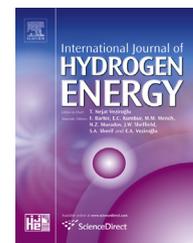


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A polarization model for solid oxide fuel cells with a Bi-layer electrolyte



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ABSTRACT

A polarization model for a solid oxide fuel cell (SOFC) with a bi-layer electrolyte is developed and a set of explicit expressions for output current, maximum power and thickness ratio of bi-layer electrolyte are obtained. In the model, two dominating polarizations, activation polarization and ohmic polarization, are considered and the concentration polarization is neglected. The activation polarization at the electrodes is described by the Butler–Volmer equation. The ohmic polarization is represented by the charge transport equation, and this equation is solved with the assumption of constant ionic conductivity. To close the model equations, a supplemental relation is introduced by the energy conservation analysis. The modeling results compare well with the experimental data. The model is further used to study the effect of cathode exchange current density on the working characteristics of a solid oxide fuel cell with a bi-layer electrolyte.

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Introduction

Acceptor doped ceria (ADC) and stabilized bismuth oxide (SBO) are promising electrolytes for solid oxide fuel cells (SOFCs) at intermediate temperature (500–800 °C) [1–4] due to their higher ionic conductivity than yttria stabilized zirconia (YSZ). However, acceptor doped ceria shows considerable electronic conductivity at typical SOFC operating conditions due to the partial reduction of Ce⁴⁺ to Ce³⁺ at low oxygen partial pressure; and stabilized bismuth oxide is unstable under moderately reducing atmosphere at intermediate temperature [5]. A SOFC with a bi-layer electrolyte can block

the electronic leakage current and protect the unstable electrolyte, so such a bi-layer electrolyte has the potential to offer both high ionic conductivity and chemical stability without significantly sacrificing the open-circuit potential at intermediate temperature [6].

Yahiro et al. [7] found that a thin YSZ layer coated on an Yttria Doped Ceria (YDC) electrolyte near the anode can protect the YDC from reduction and block the electronic current, implying that YSZ/YDC bi-layer electrolyte can improve the open-circuit voltage and chemical stability of the SOFC. Thereafter, the YSZ/ADC bi-layer electrolyte was fabricated by sputter deposition [8,9], Sol-Gel processing (spin-coating) [10–12], wet ceramic co-sintering [13], electrophoresis

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deposition [14], and pulsed laser deposition [15–19] respectively, and experimental results showed that a much higher open-circuit voltage could be reached with a bi-layer electrolyte [8–19]. Furthermore, Wachsman et al. [20–23] fabricated a ADC/SBO (Stabilized Bismuth oxide) bi-layer electrolyte SOFC and demonstrated that the SBO can block the leakage current and ADC can protect the SBO from reduction, so the bi-layer electrolyte SOFC exhibited very high power density (about 1.5 Wcm^{-2} at $650 \text{ }^\circ\text{C}$ [23]).

Except these experimental works, very limited theoretical analyses have been reported in the literature. Virkar [24] theoretically analyzed the chemical stability of the bi-layer electrolyte SOFC by an equivalent circuit approach and pointed out that the chemical stability of the electrolyte depends on the transport characteristics of the bi-layer electrolyte, in particular the transport characteristics of the electrolyte on the anode side. Marques and Navarro [25,26] studied the performance of a bi-layer electrolyte SOFC by an oxygen permeation model and analyzed the effect of relative thickness of the bi-layer electrolyte on the open-circuit voltage and chemical stability. Chan et al. [27] developed a simple bi-layer electrolyte model based on the charge transport equations and theoretically analyzed the effect of relative thickness of the bi-layer electrolyte on the performance of bi-layer electrolyte. Shen et al. [28,29] developed an analytical model for the bi-layer electrolyte SOFC based on the charge transport equations and constant ionic conductivity assumption and theoretically analyzed the characteristics of the bi-layer electrolyte. Based this analytical model, Shen and Ni [30] developed a 2D segment model for the bi-layer electrolyte SOFC to study the effect of the distribution of reactants on the leakage current.

The 1D SOFC model is important for the initial design and mechanism analysis, moreover the 1D model is also the basic of the stack model. However, the above 1D analytical models mostly neglect activation polarization in the electrode, which is a significant loss for SOFCs at intermediate temperature. In this work, a polarization model for the bi-layer electrolyte SOFC is developed based on the charge transport equation and constant ionic conductivity assumption. The cathodic polarization is calculated by the Butler–Volmer equation and an energy conservation equation is introduced as a supplementary relation. The results from the polarization model are compared with experimental data and good agreements are obtained. Finally, the effect of cathode exchange current density on the performance of bi-layer electrolyte SOFC is analyzed.

Development of the polarization model

A 1D bi-layer electrolyte SOFC shown in Fig. 1 is studied in this work. The concentration polarization at the electrode is neglected for simplicity, so the gas partial pressures are specified in the model. Under the normal SOFC operating condition, the ADC or SBO is a mixed ionic and electronic conductor (MIEC) and the blocking electrolyte (e.g. YSZ) also allows slight electronic current. Thus, in this model both oxygen ion and electron are treated as mobile charges in the bi-layer electrolyte and their currents are continuous at the

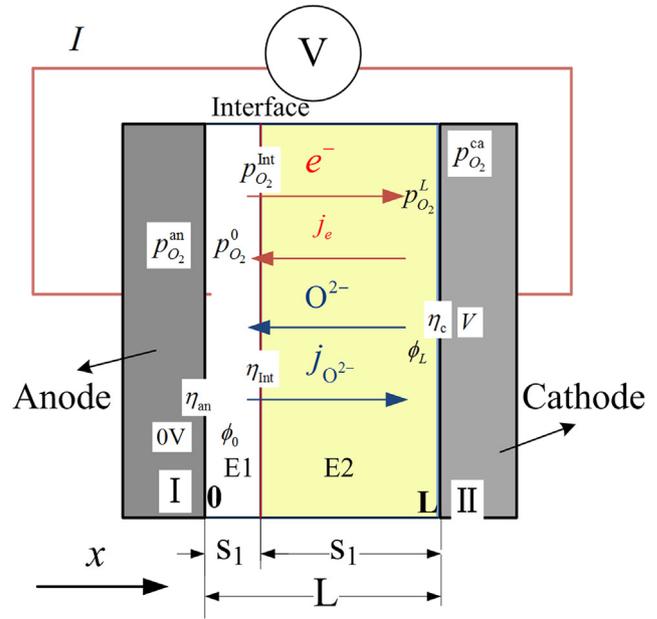


Fig. 1 – The schematic of charge transport in a SOFC with a bi-layer electrolyte.

interface in the bi-layer electrolyte. The current direction from anode to cathode is taken to be positive, so the ionic current is positive and the electronic current is negative. The two layers of the electrolyte are denoted as E1 and E2 respectively, and the contact resistance between E1 and E2 is neglected. The voltage is specified to be 0 for the anode and V for the cathode, respectively.

Fundamental equations

The fundamental equations for ohmic polarization are the charge transport equation (Nernst–Planck equation) and the steady-state continuity equation are showed as,

$$J_i(x) = -D_i \frac{dc_i(x)}{dx} - \frac{\sigma_i(x)}{z_i q} \frac{d\phi(x)}{dx} \quad (1)$$

$$\frac{d}{dx} J_i(x) = 0 \quad (2)$$

where $J_i(x)$ is the mole flux of the charge i (O^{2-} and e^-), D is diffusion coefficient, c is the concentration, σ is the conductivity and ϕ is the inner electric potential. There are three unknown variables in the two fundamental equations including the charge flux J , charge concentration c and electric potential ϕ , so several assumptions and supplemental conditions are needed to solve the fundamental equations.

Assumptions and boundary conditions

To solve the charge transport equations, the assumption of constant ionic conductivity [31–35] was commonly used in the literature. For the electrolyte in SOFC, the ionic conductivity or oxygen vacancy is mainly dependent on the doping concentration of the acceptor element, thus the constant ionic

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