Lehrstuhl für Werkstoffwissenschaften
TUM School of Engineering and Design
Technische Universität München

Assessing and optimizing microflow in 3d printed fuel cell electrodes

Fluid Management for Electrochemical Devices

Research Area

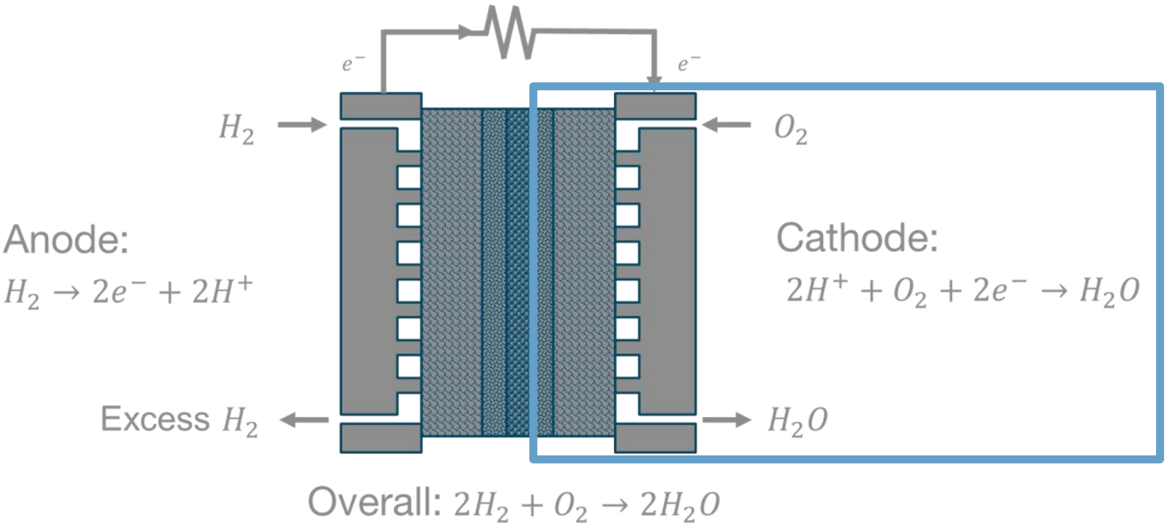
Electrochemical energy conversion, fuel cells, material science, high resolution additive manufacturing, process engineering, fluid dynamics, micro-electromechanical systems (MEMS)

Project Description

Background

The independent scalability of storage tank (capacity) and reactor size (power) allows for immense flexibility in fuel cells. Their superior energy density today paired with flexible throughput is attractive. Nevertheless, even the emergent H_2-O_2 Proton Exchange Membrane Fuel Cells (PEMFC) remain confined to a small number of applications due to costs, lifetime and durability, power density and efficiency limitations.

Interestingly, the maximum theoretical efficiency of a fuel cell is over 80% (if waste heat is recovered). This presents plenty of opportunity for improvement over the current state-of-the-art at approximately 65%. One approach to cost reduction and performance improvement is to increase the operating current densities beyond the state-of-the-art of around 2 A/cm^2 which can be done optimizing the devices' electrodes. The limiting case for PEMFC electrodes is the cathode, where oxygen gas is reduced to water.



The transport of oxygen, water, and electrons through the electrode represents the key limitation to increasing current density beyond 2 A/cm^2. One particular component, the gas diffusion layer (GDL), contributes considerably to the electric transport and is almost entirely responsible for fluid transport management. The current designs (Carbon Papers or Cloths), however, consist of a web of micrometer-sized carbon fibers, where electron and fluid transport can be considered spatially varying rendering the management of each transport mode uncontrollable leading to heterogeneity in reaction rates.

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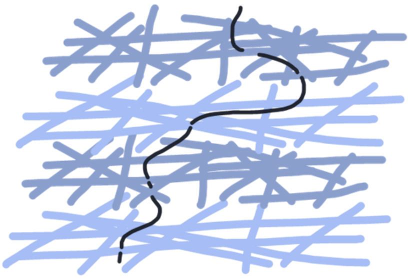
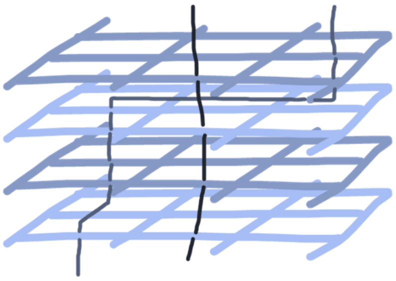


Carbon-cloth:

- 3-dimensionally complex
- Unpredictable
- Varying hydraulic diameter



Architected geometry:

- Controllable complexity
- Predictable
- Controllable hydraulic diameter

Recent advances in additive manufacturing have enabled the production of high resolution and geometrically complex amorphous carbon structures in the dimensions required for making gas diffusion layers. As the geometry can be tailored in 3D according to a CAD design, a direct link between physical prototypes and modelling can now be established, where the local geometry of the GDL can be tuned for optimizing the overall fuel cell performance.

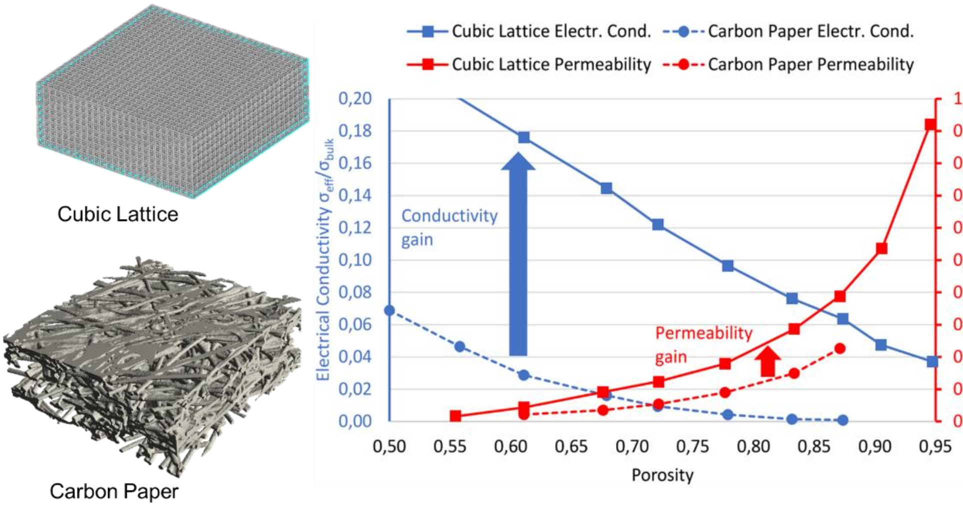


Figure 1:CT representations of a Carbon Paper GDL (red) and a simple cubic lattice with similar void fraction (blue), Left: Variation in the ratio of effective electrical conductivity to bulk conductivity (blue) and permeability (red) of a cubic lattice and a Carbon paper GDL, respectively, both have a fiber diameter 9 µm (adapted from [1]).

Individual Tasks

The primary objective of this thesis is to establish a set of experiments to investigate flow in 3D printed gas diffusion layers. The experiments will bridge together a given analytical solution and microflow simulations performed by other members of the team. The proposed work therefore follows:

- Design lab-on-chip for assessment of simple, tubular microcapillary channels
- Print and iterate design using two-photon polymerization (2PP) printer, a high-resolution 3D printer that can print features down to 100 nanometers.

- Expand gas diffusion layer designs to include different profile designs (ie. Square, pentagon, hexagon shaped pores)
- Compare experimental results to analytical and numerical simulation results

Prerequisites

Required:

- Strong interest in electrochemical energy conversion devices, particularly PEMFCs.
- Experience with CAD software
- Interest in fluid dynamic behaviour

Beneficial:

- Experience with SLA 3D printing
- Electrochemistry fundamentals
- Microflow and capillary flow fundamentals

Expected Outcomes

At the end of this project, the student is expected to understand the theoretical fundamentals underlying bulk flow and microflow models for porous materials. This includes a special appreciation for capillary dynamics. The student is expected to gain a strong understanding of experiment design and development. This includes use of 3D printing and microscopic characterization, heat treatment, drop shape analyzer, and building custom experimental apparatus. There are tangential opportunities for the student to gain skills with open-source modelling software (although not required). The student will get to know fuel cell operation and understand key metrics in electrochemical conversion important for flow batteries, fuel cells and electrolyzers.

Literature

[1] D. Niblett, V. Niasar, S. Holmes, Enhancing the Performance of Fuel Cell Gas Diffusion Layers Using Ordered Microstructural Design, J. Electrochem. Soc. 167 (2019) 013520. https://doi.org/10.1149/2.0202001JES.

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