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Electrical performance of nanostructured strontium-doped lanthanum manganite impregnated onto yttria-stabilized zirconia backbone

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HIGHLIGHTS

- Conductivity of nanosized LSM depends strongly on the fabricating parameters.
- The intrinsic conductivity is estimated with the analytical model.
- The impregnated electrode with 5 vol.% LSM exhibits the highest performance.
- Ohmic resistance of the impregnated LSM electrode is negligible.

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ABSTRACT

Strontium-doped lanthanum manganite (LSM) nanoparticles are deposited onto porous yttria-stabilized zirconia frameworks via an ion impregnation/infiltration process. The apparent conductivity of the impregnated LSM nanostructure is investigated regarding the fabricating parameters including LSM loading, heat treatment temperature, heating rate, and annealing at 750 °C for 400 h. Besides, the conductivity, the intrinsic conductivity as well as Bruggeman factor of the impregnated LSM is estimated from the apparent conductivity using the analytical model for the three-dimensional impregnate network. The conductivity increases with LSM loading while the interfacial polarization resistance exhibits the lowest value at an optimal loading of about 5 vol.%, which corresponds to the largest three-phase boundary as predicted using the numerical infiltration methodology. At the optimal loading, the area specific ohmic resistance of the impregnated LSM is about 0.032 Ω cm^2 at 700 °C for a typical impregnated cathode of 30 μm thick. It is only 5.5% of the cathode interfacial polarization resistance and 3.3% of the total resistance for a single cell consisting of a Ni-YSZ support, a 10 μm thick electrolyte and a 30 μm thick cathode, demonstrating that the ohmic resistance is negligible in the LSM impregnated cathode for SOFCs.

1. Introduction

Infiltration/impregnation processes have been widely used to fabricate nanostructured electrodes of solid oxide fuel cells (SOFCs) [1–5]. These electrodes own an ideal microstructure possessing the advantages of high electro-catalytic activity and enlarged three-phase boundaries (TPB). They usually consist of two phases, *i.e.*, one oxygen ionic conductive electrolyte phase and the other electronic conductive electro-catalyst phase. And each phase can be made into the backbone and the other into nanoparticles. Using the electrode with an ionic conductive backbone and electronic conductive nanoparticles as an example, it is prepared by infiltrating the relevant nitrate solution onto the pre-sintered porous backbone, which is co-fired with the dense electrolyte at a high temperature, and then decomposing the solution at a relatively low temperature to form nanoparticles. Sr-doped $LaMnO_3$ (LSM) is one of the most commonly used electro-catalysts because of its high stability, good catalytic activity toward oxygen reduction reaction,

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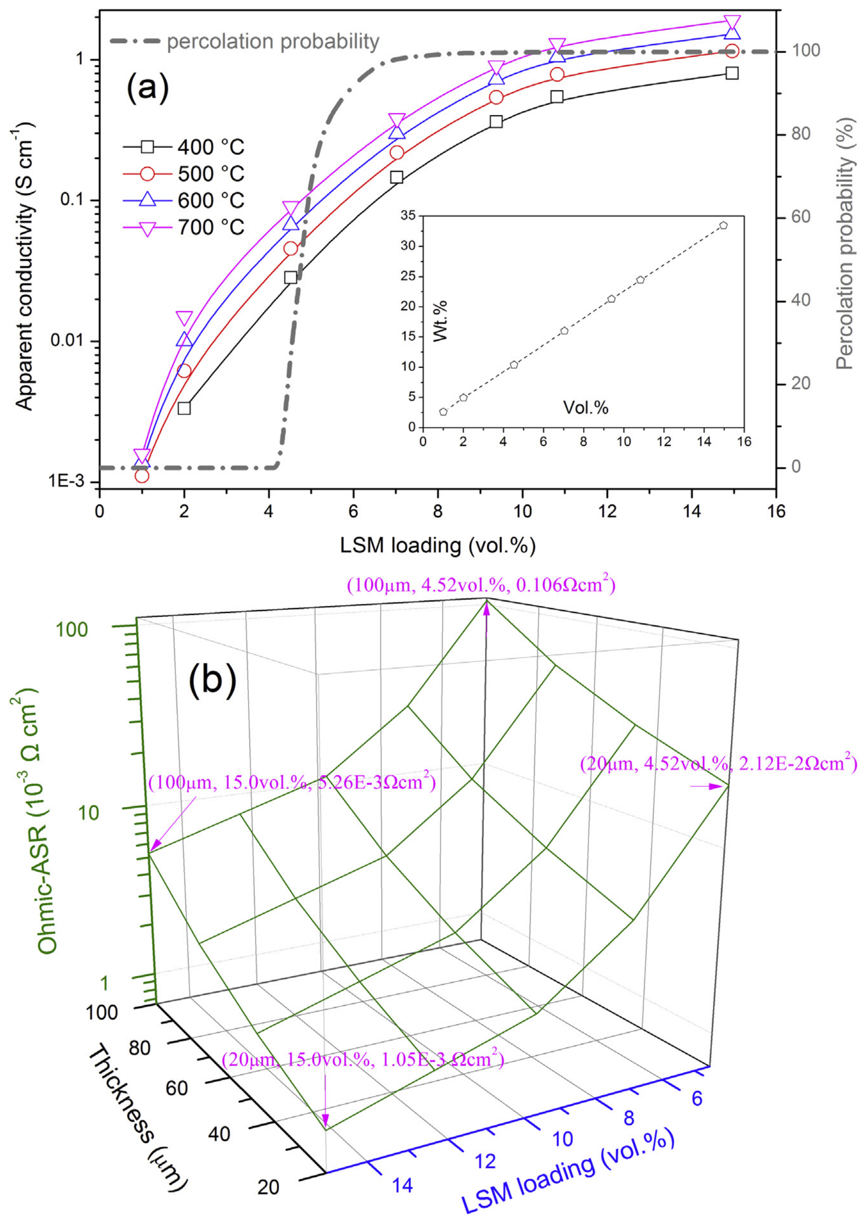

Fig. 1. (a) Effect of LSM loading on the apparent conductivity of impregnated LSM and calculation results of the percolation probability of LSM nanoparticles using the numerical infiltration methodology [13] based on the practical geometric characteristics, *i.e*., YSZ particle radius is 1 μm, LSM particle radius is 15 nm, backbone porosity is 55%, the aggregation factor is 0.9. Inset is the relationship between volume fraction and weight fraction of the impregnated LSM. (b) The ohmic-ASR at 700 °C versus the electrode thickness and LSM loading.

and excellent compatibility with the yttria-stabilized zirconia (YSZ) electrolyte [6–11]. Usually, nanosized LSM is deposited on the backbones of ionic conductors, such as YSZ [6–8], scandia-stabilized zirconia [9], and yttria-stabilized bismuth [10], to compose high-performance nanostructured cathodes. In such structures, the backbones provide the ionic conductivity while LSM nanoparticles provide the electronic conductivity as well as the catalytic activity for the oxygen reduction reaction.

The impregnated LSM electrodes have shown excellent electrochemical performance. Theoretically, much lower area specific interfacial polarization resistance is predicted for the nanostructured electrodes using the particle-layer model [12,13]. Experimentally, good cell performance has been observed no matter when LSM nanoparticles are impregnated as one part of the composite cathodes or as the electro-catalysts. For example, Huang et al. have reported an interfacial polarization resistance of 0.48 Ω cm^2 at 700 °C for a symmetric cell with impregnated LSM + YSZ electrodes [6]. It is about twenty times lower than the cell with the conventional LSM-YSZ composite electrodes, 9 Ω cm^2 [14]. Liang et al. have demonstrated a peak power density of about 0.7 W cm^{-2} at 700 °C for a Ni-YSZ anode supported single cell with impregnated cathode. It is much higher than 0.19 W cm^{-2} for a cell with the conventional LSM-YSZ electrode [7]. When LSM nanoparticles are impregnated as the electro-catalyst, performance promotion has also been obtained. When 4 μL 0.03 M LSM solution is impregnated into the porous $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3-\delta}$ cathode, the peak power density increases from 0.86 to 1.07 W cm^{-2} and the cell resistance decreases from 0.18 to 0.12 Ω cm^2 at 825 °C [11].

Usually, the ideal SOFC cathode would have excellent catalytic activity, together with adequate electronic conductivity [15,16]. While the high electro-catalytic activity of the impregnated LSM has been experimentally and modally demonstrated [6,7,11–14],