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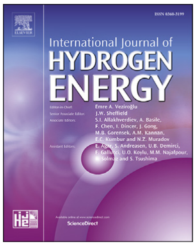

Review Article

Cathode-side electrical contact and contact materials for solid oxide fuel cell stacking: A review

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ABSTRACT

In a planar solid oxide fuel cell (SOFC) stack, a number of individual cells are stacked together to increase the voltage and power output. At both the cathode– and anode–interconnect interfaces, electrical contact layers are applied between the interconnect and electrodes during cell fabrication process or stack assembly to increase the electrode-interconnect contact area and to compensate for dimensional tolerance variation of the contacting components, thus minimizing ohmic contact resistance throughout the stack. As such, electrical contact is an essential component in SOFC stacks. In this paper, we review the cathode-side electrical contact design and contact materials for application in SOFC stacks. Following an introduction of the function and working principles of electrical contact, the material requirements for cathode-side contact layer in SOFC stacks are outlined. The current materials for the cathode–interconnect contact are thoroughly reviewed, including noble metals, conductive ceramics (e.g. perovskites and spinels), composites, and other more complex structures. Several potential directions for cathode–interconnect contact material research and development are also highlighted.

Contents

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Introduction

Solid oxide fuel cells (SOFCs) are solid-state energy conversion devices that produce electricity via an electrochemical process. In an SOFC, oxygen molecules (from air) are reduced into oxygen ions in the cathode, which are transported across an ionic conducting ceramic electrolyte membrane to the anode side, where they react with the fuel (either hydrogen or hydrocarbons) in the anode to release water, CO_2, heat, and electrons for direct current power generation. High operating temperatures are required to increase the ionic conductivity of the electrolyte as well as the catalytic activity of the electrodes [1,2]. While traditional SOFC operates at elevated temperatures of 900–1000 °C, the overriding need for cost reduction and improvement of long-term stability/durability of SOFC stack and system demands that its operation temperature be reduced to the intermediate-temperature (IT) range of 600–800 °C [3,4]. At such reduced temperatures, more economically feasible and mechanically robust materials can be utilized. Compared to polymer electrolyte membrane fuel cells, IT-SOFCs are fuel-flexible, highly efficient for producing electrical power, and have high-quality waste heat for cogeneration. Moreover, they are modular in design and can be installed almost anywhere and in different sizes. Because of these characteristics, SOFC systems can potentially impact many markets such as the portable market (0.1–1 kW), the residential and auxiliary power unit (APU) markets (5–10 kW), commercial building market (100–250 kW), and large power plants (>1 MW) [5]. Currently, SOFC systems in several hundreds of kW are being developed/demonstrated and limited commercial installations have already occurred.

The current IT-SOFC development efforts focus on the planar design, as it offers a combination of high power density and potentially low fabrication cost [6,7]. In a planar SOFC stack, a number of cells are stacked together to increase the voltage and power output. Each repeating unit is composed of an anode, electrolyte, cathode, and interconnect. Fig. 1(a) shows a schematic drawing of a planar SOFC stack and the state-of-the art component materials used in the current design. Typical material choices for IT-SOFCs are yttria-stabilized zirconia (YSZ), doped ceria, or $LaGaO_3$-base oxides as electrolyte [8–10], $(La,Sr)MnO_3$ (i.e. LSM), $(La,Sr)FeO_3$ (i.e. LSF), or $(La,Sr)(Co,Fe)O_3$ (i.e. LSCF) as cathode [11,12], Ni-YSZ cermet as anode [13–15], and metallic alloys (e.g. ferritic stainless steels Crofer 22 APU, ZMG 232, AISI 441, etc.) as interconnect [16–20]. At both the cathode– and anode–interconnect interfaces, an electrical contact material (sometimes also called a current collector) is generally applied as a paste or ink during stack assembly or as part of cell fabrication process to form a continuous layer or discrete contact pads between the interconnect and electrodes.

One of the main functions of the contact material is to provide and maintain stable electrical conduction paths between the interconnect and electrodes in an SOFC stack assembly and thus minimize the interfacial ohmic resistance and stack power loss. Since both the anode and interconnect are usually metal-base materials and they experience a reducing environment on the fuel side, the contacting of these materials with each other is generally not a critical issue, and typically a combination of Ni mesh/paste can be used as the contact material. However, a more demanding contact layer is needed for the interface of the ceramic cathode and metallic interconnect, as it experiences an oxidizing environment during stack operation. Fig. 1(b) schematically illustrates the cathode–interconnect interface in an IT-SOFC, where the contact layer is in direct contact with the cathode and the oxide scale/coating on the metallic interconnect. Studies have shown that by improving the contact between the cathode and the interconnect with an additional contact layer of around 10–100 μm thick, the overall area specific resistance (ASR) can be decreased drastically by increasing the electrode-interconnect contact area and compensating the dimensional tolerance of the parts [21–23]. It should be noted that a compressive mechanical load is typically applied to the stack subsequent to its assembly in order to achieve better gas seal as well as to promote a low interfacial contact resistance between the adjacent components. Furthermore, the porous contact materials and the structures between the electrodes and interconnect can provide for additional gas channels to maximize the effective gas/catalyst/pore triple-phase boundaries (TPBs) [24] as well as mechanical bonding to mitigate the thermal cycling induced damages. Fig. 1(c) gives an example demonstrating the drastic effect of the insertion of a contact layer in lowering the ASR of the interconnect/cathode couple [23]. More specifically, a direct contact between the LSF cathode and the Crofer 22 APU interconnect led to an ASR of as high as a few hundreds of $m\Omega \cdot cm^2$, which obviously would have caused unacceptable power loss in an SOFC stack. By applying a layer of Pt paste between the cathode and ferritic interconnect, orders of magnitude reduction in ASR was achieved.