EVOLVE
FUEL CELL

A step toward the next generation of High Temperature Fuel Cells: The EU project EVOLVE

22/05/2014

R. Costa

DLR

Beyond the 3rd generation SOFC…

1st gen.	2nd gen.	3rd gen.	4th gen.
ESC	ASC	MSC	
Limited power density Fuel flexibility Robustness	High power density Fuel flexibility **Sulfur poisoning** **Thermal cycling** Redox Cycling	High power density Fuel flexibility **Sulfur poisoning** Thermal cycling Redox Cycling	High power density Fuel flexibility Sulfur resistant Thermal cycling Redox Cycling Low cost
Stationary **Transportation**	Stationary Transportation	**Stationary** Transportation	Stationary Transportation

Which materials and architecture for the next generation SOFC?

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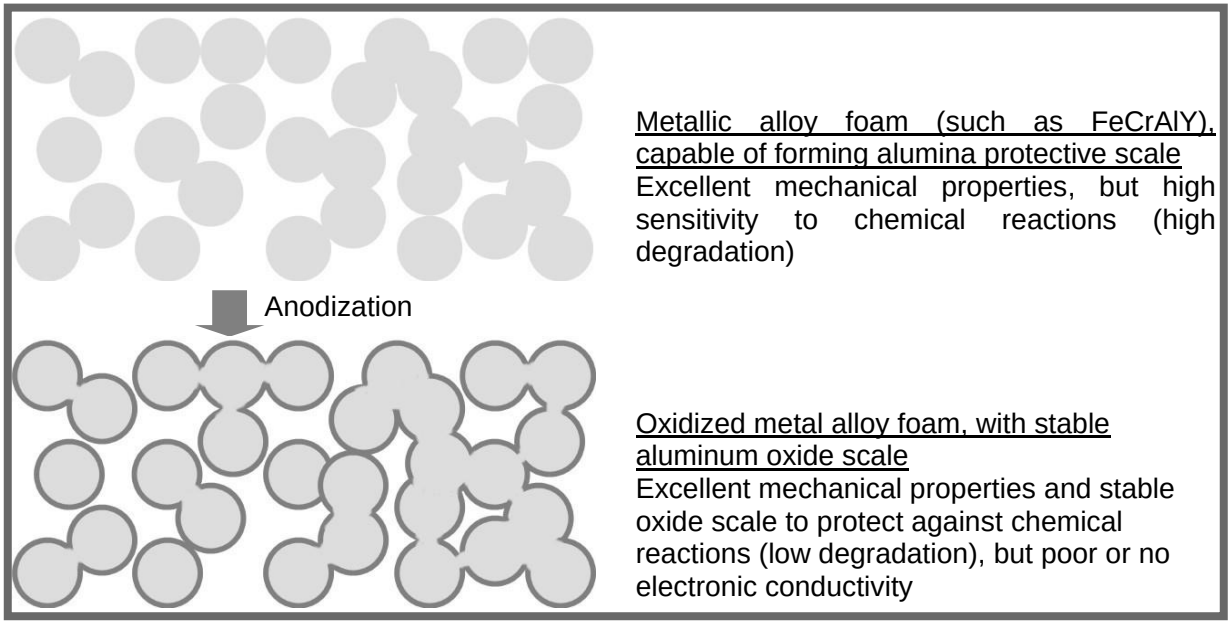
The cell concept…

… combines benefits from ASC and MSC cell architectures

Metal substrate resistant toward oxidation



Metallic alloy foam (such as FeCrAlY), capable of forming alumina protective scale
Excellent mechanical properties, but high sensitivity to chemical reactions (high degradation)

Oxidized metal alloy foam, with stable aluminum oxide scale
Excellent mechanical properties and stable oxide scale to protect against chemical reactions (low degradation), but poor or no electronic conductivity

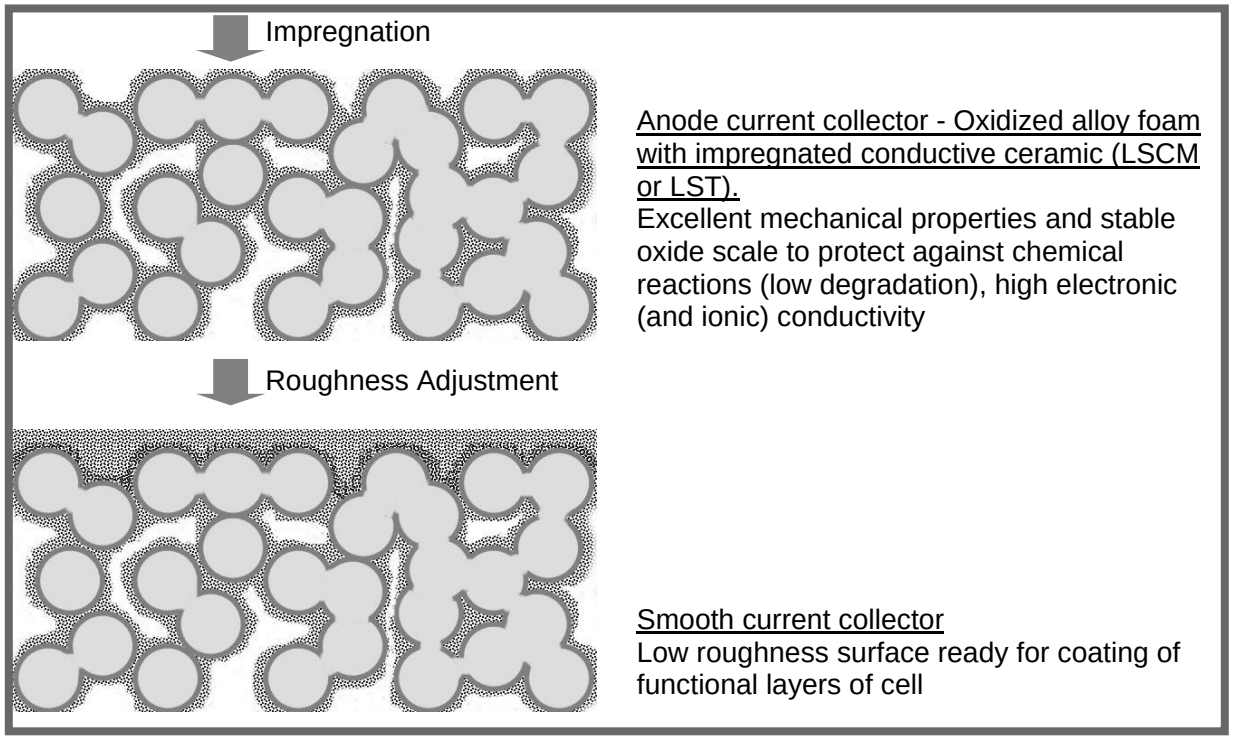
Formation of an Al_2O_3 layer as a durable protective coating

Al rich alloys, on the basis of MCrAl(Y) with M being Fe, Ni, Co or a mixture

The cell concept…

… combines benefits from ASC and MSC cell architectures

Hybrid Metal/Ceramic substrate without nickel having a mechanical or structural role



Anode current collector - Oxidized alloy foam with impregnated conductive ceramic (LSCM or LST).
Excellent mechanical properties and stable oxide scale to protect against chemical reactions (low degradation), high electronic (and ionic) conductivity

Smooth current collector
Low roughness surface ready for coating of functional layers of cell

Infiltration with an electronic conductor

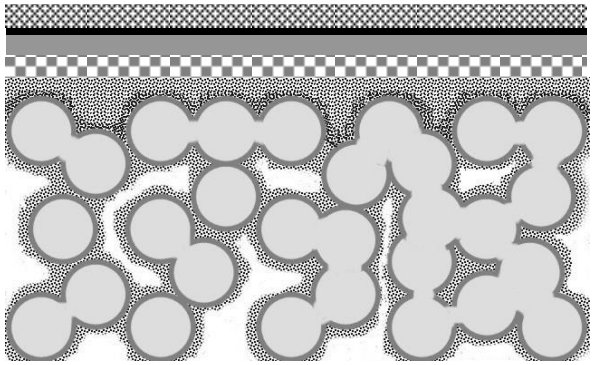
Hybrid current collector mechanically and chemically stable in both oxidant and reducing atmosphere

The cell concept…

… combines benefits from ASC and MSC cell architectures

Manufacturing of thin active layer (Anode/Electrolyte/Cathode) as for ASC

Fabrication of functional layers on top of anode current collector+ infiltration



Realization of Evolve Cell

- LSCF-CGO cathode
- CGO diffusion barrier layer
- YSZ or ScSZ Electrolyte
- LSCM-CGO anode (with infiltrated Ni)

Use of perovskite materials at the anode and cathode, being modified by addition of suitable catalysts

High power density, Sulfur resistant, Fuel flexibility, Thermal cycling, Redox Cycling???

Stationary, Transportation???

Identified Challenges

- *Formation of a protective Al_2O_3 coating without hindering the electronic conductivity…*
- *Manufacturing of a thin dense electrolyte (<5µm) without damaging the metal substrate and high T sintering…*
- *Increase of electronic conductivity in perovskite material for current collection…*
- *Improvement of catalytic properties of perovsite anode materials…*

The project EVOLVE

Evolved materials and innovative design for high performance, durable and reliable SOFC cell and stack

- ***European project funded by the FCH JU under Grant Agreement 303429***
- *Coordinator: German Aerospace Center (DLR)*
- *Starting date November 2012*
- *Duration 48months*

EVOLVE FUEL CELL

New Energy World JU
fuel cells & hydrogen for sustainability

1. 550mW/cm² at 0,7V and 750°C with hydrogen as fuel gas, with perovskite based anode material, demo at stack level up to 250W
2. Industrial relevant size up-scaling

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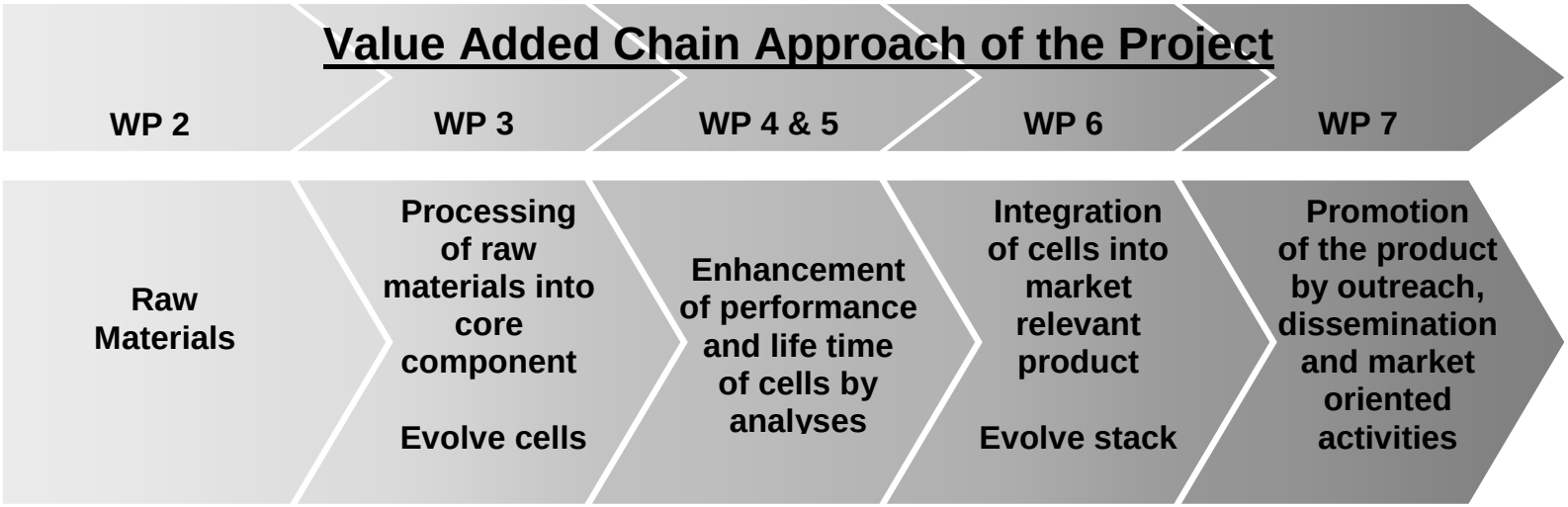
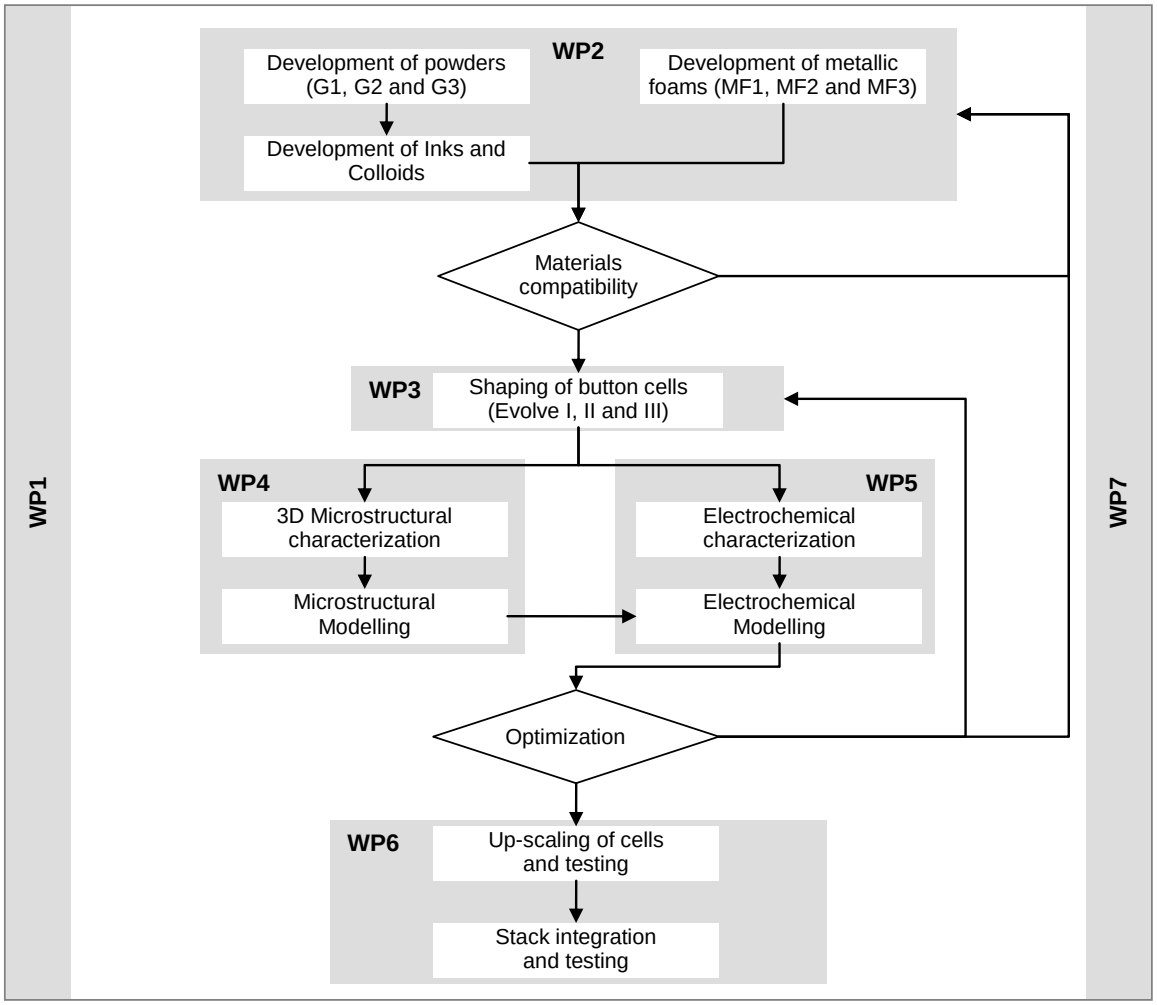
EVOLVE: value added chain



From the raw materials up to the stackable cells

EVOLVE: strategy



- ***Iterative strategy***
- ***Extensive use of modeling***
- ***Reduce the number of trial/error cycles***
- ***Shorten the process of development and integration of new material***

The consortium EVOLVE

CerPoTech
Ceramic Powder Technology
(Norway)

ceraco
ceramic coating
(Germany)

Consiglio Nazionale delle Ricerche
(Italy)

Grenoble INP
(France)

SAAN ENERGI
(Sweden)

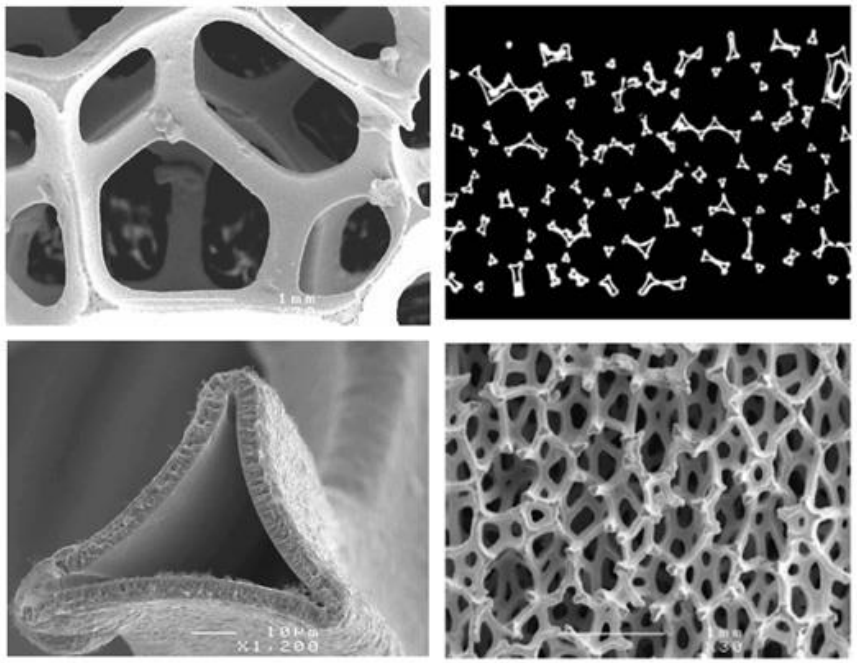
ALANTUM
Innovations in Alloy Foam
(Germany)

ARMINES
(France)

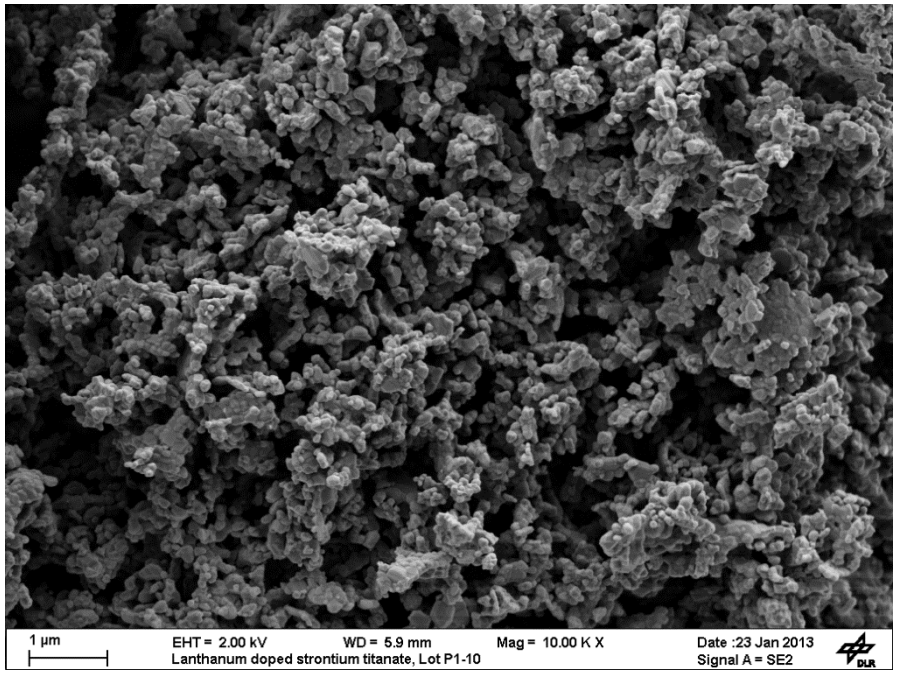
DLR Deutsches Zentrum für Luft- und Raumfahrt
(Germany)

DLR

Reference materials



Open pore NiCrAl foam (© Alantum)



Composition of the anode: $Ce_{1-x}Gd_xO_{2-\alpha}$ / $La_{0,1}Sr_{0,9}TiO_{3-\alpha}$
Electrolyte: 8-YSZ
Cathode : $Ce_{1-x}Gd_xO_{2-\alpha}$ / $La_{0,4}Sr_{0,6}Co_{0,2}Fe_{0,8}O_{3-\alpha}$

EVOLVE: development strategy

1cm² | 15-20 cm² | 100 cm²

- Reactivity tests
- Conductivity measurement
- Understanding the behaviour

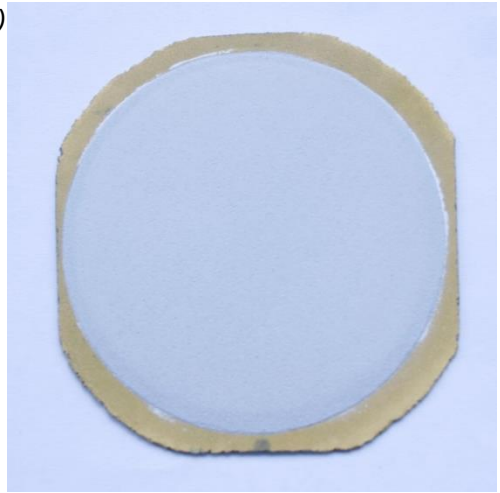
- Shaping strategy
- Prototype
- Testing and optimization

- upscaling

(CNR ISTEC)

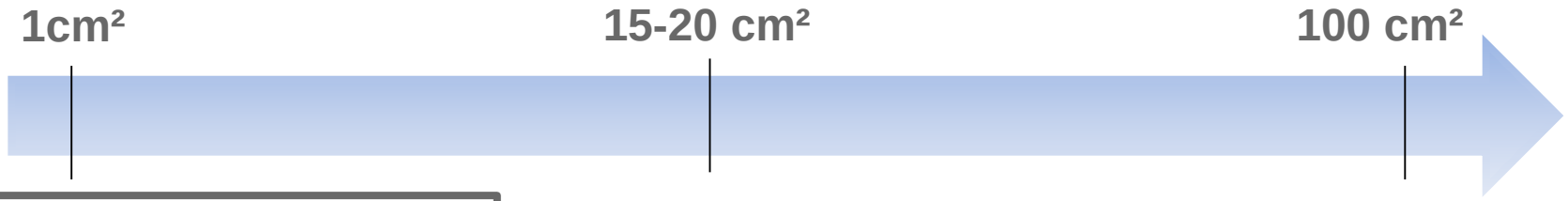
10mm

(DLR)



10mm

EVOLVE: development strategy



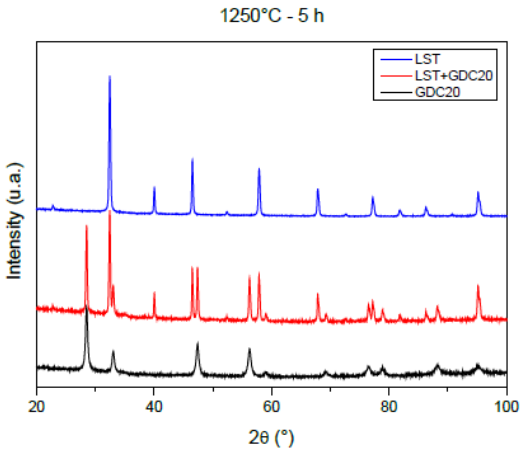
- Reactivity tests
- Conductivity measurement
- Understanding the behaviour

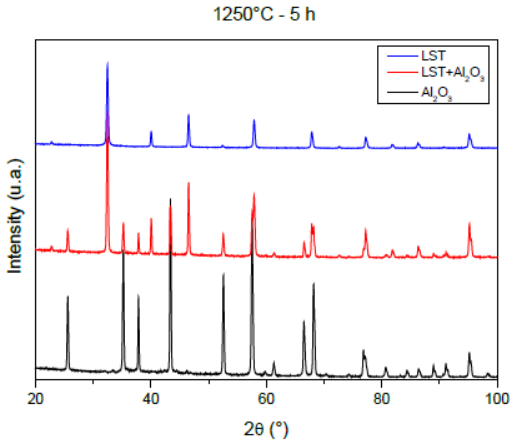
(CNR ISTEC)

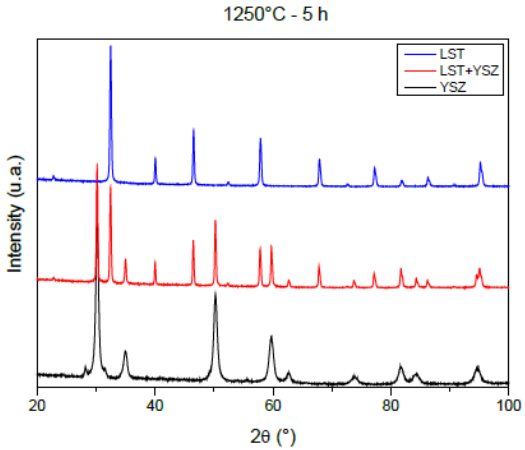
Were we are after 15 months

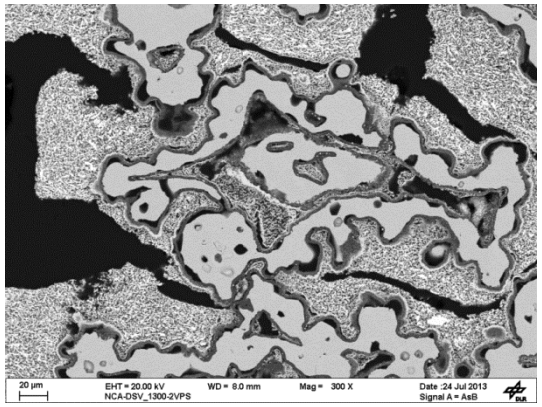
Compatibility tests *(DLR)*

1cm²









No reactivity detected between anodic materials

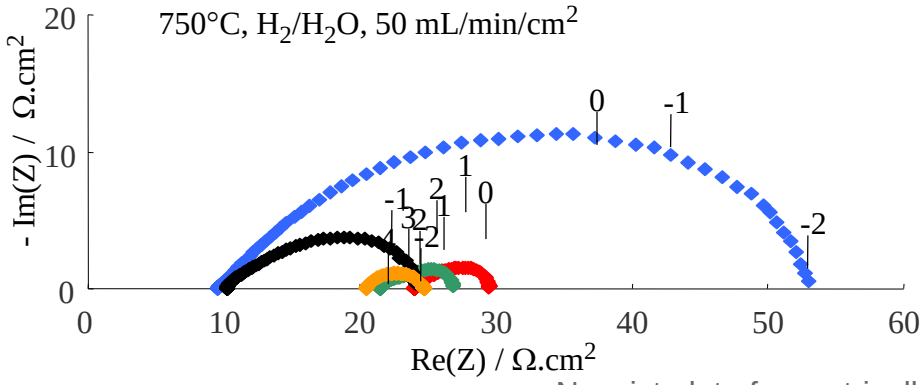
(at least with used methods)

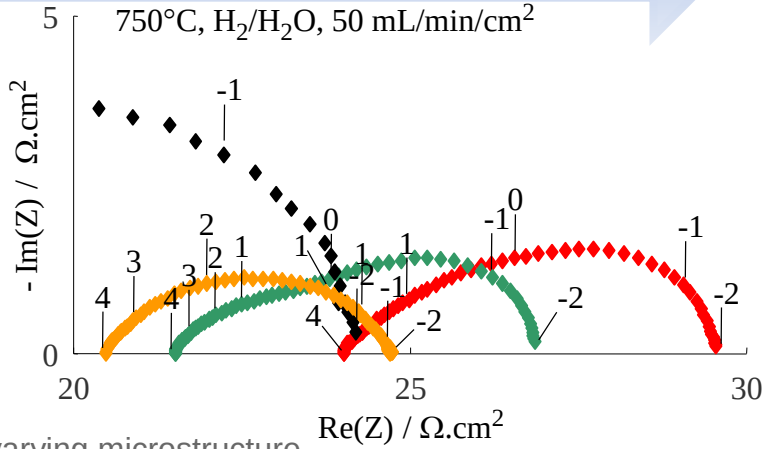
Conductivity of pure LST at about 60 S/cm at 750°C in H_2

(CNR)

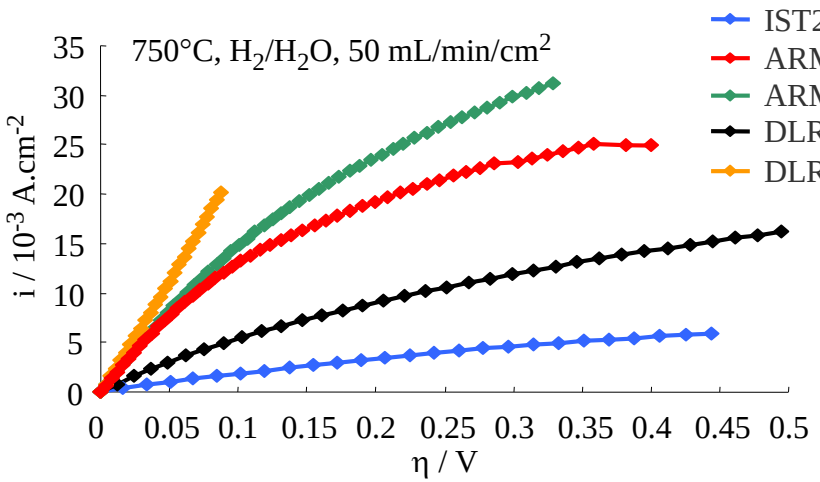
Were we are after 15 months

1cm² *Understanding perovskite as anode material (Grenoble INP)*





Nyquist plot of symetricall cells by varying microstructure



Kinetic limitation of the reponse of the anode
Major improvement of the performance by adding metal catalyst

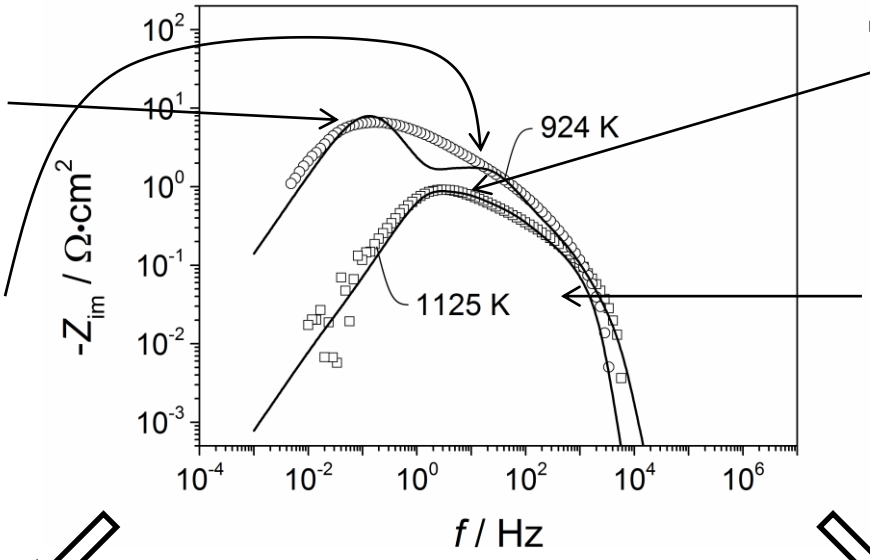
Were we are after 15 months

Understanding perovskite as anode material: Modeling (DLR)

➢ 924 K

- LF arc: hydrogen adsorption and formation of OH groups
- IF arc: oxygen charge-transfer through LST/CGO-YSZ interface

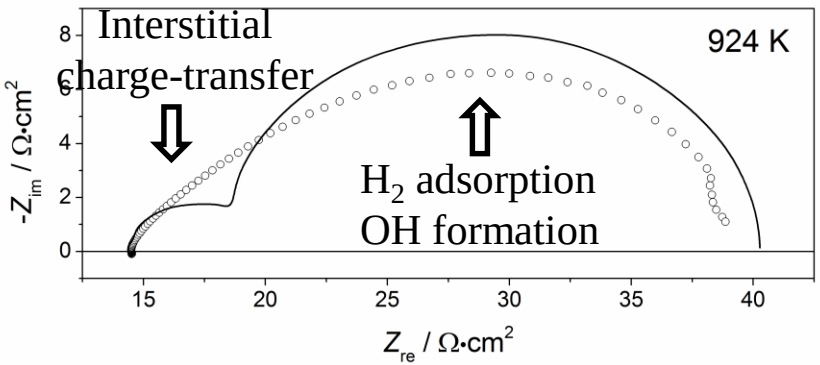
➢ Bode plot



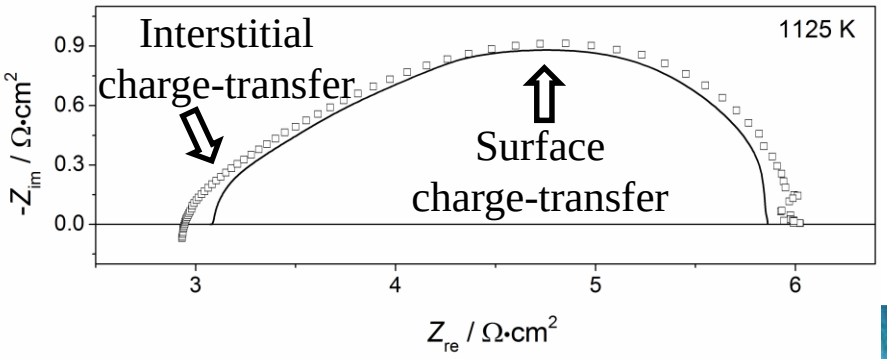
➢ 1125 K

- LF arc: LST surface charge-transfer
- IF arc: oxygen charge-transfer through LST/CGO interface

➢ Nyquist plot, T = 924 K



➢ Nyquist plot, T = 1125 K

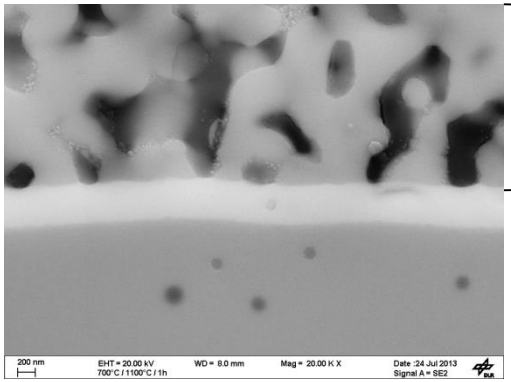


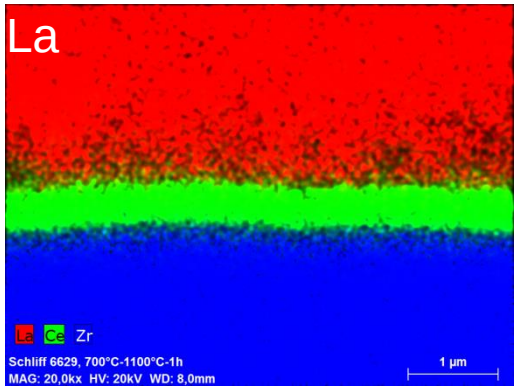
Were we are after 15 months

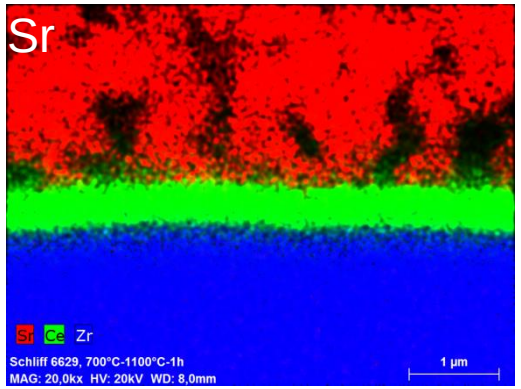
1cm²

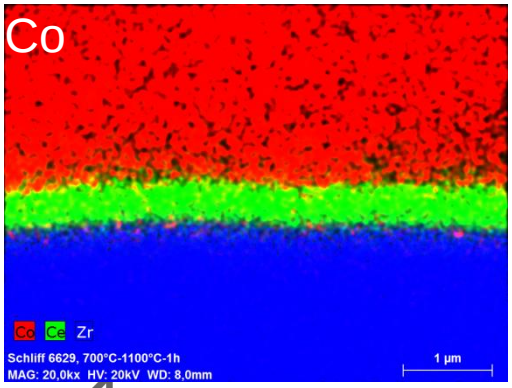
Cathodic compartment (DLR)

CGO coated at 700°C / LSCF brushed and sintered at 1100°C









development of PVD CGO barrier layer to prevent reactivity between LSCF and YSZ (cathode)

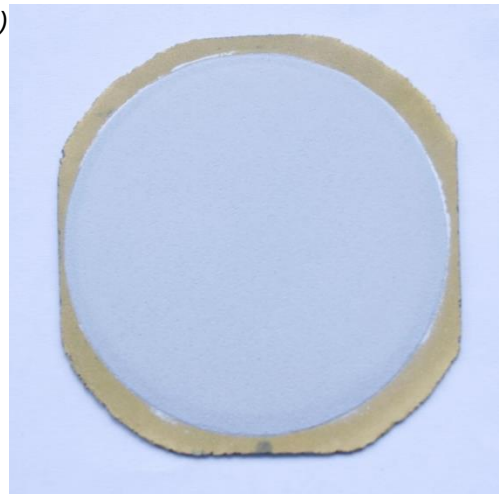
DLR

EVOLVE: development strategy

1cm² → 15-20 cm² → 100 cm²

- Shaping strategy
- Prototype
- Testing and optimization

(DLR)



EVOLVE: development strategy

Key challenge: produce a thin hermetic electrolyte

Sintering route discarded because of High Temperature problematic due to differential shrinkage

Shaping Strategy

Low risk approach
Short term / Prototype demonstration
Plasma Spraying approach

1

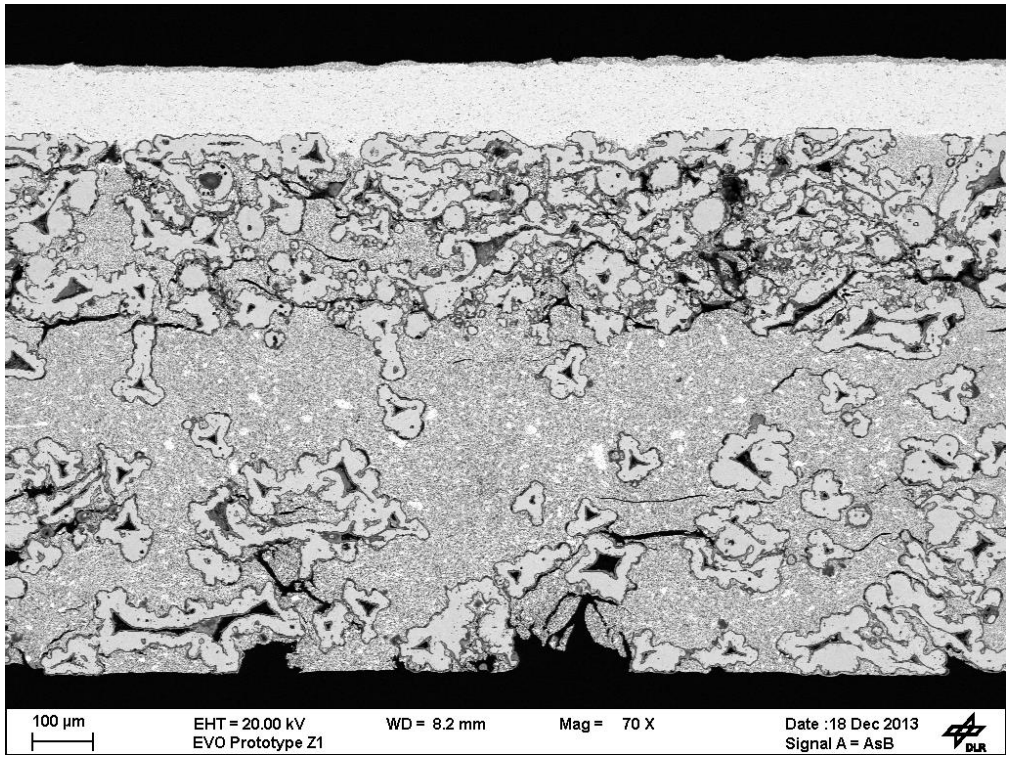
High risk / high impact
Long term
PVD Electrolyte

2

EVOLVE: shaping

1 Plasma spray approach

Low risk approach using the know how from DLR for spraying YSZ layers. No need of sintering step.



Cathode

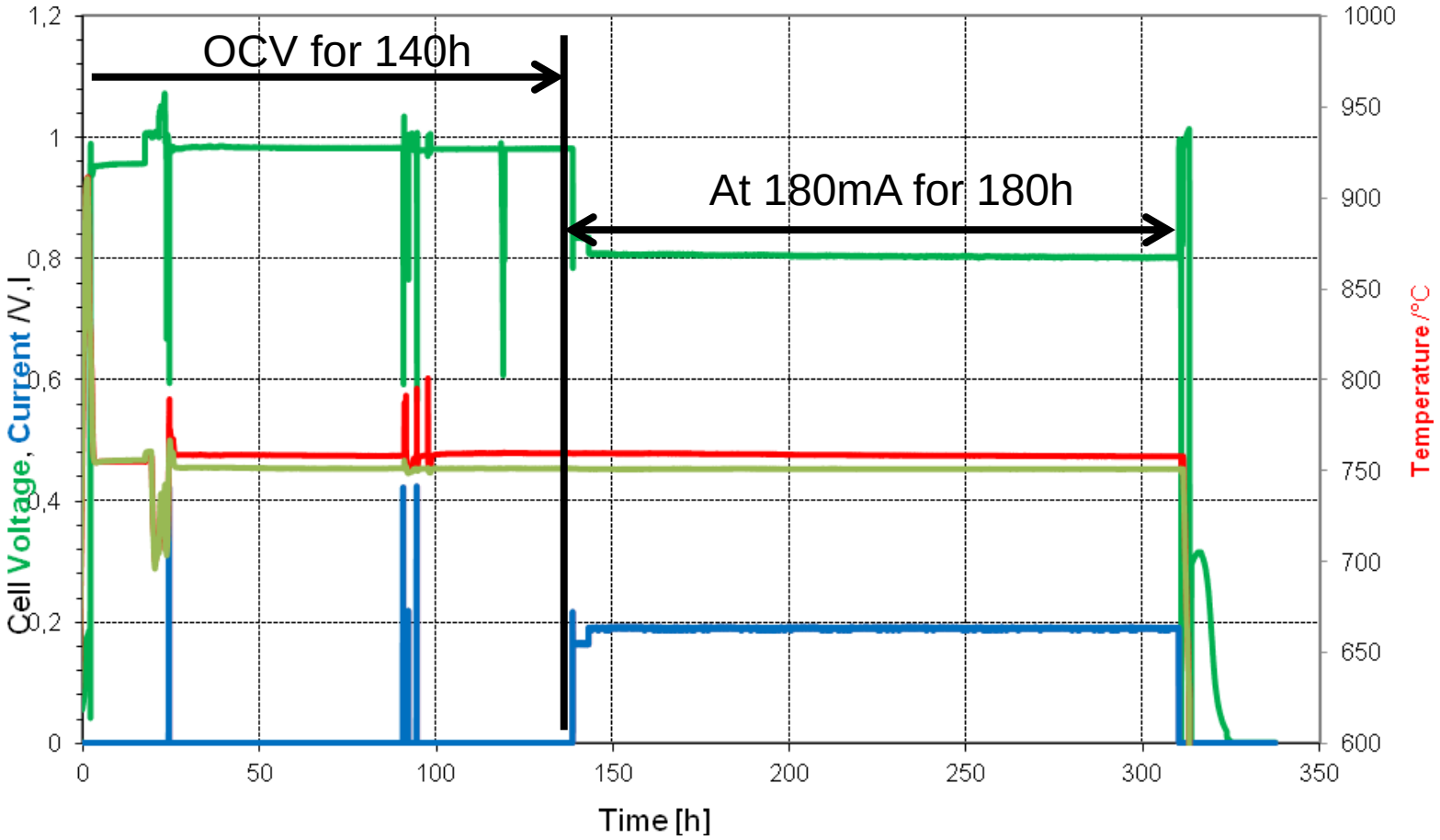
100µm thick electrolyte

Co-pressed LST-CGO infiltrated NiCrAl foam

DLR

Where we are…

Situation at M15

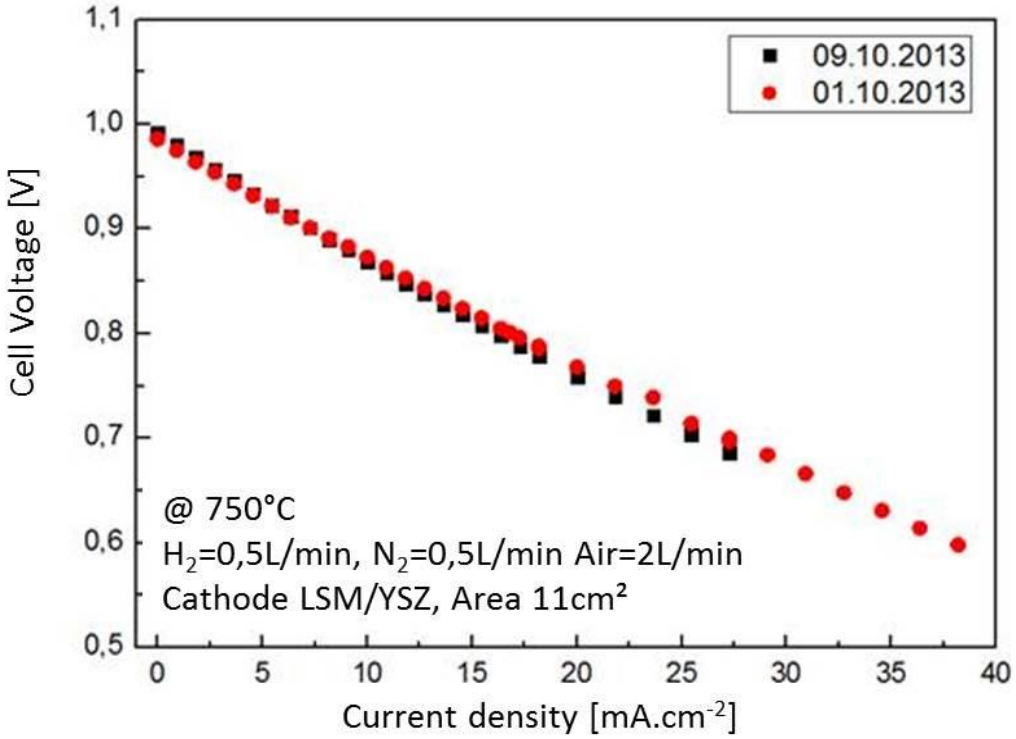


Power density : 20mW/cm² at 0,7V at 750°C H_2-N_2 (50-50) / Air

No significative degradation over 180h in galvanostatic condition

Where we are…

Situation at M15



No significative degradation over 180h in galvanostatic condition

Compatibility of used materials. Succesfull achievement of milestones criteria planed at M18

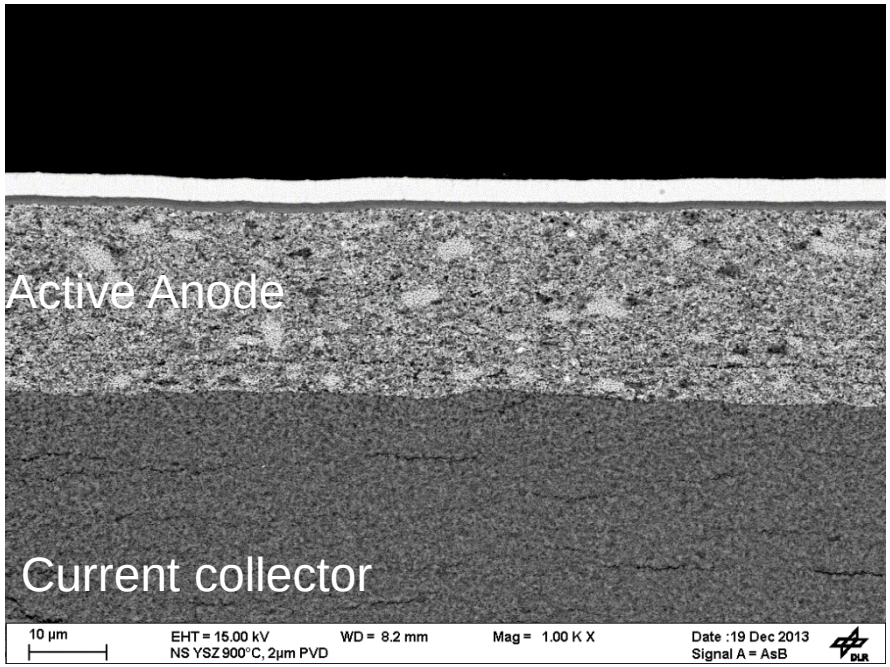
Improvement of performance requires major optimization of microstructure

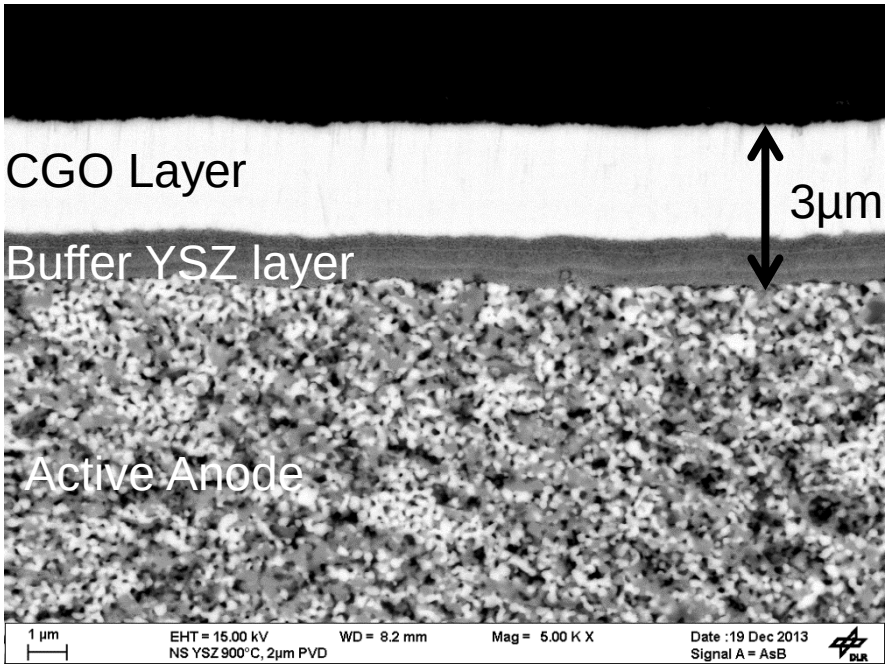
EVOLVE: shaping

2 Toward the next generation: PVD electrolyte

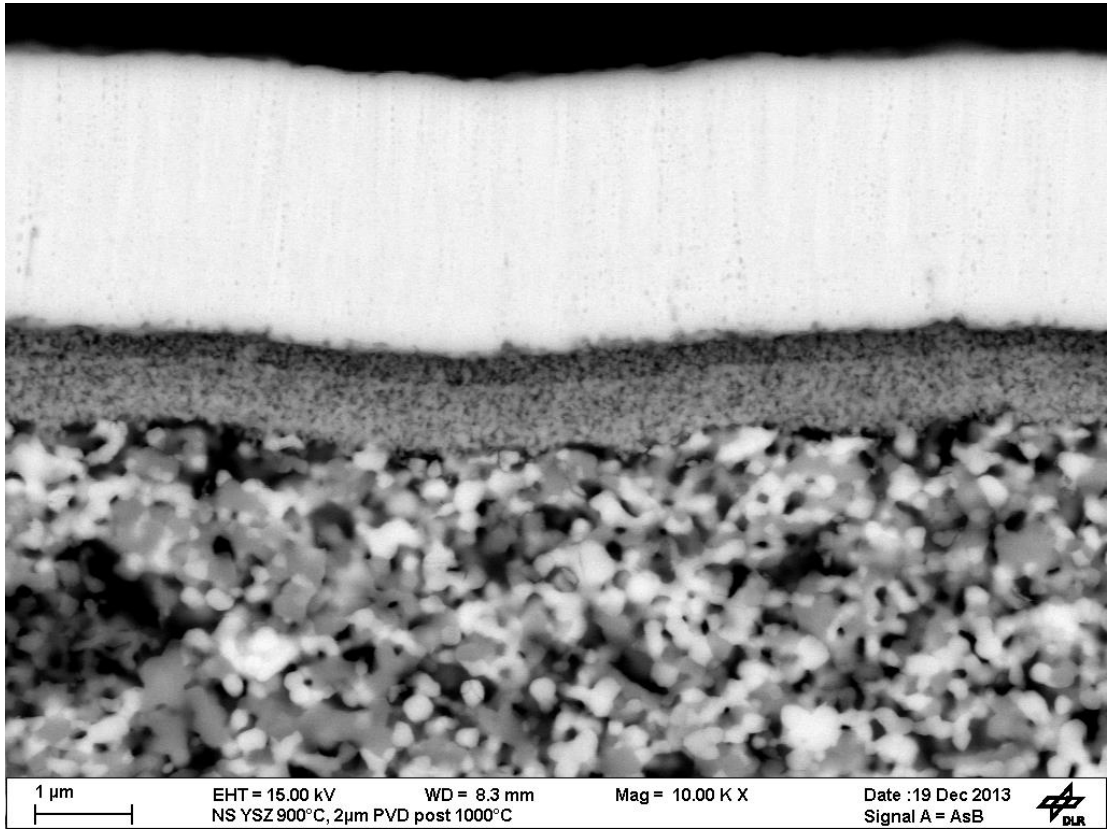
High risk approach. Breakthrough technology.

- ***Incorporation of active anode layer***
- ***Large reduction of the electrolyte thickness <5µm***





EVOLVE: shaping
Toward the next generation: PVD electrolyte



Still survive further thermal treatment at 1000°C

Note : First bi-layer 3µm thick electrolyte have been produced with leak-rate comparable

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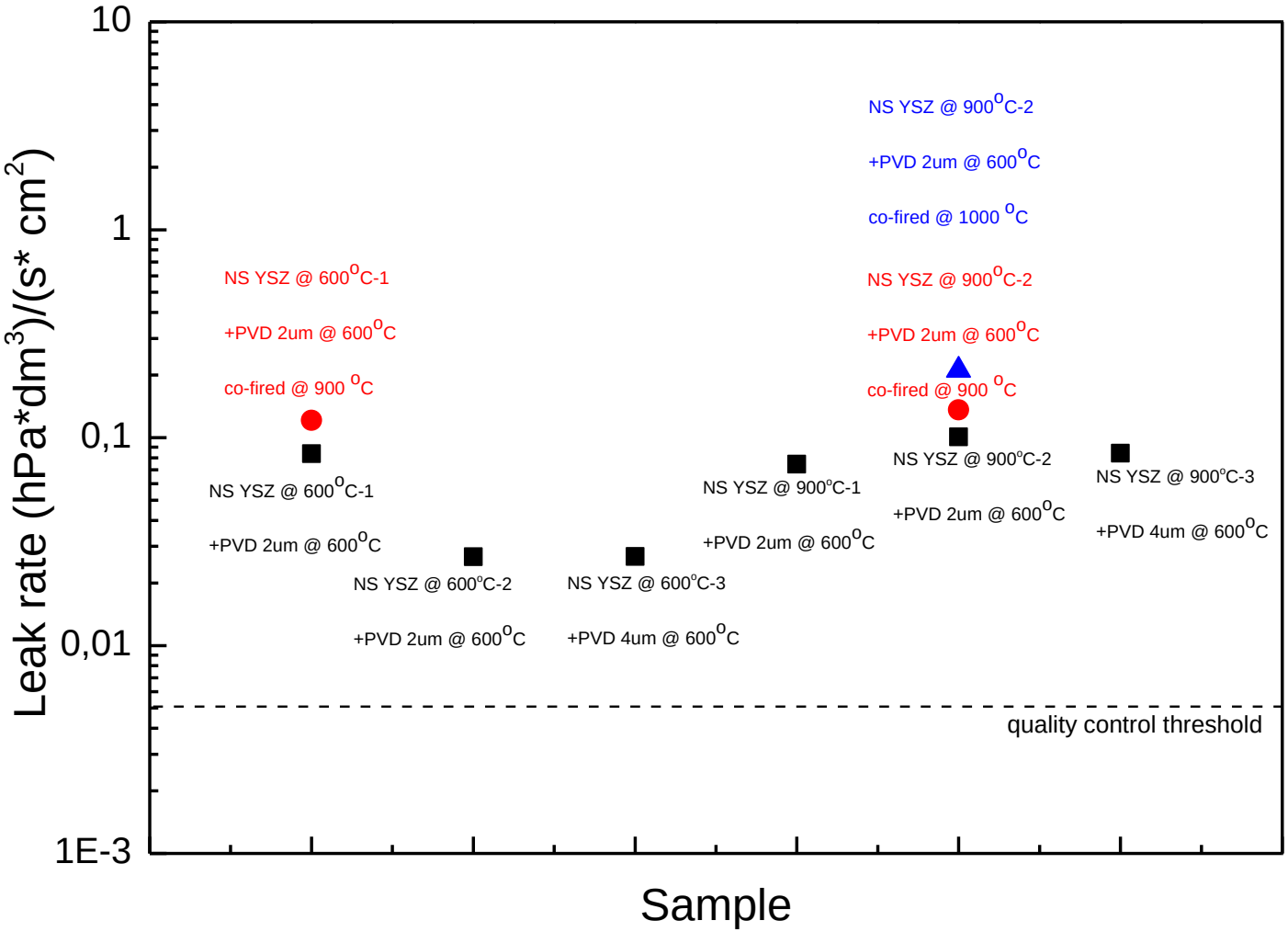
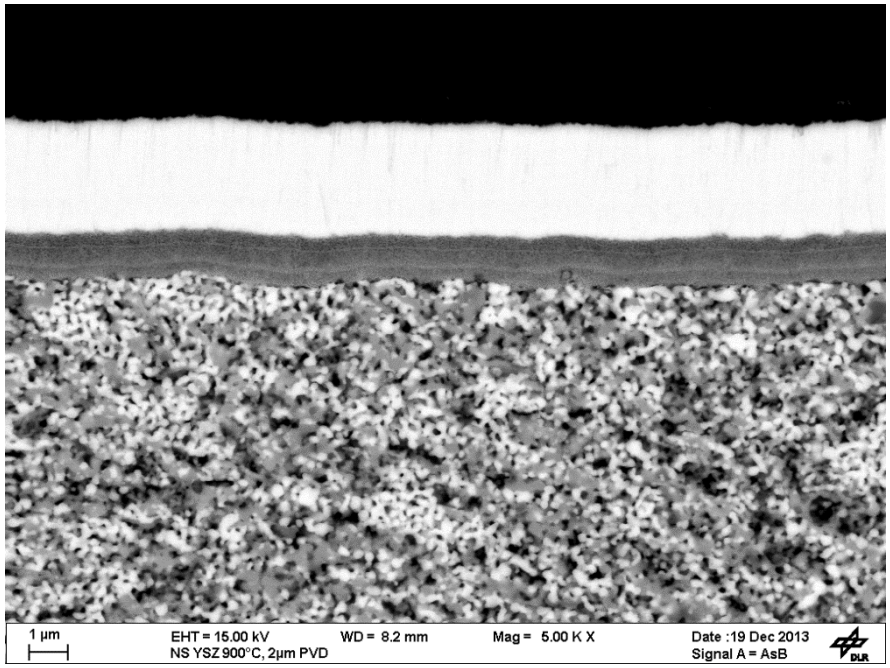


Degradation of leak rate in case of further thermal treatment

Note : First bi-layer 3µm thick electrolyte have been produced (48mm roud shape cells) with leak-rate comparable or better than state of the art plasma sprayed electrolyte. Test on going.

Conclusion:
Toward the next generation of SOFC



- *Possibility of use of perovskite materials in electrode supported cell*
- *Feasibility of the cell architecture have been proved by means of plasma spraying*
- *No sintering step in reducing atmosphere*
- *No over reactivity between cell components have been shown in the tested conditions*
- *Stability of the cell for at least 100hrs of operation at 0,8V*

Improvement of coating processes to increase the active surface area of anode material and implement succesfully PVD coatings for Electrolytes for next generation SOFC

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Thank You !

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EVOLVE FUEL CELL

New Energy World JU
fuel cells & hydrogen for sustainability

DLR: F. Han, A. Hornes, V. Yurkiv, and the whole HTE Group
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Ceraco: R. Semerad
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Grenoble INP: L. Dessemond, G. Constantin
Saan Energi: A. Ansar