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ScienceDirect

Procedia Chemistry 19 (2016) 267 – 274

Procedia Chemistry

5th International Conference on Recent Advances in Materials, Minerals and Environment (RAMM) & 2nd International Postgraduate Conference on Materials, Mineral and Polymer (MAMIP), 4-6 August 2015

Influence of Calcination on the Properties of Nickel Oxide-Samarium Doped Ceria Carbonate (NiO-SDCC) Composite Anodes

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Abstract

Apart from its composition, the starting powder properties such as particle size potentially affect the triple phase boundary and the electrochemical performance. Calcination process has been identified as one of the factors that influence the particle size of the composite anode powders. This study investigates the correlation between calcination temperature and properties (i.e., chemical, physical, and thermal) of NiO–samarium-doped ceria carbonate (SDCC) composite anodes. NiO–SDCC composite anode powder was prepared with NiO and SDCC through high-energy ball milling. The resultant composite powder was subjected to calcination at various temperatures ranging from 600 °C to 800 °C. Characterizations of the composite anode were performed through X-ray diffraction (XRD), Fourier transform infrared spectroscopy, energy dispersive spectroscopy, field emission scanning electron microscopy (FESEM), thermogravimetric analysis (TGA), dilatometry, and porosity measurements. The composite anodes exhibited good chemical compatibility during XRD after calcination and sintering. The FTIR result verified the existence of carbonates in all the composite anodes. The increment in calcination temperature from 600 °C to 800 °C resulted in the growth of nanoscale particles, as evidenced by the FESEM micrographs and crystallite size. Nonetheless, the porosity obtained remained within the acceptable range for a good anodic reaction (20 % to 40 %). The TGA results showed gradual mass loss in the range of 400 °C to 600 °C (within the low-temperature solid oxide fuel cell region). The composite anodes calcined at 600 °C and 700 °C revealed a good thermal expansion coefficient that matches that of the SDCC electrolyte.

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doi:10.1016/j.proche.2016.03.104

Keywords: Nickel oxide, samarium doped ceria carbonates, composite anode

1. Introduction

SOFC is an environmental friendly electrochemical device that efficiently converts chemical energy from fuel into electricity. SOFC has received considerable attention as a new-generation power system. A typical SOFC requires high operating temperatures (600°C to 1000 °C), which result in detrimental issues, such as cell degradation, thermal expansion mismatches, induced chemical instability, and expensive sealing and interconnecting material. These disadvantages eventually result in high operational costs. Reduction of the operating temperature is important to address these technical issues. However, the conventional combination of composite anodes, such as nickel–yttria-stabilized zirconia (Ni-YSZ) suffers from undesirable polarization resistance caused by low electrode kinetics and poor ionic conductivity at reduced temperatures[1,2,3].

Much research attention has been devoted to the development of high-performance composite anode materials for reduced-temperature applications. A potential strategy is to incorporate highly conductive doped ceria electrolytes, such as samarium-doped ceria (SDC) and gadolinia-doped ceria (GDC), into the highly electronic and catalytic constituent of Ni[4,5]. Progressive studies on Ni–SDC and Ni–GDC mostly yielded a promising power output at intermediate temperatures (600°C to 800 °C). However, doped ceria electrolytes suffer from chemical instability caused by the partial reduction of Ce^{4+} to Ce^{3+}, thereby deteriorating cell performance in the low-temperature region (400°C to 600 °C). The development of a novel composite electrolyte of samarium-doped ceria carbonates (SDCC) through the introduction of a small amount of alkaline salts shown a breakthrough for low-temperature SOFCs (LT-SOFCs) application. SDCC electrolytes exhibit distinctive performance and offer better chemical and mechanical stability than other pristine-doped ceria electrolytes performing at low temperatures[6].

NiO–SDCC is considered a new combination of composite anode materials. Jarot et al. (2011) reported the influence of different carbonate contents and pellet fabrication pressures on the physical and chemical properties of NiO–SDCC[7]. NiO–SDCC exhibited promising performance at a low temperature as a single cell with SDCC electrolyte and lanthanum strontium cobalt ferrite–SDCC cathode in the low-temperature region. Despite exhibiting good cell performance, studies on NiO–SDCC powder processing are still limited. Calcination is a common powder processing technique that has been found to influence powder properties. Consequently, selection of a suitable calcination temperature is important because powder characteristics, such as particle size, potentially affect the triple phase boundary (TPB), microstructure, and eventually the electrochemical performance[8].

In the present study, NiO-SDCC composite anodes were prepared by using ball milling process. The composite powders were subjected to calcination temperatures of 600, 700 and 800 °C. The composite anode properties (chemical, physical and thermal) were investigated in relation to calcination temperatures.

Nomenclature

SOFC	Solid oxide fuel cell
NiO	Nickel oxide
SDC	Samarium doped ceria
YSZ	Yytria stabilised zirconia
GDC	Gadolium doped ceria
SDCC	Samarium doped ceria carbonate