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# Role of Variation of Fuels and Oxidants in Performance Evaluation of Planar Anode-Supported SOFC Fabricated with Functional Anode

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## Abstract—

The present work is based on the performance evaluation of functional anode in SOFC with multi fuel capability. Optimized anode configuration with conventional anode (40 vol % Ni) towards fuel side and electroless anode (28/32 vol %) active layer (AAL) at electrode/electrolyte interface shows maximum current density of ~ 4.0 A.cm<sup>-2</sup> @ 800°C & 0.7 V using 250 SCCM of moist H<sub>2</sub> (3 % moisture) as fuel compared to much less performance (3A.cm<sup>-2</sup>) using dry fuel. Such layered anode also shows higher performance of 1.0A.cm<sup>-2</sup> with 20 % reformed methane (RH:40 %) compared to 0.5 A.cm<sup>-2</sup> obtained with SOFC fabricated with conventional anode. Electroless anode with unique core (Ni)-shell (YSZ) morphology uses lower Ni content to fulfill the required conductivity criteria and shows enhanced electrochemical reaction at electrode/electrolyte interface. Owing to such factors, electroless AAL shows much reduced coking of anode with reformed methane as fuel and enhance the endurance of SOFC with much higher performance.

**Index Terms**—SOFC; Anode; Electrochemical performance

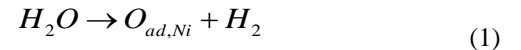
## I. INTRODUCTION

In the present world, the primary important requisite is the demand of energy due to increasing industrialization and population. At the same time there is increasing demand for green energy in order to avoid rising greenhouse gas emission, which results into deterioration of climate system. Fuel cell is an electrochemical device that is capable of converting the chemical energy of a fuel (H<sub>2</sub>, CO, methane, hydrocarbons etc.) and an oxidant (air or oxygen) into electricity without combustion and avoiding the Carnot cycle (isothermal redox reaction). Owing to such fact, the theoretical efficiency of fuel cell is reported to be more than unity. Fuel cell's are being classified on the basis of type of electrolyte and electrode materials. For all solid components, the operating temperature can be varied from 600–1000°C and termed as solid oxide fuel cell (SOFC). SOFC is under development for central station and dispersed power generation. The primary requisite of an electrolyte is to be dense, thin and either proton or oxide ion conductor [1]. Correlation among the interfacial resistance for H<sub>2</sub> oxidation with the nature of the metal electrode and ionic and electronic conductivities of the Ni-zirconia cermet

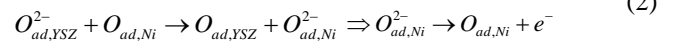
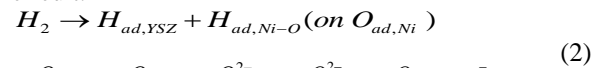
electrode is demonstrated by Setoguchi et al. [2]. The shortcomings of the conventional SOFC anode in literature reviews have been reported to be solved by using Electroless synthesised Ni-YSZ cermet as claimed by the author's in their previous communications [3]. Four salient anode configurations have been reported along with their performance evaluation and endurance study [3]. The aforementioned discussions have clearly highlighted certain factors like; a) operating temperature, b) Ni : YSZ content, c) porosity, d) thickness of anode cermet, e) microstructural distribution, f) variation in operation environment on which the electrical conduction and electrochemical performances of SOFC anode rely on. Primarily SOFC anode is responsible for oxidation of fuel (hydrogen, CO, methane etc.). The present context intend to study the role of oxygen containing species either in fuel or in oxidant towards performance evaluation of SOFC developed using the assorted anode configurations. In addition, the effect of 20 % reformed methane (RH~ 40 %) as fuel on performance of SOFC is studied.

## II. SALIENT RESULTS AND DISCUSSION

The fabricated anodes with their assorted configurations are tabulated in **Table 1**. Configuration III and IV are termed as layered configurations, wherein the both the conventional and electroless anodes are coupled to obtained easy gas diffusion through porous conventional anode (40 vol % Ni) and fast electrochemical oxidation at electroless anode (28 vol % Ni). The probable mechanism and associated results has already been established [3]. **Table 2** illustrates the dependence of both electrical conduction and redox tolerance of 28/32 AAL-4 anodes on the presence of 3 % moisture in the H<sub>2</sub> fuel. It is vivid from the table that, irrespective of Ni content, anode cermets exhibit significantly lesser conductivity in dry hydrogen. Consequently, the cermets undergo fast degradation in absence of moisture in the fuel. Moisture from the fuel undergoes dissociative decomposition to produce oxygen species which readily get adsorbed on Ni surface.



According to the mechanism, both YSZ and Ni contribute towards dissociative H<sub>2</sub> adsorption (Eq. 2) at anode. This is followed by charge transfer reaction of adsorbed O<sup>2-</sup> ion from YSZ to Ni species at active anode (Eq. 3) and thereby water is formed as the final by product by releasing electrons to the external circuit.



The decomposition of moisture therefore initiates the reaction path through bulk anode and propagates it towards the electro – active zone at the anode/electrolyte interface. This active zone contributes in the charge transfer reaction and finally forms product at the anode outlet. From **Figure-1**, it can be

observed that systematic increase in the flow rate of fuel from 20 to 200 SCCM linearly enhances the electrochemical performance of the cell. However, increasing the fuel flow rate beyond 200 SCCM does not contribute towards further enhancement of cell performance, owing to which the optimum flow is fixed at 200 SCCM.

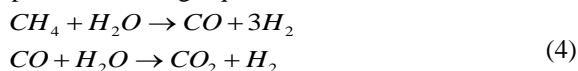
**Table 1: Fabricated anode cermets' having variable composition**

Anode composition	Ni content in conventional anode (vol. %)	Ni content in electroless anode (vol. %)	Sample ID
I [Conventional anode]	40	0	CA
II [Electroless anode]	0	28/32	28EL/ 32 EL
III [Layered anode]	40	28/32 or 28+32 Trilayer anode (TLA)	28BLA / 32 BLA or TLA
IV [Electroless anode as AAL]	40	28/32 [Tapes are thin]	28AAL/32A AL

**Table 2: Effect of moisture towards electrical conductivity of SOFC anodes**

Anode ID	Electrical conductivity (S.cm <sup>-1</sup> )		% Conductivity variation (/20 redox cycles)	
	Moist Hydrogen	Dry Hydrogen	Moist Hydrogen	Dry Hydrogen
28 AAL-4	597	474	6.5	9.87
32 AAL-4	644	530.3	7.06	13.4

Steam reformation of methane is the common source of hydrogen production using Eq. 4:



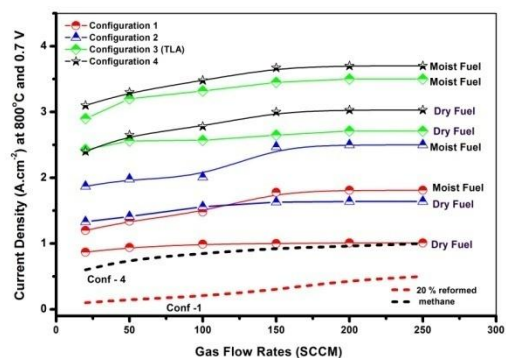
Additional hydrogen can be obtained by reacting CO with water via the water gas shift reaction. 20 % reformed methane (RH~ 40 %) as a fuel along with air as oxidant is found to exhibit a current density of ~ 1 A.cm<sup>-2</sup> with optimized anode of Configuration IV. FC with anode of Configuration I show much less performance of ~ 0.5 A.cm<sup>-2</sup> (Figure 1). High Ni content in Configuration I catalyses hydrogen oxidation efficiently, but promotes metal ripening and coking at anode. This reduces the rate of electrochemical reaction and enhances anode poisoning. Presence of AAL with unique core-shell structure and lesser Ni content intend to solve the aforementioned problems and accelerate both short and long term SOFC functionalization.

Similarly, the linear correlation is established in the experimental work for cathode polarization with partial pressure of oxygen. Therefore, reduction in electrochemical performance of the single cells with air is mainly because of reduced oxygen reaction rate (ORR) at the cathode compartment. Enhanced anodic electrochemical activity for SOFC having anodes of Configuration III or IV though accelerates the performance, but higher cathodic polarization generated with air as the oxidant contributes significantly towards diminishing the activity of SOFC (Figure 2).

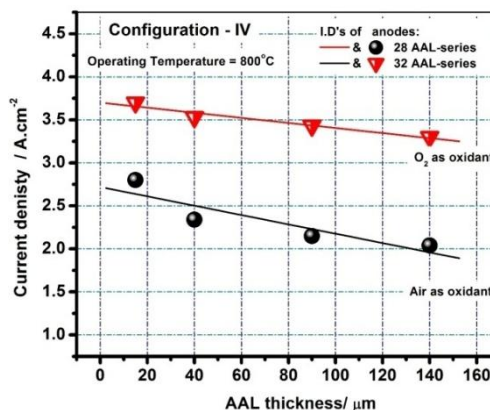
## I. CONCLUSION

Electrochemical performance evaluation of SOFC is reported with assorted anode configurations. Functional **Electroless** anode with unique core (YSZ)-shell (Ni) structure is found to exhibit maximum performance during application

as anode active layer (AAL). It has been established, that the presence of oxygen containing species either in fuel or in oxidant augment the performance of coin cell to 3.7 A.cm<sup>-2</sup> at 800°C and 0.7 V for Configuration IV wherein, the electroless anode act as AAL. Such optimized anode configuration shows higher cell performance (1.0 A.cm<sup>-2</sup>) with 20 % reformed methane thereby exhibiting multi fuel capability. Layered anode structure in Configuration IV solves the purpose of easy gas diffusion through conventional cermet (40 vol %) and enhanced electrochemical reaction with negligible coking at electroless anode (28 / 32 vol % Ni) at anode / electrolyte interface.



**Fig. 1. Influence of moist fuel on performance of SOFC**



**Fig 2. Correlation among type of oxidants and performances of single cell fabricated with Anode Configuration IV**

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