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Short communication

Dynamic-temperature operation of metal-supported solid oxide fuel cells

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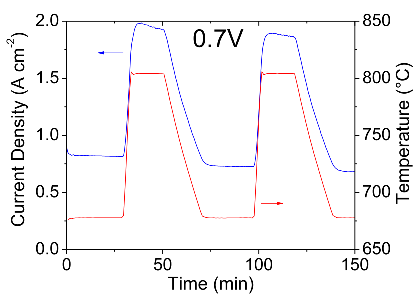
HIGHLIGHTS

- Dynamic-temperature operation proposed as new SOFC operation mode.
- Metal-supported SOFCs are operated continuously while temperature is cycled.
- Current doubles in a few minutes by rapidly increasing temperature.

GRAPHICAL ABSTRACT



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ABSTRACT

A dynamic-temperature operation strategy is proposed for SOFC systems, in which the cell temperature varies rapidly to match the SOFC stack power output to a dynamic load requirement. It is anticipated that this operation strategy may have benefits for system efficiency, size, and cost for applications with dynamic power load. Metal-supported SOFCs (MS-SOFCs) are operated continuously at 0.7 V while the temperature is varied rapidly between 675 and 800 °C or 670 and 720 °C. During the initial thermal excursion, the current density increases from 0.82 to 1.95 A cm^{-2} in 6.6 min for 675–800 °C, and from 1.0 to 1.63 A cm^{-2} in 5.4 min for 670–720 °C. Cells are subjected to continuous dynamic temperature operation for more than 100 cycles.

1. Introduction

Solid oxide fuel cells (SOFCs) operate at elevated temperature in the range 600–900 °C. Conventional anode-supported cells (ASCs) are typically operated near isothermally and with slow start-up and shutdown temperature ramp rates to avoid brittle failure of the cells arising from inhomogeneous thermal expansion stress. Power output from an SOFC is dictated by the I-V polarization curve at a given operating temperature, and it is routine to select different voltage/current operating points along the curve when adjusting power output to meet demand. As voltage is decreased, however, efficiency of the system suffers as ohmic, kinetic, and mass transport losses increase. SOFC system demonstrations therefore often operate at base load around 0.7–0.9 V [1–4], providing a good balance between efficient use of the fuel and cell output power density, which is directly related to capital cost of the system. Many potential applications for SOFC power systems, however, display power demands that are constantly fluctuating. The grid experiences large daily and annual variations in power demand, and output from smaller systems for distributed, data center, aerospace, vehicular, or personal power generation can vary on a minute-to-minute basis or faster. We propose dynamic-temperature operation of SOFC systems as a method to more closely match the capabilities of the SOFC to the requirements of the applications. It is envisioned as a control strategy wherein the cell temperature varies rapidly to meet transient load requirements; cell voltage or current variation could be limited while still providing higher temporary peak power at a higher temperature. By introducing temperature as an additional control variable, the system can maintain operation above 0.7 V for high

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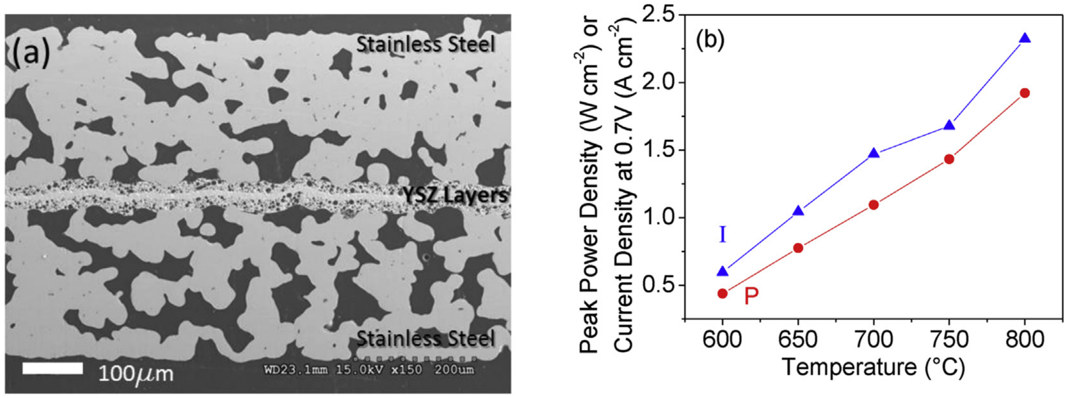

Fig. 1. MS-SOFC (a) architecture and (b) temperature-dependent performance. Current density at 0.7 V (blue triangles) and peak power density (red circles). Image reproduced and data derived from Ref. [11] with the permission of the publisher. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

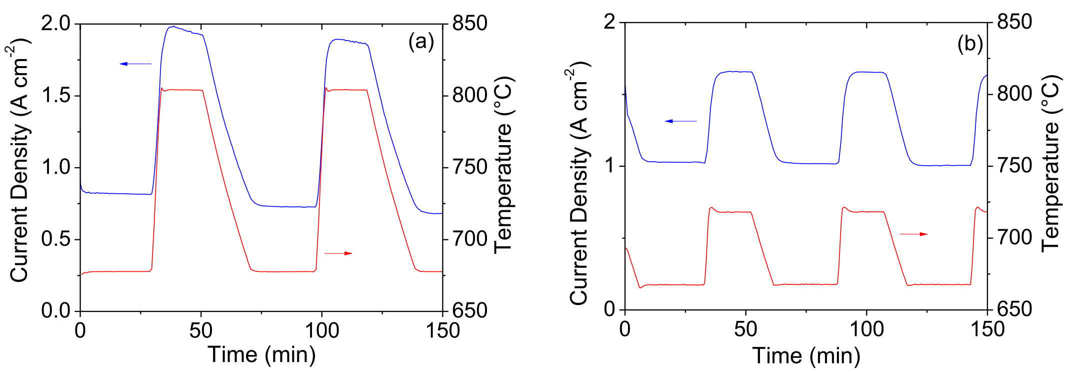

Fig. 2. Dynamic-temperature operation. Potentiostatic operation at 0.7 V while current (upper blue line) is monitored and temperature (lower red line) is varied. Temperature cycling is approximately between (a) 675 and 800 °C or (b) 670 and 720 °C. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

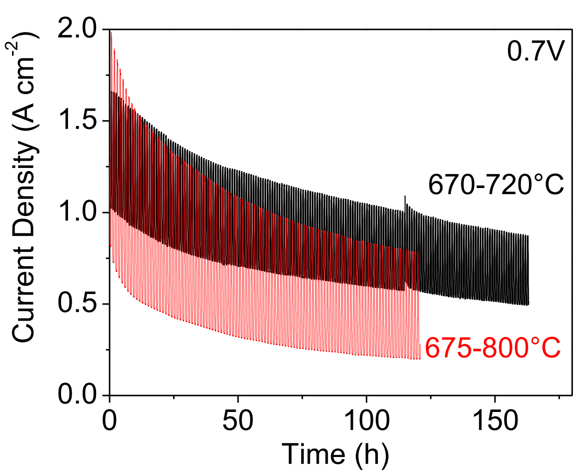

Fig. 3. Long-term dynamic-temperature operation at 0.7 V with temperature cycled between 675 and 800 °C (bottom red line) or 670 and 720 °C (top black line). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

efficiency, while modulating power output to meet demand. For example, a SOFC system producing baseload power over night could be operated at higher temperature for a few hours during the afternoon to meet peak power requirements. In another scenario, a SOFC propulsion system for an unmanned aerial vehicle (UAV) could operate at high temperature to meet lift-off power demands, then cool down quickly for cruising. It is anticipated that this strategy may also reduce capital cost of SOFC systems, as stack size can be selected for baseload rather than peak power demand. In other words, a relatively smaller and therefore less costly SOFC stack can meet peak power demand by allowing operating temperature to vary.

Metal-supported SOFCs (MS-SOFCs) are particularly well suited to dynamic-temperature operation due to their tolerance to thermal cycling. Showing that temperature can be considered a control variable, a full MS-SOFC operating stack was simulated to cool approximately 25 °C in 10 min, while voltage, current, and efficiency varied [5]. In contrast to the present work, only a single cooling event with relatively small temperature difference was reported, and the results were simulated rather than being demonstrated on a real system. LBNL previously demonstrated repeated startup of a bare planar MS-SOFC from room temperature to above 700 °C in only 10 s via flame impingement, and 200 cycles for a cell sealed to a test rig with 15 min furnace heatup from 80 to 700 °C [6,7]. MS-SOFCs with a novel composite anode were cycled 100 times with 45 °C min^{-1} heating rate [8]. Tubular MS-SOFCs have been thermal cycled 250 times at 10 °C min^{-1} [9], and 5 times at 350 °C min^{-1} maximum rate [10]. Thermal cycling is typically performed over a temperature range from near room temperature to the operating temperature, with the cell held at open circuit (no power generated) during temperature ramps. This standard protocol is relevant to start-up and shut-down of a system. In contrast, the present work demonstrates continuous operation of the cell during rapid temperature cycles over a wide range of operating temperatures, relevant to the dynamic-temperature operation strategy discussed above.

2. Experimental methods

Details of the cell fabrication and catalyst infiltration procedures are