



Challenges in fabricating planar solid oxide fuel cells: A review



L.S. Mahmud^a, A. Muchtar^{a,b,*}, M.R. Somalu^a

^a Fuel Cell Institute, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia

^b Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor Malaysia

ARTICLE INFO

Keywords:

SOFC
Planar
Fabrication
Cost-effective

ABSTRACT

Most technologies for fabricating solid oxide fuel cells (SOFCs) are adopted from ceramic-fabrication methods. Selecting an appropriate method of preparing SOFC components is a main concern for many researchers because the method can strongly affect SOFC properties and performance. The method must be reproducible and highly controllable to improve SOFC performance and durability. SOFC fabrication methods have been customized to achieve high power outputs at low operation temperatures and thus broaden the choice of material and reduce fabrication cost. This article provides an overview of planar SOFC fabrication methods. Planar SOFC fabrication methods such as uniaxial pressing, tape casting, screen printing, dip coating, and slurry spin coating are discussed because these methods are cost effective. This article also discusses the technical parameters that can influence the processes of these methods and SOFC performance. The methods of preparing the materials of SOFC components are discussed because these methods directly affect the fabrication process.

1. Introduction

Solid-oxide fuel cells (SOFCs) are highly efficient energy-conversion devices because the electrochemical reaction between fuel and air generates electrical energy without adversely affecting the environment. SOFCs can generate electricity from various types of fuels for several applications, such as in the field of stationary distributed power generation and transportation. However, this process depends on the operation temperature. Even at high operation temperatures (800–1000 °C), the direct internal reforming of natural gas and other hydrocarbon fuels occurs at the anode of a functioning SOFC power system.

The primary advantage of an SOFC is its ability to generate electricity at relatively high temperatures compared with other fuel cells. For example, high temperature SOFCs can produce high quality exhaust heat for co-generation, and can be incorporated into a gas turbine as pressure increases to improve the overall efficiency of an SOFC system. Unfortunately, the high operating temperatures of SOFCs have increased the fabrication cost, limited the choice of materials, and decreased the durability and thus shortened lifetime. These drawbacks critically limit the progress in SOFC manufacturing [1–6]. Meanwhile, reducing the operating temperature of SOFCs has

substantial benefits, such as reducing the fabrication cost, broadening the choice of materials, prolonging the durability, simplifying thermal management (decreasing the stress between the triple phase boundary, TPB), improving cell consistency, facilitating faster start-up and cool down, and preventing or reducing cell degradation [3,7–12].

Reducing the operation temperature to ≤ 550 °C is a challenging task because it can affect other factors, particularly the preparation of materials for the electrode and electrolyte components and the selection of fabrication methods. Fortunately, more researchers have been working on manufacturing smaller or micro-SOFCs, which can supply 1 W for the operation of a small device and have low operation temperatures (≤ 600 °C). In particular, a small or micro-SOFC can be used to replace the battery in small electronic devices (such as cellular phones) because it can generate an energy density that is 3–4 times higher than that of Li ion or Ni metal hydride batteries [7,13].

SOFC commercialization is currently hindered by the manufacturing costs. Accordingly, researchers have attempted to reduce the operation temperature and material cost, which are crucial to the overall fabrication cost. Small-scale production of SOFCs with a minimum thickness not only decreases the operating temperature but also minimizes the ohmic resistance across the cell. For instance, SOFCs can be operated at reduced temperature (e.g. 600 °C) by

Abbreviations: SOFCs, solid oxide fuel cells; NiO, nickel oxide; Ni, nickel; SDC, samarium-doped ceria; ScSZ, scandia-stabilized-zirconia; CGO, gadolinium-doped-ceria; LSCF, lanthanum strontium cobalt ferrite; ScSZ, scandia stabilized zirconia; LSM, lanthanum strontium magnesium; LSGM, lanthanum strontium gallium magnesium oxide; LSM, lanthanum strontium manganite; YSZ, yttria stabilized zirconia; LSCF, lanthanum strontium cobalt ferrite; GNP, glycine nitrate process; SEM, scanning electron microscope; TPB, triple phase boundary; XRD, X-ray diffraction

* Corresponding author at: Fuel Cell Institute, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia.

E-mail address: muchtar@ukm.edu.my (A. Muchtar).

reducing the electrolyte thickness and by using electrode-supported designs such as anode-supported ones [11,14,15]. Practical and suitable fabrication methods for SOFC single cells must be carefully selected and planned to decrease SOFC thickness. Preventing mechanical failures, generating a high power density outputs and improving the performance of SOFC are also essential for the commercialization of SOFCs [2,10,16–19].

Basically, tape casting and dry pressing methods are frequently used to fabricate the supported layer. The other component layers are fabricated on the supported layer via other techniques, such as wet ceramic or direct deposition methods. The former includes screen printing [20], slurry coating [21], electrophoretic deposition [22], and slurry spin coating [23]. The latter includes pulsed laser deposition (PLD) [24], aerosol-assisted chemical vapor deposition [25], spray pyrolysis [26], atomic layer deposition [27], and electron beam evaporation [28].

Forschungszentrum Julich is one of the largest interdisciplinary research institutions in Europe that researches SOFC development as renewable and sustainable energy sources of the future. Thus far, SOFC development has been focused on cost reduction without compromising industrial requirements. For example, some researchers have shifted from the classical manufacturing technologies (such as warm pressing) to tape casting for the support structure and screen printing of all functional layers. They aimed to decrease the processing steps by improving the co-firing process [18].

Bloom Energy, the company well known for producing The Bloom Box SOFCs, has also applied tape casting to fabricate electrolyte components, in which the anode and cathode are screen printed on both sides of the electrolyte and co-sintered at high temperatures. This company prefers the use of tape casting and screen printing given their simplicity in producing planar SOFCs. Thus, these methods are cost effective and suitable for large- and small-scale production [29].

Several techniques can be used to produce SOFCs, but their use depends on equipment cost. For instance, PLD can be used to produce a thin and high-quality SOFC. However, PLD is not used to mass produce SOFCs because of its high cost of equipment installation. In an experimental setup, a PLD system generally consists of a vacuum chamber, a UV transparent window with laser beam, target and substrate holders, and other additional components outside the chamber. Considering its complexity and high cost, the PLD system is practical only for small-scale laboratory work [14]. The advantages of using tape casting and screen printing techniques are further discussed in the following section.

So far, a comprehensive review focusing on the production of SOFCs which uses low-cost technologies has not been reported. Thus, the present review aims to discuss the fabrication methods for planar SOFCs that have been used by most researchers particularly the simple and cost-effective fabrication methods. SOFC performance is the most critical evaluation criterion discussed in this review. Furthermore, material preparation and types of SOFC designs are briefly reviewed.

2. Material preparation

The materials used for developing SOFCs must be selected based on the requirements and functionalities of the SOFC components. For example, anode materials must have sufficient porosity to transport fuel and to exhibit excellent catalytic activity during fuel oxidation. Moreover, cathode materials require a high catalytic activity for oxygen reduction and sufficient porous structures. Meanwhile, electrolyte materials must have an optimum ionic conductivity in solid state, improved stability during chemical reactions, and adequate mechanical strength [9,10,30].

Several researchers prefer to fabricate new materials for electrodes and electrolytes, such as the addition of new catalysts into the anode-based materials, to reduce carbon deposition, and to develop new cathode-based materials that have high activities during oxygen

reduction. Thus, research regarding the choice of suitable methods for the synthesis of the materials of SOFC components has been continually emerging [10]. Several material synthesis methods, including solid-state reaction [31–34], sol–gel [35,36], co-precipitation [37–39], Pechini process [40,41], hydrothermal synthesis [42], and combustion reaction (such as glycine nitrate process) [43,44], have been proposed to synthesize the anode, cathode, and electrolyte components of SOFCs. However, choosing a suitable synthesis method to prepare SOFC composite powders is difficult because of their respective advantages and weaknesses. Indeed, the physical characteristics and electrochemical performance of SOFCs depend on these [45–48]. The following section discusses the results and the advantages of various methods used in the preparation of anode, cathode, and electrolyte powders for SOFC application.

2.1. Solid-state reaction

Solid-state reaction is the first method used to refine and synthesize doped ceria powders because it is cost-effective. It involves the use of a ball mill to grind or mill the mixture of composite powders. Ball mills such as drum, jet, bead, horizontal rotary, vibration, and planetary ball mills are generally used in this preparation method. The solid-state reaction requires long processing time and the repetition of the milling processes to improve the particle size distribution to increase the surface area, and to obtain the desired purity and homogeneity of the reaction mixture. This method can also maintain the quality of the mixed ceramic powders with high yields and without using solvents. Unfortunately, the long period and high operating temperature of the process, as well as the repeated milling process, may lead to the contamination and to the inhomogeneity of the mixtures [10,49–51].

Chemical reactions and technical parameters are two important factors that must be considered and examined before milling. Chemical reactions refer to the types of catalysts and additives or substrates added to the raw material powder during the milling process. Meanwhile, the technical parameters, such as the type of ball mill, rotation speed or oscillation frequency, reaction time, type of milling material, size and number of milling balls, and operation mode of the ball milling process, are associated to the physical parameters in the process [49–51].

Powders prepared via the solid-state reaction require a single or repeated ball milling process, followed by calcination at high temperatures. For example, Naiqing et al. [31] prepared $\text{La}_{0.9}\text{Sr}_{0.1}\text{Ga}_{0.8}\text{Mg}_{0.2}\text{O}_{3-\delta}$ (LSGM) as an electrolyte substrate from the pure La_2O_3 , Ga_2O_3 , MgO , and SrCO_3 powders. All these powders were ball-milled and calcined for 24 h at 1250 °C. The powders were then reheated at 1500 °C for 36 h. The X-ray diffraction (XRD) pattern of the calcined powders showed that only a single LSGM phase existed, and no impurities were detected in the mixture. Zhu et al. [52] furthered this research by using pretreatment methods before the solid-state reaction process. La_2O_3 and MgO were heated at 1000 °C for 6 h for decarbonation, and Ga_2O_3 and SrCO_3 were heated at 80 °C for 6 h for dehydration. Each starting powder was ball-milled with ethanol for 24 h and then dried ultrasonically. Meanwhile, the LSGM powders were ball-milled with ethanol for 24 h at stoichiometric amounts and dried at room temperature ultrasonically. The raw materials were then calcined at 1300 °C for 18 h or 36 h (single calcination). The other raw powders were pre-calcined at 900 °C for 24 h and then calcined at 1300 °C for 18 h or 36 h (double calcination steps). The XRD patterns for the single calcination powders showed that LSGM, LaSrGaO_4 , and $\text{LaSrGa}_3\text{O}_7$ phases existed. The XRD patterns for LSGM powders with double calcination process showed that the LSGM powders that were calcined at 1300 °C for 18 h contained some impurities, but LSGM powders (denoted as LSGM–B36) that were calcined at 1300 °C for 36 h only showed a single LSGM phase. LSGM–B36 powders also contained finer particles with a particle size of 3.0 μm. These particles were smaller than those from the study of Naiqing et al. [31]. These results show that the two steps of wet ball-milling processes with ethanol

Download English Version:

<https://daneshyari.com/en/article/5482351>

Download Persian Version:

<https://daneshyari.com/article/5482351>

[Daneshyari.com](https://daneshyari.com)