

# Welcome to the...



Chair of  
Technical Electrochemistry

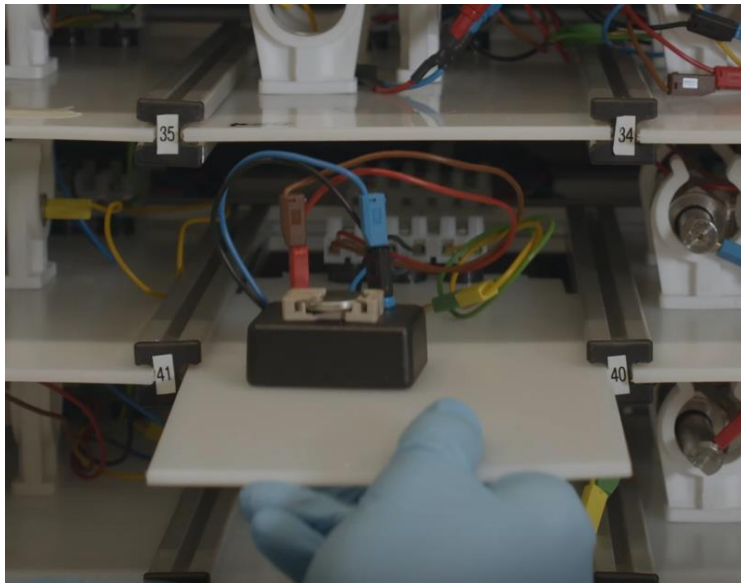


# What are we doing?

## Research Focus @ TEC

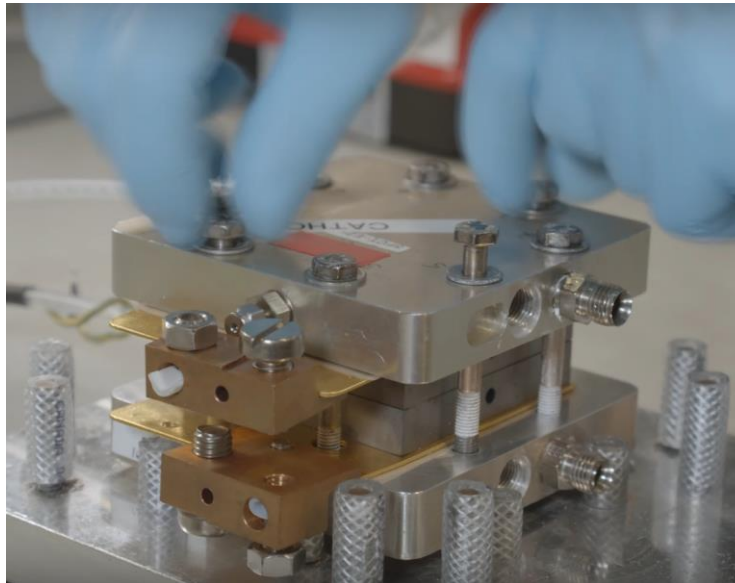
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Batteries



2

Fuel Cells



3

Electrolysis



Chair of Technical Electrochemistry

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# BATTERY RESEARCH

# Overview of Battery Research @ TEC

Our activities cover several steps along the value chain of battery research for next generation anode and cathode materials, starting with material preparation, development and application of different analytical methods up to electrochemical performance testing using different cell setups.

## Fields of Research:

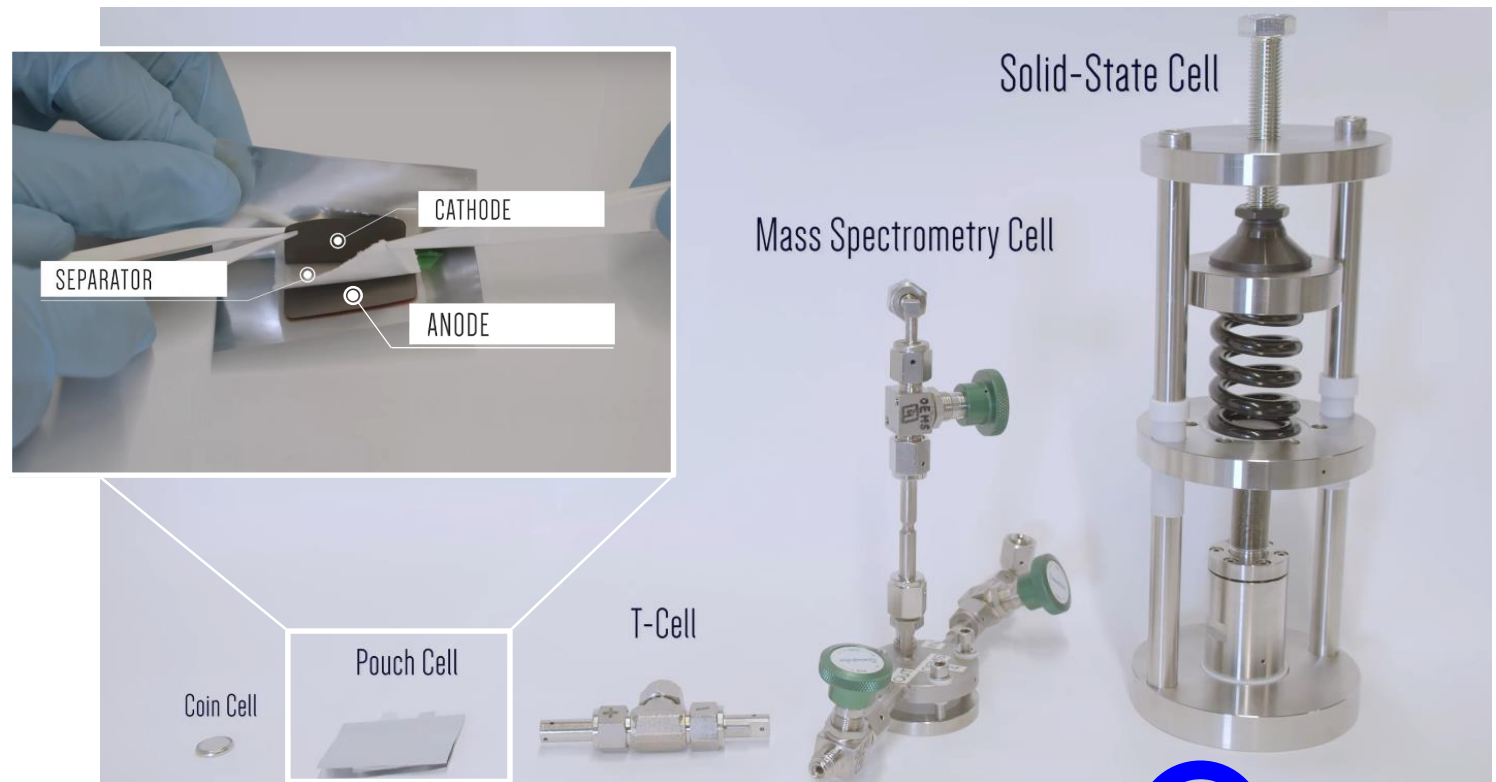
Negative Electrode (Anode)

Positive Electrode (Cathode)

All-Solid-State-Batteries

Kinetic & Transport Parameters

Scale-up



See how Battery Research in our lab looks like!



# Negative Electrode (Anode)

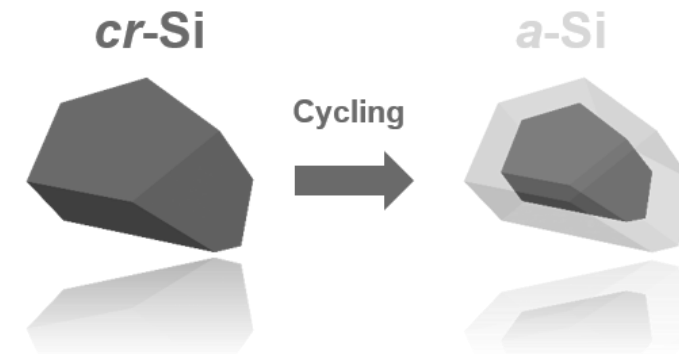
The anode research focuses on processes of the intercalation material graphite and (de-)alloying material silicon. The anode acting as a lithium host material and plays an important role on cycling performance and battery lifetime. Thus, we investigate degradation mechanisms on the material level, such as morphological changes of silicon particles, as well as the buildup of an effective solid electrolyte interface (SEI) and its changes upon cycling.

## Our interests:

- Monitoring structural changes of Si-particles (e.g. partial amorphization) with varying cycling conditions
- Understanding the mechanism and effect of novel solvent additives on anode materials
- Correlate the SEI formation with Li-inventory loss and cell performance

## Contact:

Maximilian Graf, [maximilian.graf@tum.de](mailto:maximilian.graf@tum.de)



Amorphization of a crystalline  $\mu$ -sized Si-particle upon (de-)lithiation.



# Positive Electrode (Cathode)

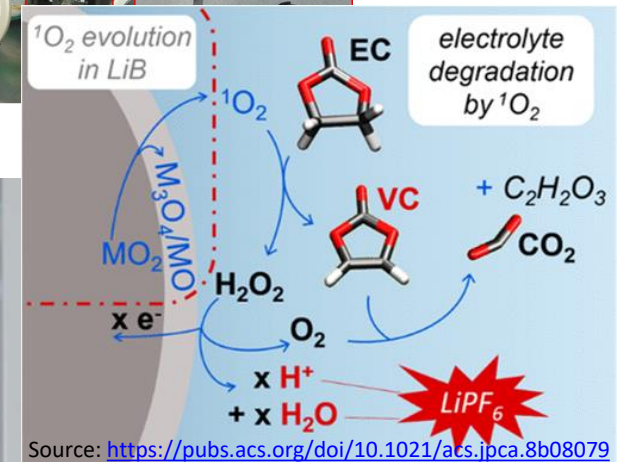
The cathode active material traditionally used in commercial Li-Ion battery is a layered lithium metal oxide. This ternary system delivers high energy densities over a long cycle life. Unfortunately, these materials are thermodynamically limited and only 75 % of the containing Li can be used, which intrinsically limits the energy density of these materials. The crystal lattice collapses if more Li is removed and the cycle performance is diminished. Our group is focusing on understanding the effects at play during this decomposition. Furthermore, new classes of cathode active materials are also investigated which offer higher energy densities while suffering from poorly understood stability issues, such as release of singlet oxygen.

## Our interests:

- Characterization of next generation cathode materials (Ni-rich or Li-/Mn-rich NMC, LNMO) with *operando* analytical techniques (OEMS, XRD, XAS, EIS)
- Optimization of commercial calcination and washing steps
- Surface stabilization of cathode active materials by generating a resilient protection layer

## Contact:

Louis Hartmann, [louis.hartmann@tum.de](mailto:louis.hartmann@tum.de)



# All-Solid-State-Batteries

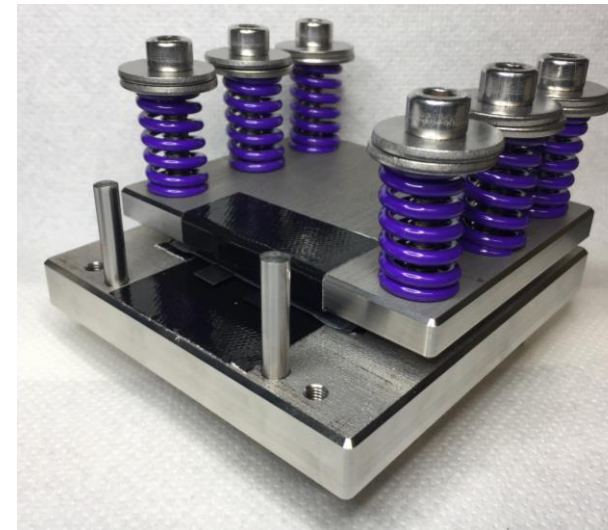
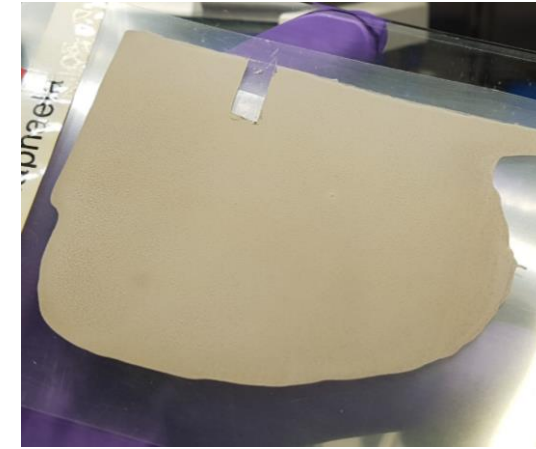
All-solid-state lithium-ion batteries (Li-ASSBs) are regarded as promising candidates for the next generation of energy storage systems for electric vehicles and mobile devices. ASSBs offer potentially higher energy densities due to the usage of Li-metal as anode material and higher safety due to the non-flammability of many solid electrolytes compared to the state of the art Li-ion batteries (LIBs) with flammable organic electrolytes. At TEC, we investigate the complete variety of ASSBs from material characterization of new solid electrolytes to cell manufacturing in different cell designs (e.g. pressure cells and pouch cells).

## Our interests:

- Development and validation of cell setups for high pressure impedance analysis
- Preparation of all-solid-state lithium-ion battery cells
- Characterization of the solid electrolyte/lithium interface as well as the cathode electrolyte interface (CEI)

## Contact:

Tobias Kutsch, [tobias.kutsch@tum.de](mailto:tobias.kutsch@tum.de)



# Kinetic & Transport Parameters

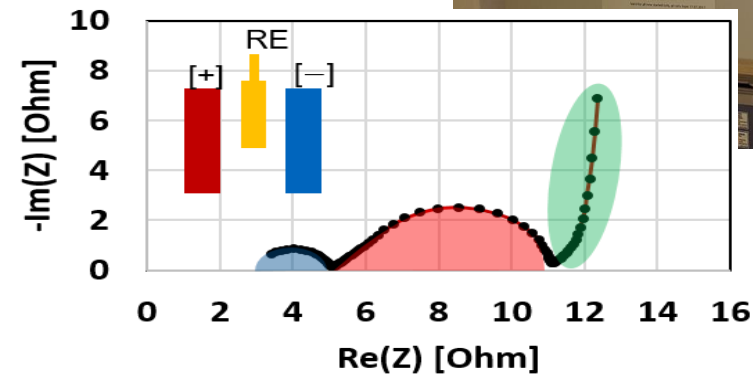
For an accurate simulation of lithium-ion batteries, a large number of model parameters is needed. At TEC we developed measurement techniques and cell designs to measure a large number of these parameters, especially geometric parameters of porous electrodes, the kinetics of battery active materials as well as electrolyte transport parameters.

## Our interests:

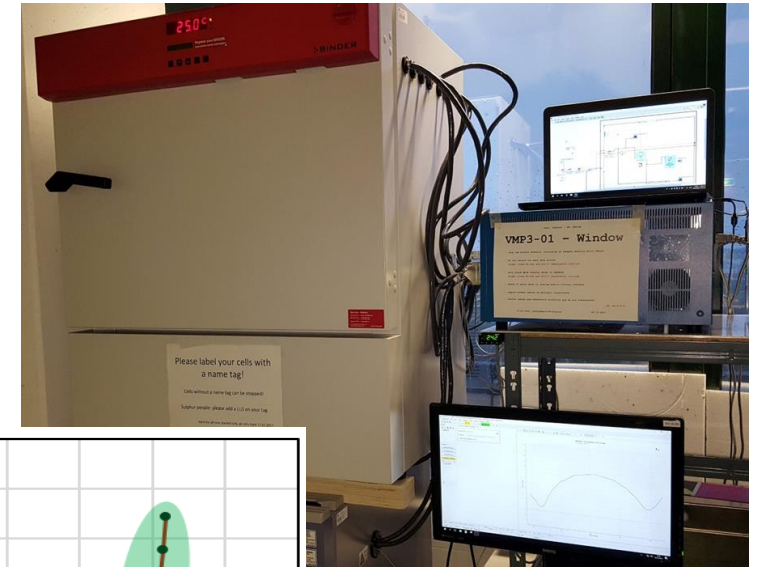
- Understanding the limitation of porous electrodes
- Direct experimental determination of transport parameters in different electrolytes
- Development of new experimental setups for parameter determination

Contact:

Robert Morasch, [robert.morasch@tum.de](mailto:robert.morasch@tum.de)



1. Contact Resistance
2. Convolution of Double Layer Capacitance, Ionic-, Charge Transfer- and SEI resistance for graphite electrode
3. Solid Phase and Electrolyte Phase Diffusion Processes





# Scale-up

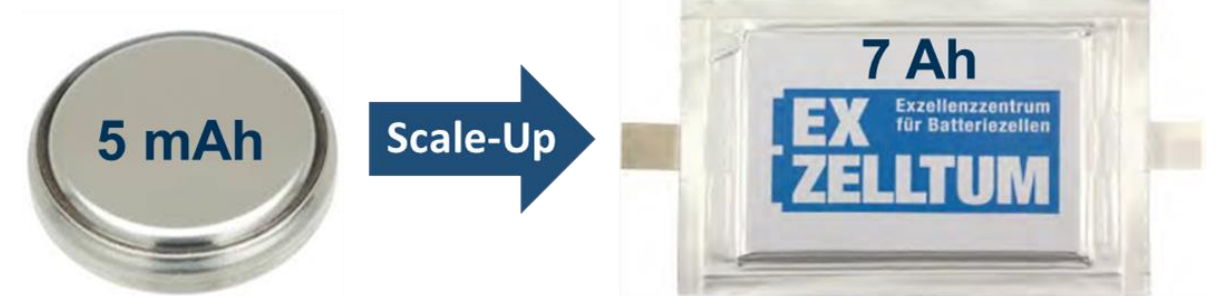
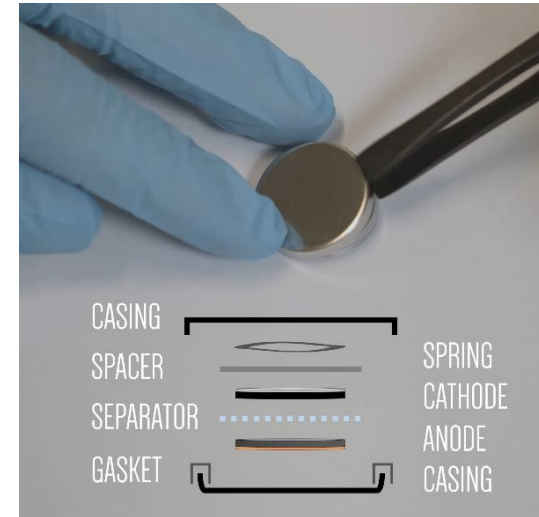
The manufacturing of battery cells is a multi-step process, including mixing of electrode materials, coating, calendaring, drying, cell confectioning, electrolyte filling and formation. At TEC, we investigate the cell manufacturing process in close collaboration with the [Institute for Machine Tools and Industrial Management \(iwb\)](#). We transfer lab scale developed process parameters for new materials to their pilot production line and study the influence of up-scaled production and cell and material properties with several diagnostic methods.

## Our interests:

- Studies on the mechanical and electrical properties of the electrodes manufacturing process
- Gassing behavior depending on cell geometries, electrolytes and the formation process
- Pressure and temperature difference in lab cells and multilayer pouch cells and their influence on the material and cell performance

Contact:

Tanja Zünd, [tanja.zuend@tum.de](mailto:tanja.zuend@tum.de)



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# FUEL CELL RESEARCH

# Overview about PEMFC\* Research @ TEC

\* PEMFC: Polymer Electrolyte  
Membrane Fuel Cell

**Anode**  
 $2\text{H}_2 \rightleftharpoons 4\text{H}^+ + 4\text{e}^-$

**Cathode**  
 $\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}$

## Fuel Cell Testing

- Fuel cell performance testing  
→ catalyst activity  
→ mass transport
- Accelerated stress tests to evaluate the durability

## Membrane Electrode Assembly

- Catalyst synthesis and characterization
- Catalyst support modification
- Ionomer optimization
- MEA fabrication

## Gas Diffusion Layer

- Compression tests inside the fuel cell
- Characterization in terms of porosity and tortuosity

## Further characterization methods

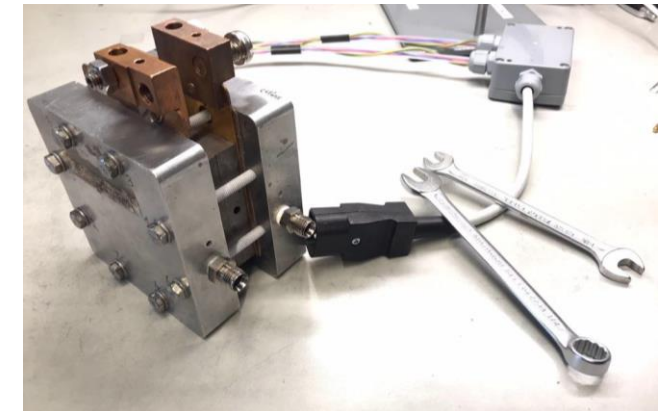
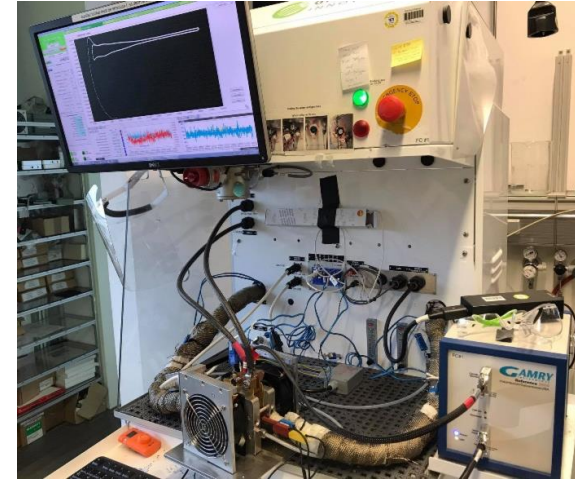
- RDE (Rotating Disc Electrode)
- XPS (X-ray photoelectron spectroscopy)
- BET (Brunauer-Emmett-Teller-Measurement)
- Mercury porosimetry
- TGA (Thermal gravimetric analysis)
- SEM/EDX

# PEM Fuel Cell Durability & Diagnostics

PEM FCs must meet defined lifetime expectations to increase their appeal for transportation applications. This key performance factor (namely, durability) points out the need of understanding degradation mechanisms intrinsic to the operation of a PEM FC. One crucial part of our job at Technical Electrochemistry is the application of accelerated stress tests (ASTs) to trigger degradation in laboratory scale setups, followed up by the assessment of the targeted component status by *in situ* and *ex situ* diagnostic tools, leading to a final correlation between the observed degradation and performance loss.

## Our interests:

- Testing of aging protocols for localized component degradation (catalyst layer, proton-exchange-membrane and bipolar plates).
- Utilization of *in situ* and *ex situ* diagnostic tools to correlate degradation to performance losses in PEM FCs.
  - Catalyst degradation under transient operations e.g. start-up and shutdown cycles (SUSD).
  - Membrane state-of-health after wet / dry cycles.
  - Effect of high oxygen permeable (HOP) ionomers on mass transport limitations during high current operation.
  - Morphological changes in the MEA (membrane electrode assembly) via SEM imaging.



Contact:  
Leonardo I. Astudillo, [leonardo.astudillo@tum.de](mailto:leonardo.astudillo@tum.de)



# Catalyst Synthesis & Catalyst Layer Design

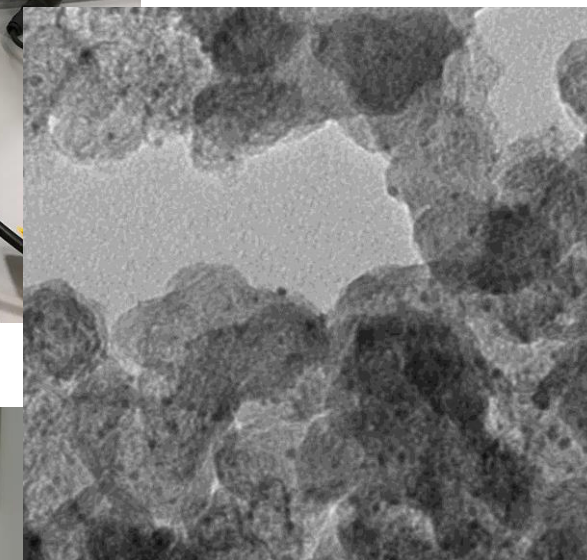
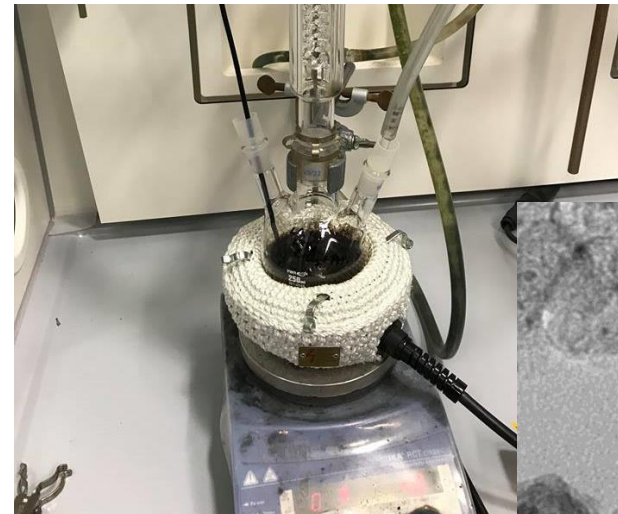
At the atomic level, fuel cells rely on supported catalysts based on platinum group metals (PGM) to minimize the overpotentials associated with oxygen reduction (ORR) and hydrogen oxidation (HOR). Activity and stability of these systems can be tuned by tailoring their electronic and morphological structure in synthesis. At the device level, integration of these novel materials requires a catalyst layer fabrication process optimized for efficient mass transport in the three-dimensional microstructure.

## Our interests:

- Synthesis and characterization of PGM-based catalysts and catalyst alloys
- Modification of support morphology and surface properties
- Multi-objective optimization of electrode microstructure and transport properties

## Contact:

Timon Lazaridis, [timon.lazaridis@tum.de](mailto:timon.lazaridis@tum.de)



# Pt-free Catalysts

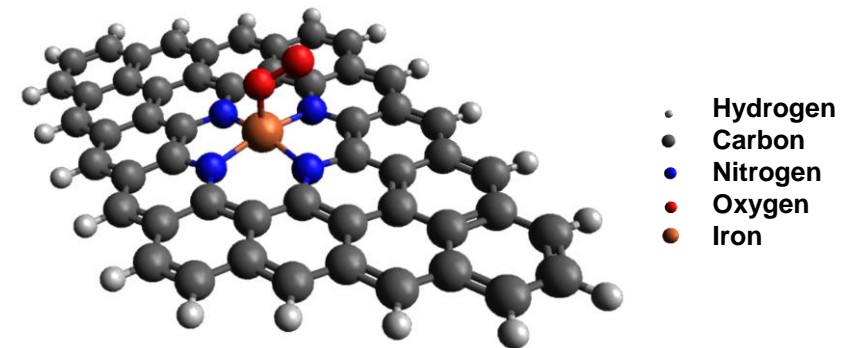
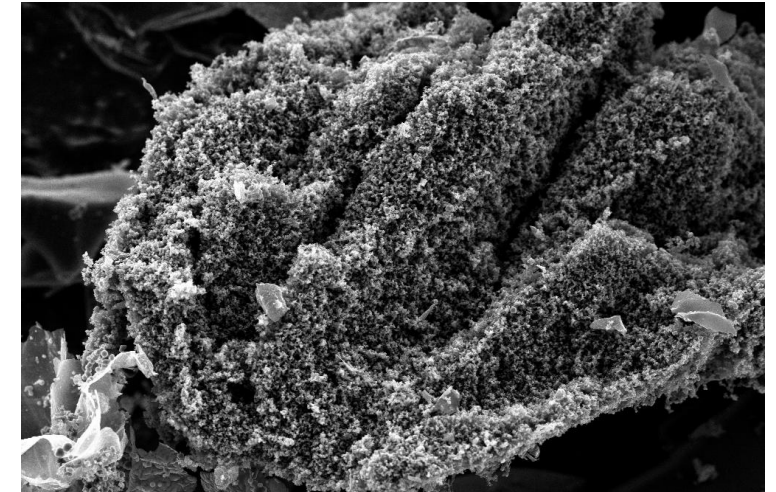
The high cost and the restricted availability of Pt and other critical raw materials (CRM) used in current catalysts is one of the major hurdles for the large-scale commercialization of Proton Exchange Membrane Fuel Cells (PEMFCs). Our research deals with finding appropriate and inexpensive alternatives to CRM in terms of activity and stability, with a major focus on catalyst layer design and testing, both for commercially-available and home-made catalysts.

## Our interests:

- Novel Pt-free catalyst developing
- In-situ quantification and mechanistic study of active sites for Pt-free catalyst
- Catalyst layer design and characterization in PEMFC

Contact:

Yan-Sheng Li, [yan-sheng.li@tum.de](mailto:yan-sheng.li@tum.de)



# Gas Diffusion Layers

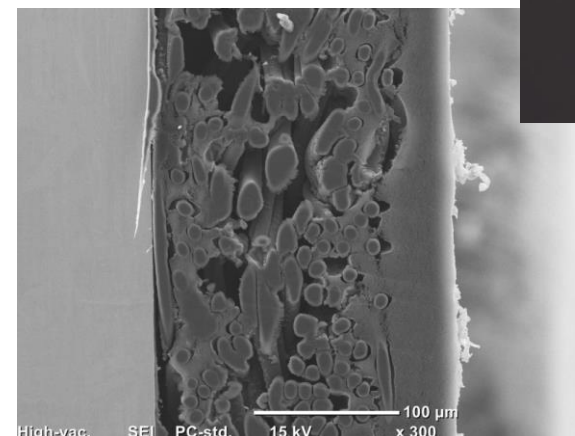
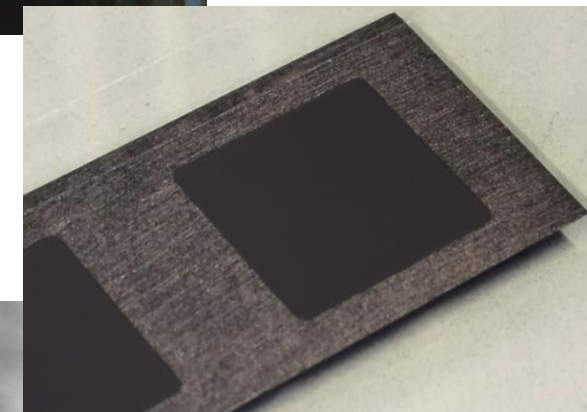
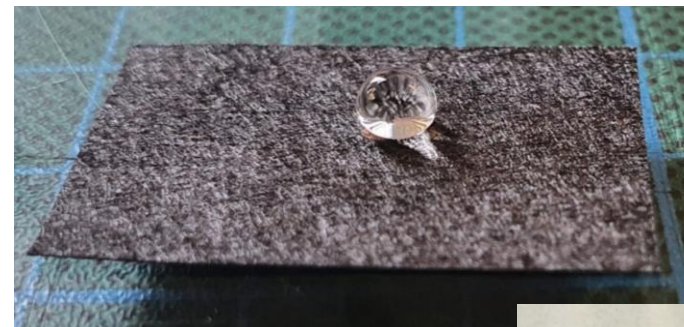
The role of the gas diffusion layer (GDL) is to homogeneously distribute reactant gases over the electrode surface, to efficiently remove product water, and to provide good electrical and thermal contact. At TEC, we are investigating the complex transport processes and optimizing the properties with regard to high current density operation.

## Our interests:

- Preparation and characterization of innovative microporous layer (MPL) coatings
- Determination of effective mass transport properties by limiting current approach in differential single cell
- Development of novel GDL/MPL characterization techniques

Contact:

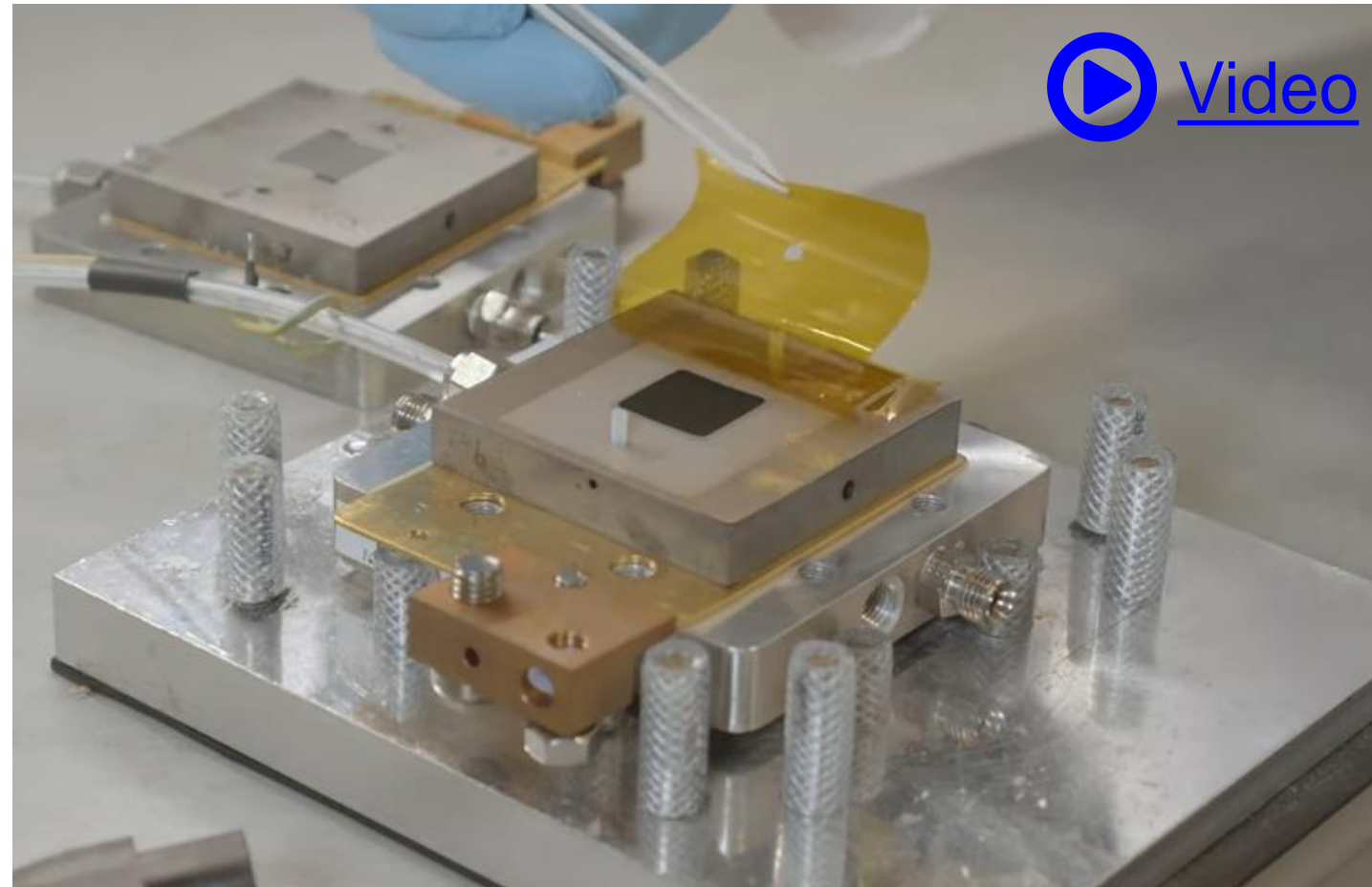
Anne Berger, [anne.berger@tum.de](mailto:anne.berger@tum.de)





# Interested to see more?

See how Fuel Cell Research in our lab looks like in the video below!





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# ELECTROLYSIS RESEARCH

# Proton Exchange Membrane (PEM) Water Electrolysis

PEM water electrolysis could become a key component in future carbon free energy systems by providing sustainable hydrogen for large scale energy storage. In PEM water electrolyzers with a solid state proton conductive membrane, water is electrochemically split into oxygen and hydrogen. To improve the economic competitiveness of PEM electrolyzers, inter alia, developments in the fields of catalyst materials and membrane electrode assemblies (MEA) are necessary.

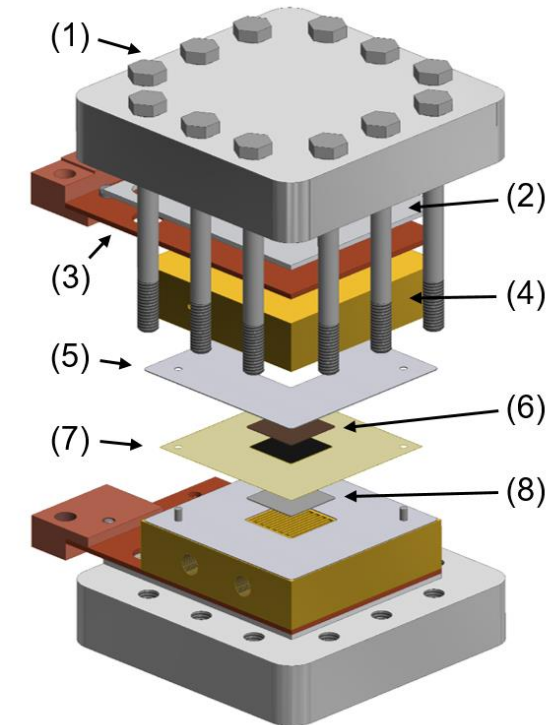
## Our interests:

- Characterization and optimization of membrane electrode assemblies (MEAs) with novel catalyst and membrane materials
- Optimization of porous transport layers
- Identification of aging mechanisms under transient operation conditions
- Gas permeation measurements during high pressure electrolysis

## Contact:

Matthias Ernst, [m.ernst@tum.de](mailto:m.ernst@tum.de)

Matthias Kornherr, [matthias.kornherr@tum.de](mailto:matthias.kornherr@tum.de)



**Figure:** Schematic drawing of a 5 cm<sup>2</sup> high pressure electrolysis cell: (1) aluminum end plate, (2) Gylon® layer, (3) copper current collector, (4) gold coated titanium flow-fields, (5) PTFE gaskets, (6) carbon PTL, (7) MEA, and (8) titanium PTL.

Maximilian Bernt and Hubert A. Gasteiger, *J. Electrochem. Soc.* **2016**, 163(11), F3179-F1389