Nanoscale Architectural Engineering for High-Performance Solid Oxide Fuel Cells

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Solid oxide fuel cells (SOFCs) are the most efficient devices known to convert chemical energy stored in a fuel to electrical energy

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- Efficiencies as high as 75% are projected, far in excess of what is possible with combustion systems.
- Substantial reductions in global CO_2 emissions
- A wide range of fuels can be utilized: hydrogen, methanol, methane, propane, coal-derived syngas, and diesel reformate.

However...

- Cost per kW of current-generation SOFCs is an order of magnitude higher than DOE target of $400/kW.

New nanofabrication methods have the potential to completely change how SOFCs are made, resulting potentially in much higher performance, and substantially lowering the cost per kW.

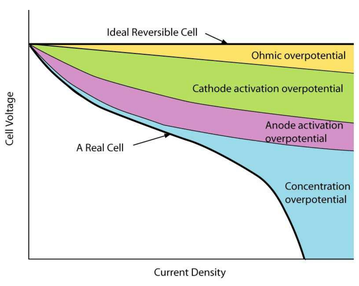
High Performance SOFCs: What is possible?

We have developed a detailed physical model of SOFC performance that is well-validated with experiment.

Overpotentials – voltage drops that subtract from the ideal cell output voltage, and determine the maximum power output from the cell.

- finite-rate kinetics at the electrodes (activation overpotentials),
- finite electrical conductivity of the electrolyte (ohmic overpotential),
- finite mass transfer rates through the porous electrodes (concentration overpotentials).

The key to achieving a high-performance, high-power SOFC is to significantly reduce all of these overpotentials.



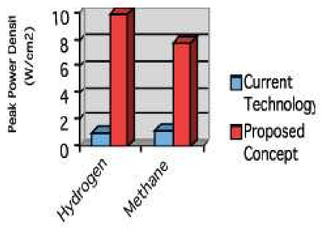
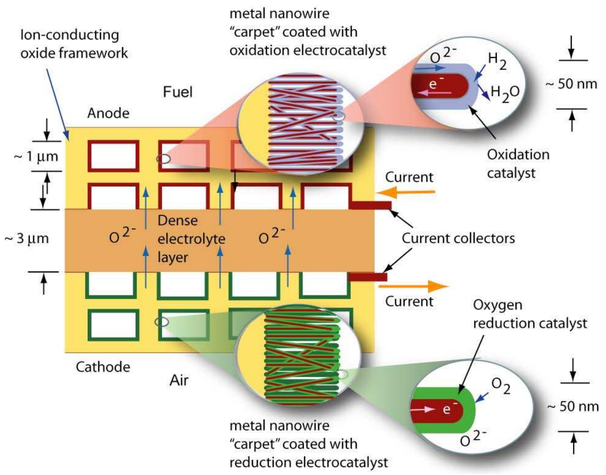


Illustration of the overpotentials that limit SOFC performance, left. Comparison of model predicted peak power for current technology and for optimized cell.

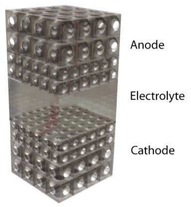
An Alternative Vision: Architecturally Engineered Multiscale Fuel Cell Structures

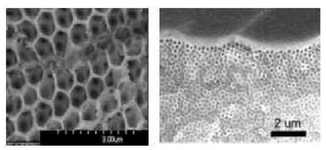


Conceptual design of an engineered, high-performance membrane electrode assembly (MEA).

Lowering concentration overpotential: Optimizing gas transport

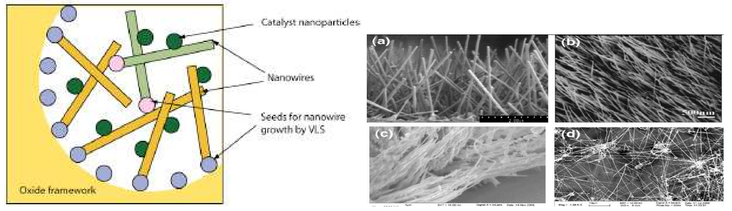
- The structural backbone of the MEA is the oxide skeleton or framework.
- Micron-sized porous framework "carpeted" with nanowire arrays.





Inverse Opals

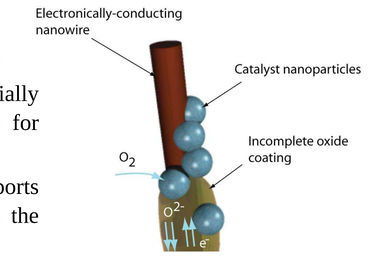
- Fabricated using templates of polystyrene spheres that are later burned out.
- Allows for a fully-connected network even at very high porosities.

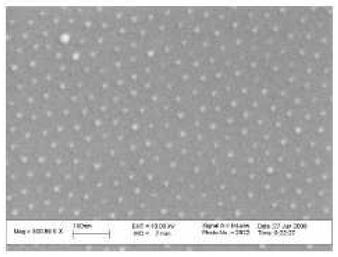


Nanoparticles and nanowires infiltrated into the oxide framework, left. Nanowires grown from catalyst particles.

Lowering the activation overpotentials

- Nanostructured catalysts to substantially increase the surface area available for electrochemistry.
- Catalyst particles on nanowire supports to allow gaseous species access to the surface reaction sites.





Self-assembly of nanoparticle catalysts

- Block copolymer lithography–self assembly with conformal coatings.
- Particle size and inter-spacing can be controlled.

Materials

- Electrolyte: Samaria doped ceria (SDC)- high ion conductivity at intermediate temperatures. Novel, low-temperature deposition to achieve enhanced conductivity.
- Cathode: BSCF ($Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}O_{3-\delta}$) - the highest known activity for oxygen electroreduction of any SOFC cathode.
- Anode:SDC + Ni cermet-SDC can be a highly effective electroreduction catalyst under anodic conditions.

Acknowledgements

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