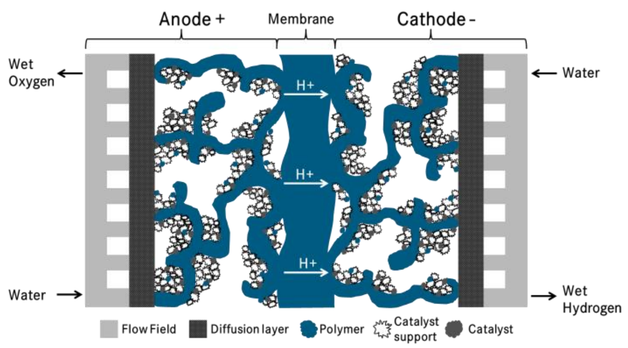
Concept and Challenges in the Production of Structured Electrodes

Regarding the conversion of electrical energy into chemical energy carrier and vice versa, electrodes with a high efficiency are required. During the different production steps the electrode structure is formed and influenced by changing process parameters.

The chemical processes inside an MEA of a PEM-water electrolysis cell are shown below.



The crucial physical and chemical processes are:

- Diffusion of water to the catalyst layer (wetting, diffusion)
- Electrochemical reaction at the catalyst
- Transport of oxygen from the electrode to the flow field
- Transport of protons through the catalyst layer and membrane to the cathode
- Transport of electrons through the diffusion layer and catalyst
- The amount of unconnected catalyst and electrolyte phases should be small

One way to influence the electrode structure is to use the intermolecular forces between catalyst, catalyst support, and polymer particles by using different process parameters and additives during dispersion production. Following investigations are necessary:

- Correlation between production parameters, additives and the dispersion structure
- Understanding of the structure-forming processes during dispersing, coating and drying
- Relationship between electrode structure and the electrode efficiency
- Rules for scale-up of laboratory processes into pilot plant scale

Cooperation

The development and evaluation of catalyst systems, catalyst coated membranes, current collectors, and bipolar plates for the implementation of PEM electrolysis, extending up to complete systems (stacks), will be a core competence of the Institute of Energy and Climate Research – Electrochemical Process Engineering (IEK-3) together with cooperation partners.

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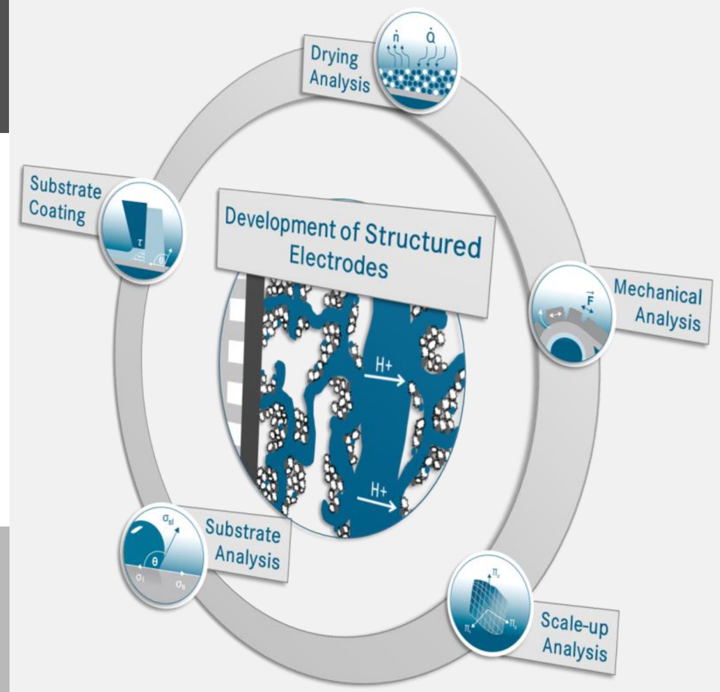


Development and Manufacturing of Structured Electrodes for Polymer Electrolyte Water Electrolysis and Fuel Cells

JÜLICH
FORSCHUNGSZENTRUM

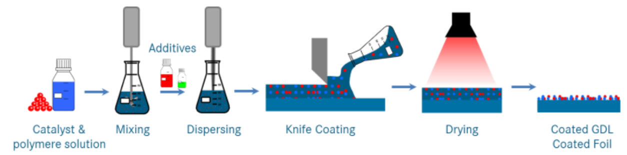
Introduction

Stacks of Membrane Electrode Assemblies (MEAs) are the core components of electrolysis and fuel cell technology. Both applications are of central importance for storage and conversion systems in a renewable energy supply.

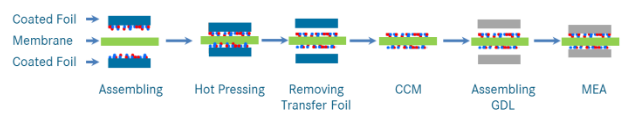
In order to get a high efficiency for the conversion of electrical energy into chemical energy and vice versa, the physico-chemical processes inside the MEA need to be well adjusted by optimizing the materials and production processes used for MEA preparation.

MEA Production Processes

The basic processes for electrode production are mixing, dispersing, coating, and drying. Each of these process steps influences the structure of the electrode which affects the efficiency.



In case gas diffusion layers (GDLs) are deployed as substrates, the coated GDLs (gas diffusion electrodes – GDEs) are assembled with a membrane by hot pressing (GDE technique).



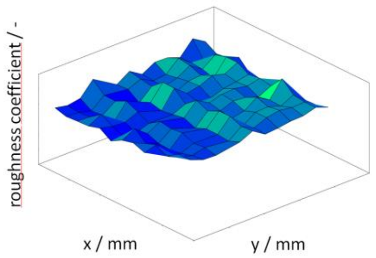
The CCM technique (catalyst coated membrane) uses transfer foils as substrate. Hereby the MEA is prepared by removing the foil after the hot pressing and assembling the GDLs.

To optimize the electrode structure, the impact of material and process parameters on this structure during the manufacturing needs to be analyzed. Furthermore, to ensure the process scalability, on-going reconciliation between laboratory development and roll-to-roll pilot plant production is necessary.

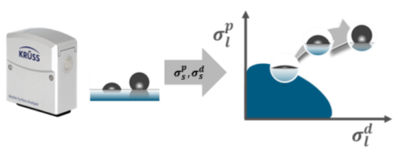
Substrate Analysis

Substrate analysis is one important precursor to achieve homogenous coating results. The focus is on surface morphology, surface free energy, thickness, and basis weight distribution.

Surface morphology gives an indication of the adhesion mechanism between coating and substrate. Surface analysis is supported by laser scan microscopy.



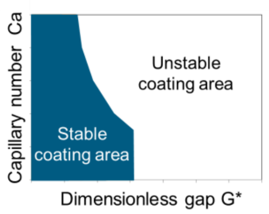
The surface free energy is essential for understanding the substrate wettability. The measurement is taken by contact angle measurement with drop shape analyzers and calculated by methods generally used like OWRK or Wu. By the knowledge of the surface free energy and application of the wetting envelope it can easily be seen whether catalyst dispersion wets a substrate or not.



Substrate Coating

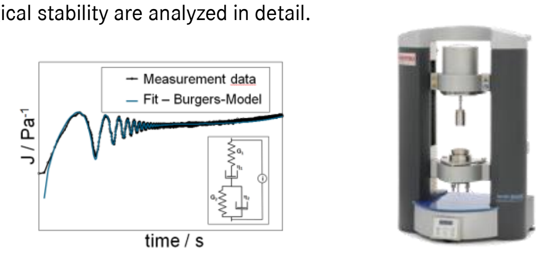
Substrate coating is developed under laboratory conditions with regard to subsequent scale-up to pilot plant dimensions.

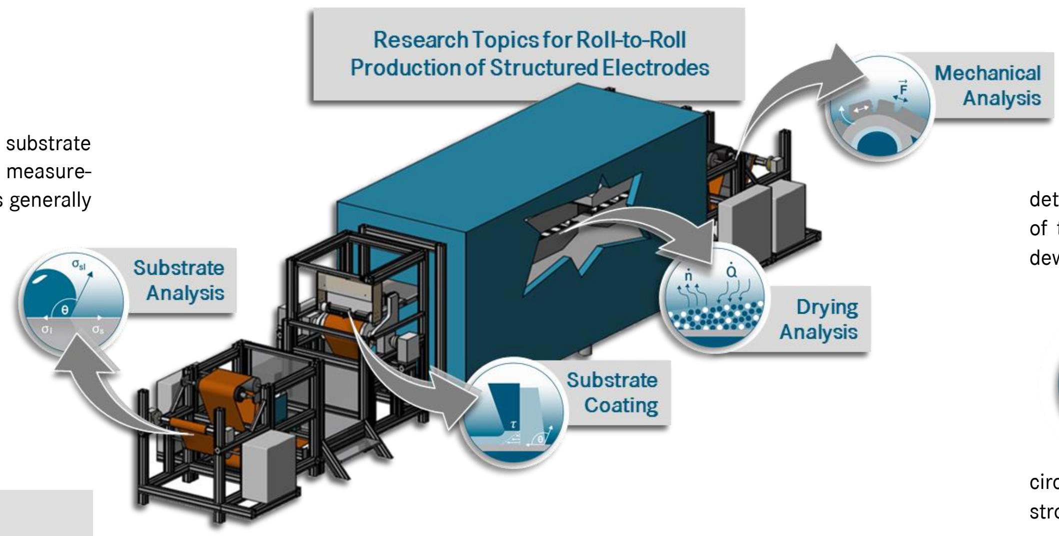
The coating parameters need to be chosen with respect to the coating window, showing the dependency between capillary number Ca and dimensionless gap G*.



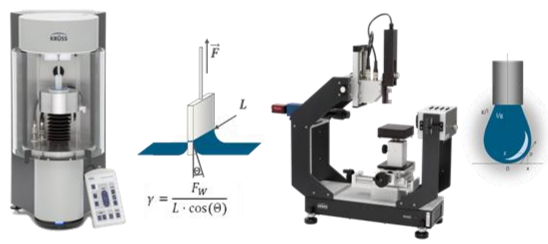
Apart from analyzing the surface tension of the catalyst dispersion, a rheological characterization is needed to determine the capillary-number Ca.

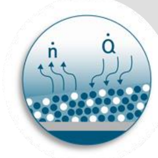
Rheological properties like viscosity, viscoelasticity, thixotropy, and rheological stability are analyzed in detail.





Surface tension is measured by drop shape analysis of pendant drop or by application of Wilhelmy's or Du Noüy's method using a force sensor tensiometer.

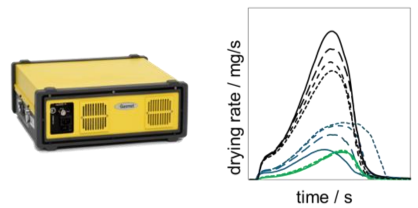




Drying Analysis

The drying process is a further key step to influence the quality of the coating and the electrical structure.

During the drying of the coated wet film the chemical composition can change over time. This leads to variation of density, surface tension, and rheological structure with the result of Marangoni convection. The selectivity of the drying process can be analyzed by Fourier transform infrared spectroscopy.

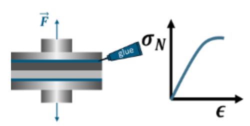


The knowledge of time dependent coating composition allows the determination of rheological and tensiometric properties as a function of temperature and composition in order to investigate wetting and dewetting phenomena during the drying step.

Mechanical Analysis

In the roll-to-roll coating process the final layer is coiled up. Afterwards, the layer is transferred to the membrane by hot pressing. To meet these circumstances, adhesion between coating and transfer foil needs to be strong enough that handling the coated substrate like winding and unwinding is possible, but adhesion needs to be weak enough for an entire transfer.

Adhesion properties are analyzed by measuring the tensile strength between the coated layer and the transfer foil. The adhesion characterizing parameters can be analyzed as a function of process parameters like coating thickness or drying temperature.



Cohesion properties inside the catalyst layer are investigated by analyzing the crack shape and width inside the layer.

Pilot Plant Production

The different process steps are developed and optimized on laboratory scale. These processes need to be scaled up for the pilot plant production which is focused on a roll-to-roll knife coating process.

Available Processes

Winding/ Unwinding	Coating	Drying	Sintering
• Maximum roll width: 55 cm • Maximum force control: 250 N	• Knife-Coating • Slot Die Coating • Maximum coating width: 45 cm	• Maximum drying temperature: 230 °C • Independent temperature control in 3 sections	• Maximum sintering temperature: 400 °C

Project Work

- Production of electrodes for water electrolysis
- Production of gas diffusion electrodes for DMFC
- Further development of the coating processes for increasing the homogeneity of the electrode properties

Contract Work for Industry

- Production of diffusion and catalyst layers with lengths of up to 50 m