ARTICLE IN PRESS

INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2017) 1–17

Available online at www.sciencedirect.com

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journal homepage: www.elsevier.com/locate/he

Review Article

Novel materials for solid oxide fuel cell technologies: A literature review

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ARTICLE INFO

Article history:
Received 10 May 2017
Received in revised form
14 July 2017
Accepted 17 August 2017
Available online xxx

Keywords:
Solid oxide fuel cell
Anode
Cathode
Electrolyte
Materials

ABSTRACT

This study aims to review novel materials for solid oxide fuel cell (SOFC) applications covered in literature. Thence, it was found that current SOFC operating conditions lead to issues, such as carbon surface deposition, sulfur poisoning and quick component degradation at high temperatures, which make it unsuitable for a few applications. Therefore, many researches are focused on cell performance enhancement through replacing the materials being used in order to improve properties and/or reduce operating temperatures. Most modifications in the anode aim to avoid some issues concerning conventionally used Ni-based materials, such as carbon deposition and sulfur poisoning, besides enhancing catalytic activity, once this component is directly exposed to the fuel. It was also found literature about the cathode with the aim of developing a material with enhanced properties in a wider temperature range, which has been compared to the currently used one: LSM perovskite ($La_{1-x}Sr_xMnO_3$). Novel electrolyte materials can have ionic or protonic conductivity, thus performance degradation must be avoided at several operating conditions. In order to enhance its electrochemical performance, different materials for electrodes (cathode and anode) and electrolytes have been assessed herein.

Contents

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http://dx.doi.org/10.1016/j.ijhydene.2017.08.105
0360-3199/

Introduction

Fuel cells are electrochemical devices that convert chemical energy into electrical energy with high efficiency from fuel oxidation, while at the same time reducing the amount of oxidant [1,2]. Chemical energy conversion into electricity is completely electrochemical, i.e. it occurs without any movement [3]. Among the various types of fuel cell, solid oxide fuel cells (SOFC) stand out on account of several aspects, such as having high energy conversion efficiency, fuel flexibility, high-quality exhaust heat, all-solid-state structure, high power density, low greenhouse gas emissions, reduced noise and environmental impact [1,4–6]. A SOFC consists of electrodes (anode and cathode) and an electrolyte. The anode receives the fuel and the cathode receives an oxidant, while the electrolyte allows oxide ions or protons to pass through it. Fig. 1 illustrates a general SOFC performance with an oxygen-conducting electrolyte fueled by hydrogen.

The first SOFC model was developed by Baur and Preis in 1937, which operates at 1000 °C. Ever since, most commonly used SOFC models operate at high temperatures (close to 1000 °C) [7]. This fact leads to material degradation at great speed and incurs high maintenance costs, thus hindering their economic feasibility [8], which can be overcome by lowering operating temperatures to an intermediate range (500–800 °C), once it can reduce their cost and improve stability [9].

A considerable hindrance to SOFCs operation temperature reduction is the low performance of traditional electrode materials working within this temperature range [10]. As regards electrolyte membrane materials, they may exhibit a pattern of behavior which is inappropriate to fuel cell application [11]. Studies have focused on seeking novel electrode and electrolyte materials that can withstand SOFCs operating conditions, while showing great performance at intermediate or even high temperatures simultaneously. Thereby, the present work aims to review some literary studies in which novel SOFC electrode and electrolyte materials have been introduced by focusing on enhancing fuel cell performance and/or reducing operating temperatures in order to provide a nice and simple access point and show some progresses by introducing novel compounds, along with briefly summarizing the present results.

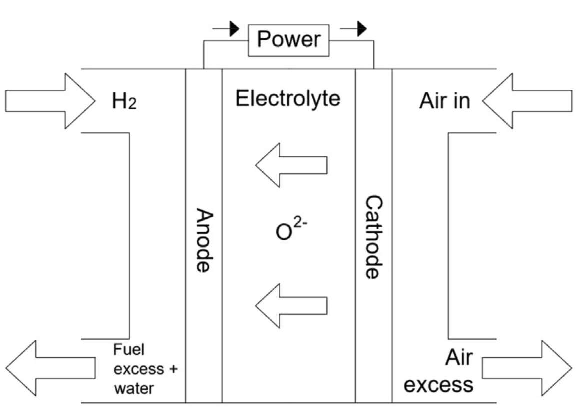

Fig. 1 – Working principle of a solid oxide fuel cell.

Materials

Current SOFC models make use of 8 mol%Y_2O_3 and stabilized ZrO_2 (8-YSZ)/Ni as anodes, YSZ (yttria-stabilized zirconia) as electrolytes and $La_{0.8}Sr_{0.2}MnO_3$ (LSM) as cathodes [12]. Ordinary solid oxide fuel cells must work at temperatures of over 800 °C in order to provide optimal electrolyte and electrode performance [13]. In order to make the equipment more commercially feasible, it is necessary to develop novel electrode materials that exhibit high electrocatalytic activity [14] and electrolyte materials that prevent detrimental reactions which lead to performance degradation [15] at lower operation temperatures. Its components should also have similar thermal expansion coefficients (TEC) in order to minimize thermal stress [16].

Electrode materials

Anode

Anode is the component which directly exposes the catalyst to fuels [5], therefore being one of the most important components of SOFCs [17], once it must catalyze the following oxidation reaction (Eq. (1)):

$$H_2 + O^{2-} = H_2O + 2e^- \quad (1)$$

Although conventional Ni-based anodes in SOFCs serve their fuel catalysis role due to excellent electrochemical properties and low cost [18], there are a few problems yet to be circumvented, such as nickel sintering, carbon surface deposition and sulfur poisoning when impure hydrocarbon fuels are used, thus leading to component degradation [5,19,20]. Fig. 2 illustrates these issues related to NI-YSZ anode behavior. Therefore, it is imperative to invest in the development of new materials with increased tolerance to sulfur poisoning and carbon deposition in order to produce SOFCs with more robustness and fuel flexibility [21]. Materials to be used for anode production must have a few important properties, such as high electrical conductivity, thermal expansion compatibility with the electrolyte material and high porosity [17].

Modified nickel-zirconia. Ni-YSZ cermet has been commonly used as SOFC anode due to its great features, such as high