EC17 2025

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SOFC@uma.es

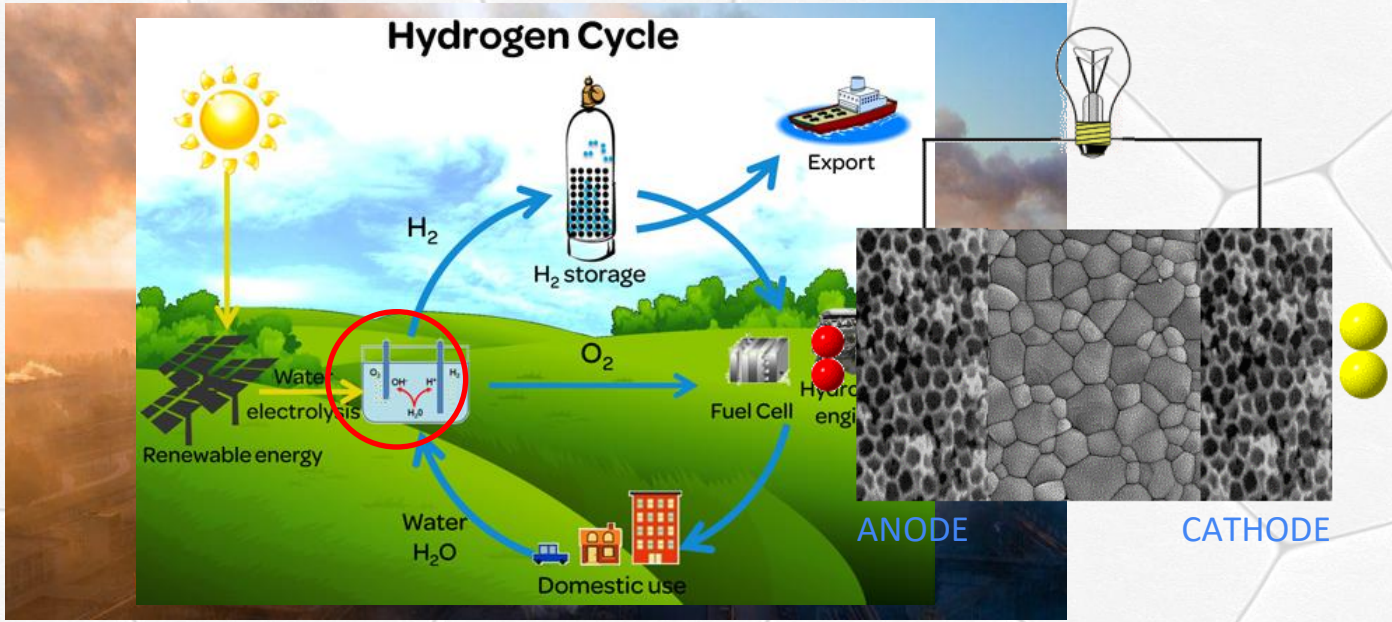
# Enhanced electrochemical behavior and lower thermal expansion in Pr-doped $SrFeO_3$ for symmetric SOFC electrodes

Abraham Sánchez-Caballero, José M. Porras-Vázquez, Lucía dos Santos-Gómez, Javier Zamudio-García, David Marrero-López

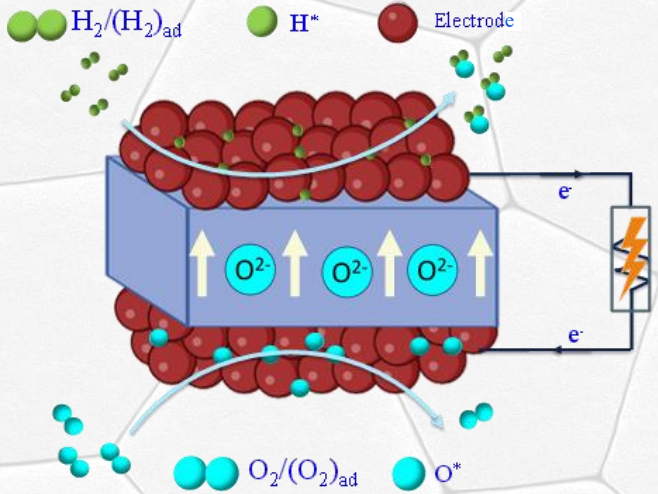
abraham11sc@uma.es

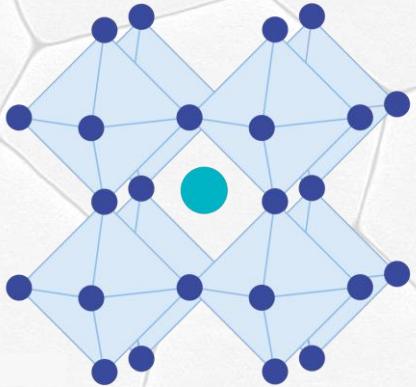
Dpto. Química Inorgánica, Cristalografía y Mineralogía
Dpto. Física Aplicada I

# HYDROGEN ($H_2$)


Hydrogen Cycle
Export
$H_2$
$H_2$ storage
$O_2$
Fuel Cell
Renewable energy
Water
electrolysis
Water
$H_2O$
Domestic use
ANODE
CATHODE

# Symmetrical SOFCs (SSOFCs)



Perovskite

- $La(Cr,Mn)O_3$
- $SrTiO_3$
- $(La,Sr)FeO_3$
- $PrBa(Mn,Fe)_2O_{5+\delta}$

→ One-stage electrode assembly

→ Electrode-electrolyte compatibility

→ Electrode regeneration!

# OBJECTIVES

$(Pr_xSr_{1-x})_{0.95}FeO_{3-\delta}$

x = 0.2, 0.4, 0.6, 0.8, 1

Synthesize the materials by the freeze-drying precursor method.

Study the influence of Pr on the structure and electrical properties.

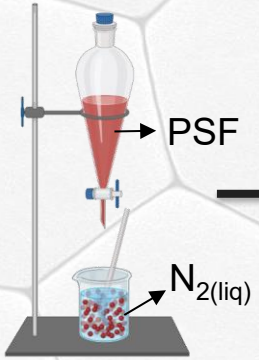
Characterize the materials obtained using XRD, NPD, SEM, complex impedance spectroscopy, ATD-TG, among others.

*Sánchez-Caballero et al., ACS Appl. Mater. Interfaces, 2025, 17(14), 21380–21391*

# EXPERIMENTAL PROCEDURE


~ pH 7

Final crystalline solution




48h

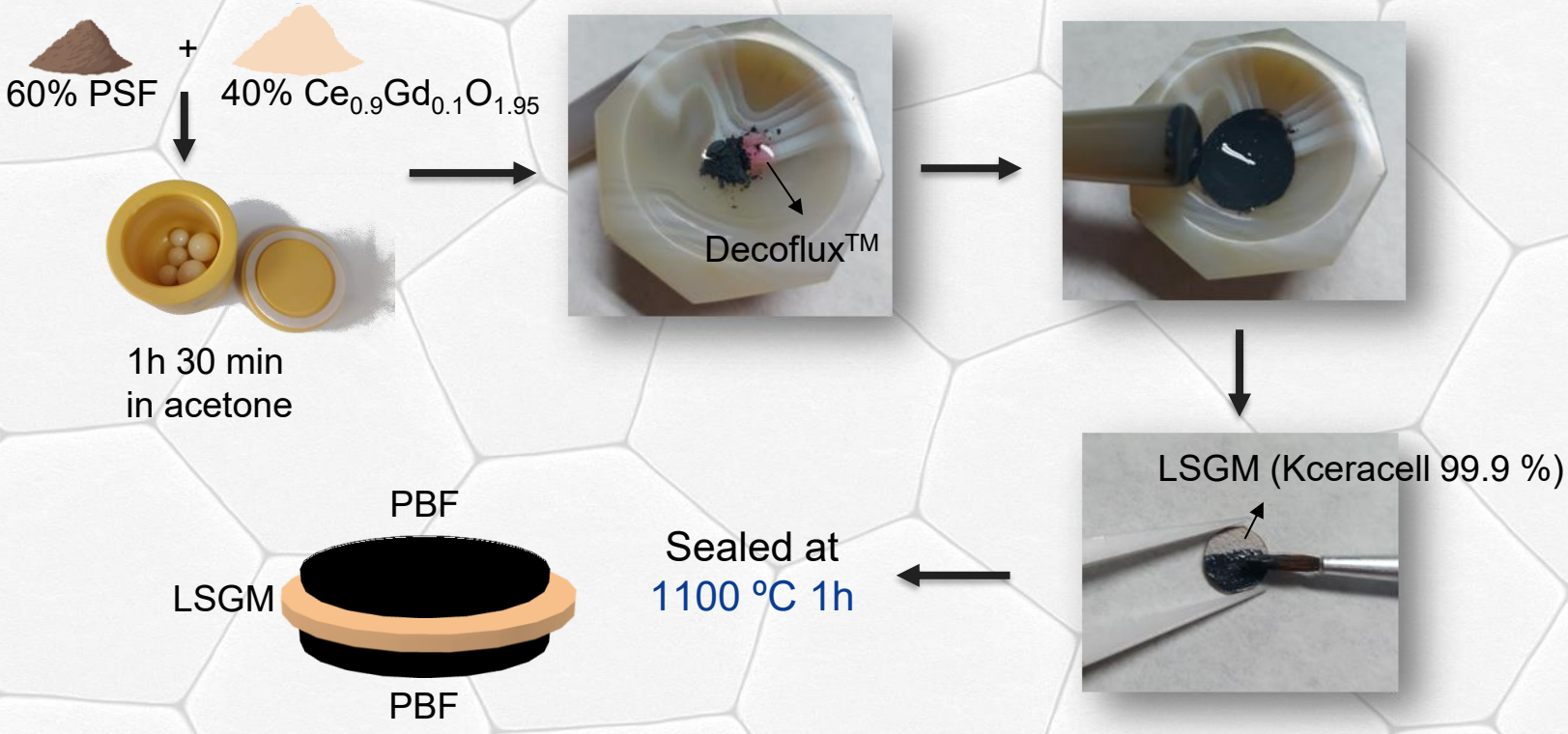
Calcined at 300 °C / 1 h

Grind

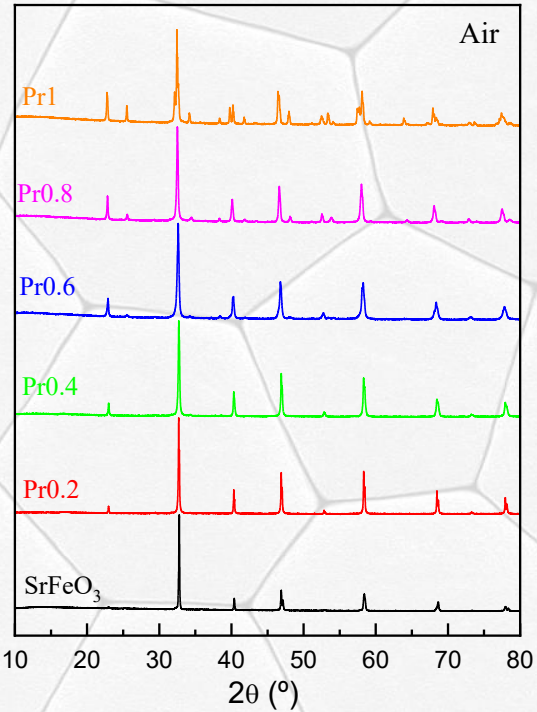
Calcined at 800 °C / 1 h


Sinterization at 1100 °C / 1 h

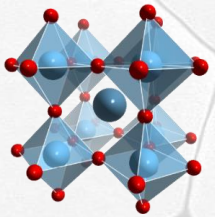
# PSF-CGO Electrode Preparation

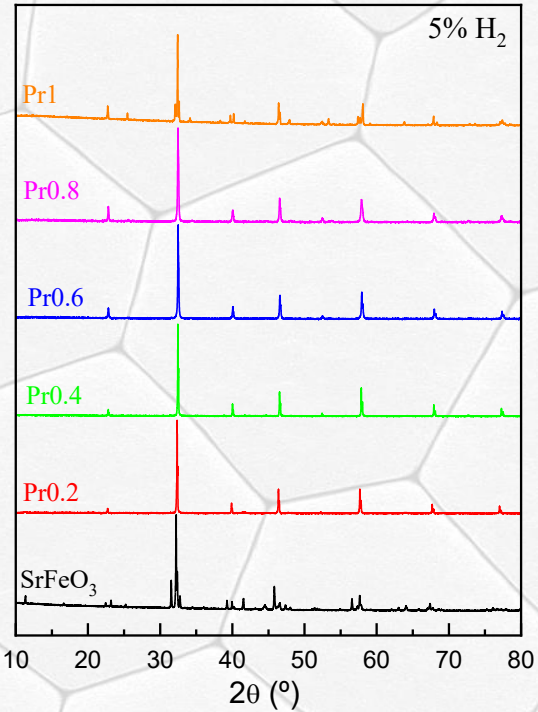


# Structural Characterization




800 ºC 12 h
5% $H_2$-Ar






X-ray patterns of $(Pr_{1-x}Sr_x)_{95}FeO_{3-\delta}$, (x= 0, 0.2, 0.4, 0.6, 0.8, 1) series calcined at 1100 °C for 1

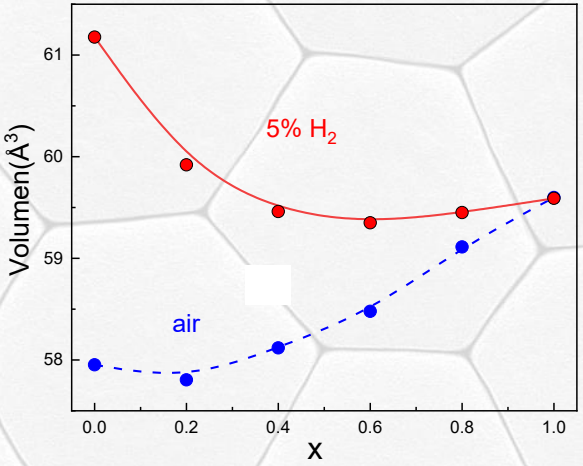
X-ray diffractograms for $(Pr_{1-x}Sr_x)_{0.95}FeO_{3-\delta}$, (x= 0, 0.2, 0.4, 0.6, 0.8, 1) reduced at 800 °C for 12 hour in 5% $H_2$-Ar

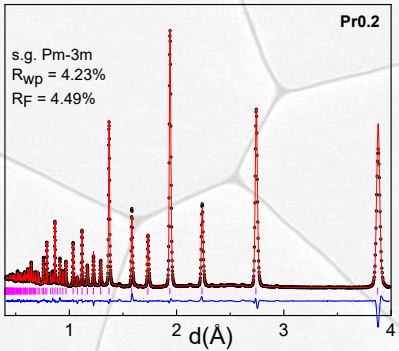
*Sánchez-Caballero et al., ACS Appl. Mater. Interfaces, 2025, 17(14), 21380–21391*

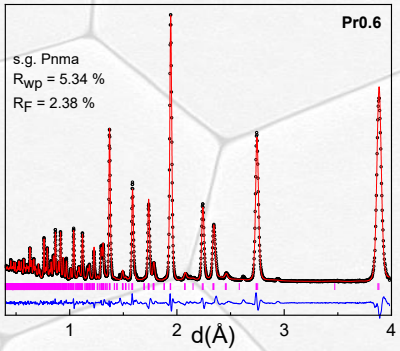
# Neutron Powder Diffraction Analysis

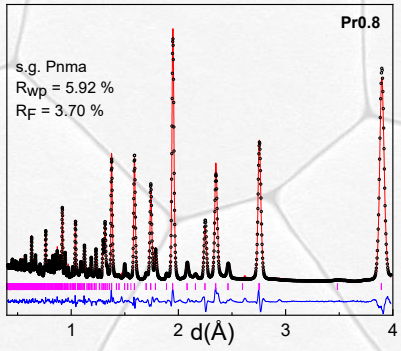
Neutron powder diffraction pattern of samples: Pr0.2, Pr0.6, Pr0.8 in air.

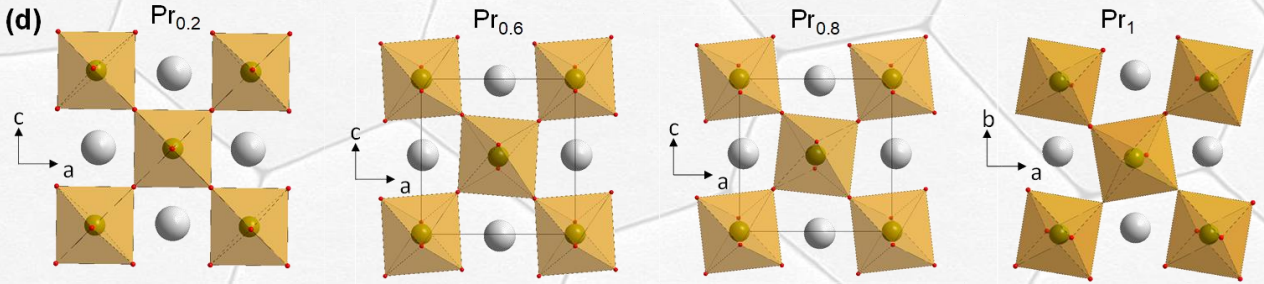
Lattice cell volume variation as a function of Pr-content



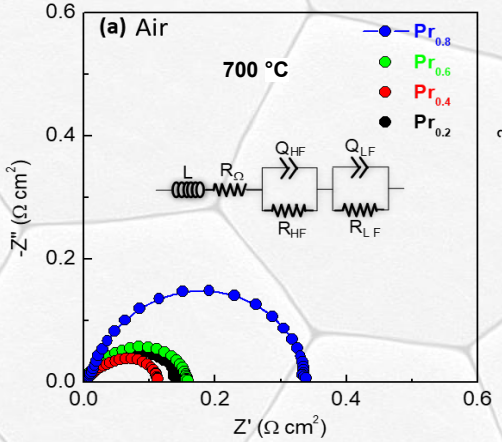



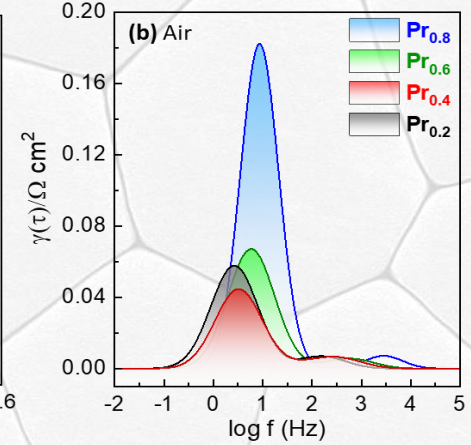



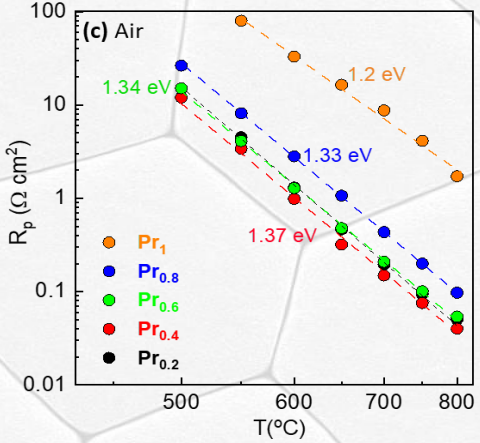



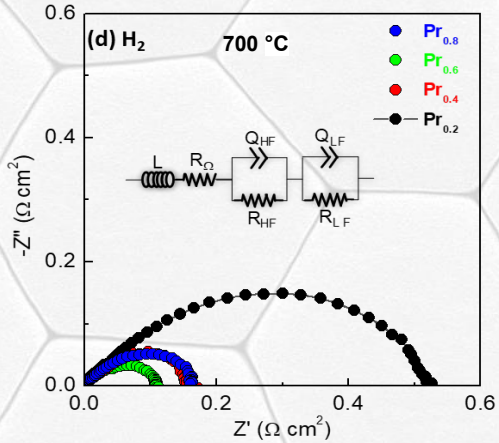



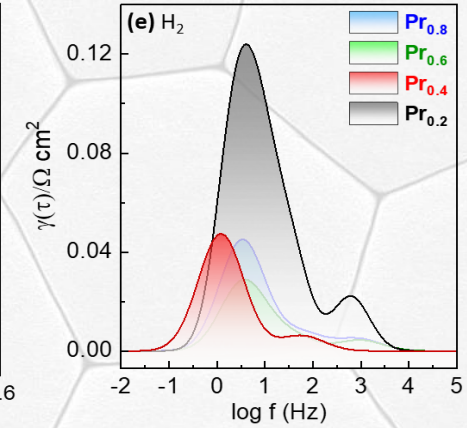
# Electrical characterization

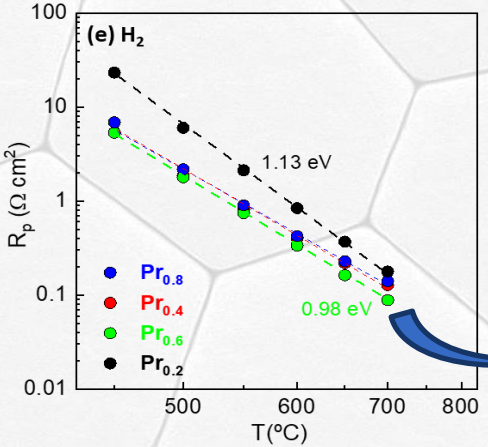


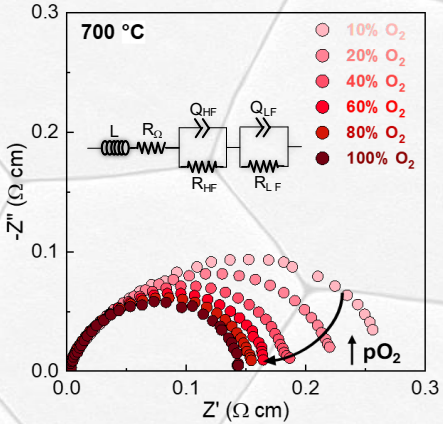

**(a,d)** Impedance spesctra **(b,e)** DRT analysis and **(c,e)** Temperature dependence of the polarization resistance in air and $H_2$.

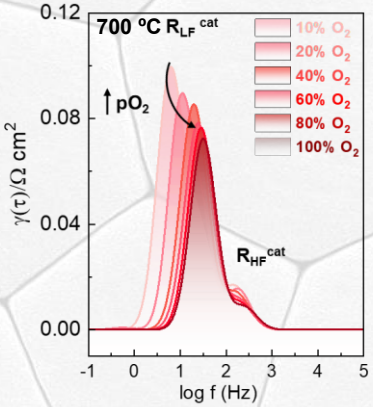
**Pr0.6**

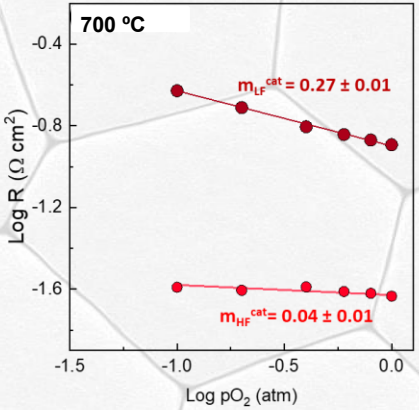
0.09 Ω cm$^2$ at 700 ºC

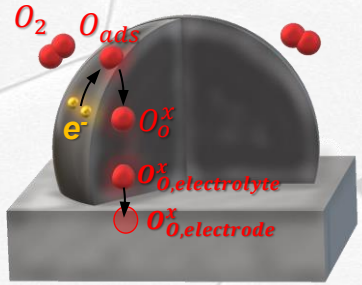
# Electrical characterization

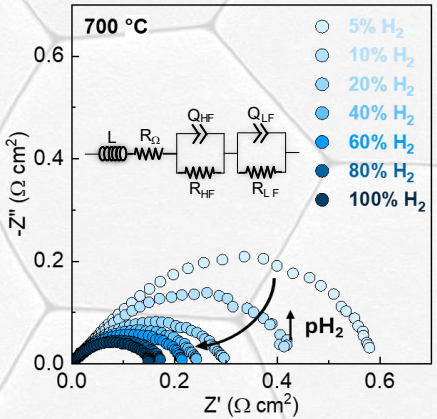
Impedance spectra, DRT analysis and pO2 and pH2 dependende of the polarization resistance

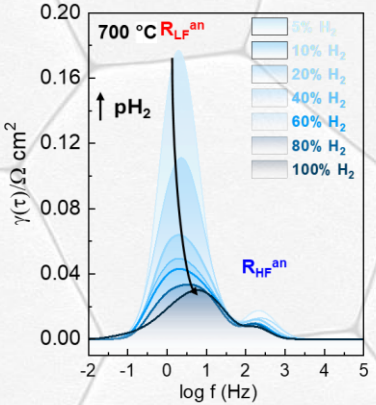


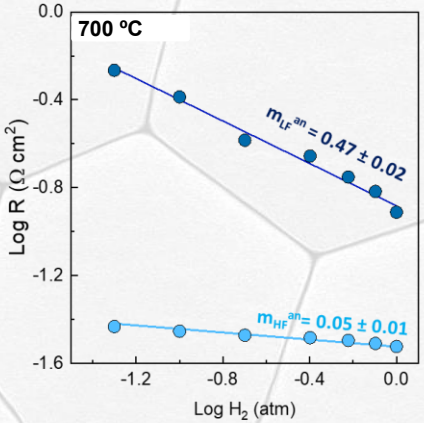



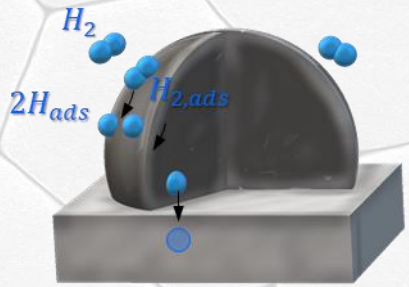



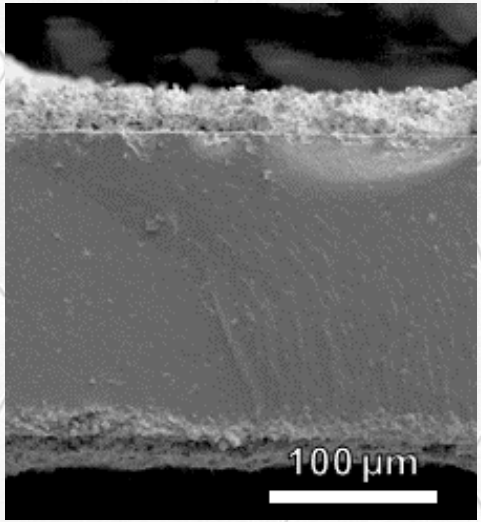



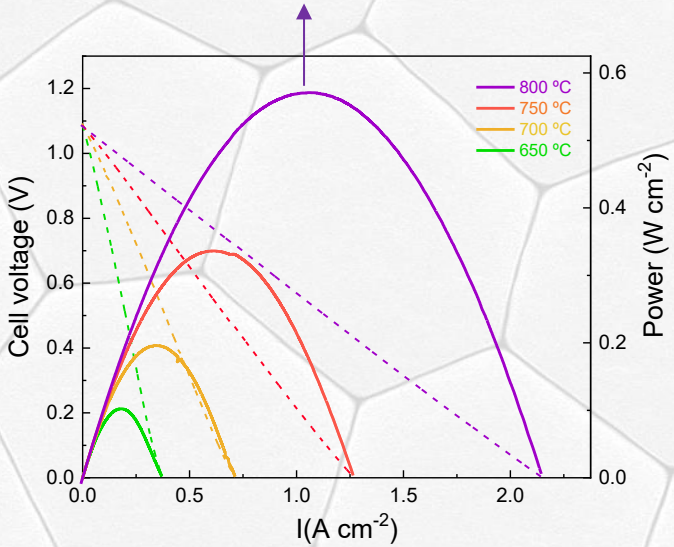
# Electrical characterization

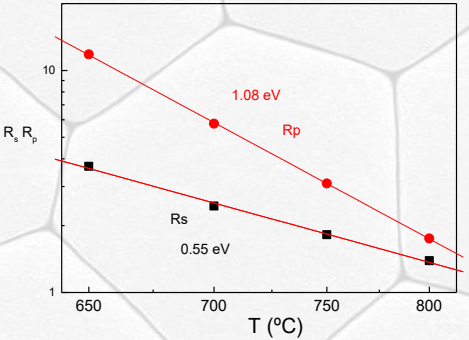
Symmetrical SOFC single-cell power performance (Pr0.6+CGO/LSGM/ Pr0.6+CGO)

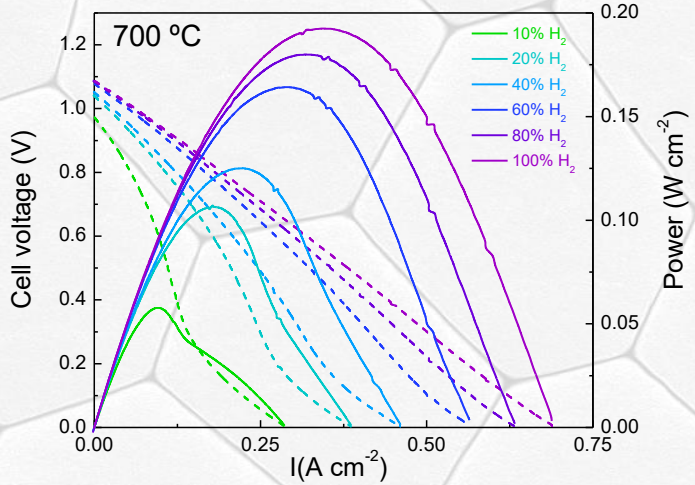



SEM imagen of single-cell

**0.6 W cm$^{-2}$ at 800 ºC**



# Conclusions

- New symmetrical electrodes are investigated **$(Pr_xSr_{1-x})_{0.95}FeO_{3-\delta}$ (0<x<1)**
- In air atmosphere, the crystal structure change from cubic symmetry for x<0.4 and orthorhombic for higher Pr-content due to tilting of the perovskite octaedra.
- The lowest $R_p$ values in air are obtained for $Pr_{0.6}$: 0.19 Ω $cm^2$ in air and 0.09 in Ω $cm^2$ $H_2$ at 700 ºC
- The rate-limiting steps for the oxygen reduction reaction and hydrogen oxidation reaction are attributed to superficial processes on the electrode surface.
- TG and dilatometric analysis confirm that the increase of Pr-content in $SrFeO_3$ minimizes both oxygen lattice release and thermal expansion.
- A manufactured symmetrical SOFC generated a power output of 0.6 W $cm^{-2}$ at 800 ºC.

*Sánchez-Caballero et al., ACS Appl. Mater. Interfaces, 2025, 17(14), 21380–21391*

# About the researching group

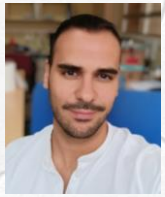
**David Marrero López**
Full Professor

**Enrique Ramírez Losilla**
Full Professor

**José Manuel Porras Vázquez**
Associate Professor

**Lucía dos Santos Gómez**
Associate Professor

**Javier Zamudio García**
Post-doctoral researcher



**Abraham Sánchez Caballero**
PhD Student

# About the researching group

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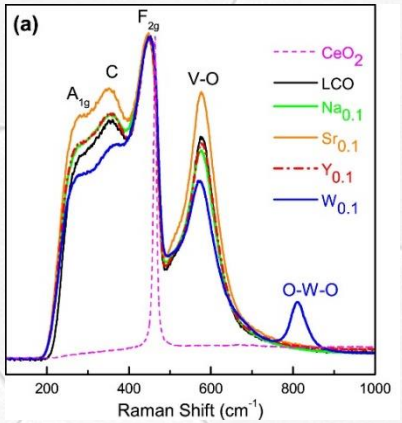
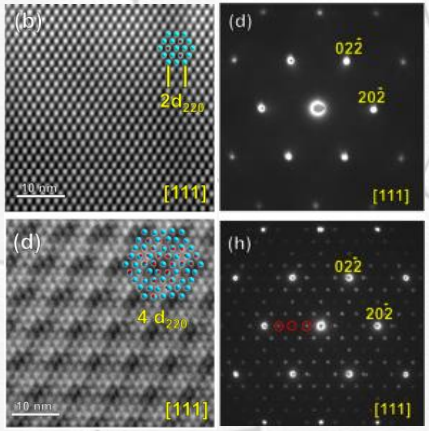
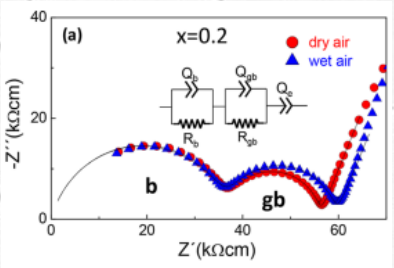
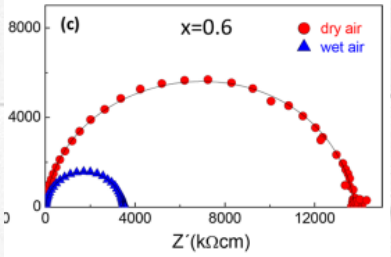
## Proton conductors

$Ce_{1-x}La_xO_{2-\delta}$ $(0 \leq x \leq 0.8)$



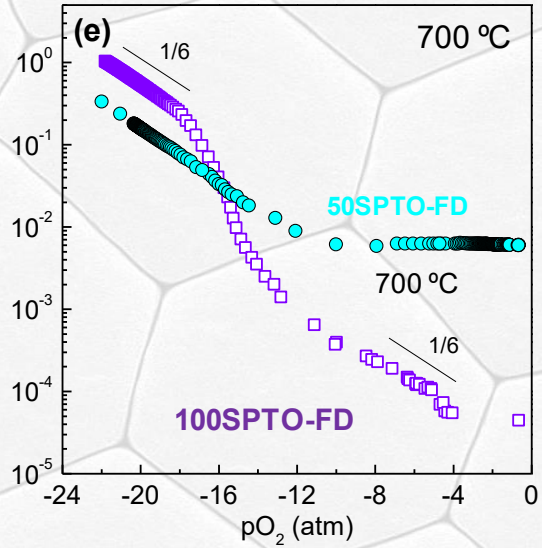



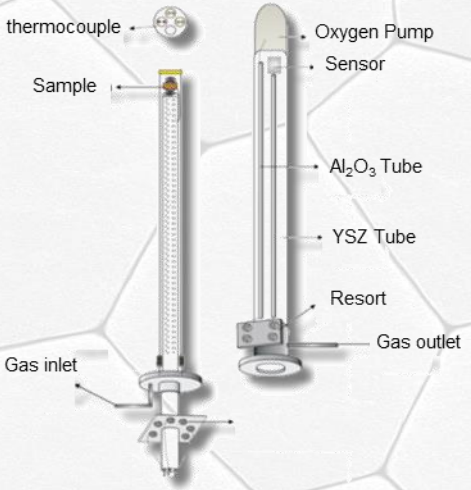




Zamudio-García et al. *Inorg. Chem.* **2019**, 58, 9368

Zamudio-García et al. *J. Alloys Compd.* **2020**, 816, 152600

## Van der Pauw meauserments in different $pO_2$




Zamudio-García, J. et al. *J. Eur. Ceram. Soc.* **2023**, 43, 4, 1548-1558.

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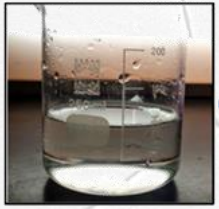
## Solid-state reaction

## Freeze-drying precursor method

Homogenous solution

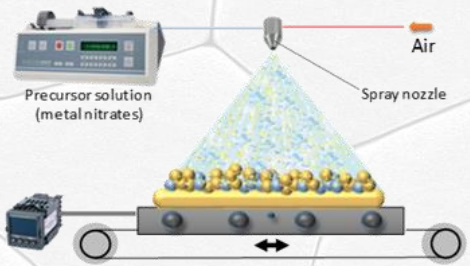


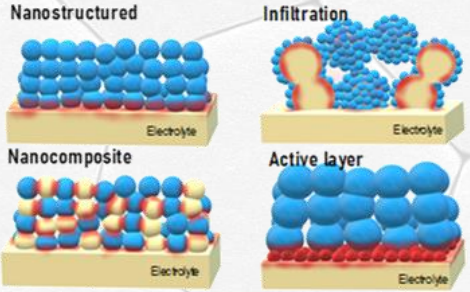
Freezing process (liquid $N_2$)

Freeze-drying

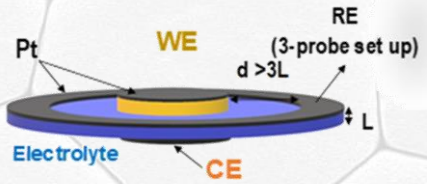
Precursor at 800 ºC

## Spray-pyrolysis



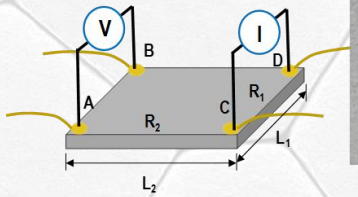



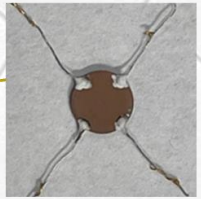

## BIAS measurements



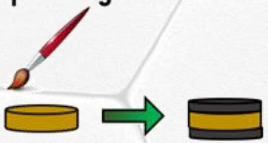

## Total conductivity measurements

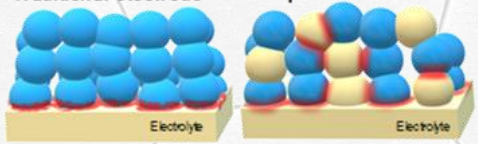
$R_{AB,CD} = V_{AB}/I_{CD}$

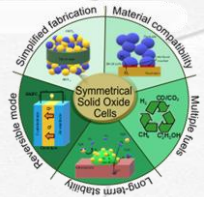


## Screen-printing





# About the researching group

### 🔬 1. Synthesis & Thin Film Processing
•Freeze-drying
•Spray pyrolysis
•Doctor Blade
•Pulsed Laser Deposition (PLD)

**Materials:**
•Electrodes & electrolytes
•Exsolution particles
•Vertically aligned nanostructures (VANs)

### 🔎 3. Spectroscopic & Surface Techniques
•Raman Spectroscopy
•X-ray Photoelectron Spectroscopy (XPS)

### ⚡ 4. Electrochemical Testing
•Symmetrical SOFC & SOEC cells
•Electrochemical Impedance Spectroscopy (EIS)
•Distribution of Relaxation Times (DRT)
•Electronic conductivity (DC method / Van der Pauw method)

### 🛠️ 2. Structural & Morphological Characterization
•X-ray Diffraction (XRD)
•Neutron Diffraction
•Rietveld & Le Bail refinements
•Thermomechanical Analysis (TEC)
•Differential Thermal Analysis / Thermogravimetric Analysis (DTA–TGA)

**Microscopy & Imaging**:
•Scanning Electron Microscopy (SEM)
•Transmission Electron Microscopy (TEM)
•Atomic Force Microscopy (AFM)
•Electron Diffraction (SAED/NBD)
•Energy Dispersive X-ray Spectroscopy (EDS)

*Some of these techniques are conducted in collaboration with academic institutions and research centers, both national and international.*

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SOFC@uma.es

# Thanks for your attention!

## Enhanced electrochemical behavior and lower thermal expansion in Pr-doped $SrFeO_3$ for symmetric SOFC electrodes

Any Question

Abraham Sánchez Caballero

abraham11sc@uma.es

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