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An additional layer in an anode support for internal reforming of methane for solid oxide fuel cells

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ABSTRACT

Anode supported solid oxide fuel cells (SOFCs) have been extensively investigated for their ease of fabrication, robustness, and high electrochemical performance. SOFCs offer a greater flexibility in fuel choice, such as methane, ethanol or hydrocarbon fuels, which may be supplied directly on the anode. In this study, SOFCs with an additional Ni–Fe layer on a Ni–YSZ support are fabricated with process variables and characterized for a methane fuel application. The addition of Ni–Fe onto the anode supports exhibits an increase in performance when methane fuel is supplied. SOFC with a Ni–Fe layer, sintered at 1000 °C and fabricated using a 20 wt% pore former, exhibits the highest value of 0.94 A cm⁻² and 0.85 A cm⁻² at 0.8 V with hydrogen and methane fuel, respectively. An impedance analysis reveals that SOFCs with an additional Ni–Fe layer has a lower charge transfer resistance than SOFCs without Ni–Fe layer. To obtain the higher fuel cell performance with methane fuel, the porosity and sintering temperature of an additional Ni–Fe layer need to be optimized.

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Introduction

Solid oxide fuel cells (SOFCs) are considered as the most promising energy conversion component in power systems because they can directly convert chemical energy of various fuels to electrical energy through electrochemical processes with high efficiency. SOFCs, compared to other fuel cell systems, have a greater flexibility in terms of fuel because an internal reforming of natural gas, ethanol or hydrocarbon fuels may occur directly on the anode [1–5]. One of the challenges in commercialization of fuel cells is the fact that high purity hydrogen is required and its production and distribution add additional cost to the system. Therefore, oxidation of

hydrocarbon fuels directly on SOFC anodes has been experimentally demonstrated by a number of researchers [6–10]. Nowadays, there is a great interest of SOFCs operating on methane fuel [6,11–14], because it is the simplest and widely available hydrocarbon and is the main component of natural gas, coal gas, and biogas.

State-of-the-art SOFC anodes are composed of nickel-based cermets, which have high electrical conductivity and excellent activity for hydrogen electrochemical oxidation [15,16]. Nickel in an anode has high catalytic activity in hydrocarbon cracking reaction. However, coke is easily formed on anode surface and causes rapid deterioration of the fuel cell performance when hydrocarbons are used as the fuels [17–21]. As a result, Ni–YSZ cermet anodes can only be used

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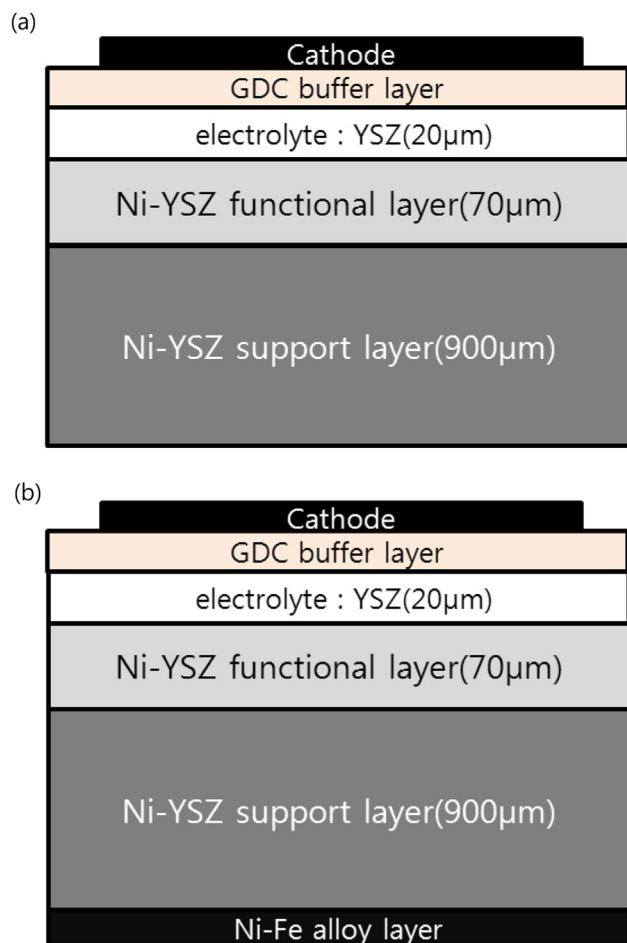


Fig. 1 – Schematic diagram of SOFCs (a) without an additional layer and (b) with an additional layer.

for hydrocarbon fuel if a high excess of steam to fuel is present in the cell anode in order to ensure complete fuel reforming and to suppress carbon deposition. Therefore, the development of an anode material for SOFCs that operates on hydrocarbons at lower carbon to water ratios (at least close to the stoichiometric ratio) is widely recognized to be an important technical objective [3,7,8,11,22]. Various kinds of cermets of precious metals such as Pt, Ru, Pd, and Rh with oxide of Y_2O_3 -stabilized zirconia (Ni-YSZ), $\gamma-Al_2O_3$, ScSZ and CeO_2 have been investigated for reforming of methane as a solid oxide fuel cell (SOFC) anode [3,23–25]. However, the high cost of precious metals is the major hurdle for commercialization. Development of alternative cost-attractive catalyst layer is then of great importance for practical operation of SOFCs on methane fuel.

This paper proposes a nickel–iron alloy catalyst layer as an additional layer over a traditional Ni–YSZ anode and support for operating with methane fuel. Ni has high catalytic activities for methane reforming, which results in a high carbon deposition. Iron has lower activities and is expected to resist a carbon deposition. The alloy of Ni–Fe is expected to have complementary effects for methane internal reforming in SOFC to resist the degradation of Ni anode functional layer for hydrogen oxidation. Additional Ni–Fe layers are fabricated and characterized with various compositions and processing temperatures. The fuel cell performances and stabilities of SOFCs are characterized and compared with hydrogen and methane fuel.

Experimental procedures

The anode supported SOFC was fabricated by a co-firing process in three thin layers, anode support, AFL, and electrolyte layers as described in previous works [26]. The porous anode support tape consists of NiO (0.4 µm, High Purity Chemicals,

Table 1 – Schedule of fuel cell test.

Temperature (°C)	Test	Fuel	Mode	Explanations
800	Reduction (3 h)	H ₂		
750	I–V	H ₂	Mode BeC	I–V characteristics with 1st H ₂ before fuel cycle
	V with time at 0.4 A (1 h)	H ₂	Mode H1	Voltage at constant current with 1st H ₂ before fuel cycle
	Impedance	H ₂	Mode IM1	Impedance characteristics with 1st H ₂ before fuel cycle
	I–V	H ₂		
	V with time at 0.4 A (1 h)	CH ₄	Mode CH1	Voltage at constant current with 1st CH ₄
	I–V	CH ₄	Mode Met	I–V characteristics with 1st CH ₄
	V with time at 0.4 A (20 min) & 0.8 A (1 h)	H ₂	Mode H2	Voltage at constant current with 2nd H ₂ after 1st CH ₄ fuel
	I–V	H ₂		
	V with time at 0.4 A (20 min) & 0.8 A (1 h)	CH ₄	Mode CH2	Voltage at constant current with 2nd CH ₄
	I–V	CH ₄		
	V with time at 0.4 A (1 h)	H ₂	Mode H3	Voltage at constant current with 3rd H ₂
	I–V	H ₂		
	V with time at 0.4 A (1 h)	CH ₄	Mode CH3	Voltage at constant current with 3rd CH ₄
	I–V	CH ₄		
	I–V	H ₂	Mode AfC	I–V characteristics with 4th H ₂ after fuel cycle
	Impedance	H ₂	Mode IM2	Impedance characteristics with 4th H ₂ after fuel cycle

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