

**STUDIES ON PORE MORPHOLOGY OF PREFORMED Ni-  
IMPREGNATED POROUS ANODES AND ITS EFFECT ON THE  
PERFORMANCE OF A SOLID OXIDE FUEL CELL**

by

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## **Certificate**

This is to certify that the thesis entitled “**Studies on pore morphology of preformed Ni-impregnated porous anodes and its effect on the performance of a Solid Oxide Fuel Cell**” being submitted by **C. Anand Singh** to the Department of Chemical Engineering, Indian Institute of Technology, New Delhi, for fulfillment of the requirements for the award of Doctor of Philosophy in Chemical Engineering is a record of bona fide work carried out by him under my supervision.

The research report and results presented in this thesis have not been submitted, in part or full, to any other university or institute for the award of any degree or diploma.

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## Abstract

Solid oxide fuel cells (SOFC) are high temperature energy conversion devices which convert the chemical energy of fuels directly into electrical energy. The conventional Ni-based SOFC anodes, fabricated by mixing NiO and YSZ powders followed by sintering, requires a minimum loading of 30 vol% Ni to ensure percolation of Ni over the matrix of the cermet, thereby ensuring sufficient conductivity. Intolerance to redox and thermal cycling of the conventional Ni-YSZ SOFC anodes is a major stumbling block in the path of SOFC commercialization. This intolerance is generally attributed to the microstructure of the Ni-YSZ cermet and tends to be enhanced at high Ni content prevalent in conventional anodes. In this work, anode supported SOFCs with low Ni content have been fabricated and tested for tolerance towards redox and thermal cycling. The low Ni content anodes have been prepared by infiltration of Ni on to preformed porous YSZ substrate by aqueous impregnation.

The dense electrolyte and porous YSZ anode substrate have been fabricated by tape casting in most cases in this thesis. The influence of the various components of the tape casting slurry on the green tape quality has been studied and the composition of tape casting slurry has been optimized. The calcination behavior of the individual components of the green tape has been studied by TGA/DTA analysis and sintering schedules have been optimized to fabricate defect free electrolytes and electrolyte-anode bi-layers. Electrolytes with thickness as low as 12.5  $\mu\text{m}$  have been cast without defects like pin holes. Anode functional layers (AFL) with thicknesses between 12.5 and 50  $\mu\text{m}$  have been cast. Anode preforms with thickness as high as 1 mm have been tape casted by successive tape casting of thinner layers. For conductivity experiments anodes preforms with high sintered thickness of

2 mm have been cast. Different methods of preparation of  $\text{La}_{0.8}\text{Sr}_{0.2}\text{MnO}_3$  (LSM); drip pyrolysis, combustion synthesis and sol gel method, have been evaluated and drip pyrolysis technique was chosen to prepare LSM in our lab.

Anode preforms with different pore morphologies were fabricated and the effects of pore morphology and Ni content on the electrical conductivity of Ni-impregnated anodes have been studied. Their influence on the stability of conductivity at high temperatures ( $700^\circ\text{C}$ ) has also been studied. A theoretical model has been developed to predict the variation of electrical conductivity with Ni content in a porous solid. Sufficient conductivities ( $>100 \text{ S/cm}$ ) were observed at Ni contents as low as 10 vol %.

The effect of pore size, pore shape, pore orientation, porosity, tortuosity, Ni content, etc of the anode on the cell performance has been studied. A simple mathematical model has been developed to calculate the contribution of the activation and concentration polarizations at the cathode and anode and Ohmic polarization to the total cell polarization. A maximum power density of  $680 \text{ mW/cm}^2$  has been achieved during the initial stages at  $800^\circ\text{C}$  using hydrogen as fuel and air as oxidant with an anode having a Ni content of 44 vol % in the AFL and only 15.2 vol % in the current collector layer (CCL). The cells with Ni-impregnated anodes have been subjected to both slow or fast redox and/or thermal cycling. There was an initial loss in performance due to sintering of Ni particles. The performance became steady after  $\sim 24$  hrs. These alternate anodes with low Ni content have shown excellent tolerance to redox and thermal cycling.

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