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Fabrication of metal-supported tubular solid oxide fuel cell by phase-inversion method and in situ reduction

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ABSTRACT

Ni–Fe alloy supported tubular solid oxide fuel cells (SOFCs) were successfully fabricated by a low cost and simple process involving phase-inversion, co-sintering and in situ reduction. The tubular metal supports have a special structure consisting of uniformly distributed sponge-like pores. It has proven that co-sintering the as-prepared tubular supports together with half cells (anode and electrolyte layers) is in favor of obtaining the YSZ crack-free electrolyte film. In addition to the support for SOFC, the Ni–Fe alloy tube also serves as current collector at the anode side after fully in situ reduction. The maximum power densities of the Ni–Fe alloy supported tubular SOFCs are 0.26 W cm^{-2} at 800 °C, using moist hydrogen as fuel and ambient air as oxidant. The present work demonstrates the feasibility for the fabrication of metal-supported SOFCs with acceptable performance using economical techniques.

Introduction

Solid oxide fuel cell (SOFC) is a promising clean energy conversion device that can convert the chemical energy in fuels directly into electricity through electrochemical reactions, which is more efficient and environmentally benign than conventional thermal power generation [1]. Through several decades of development, SOFC technology has achieved a very high level of technical refinement. Many practical applications incorporating SOFC technologies have been demonstrated throughout the world with impressive technical progress [2]. However, the cost of today's state-of-the-art SOFC technology remains much too high to compete with entrenched power generation technologies [3]. The majority of conventional SOFC development to date mainly focused on electrolyte-supported, cathode-supported or anode-supported SOFCs, of which the mechanical supports usually are brittle ceramic or cermet containing expensive rare earth materials. Compared to the conventional electrode- and electrolyte-supported SOFCs, metal-supported SOFCs offer a significant advantage of low materials cost [4]. Generally, the metal-supported SOFCs are composed of inexpensive and robust porous metal as support, and utilize ceramic layers only as thick as

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necessary for electrochemical function (within processing constraints). Besides, many problems can be solved or avoided in the fabrication process due to the mature metal welding and processing technologies. A variety of metal compositions have been demonstrated as the potential candidate support materials for SOFCs in previous literature, such as Fe-Ni alloy, Fe-Cr alloy, Hastelloy and ferritic stainless steel (e.g. 430 L) [5–8].

Previous studies mainly focused on the development of metal-supported SOFCs in planar configuration [9–11]. However, internal thermal stress and gas sealing have always been the difficult issues for planar SOFCs. Tubular SOFC configuration has shown many advantages compared with the planar SOFC, including higher mechanical robustness, better thermal-cycling behavior and simpler gas sealing [12,13]. Many traditional techniques have been demonstrated in the last decade to fabricate the tubular SOFCs, mainly including plastic extrusion [14], slip casting [15] and dip coating [16]. Last few years, a phase-inversion method has been employed to fabricate tubular SOFCs with conventional electrode or electrolyte materials [17–19]. This method is carried out through a relatively simple process involving no expensive equipment, which is conductive to reduce the total cost [20–23]. Another prominent advantage of phase-inversion method is the controllable microstructure tailoring of the prepared porous membranes [24]. Besides, previous studies usually employed elemental metals or alloys as the support materials, which compelled the sintering process under reducing or inert atmosphere. This significantly increased the complexity of the fabrication process. In the present work, metal-supported tubular SOFCs were successfully fabricated using a low cost and simple process involving phase-inversion, co-sintering and in situ reduction. Metallic supports were prepared with mixed NiO and Fe_2O_3 powders, which was in situ reduced into Ni–Fe alloy. The aim of this study was to investigate the fabrication process and electrochemical properties of the Ni–Fe alloy supported tubular SOFCs.

Experimental

Cell fabrication

Commercially available NiO, Fe_2O_3, yttria-stabilized zirconia (YSZ) and $(La_{0.8}Sr_{0.2})_{0.95}MnO_{3-\delta}$ (LSM) powders with purity of 99.9% were purchased from Huatsing Power (Kunshan, China) for this study. Polyethersulfone (PESF) and N-methyl-2-pyrrolidone (NMP) were used as the polymer binder and solvent respectively, which were purchased from Lanyi Inc. (Beijing, China). For preparation of the tubular supports, the phase-inversion method was employed in the present work. NiO and Fe_2O_3 powders were uniformly mixed at 1 to 1 atomic ratio by ball milling. The powders were mixed with solution of PESF in NMP and milled to obtain viscous slurry. The slurry was uniformly coated on the surface of a tubular glass stick by flowing down according to its own weight. Then the glass stick with the coating was immersed in water to solidify the outer coating layer. Green NiO–Fe_2O_3 tubular supports were obtained after removing the glass stick (Fig. 1).

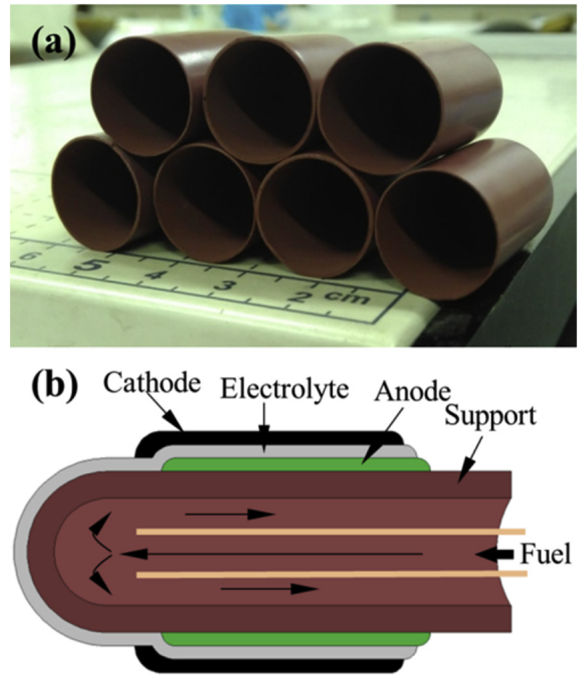

Fig. 1 – As-prepared tubular supports (a) and the schematic drawing of an one-end-closed metal-supported tubular SOFC (b).

Fig. 2 shows the fabrication process of the metal-supported tubular SOFCs. In this work, the anode, electrolyte and cathode materials were NiO–YSZ, YSZ and LSM respectively, both of which were prepared into viscous slurry by mixing with terpineol, fish oil and ethylcellulose. After drying up the NiO–Fe_2O_3 tubular supports at 70 °C, the NiO–YSZ (equivalent to 50% NiO and 50% YSZ by weight ratio) anode functional

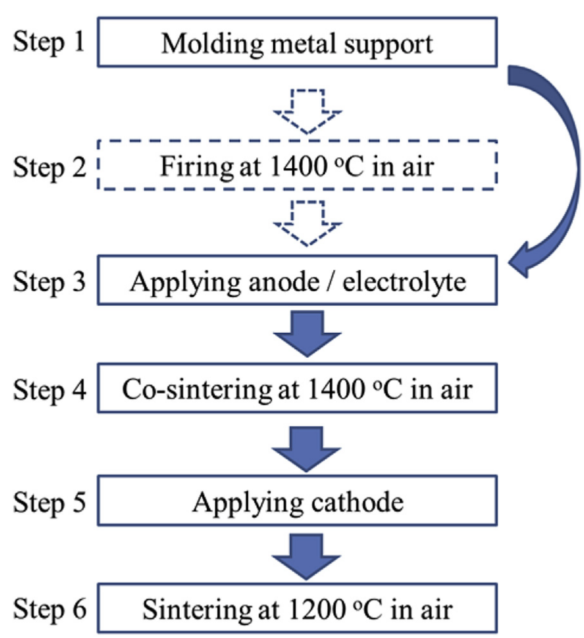

Fig. 2 – Flow diagram of the fabrication process of metal-supported tubular SOFCs.