

## **Status of Planar SOFC Technology Development at CGCRI, Kolkata, India**

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In India, Central Glass and Ceramic Research Institute (CGCRI), Kolkata has the strongest R&D group for technology development in the area of solid oxide fuel cells (SOFC). The related activities are being pursued for the last couple of decades. Initially, the main emphasis was on the materials/component development. The R&D work has led to the successful development of fine powders of different SOFC components, namely Sr-substituted LaMnO<sub>3</sub> (LSM) cathode, NiO-8 mol% yttria stabilized zirconia (YSZ) anode and Ca-substituted LaCrO<sub>3</sub> (LCR) interconnect. The expertise in Lab scale powder preparation has been transformed to a large volume (in Kg level) continuous powder production facility using a modified spray pyrolyser designed by CGCRI. Since 2004 efforts have been primarily made to develop and demonstrate working SOFC stacks based on the planar anode-supported design under a National program.

Under this National project, large numbers of anode-supported single cells of dimension 10 cm x 10 cm x 1.5 mm have been fabricated using simple and up-scalable techniques such as tape casting and screen printing (Basu et al. 2008: 5748). The processing parameters have been optimized to get a thin (~10 µm) layer of fully dense electrolyte (YSZ) film that is well-adhered to the 1.5 mm NiO-YSZ porous anode-support on one side and LSM-based cathode on the other side. The developed cells show reasonably good power output at an operating temperature of 800°C (~ 2.0 W/cm<sup>2</sup> at a cell voltage of 0.7 V).

Glass-based sealants, an essential component of planar SOFC stack, have also been developed in-house. Several glass compositions within Magnesium aluminosilicate (MAS), Barium aluminosilicate (BAS), Barium magnesium silicate (BMS) and Barium calcium aluminosilicate (BCAS) systems have been developed. The developed glasses exhibit very high electrical resistivity (>10<sup>6</sup> Ω-cm) in both oxidizing and reducing environments. In order to seal dissimilar materials such as YSZ electrolyte with Crofer22APU, a distinctly new approach of applying a bi-layer glass, with a compositional gradation within the BAS and BCAS systems (so as to have a graded CTE within the bi-layered structure) have been successfully employed to make crack-free joints between the metal-glass-YSZ interfaces (Ghosh et al 2008: B473). The bi-layered glass seal has extremely low leak-rate (of the order of 10<sup>-7</sup> Pa-m<sup>2</sup>-sec<sup>-1</sup>) as compared to others even after 5 thermal cycles (between 500 and 800 °C).

Using the developed 10 x 10 single cells, glass-based sealants, and ferritic steel-based metallic (Crofer22APU) interconnect and gas manifolds, several SOFC short stacks (upto 10-cell level) with counter flow design have been fabricated and demonstrated successfully for the first time in India. At 800 °C, the OCV per cell is found to be ~ 1.1 V which is quite close to the theoretical value. Peak power obtained from short stacks is not satisfactory at this point of time. However, intense research work is in progress to get improved performances.

In parallel to the above technology development on planar anode-supported SOFC, CGCRI is also engaged in several frontier areas of research as mentioned below:

a) Electrode material for high performance SOFCs:

*Anode:* CGCRI, Kolkata has developed a novel functional cermet anode by a novel electroless technique that contains much lower volume percentage of Ni (~ 30 vol %) compared to the conventional Ni-YSZ cermet anode with ~ 40 vol % of Ni (Mukhopadhyay et al 2008). Such functional anode has a thin coating of fine Ni-particles on the YSZ surface resulting in a core-shell microstructure.

*Cathode:* Nanocrystalline lanthanum ferrite-based (LSCF) cathode materials have been synthesized at a relatively low temperature by combustion synthesis using alanine as novel fuel (Dutta et al 2009). Recently, using spray pyrolysis technique, such nanostructured cathodes with tailor-made morphology have been developed for improved electrical and electrochemical properties.

Initial results of electrochemical experiments performed on planar anode-supported cells fabricated using such functional electrodes has shown a significant improvement in performance (current density > 3.0 A/cm<sup>2</sup> at 800°C, 0.7 V)

b) Robust Glass-based sealants: Recently, a novel glass-ceramic sealant has been developed at CGCRI that can be sealed at a much lower temperature (~ 700 °C) than the SOFC operating temperature (>750 °C) leading to a much reduced chemical interaction with metallic interconnect like Crofer 22APU. Attempts are now being made to develop robust sealants (with repeated thermal cyclability between ambient to operating temperature) by adding suitable ceramic/metallic filler materials into such glasses.

c) Low temperature SOFC (LT-SOFC) Materials: Using combustion synthesis technique, nanocrystalline and phase pure Gd-doped CeO<sub>2</sub> as well as pure LaGaO<sub>3</sub> has been prepared. Nanocrystalline and phase pure CeO<sub>2</sub> powders with co-doping of cobalt and gadolinium (Ce<sub>0.79</sub>Gd<sub>0.20</sub>Co<sub>0.01</sub>O<sub>2-δ</sub>) have also been synthesized. The developed powders have very high sinteractivity and at a temperature of only 1100 °C, almost theoretical density is achieved in the resultant sample. High oxygen ionic conductivity of 0.021 S/cm<sup>2</sup> at 600 °C is obtained for such a dense electrolyte (Dutta et al 2009).

d) Modeling and Simulation: Research activities regarding the modeling and simulation of the flow fields and stack designs have been initiated using computational fluid dynamics (CFD) and gPROMS-based softwares.

Apart from establishing linkages with various national laboratories and academic institutes, CGCRI has also established international linkages with reputed organizations like Forschungszentrum Jülich GmbH, Karlsruhe University and RWTH Aachen University, Germany. CGCRI has successfully (co-)organized two Indo-German Workshops on "Fuel Cells and Hydrogen Energy", one at CGCRI, Kolkata (January, 2007) and the other at University of Karlsruhe (March, 2009). We are looking forward for a future research collaboration of mutual interests.

The expertise developed in the area of SOFC has led the Ministry of New and Renewable Energy (MNRE), Government of India, to bestow upon CGCRI the responsibility to act as the Lead Institute for the development of SOFC technology for India under a Mission-mode Project.

**References:**

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