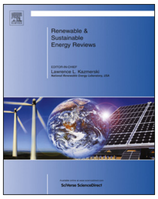
Renewable and Sustainable Energy Reviews 56 (2016) 1101–1121

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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



A review on cell/stack designs for high performance solid oxide fuel cells

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ARTICLE INFO

Article history:
Received 16 July 2014
Received in revised form
3 November 2015
Accepted 3 December 2015

Keywords:
Solid oxide fuel cell
Cell design
Geometrical modification
Structural modification
Review

ABSTRACT

Besides the general advantages of fuel cells, including clean and quiet operation, solid oxide fuel cells (SOFCs) as being one of the high-temperature fuel cells also provide a relatively high efficiency due to enhanced reaction kinetics at high operating temperatures. The high operation temperature of SOFC also enables internal reforming of most hydrocarbons and can tolerate small quantities of impurities in the fuel. However, a high operation temperature limits the SOFC application areas to stationary applications because of a long start-up period and also is not desirable from the viewpoint of cost reduction and long-term stability especially for the cell materials. Therefore, the lowering the operation temperature of SOFCs is crucial for the cost reduction and the long term operation without degradation as well as the commercialization of the SOFC systems. The reduced operating temperature also helps to reduce the time and to save the energy required for the system start-up enabling SOFCs to have wider application areas including mobile/portable ones. Apart from the low operating temperature, the high performance along with a small volume is another requirement for SOFC to be used in mobile applications. Both can be achieved by fabricating novel SOFCs generating a high power output at low operating temperatures. Therefore, this paper reviews the current status and related research on the development of these high performance-SOFC cell/stack designs.

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http://dx.doi.org/10.1016/j.rser.2015.12.034
1364-0321/

1. Introduction

Solid oxide fuel cells (SOFC) are new generation electrochemical devices which convert the chemical energy of a fuel directly into electrical energy with an additional amount of valuable heat energy. They can be also considered to be environmentally friendly technology depending on how the fuel is processed. Since the energy conversion is totally electrochemical and does not contain any other intermediate energy conversion steps, the electrical efficiency of SOFCs is relatively higher than the similar mature technologies such as internal combustion engines or generators. SOFCs may operate at very high temperature (600–1000 °C) depending on the electrolyte material. Thus, they have a higher tolerance to fuel impurities than that of the low temperature fuel cell types. The enhanced reaction kinetics as a result of the high operation temperature further improve the electric efficiency of SOFC hence SOFC can be considered to be one of the most efficient fuel cells. In addition to pure hydrogen, gaseous hydrocarbon fuels can be used as a fuel in SOFC directly or after a reforming process. Despite the superior advantages mentioned, the commercialization of the technology has not fully succeeded and thus SOFC is still not competitive in the energy market due to mainly very high operation temperatures leading to stability problems as a result of material issues and economic obstacles because of the high costs of special materials required especially for the high temperature sealing and current collection. The companies in this field like Siemens Westinghouse stopped their R&D activities due to the slow development of the fuel cell market and the growth of the global economies. In the material point of view, a strategic constraint is to improve the ionic conductivity of the electrolyte at a low temperature and to provide a stable device. If succeeding these goals would mean a technology breakthrough.

1.1. *SOFC operation principle and cell/stack structure*

Ceramic membrane electrode assembly (MEA) composed of a porous anode, a dense electrolyte and a porous cathode is the key element of the SOFC system. While the anode is responsible for the fuel oxidation, the oxygen ions generated at the cathode as a result of the cathode electrochemical reaction are transferred through the electrolyte to the anode layer. The generation of the electrical current is achieved via the external circuit during the transfer of electrons produced at the anode site to the cathode site. The current collection is achieved by using ceramic or metallic current collectors at both sides known as interconnectors. The operation principle of hydrogen fueled SOFC with the electrochemical reactions occurring each layer is shown in Fig. 1. The electrochemical reactions, on the other hand, take place at triple phase boundaries (TPBs) where an ion conductor, an electronic conductor or catalyst and reactant phases meet. In order to improve the ionic conductivity of the electrodes and thus expand TPBs to all over the electrode volume, a certain amount of electrolyte material is often mixed with the corresponding catalyst material. In this aspect, a typical SOFC MEA consists of porous NiO/8YSZ (yttria stabilized zirconia: 8 mol% Y_2O_3–ZrO_2) anode, dense 8YSZ electrolyte and porous LSM (lanthanum strontium manganite)/8YSZ cathode. SOFC composed of a MEA and two interconnects with required sealing is called as a single cell or short stack. In order to produce higher power as well as higher potential, single cells are connected in series/parallel to construct SOFC stacks. An SOFC single cell and three-cell stack are illustrated in Fig. 2(a) and (b), respectively. The sealant is not included in the figures for better understanding of the cell/stack configuration.

1.2. *SOFC classifications*

SOFCs can be categorized according to the type of the cell support (i.e. anode, cathode, electrolyte or porous substrate supported)

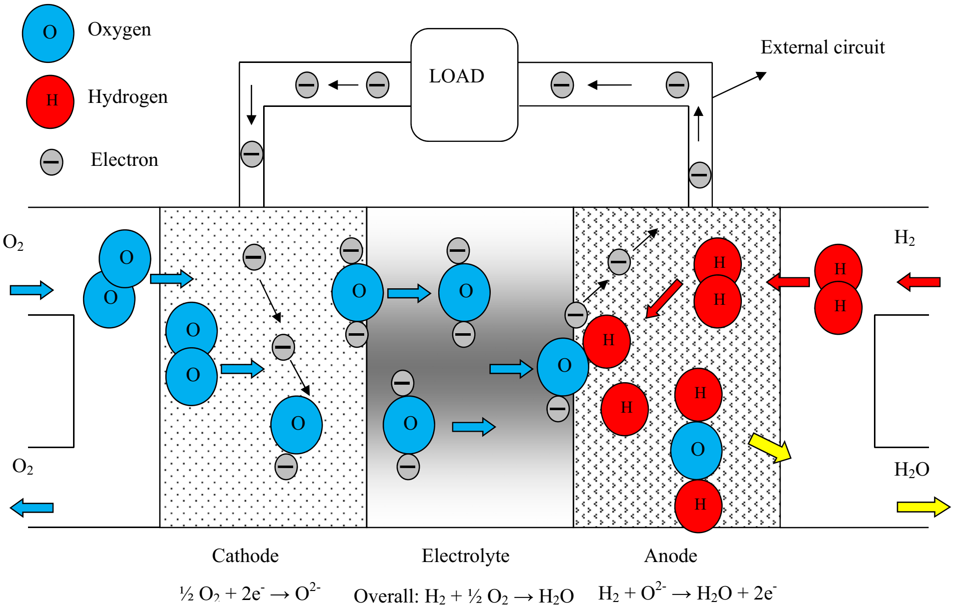

Fig. 1. Schematic of SOFC working principle.