

Efficient Gas Separation with Inorganic Membranes

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The reduction of carbon dioxide (CO₂) emissions is a major global issue. Energy-intensive industries account for a significant part of these emissions. With respect to the increasing demand for energy and the lack of large-scale energy storage solutions, we are still forced to rely on fossil power plants, thus making carbon capture and storage (CCS) technology essential. A key technology for CCS power plants is, however, the cheap production of pure oxygen. This can be achieved by introducing gas separation techniques making use of membrane technology, which is associated with significantly lower efficiency losses as compared to conventional separation technologies, e.g., cryogenic air separation.

Several electrochemical high-temperature devices have already utilized, e.g., solid oxide electrolytes with predominantly ionic conduction of oxygen (e.g., lambda sensors). Over the past decades, there has, however, been an increasing focus on mixed ionic-electronic conducting (MIEC) oxide materials, e.g., for solid-oxide fuel cell electrodes. These oxides allow an ambipolar transport of (charge-neutral) oxygen through the solid state in the presence of an oxygen chemical potential gradient.

Several MIEC materials, namely members of the composition A_xSr_{1-x}Co_yFe_{1-y}O_{3-δ} (A = La, Ba), are known to exhibit excellent oxygen-ionic and electronic transport properties, thus showing promise for applications as dense (gas-tight) ceramic membranes operated at temperatures of 700...1000 °C with a high permeability and selectivity for O₂/N₂ separation. The perovskite-type oxide (Ba_{0.5}Sr_{0.5})(Co_{0.8}Fe_{0.2})O_{3-δ} (BSCF), in particular, has been reported to exhibit unmatched permeation values to-date, hence making a large-scale oxygen production appear feasible.

However, materials stability has also to be ensured over several years under possibly harsh operating conditions (high temperatures, lower oxygen partial pressures down to, e.g., 10⁻³ bar, and – depending on an operation in either 3-end or 4-end mode – possible reactive gas components such as CO₂ or SO₂ strongly affecting materials stability). This requires electrochemical investigations as a function of temperature, gas atmosphere, and time.

High-flux membranes are usually composed of a porous support (ensuring mechanical stability) that is coated with mixed-conducting thin-film membrane layers. Such a structure can be achieved by various production techniques and leads to the highest possible oxygen fluxes which, however, exhibit surface-controlled oxygen exchange kinetics. Any significant flux enhancement is then no longer feasible by thinning the membrane any further, but only by a geometric increase of the gas/solid interface, e.g., by an application of porous functional surface layers – or by a catalytic modification of the chemical surface composition. This shall be discussed on the basis of performance-modelling activities addressing the influence of microstructure on oxygen-transport kinetics and, thus, facilitating an optimized multi-layer membrane design.