Fraunhofer Institute for Micro-engineering and Microsystems IMM

Enabling sustainable chemistry

Production of chemicals by electrochemical microreactors

Quick Facts

- flexible and scalable reactor concepts
- small electrode distances and great surface-to-volume ratios for improved process control
- environmentally-friendly production of chemical compounds

There is currently a renaissance of electrochemistry especially also for the synthesis of organic compounds observable. It is driven by the search for "green" synthesis routes and by the emergence of novel synthesis strategies. But also the ambition for a direct use of sustainably generated (excess) electric current plays a role. So, organic electrochemistry is considered as future technology for the environment-friendly production of chemical compounds. Nevertheless, there are still challenges and problems linked to electrosynthesis and there is also a need for flexible reactor concepts.

Advantages of electrochemical microreactors

Electrochemical microreactors contribute to a resolution of these issues. Fraunhofer IMM has a long track in developing and realizing electrochemical microreactors characterized by small electrode distances and great surface-to-volume-ratios as key features [1]. These thin-gap electrochemical microreactors disclose the following advantages:

- attainment of high current densities over the whole electrode surface
- reduction of the amount of required conducting salts or even conducting salts free operation
- large surface areas for electrode reactions
- the integrated heat exchanger structures remove reaction heat efficiently and avoid in consequence hot spots decreasing reaction yield
- low voltage drop by low Ohmic resistance
- enhanced selectivity by constant and uniform current density distribution, homogeneous flow and defined residence times

Novel, flexible reactor concept

Fraunhofer IMM has developed and implemented in its recent project works a novel innovative reactor concept addressing especially the aspects modularity, flexibility, high pressure operation and scalability. This reactor concept follows a plate stack design. A single electrochemical cell is made up by a set of plates. The stack can comprise either one cell for individual operation or a larger number of cells for parallel, serial or mixed operation. The stack then is integrated in a housing in form of a press suited for a varying number of cells.

Typically, the core plates of the stack represent on both sides structured electrodes and are equipped with an integrated heat exchanger. These are realized by a combination of additive manufacturing to obtain the basic plates with their complex fluid structures, surface coating (e.g. with PTFE) of the basic plates for electric insulation, milling to create the micro channels on the plates surface and electroplating to deposit different electrode materials on the plates.

The reactor concept is flexible in details of its design depending on targeted application but typically the core reactor plates are characterized as follows:

- electrode outer dimension: ca. 100 mm x 120 mm
- active electrode surface per structured plate side: ca. 55 cm^2 provided via about 70 micro channels
- channel dimensions: about 800 µm x 100 µm x 100 mm
- channel volume per structured plate side: about 0.5 cm^3

The reactor concept is designed to cover operation conditions up to 200 °C and up to 100 bar, for electrolyte flow rates up to 100 ml min^{-1} and for coolant flow rates up to 50 ml min^{-1} per electrochemical cell.

The reactor concept allows a multitude of operation possibilities:

- use of 1 to 9 electrochemical cells made from the core plates and matching endplates in the overall reactor housing
- use of 2 to 16 electrochemical cells if the core plates are combined with unstructured electrodes
- operation of the cells as mono or bipolar cells
- operation of the cells as undivided or divided cell (by use of diaphragmas or ion exchange membranes, e.g. PEM)
- individual designation of the cells is feasible when using a multichannel galvanostat

As electrode materials / electrode coatings stainless steel, platinum and boron doped diamond (BDD) are already in place. Materials as e.g. nickel, graphite, glassy carbon, lead or lead oxide are in principle also feasible as electrode materials.

Application possibilities and examples

In general, electrochemical procedures are broadly applicable from water treatment, hydrogen peroxide production to a multitude of electroorganic synthesis like the oxidation of alcohols, phenols, aldehydes, halogenation of aromatics, alkoxylation reactions, synthesis of aromatic aldehydes, C-C cross coupling reactions and reduction of nitro groups to name of few.

In its recent works, Fraunhofer IMM has especially gathered experience in the cation pool and cation flow method as modern organic synthesis approach [2], in the Kolbe electrolysis [2,3], the electrochemical synthesis of peroxodicarbonate [2], and the formation of formate starting from CO_2. The latter required the implantation of gas diffusion electrodes in the reactor representing a further decisive widening of the applicability or the followed reactor concept.

Contact

Dr. Athanassios Ziogas
Division Chemistry
Phone +49 6131 990-452
athanassios.ziogas@
imm.fraunhofer.de

Fraunhofer Institute for
Microengineering and
Microsystems IMM
Carl-Zeiss-Strasse 18-20
55129 Mainz | Germany
www.imm.fraunhofer.de

All flyers of the division Chemistry
https://s.fhg.de/flyers-chemistry

1 A. Ziogas et al., J. Appl. Electrochem. 39 (12) (2009) 2297-2313 | **2** A. Ziogas, C. Hofmann, S. Baranyai, P. Löb, G. Kolb, Chemie Ingenieur Technik 92 (5) (2020) 513-524 | **3** A. Ziogas et al., WO 2016/70075 A1