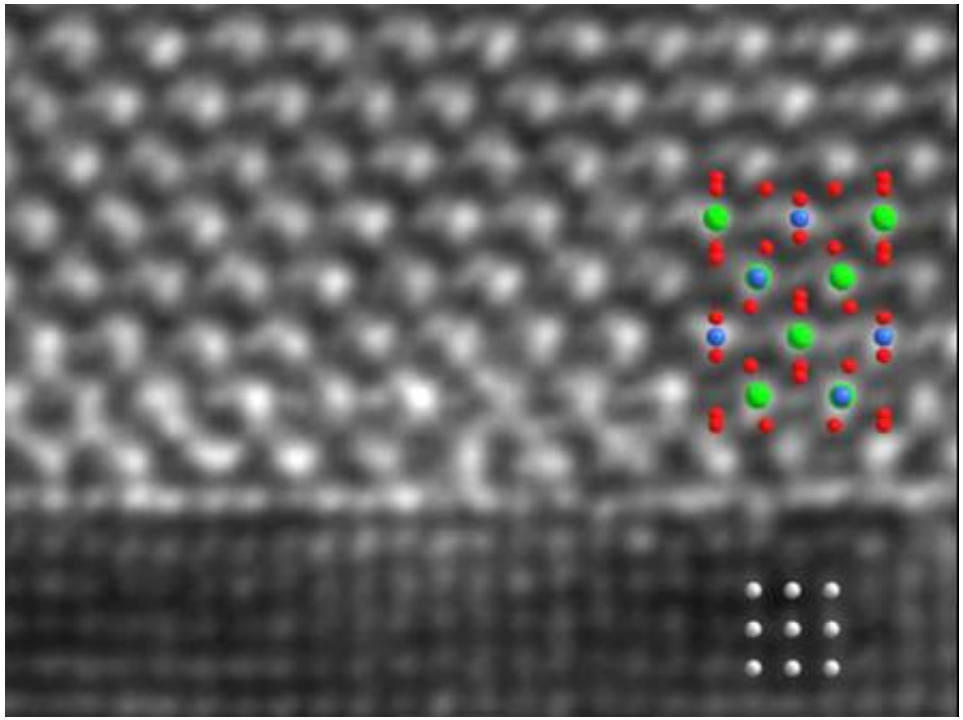
- Chemical solution deposition



Process Technology

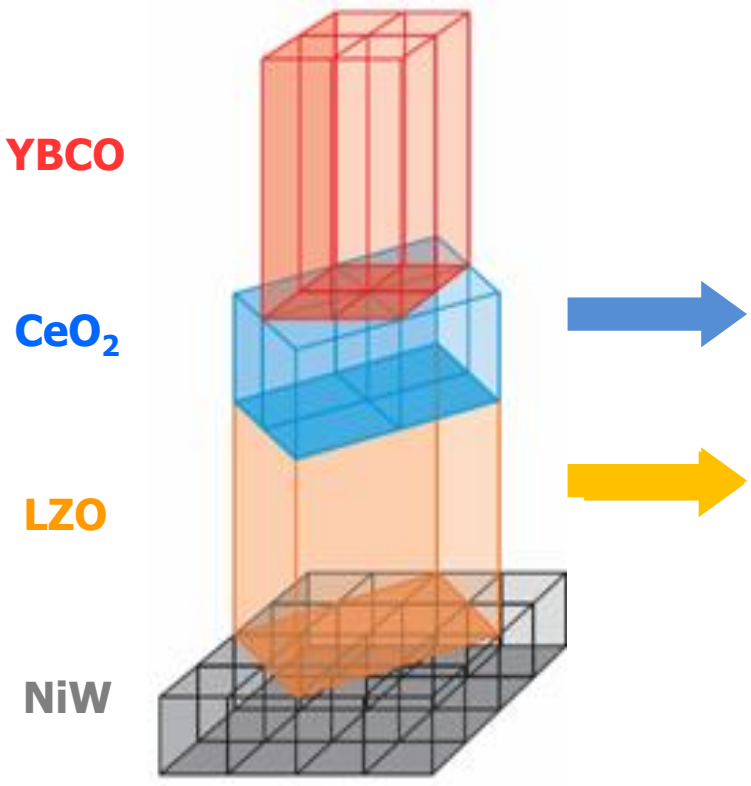
- Epitaxial growth



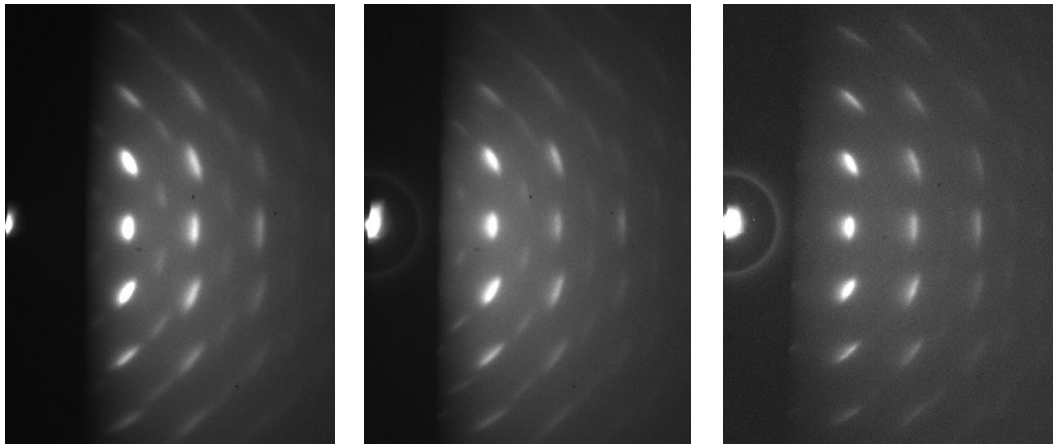


Process Technology

- Epitaxial growth



View along <100>



1x LZO | 2x LZO | CeO_2

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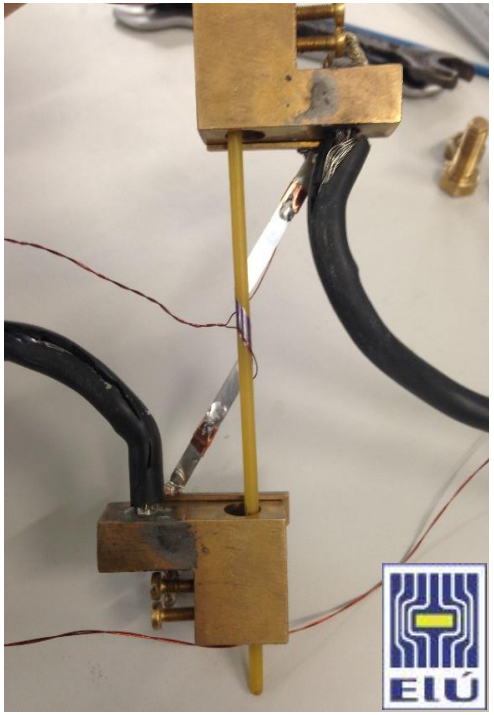
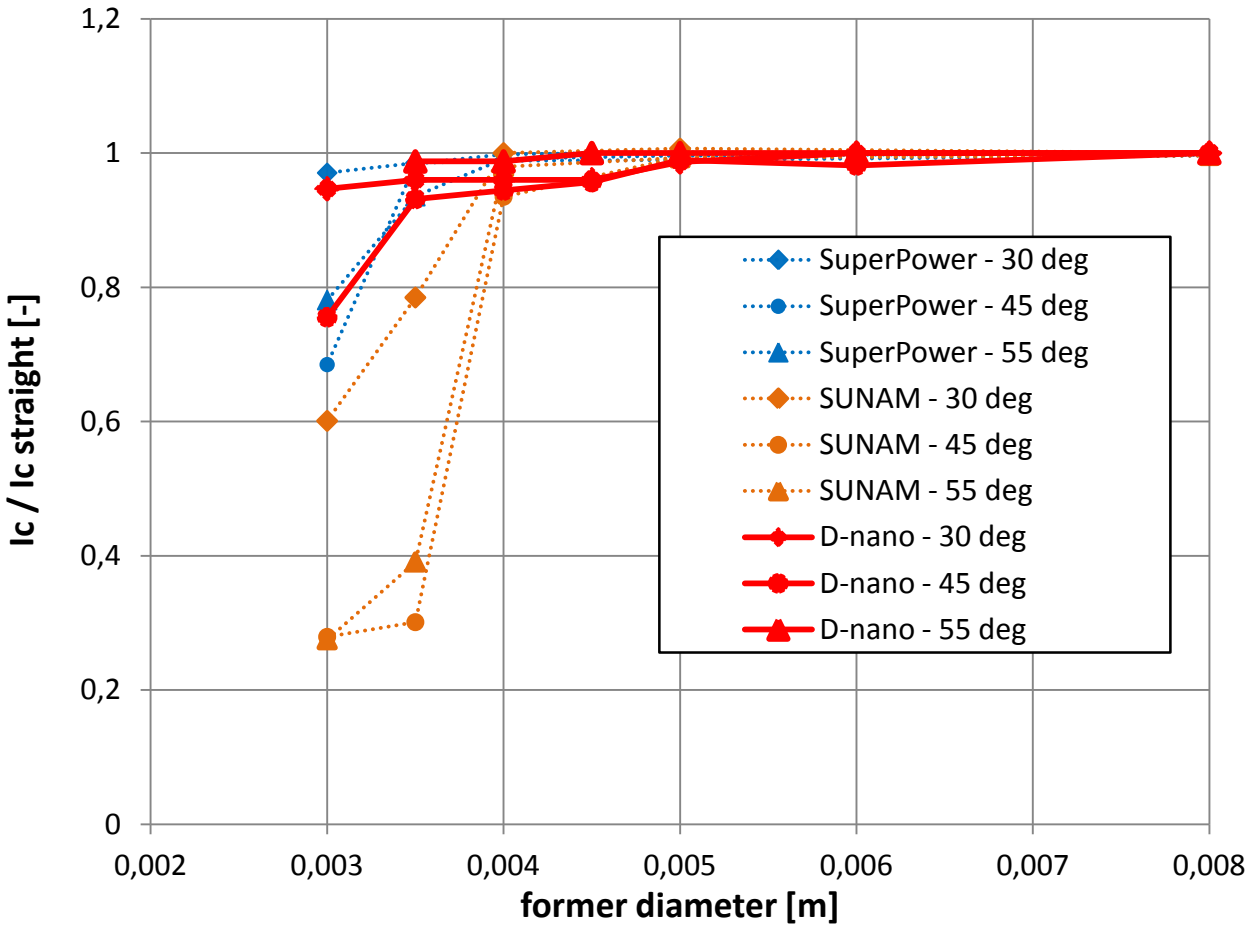
torsion-bending experiment

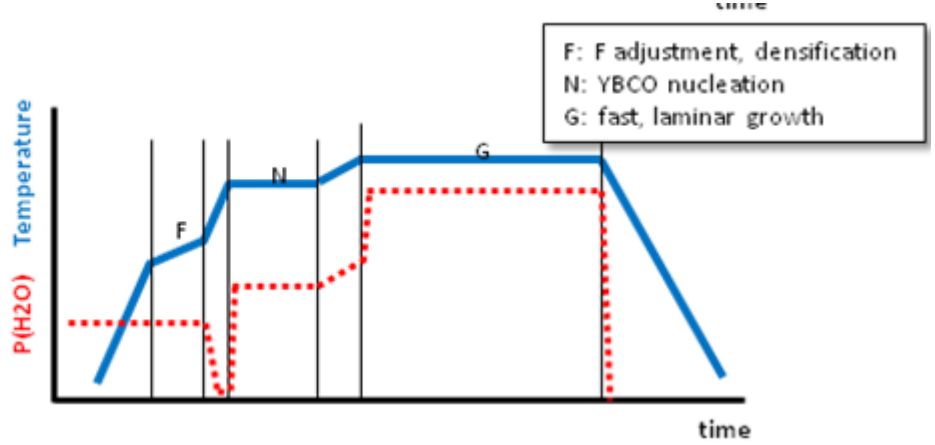




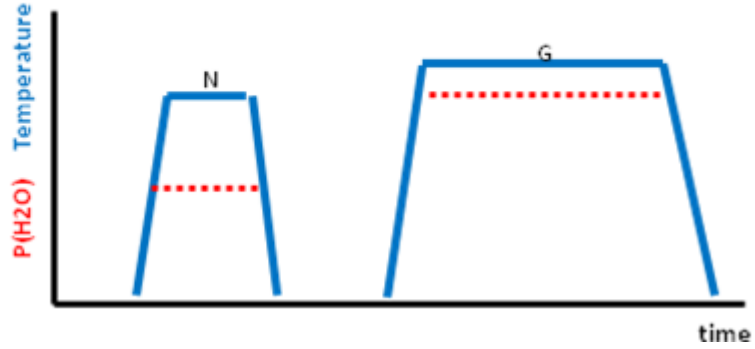
torsion-bending capability of D-Nano tape is comparable with SuperPower tape

Nucleation at the interface

ORNL (batch)



Grundidee ORNL – d-nano (kontinuierlich, 2 Stufen)



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