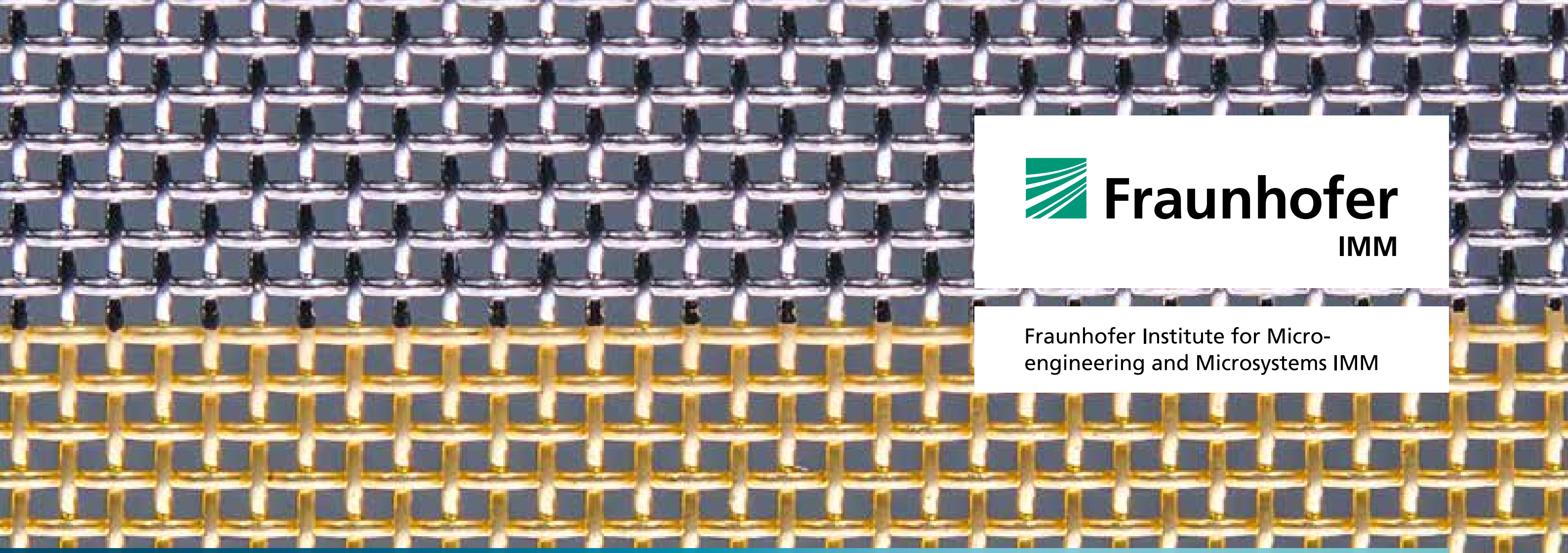


Fraunhofer IMM

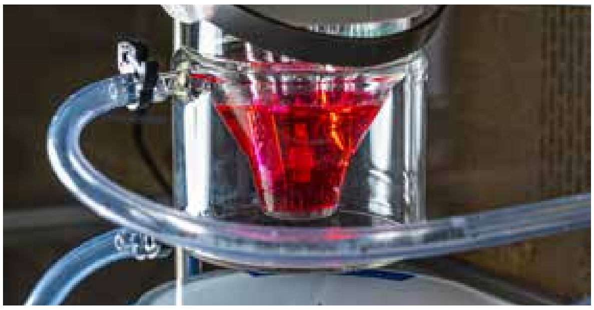
Fraunhofer Institute for Micro-engineering and Microsystems IMM

Electrification chemical processes

Continuous flow reactors for electrochemistry

Organic electrochemistry is regarded a future technology for the environmentally friendly production of chemicals. There is currently a renaissance of electrochemistry, especially for the synthesis of organic compounds. It is driven by the search for "green" synthesis routes and by the emergence of novel synthetic strategies. The direct use of cheap sustainably generated (excess) electricity presents an opportunity for cost benefits over regular chemical reagents. Suitable electrochemical reactors are essential for the successful operation of electrosynthetic processes. They simultaneously need to be flexible and tailored for the desired reaction conditions.

Fraunhofer IMM has a long track in developing and realizing electrochemical reactors for a wide range of electrolytic processes. Electrochemical microreactors are characterized by their small electrode distances and high surface-to-volume ratios. Thin-gap electrochemical microreactors offer the following benefits:



Undivided electrolysis cell for batch testing

- Due to the optimized design, current density and fluid distribution of high homogeneity are achieved.
- Reduction of the amount of required supporting electrolyte or even supporting electrolyte-free operation
- Large electrode surface area to volume ratio provides high space-time yield
- Integrated heat exchanger structures within a cell or reactor efficiently dissipate reaction heat, preventing hot spots and ensuring reliable temperature control.
- Small electrode distances induce low ohmic resistances and correspondingly low voltage drops.
- Enhanced selectivity by constant and uniform current density distribution, homogeneous flow and defined residence times.

Engineer your technology! Design your chemistry! Flow electrochemistry as the toolbox for building complex molecules with electricity!

Our flow electrochemistry reactors at a glance

ELMIFLEX reactor

ELMIFLEX reactor

Microchannel flow cell

A microstructured stacked plate reactor designed for electroorganic synthesis, especially Kolbe-electrolysis. The stainless steel plates are insulated with a PTFE coating and contain integrated heat exchangers for precise temperature control. Up to ten double cells can be combined in a stack resulting in an active electrode area of ≤ 800 cm². The middle electrode plate can be exchanged for a separator (diaphragm or ion exchange membrane) to create a divided cell setup.

- Material: PTFE coated stainless steel plates
- Anode: glassy carbon, BDD, graphite, stainless steel, Pt (5 µm) on Ti, Ni, Ti
- Cathode: Stainless steel, Ni and Pt (5-10 µm coating)
- Microchannel dimensions: 56 channels (L W H 100 × 0.76 × 0.15 mm³)
- Active volume: 0.64 mL per plate
- Electrode area: 42.5 cm² per plate
- Flow rates: ≤ 50 mL min^{-1} per plate
- Operating temperatures: < 200 °C
- Operating pressure: < 100 bar

ShaPID reactor

Zero-gap divided cell

This reactor is designed for the direct reduction of CO_2 to formic acid. The zero-gap configuration is separated by an ion exchange membrane. The electrode plates are equipped with gas/liquid diffusion channels in a stainless steel current collector to contact gas diffusion electrodes and mesh electrodes.

- Material: PTFE coated stainless steel
- Anode: MMO on Ti
- Cathode: carbon GDL with electrocatalyst
- Electrode area: geometric area 60.72 cm²
- Fluid distribution microchannels: 35 per side
- Flow rates: Anode: 0–10 mL min^{-1}, Cathode:
- 0–800 ml min^{-1} humidified CO_2
- Operating temperature: 25–95 °C
- Operating pressures: 0–5 bar

Mechanical press for up to 5 cells

ShaPID reactor for formiate synthesis from CO_2

Low-temperature electrochemical reactor

ELMICRYO

Microchannel flow cell

This reactor is designed for low temperature electrolysis of reactive intermediates. It uses a diaphragm or ion exchange membrane for separation of the anolyte and catholyte compartments. Temperature control is realized by contacting the reactor to a suitable cooler.

- Material: stainless steel plates coated with Pt
- Anode: Pt (5 µm coating on stainless steel)
- Cathode: Pt (5 µm coating on stainless steel)
- Electrode area: 12.4 cm^2
- Microchannel dimensions: 22 channels (L W H 44 × 0.8 × 0.2 mm^3), distribution and collection channels (Ø 3 mm, L 54 mm)
- Active volume: 0.155 mL per side
- Flow rates 0.8 mL min^{-1} per side
- Operating temperatures: – 80 to 60 °C

ELMISCREEN reactor

Flexible divided cell

The ELMISCREEN reactors are designed for the screening of electrocatalysts. Each half cell contains a titanium current collector equipped with gas channels making them suitable for the use of GDLs. The electrode is positioned onto the current collector. Fluid distribution of anolyte and catholyte are included in the housing. A separator (diaphragm or ion exchange membrane) can be positioned between the compartments. Different configurations include finite-gap, a zero-gap, and a high-pressure version with variable electrode areas.

- Material: insulating PEEK housing
- Anode: variable
- Cathode: variable
- Electrode area: 5–20 cm^2
- Cell Dimensions: 12.2 × 10 × 6 cm^3
- Flow rates: 0–50 mL min^{-1} per half cell
- Operating temperatures: 20–90 °C
- Operating pressures: up to 5 bar for the finite-gap and up to 80 bar for the zero-gap

ELMISCREEN reactor for catalyst screening

AVATOR reactor

Sandwich type parallel plate cell

A parallel plate reactor with integrated heat exchanger suitable for synthesis or peroxodicarbonate generation. High current densities are possible with sufficient cooling (up to 1 A cm^{-2}).

- Material: insulating PEEK housing, stainless steel
- Anode: BDD, glassy carbon, Pt, other materials possible
- Cathode: stainless steel, coating with Ni, Pt possible
- Electrode area: 2 × 25 cm^2
- Typical electrode gap: 0.9 mm
- Active volume: 2.3 mL
- Flow rates: typical flow rate 1.5 L min^{-1}
- Operating temperatures: 5–80 °C
- Operating pressures: 0–3 bar

AVATOR reactor

HAVANA reactor

HAVANA reactor

Sandwich-type parallel plate cell

This reactor is design for electroorganic synthesis consisting of stainless steel cathodes plates with integrated flow distribution and heat exchangers and a middle anode plate.

- Material: Stainless steel plates
- Anode: glassy carbon, other materials possible
- Cathode: Stainless steel
- Electrode area: 2 × 100 cm^2
- Electrode gap: 1 mm
- Active volume: 10 mL
- Flow rates: optimized for 1–6 L min^{-1}
- Operating temperature: 5–120 °C
- Operating pressure: tested to 3 bar

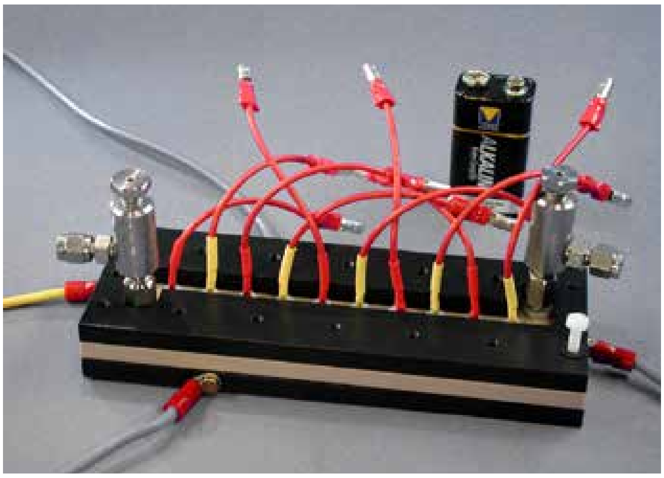
ELMI1

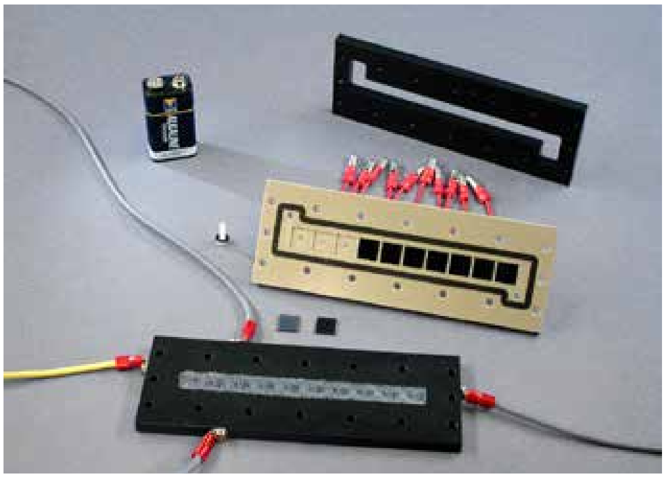
Undivided sandwich-type micro cell

A compact electrochemical microreactor with integrated heat exchanger in a double cell configuration. Very small electrode gaps are possible enabling low supporting electrolyte concentrations.

- Material: PTFE-coated stainless steel, FFKM gaskets
- Anode: glassy carbon, platinum, Pb/PbO_2
- Cathode: stainless steel, nickel, titanium, platinum coating, lead
- Electrode area
- Microchannel dimensions: 27 channels per plate (L W H 29.5 × 0.8 × 0.1 mm^3)
- Typical electrode gap: 100 µm
- Active volume: 127 µL
- Flow rates: typical flow rate 0.1–10 mL min^{-1}
- Operating temperatures: up to 200 °C
- Operating pressures: up to 10 bar

ELMI1 – Electrochemical Microreactor





ECSMR Electrochemical Segmented Microreactor

ECSMR-Screen

Segmented screening reactor

This cell has a segmented anode allowing for variation of the electrode area during electrolysis.

- Material: PEEK inlay, PTFE coated stainless steel housing, FFKM seals
- Anode: glassy carbon chips
- Cathode: stainless steel, coating with Ni, Pt possible
- Electrode area: 10 × 1 cm²
- Typical electrode gap: 0.1 mm
- Active volume: 2.3 mL
- Flow rates: typical flow rate 0.1–10 mL min^{-1}
- Operating temperatures: up to 80 °C
- Operating pressures: 0–3 bar

Services and benefits

Our services in the field of electrochemistry in flow

We offer you a one-stop service including the entire development chain from batch to flow process testing with reactor and plant development for your dedicated flow electrochemistry equipment. Just a few examples from our application portfolio for electrochemistry in flow:

- Hofmann rearrangement [1]
- Kolbe electrolysis [2]
- Peroxodicarbonate production [3]
- CO_2 conversion [4]
- Cation flow applications [5]
- Water electrolysis [6]

Feasibility studies to meet your needs

- Transfer of your batch process to continuous flow mode
- Development of your unique flow reactor for your needs
- Dedicated plant development as blueprint for your future process.

Contact

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