

Flow electrosynthesis: Making fine chemicals using electrons

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Thanks to a number of key fundamental scientific and technology advances including those in electrode and electrochemical cell manufacturing, using electrons to synthesize organic molecules at the surface of electrodes has become the object of intense chemical researches in several countries (1).

Today's electrosynthesis proceeds via electrocatalysis. In the preferred configuration electrocatalysis is heterogeneous with the substrate molecules reacting at the surface of a functionalized, electrocatalytic electrode, rather than undergoing electron transfer with the electrode surface. Under homogeneous electrocatalysis conditions, the substrate reacts with the oxidised or reduced form of a mediator dissolved in solution (2).

In 2017 Baran identified the "lack of standardized equipment" as the first major challenge to the uptake of electrosynthesis "in modern synthesis laboratories" (1).

From a fundamental viewpoint, the reaction flask commonly used in modern (and old) synthesis laboratories is no different from batch reactors typically used in the multi-purpose plant typical of the fine chemicals industry (3). Photochemical syntheses in batch reactors are limited by the Beer-Lambert law limiting light absorption from molecules in solution beyond a very short distance from the lamp (4).

Worsened by the need for high concentrations of electrolytes, electrochemical syntheses in batch mode are limited by the need for large electrodes, inhomogeneity of the electric field, poor energy efficiency due to Joule heating, and difficult temperature control.

Accordingly, the uptake of electrosynthesis in the fine chemicals industry for decades has remained limited to three or four examples from

selected companies typically summarized in review articles devoted to the field.

All changed with the introduction of flow electrochemistry (micro)reactors. Now, a solution containing the substrate flows in a channel between two electrodes at short distance allowing for dramatic reduction in the amount of electrolyte needed (5).

Thanks to enhanced mixing, fast heat exchange, shorter diffusion distances, and large electrode-surface-to-volume ratio, electrochemical reactions under flow can now be carried out quickly and with full reproducibility (5). Scale-up furthermore is easily achieved by combining in parallel the modular flow reactor cells.

The route is therefore open to the industrial uptake of electrocatalysis to synthesize valued fine chemicals with no waste (by-product) production in a number of key organic process syntheses, including oxidation and reduction reactions.

For example, a large pharmaceutical company in 2017 patented a flow electrochemical process to increase the yield of an active pharmaceutical ingredient evaluated for the treatment of kidney disease in type 2 diabetes mellitus patients, by converting the undesired R enantiomer back to racemic product via a flow electrochemical process including oxidation and reduction steps (6).

ZEmOEI - ZERO-EMISSION OXIDATION ELECTRODE FOR WASTE-FREE ALCOHOL OXIDATION

"ZEmOEI", namely Zero-Emission Oxidation Electrode (Figure 1), is the name given by the joint scholarly team to a new sol-gel electrode enabling the selective oxidation of alcohols to aldehydes and ketones

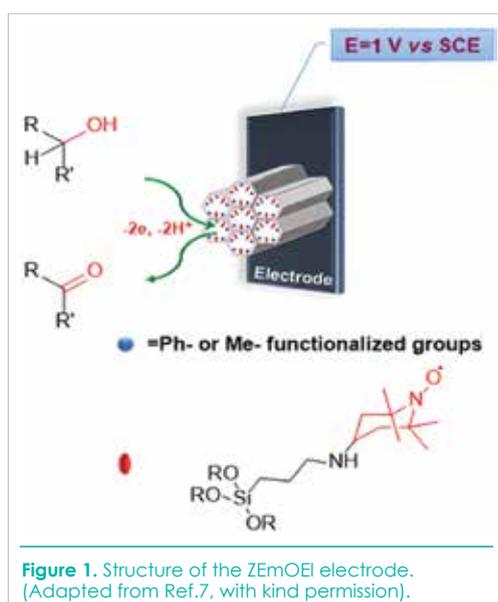


Figure 1. Structure of the ZEmOEI electrode. (Adapted from Ref.7, with kind permission).

with high selectivity and unprecedented stability of the electrocatalytic electrode (7).

The first sol-gel electrode based on organosilica functionalized with the TEMPO moiety was reported in 2006 (8). but it was only in 2015 that the first practically useful electrode was described (9). The latter electrode enabled unprecedented turnover frequencies (TOF) of up to 3070 h^{-1} , considerably higher than TOF reported until then for nitroxyl radicals under chemical, electrochemical, or aerobic oxidation conditions.

Unfortunately, the electrode showed poor catalytic stability, rapidly losing its high activity with ongoing use.

The nanostructured ZEmOEI electrode conjugates similar exceptionally high selective activity with the required high stability for practical applications.

When electricity to accomplish the oxidation originates from photovoltaic modules or wind farms, as it is increasingly the case in many regions of the world, this and related catalytic electrodes will enable to carry out synthetic transformations of this relevance with solar energy only (10).

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