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Electrophoretic deposition of functionally-graded NiO–YSZ composite films

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Abstract

Functionally-graded NiO–8 mol % YSZ composite films were prepared by a controlled voltage-decay electophoretic deposition (EPD) process. The films consisted of three layers with varying NiO concentrations and porosities. Effects of different parameters including the type of the organic media, solid concentration, NiO:YSZ ratio, and iodine on the stability of EPD suspensions and deposition kinetics were studied. A stable NiO–YSZ suspension was attained in isopropanol with NiO–YSZ ratio of 60:40 and iodine concentration of 0.5 mM. The composite film contained varying NiO concentration from 46 wt.% near the substrate to 32 wt.% close to the electrolyte with 42 wt% NiO in the intermediate region. The thickness of each layer is about 10, 44 and 68 μm, respectively. The prepared anode could be promising for solid oxide full cells as it compromises good contact to the electrode with higher corrosion resistance and active reaction zone with the electrolyte.

Keywords: Electrophoretic deposition; NiO–YSZ; Suspension stability; Functionally graded materials; SOFC

1. Introduction

A solid oxide fuel cell (SOFC) is an electrochemical conversion device that produces efficient and clean power via oxidizing a fuel. Albeit the advantages of SOFC over the other kinds of fuel cells such as operation on a wide variety of fuels, lower corrosion problems and cogeneration of heat and electricity, high fabrication cost with relatively low conversion efficiency have hindered their widespread application.[1] Future of SOFC is thus highly dependent on cost-reduction strategies through employing inexpensive materials and shaping processes as well as improving their efficiency and performance by microstructure modification of the cell components. An alternative approach is to decrease the operation temperature that eventually expands the selection of inexpensive materials for different components, reduces the degradation rate, and improves the cell reliability.[2–5] Meanwhile, decreasing of the working temperature has not been successful so far as the electrolyte resistivity and the polarization resistance in electrodes would increase at lower temperatures that lead to a performance loss.

Yttria stabilized zirconia (YSZ) has been the most popular electrolyte for high temperature SOFC, owing to its high oxygen conductivity, low electronic conduction, and high thermodynamic stability over a wide range of temperatures.[6–8] The most common anode is usually made of porous cermets of Ni–YSZ because of nickel's high electronic conductivity and catalytic activation toward the oxidation of fuels.[9–12] To fabricate the anode, different procedures such as physical vapor deposition (PVD), tape casting, chemical vapor deposition (CVD), and gel casting can be utilized.[13] Recently, electrophoretic deposition (EPD) process has attracted considerable attention as it is simple, rapid, inexpensive, and applicable to different materials.[14–17] Additionally, the thickness and morphology of the deposited film can easily be controlled via tuning of the processing parameters such as time and applied voltage.[18,19] Recently, Besra et al.[20,21] have shown that a NiO–YSZ anode prepared by EPD on a carbon sheet with an over layer of dense YSZ (10 μm) yields a peak power density of 434 mW cm^{-2} at 800 °C with H_2 gas as

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the fuel. The improved performance was achieved by manipulating of the anodes' microstructure and composition that was gained via controlled EPD process.

One of the advantages of EPD is its ability to fabricate multilayers[22] and functionally graded materials[23] (FGMs). It is believed that functionally graded composition and structure in the SOFC film could increase the cell performance and working life. Studies[20,24–26] have determined that the concentration of nickel in Ni/YSZ anodes changes both IR resistance and polarization but in an inverse way. On the other hand, with increasing the concentration of nickel, the delamination of the anode and electrolyte due to enhanced thermal mismatch becomes more susceptible. Therefore, functionally graded anodes are becoming attractive in order to meet the requirements of different compositions and microstructures through the film. An appropriate anode should have higher YSZ composition with finer particles close to the electrolyte to prevent degradation and increase the active reaction zone while the support layer should contain high nickel to ease fuel transportation and make a good contact with the inter-connector. In this work, we studied EPD of NiO–YSZ composite suspensions in order to fabricate functionally graded structure, which is to the best of our knowledge, has not been reported before. First, we investigated the effect of composition of the NiO–YSZ suspensions (i.e. solvent, NiO concentration and iodine content) on the stability of suspension. Then, constant voltage EPD was utilized to deposit NiO–YSZ suspensions and the deposition kinetics was evaluated. Finally, through stepwise change in the voltage, we examined the fabrication of NiO–YSZ FGM.

2. Experimental procedure

8 mol.% yttria stabilized zirconia (YSZ) powder with an average particle size of 200 nm was purchased from Tosoh Co., Japan. NiO powder with an average particle size of 5 μm was supplied by Sigma Aldrich, USA. The nickel oxide powder was mechanically milled by Spex 8000 miller (SPEX, USA) for 60 min in ethanol to reduce the average particle size. Zirconia vial (250 cm^3) and balls (2 mm) were utilized. The particle size distribution of the NiO powders was determined by a Fritsch particle size analyzer (analysette 22). Scanning electron micrographs (SEM, Tescan Vega, USA) and the particle

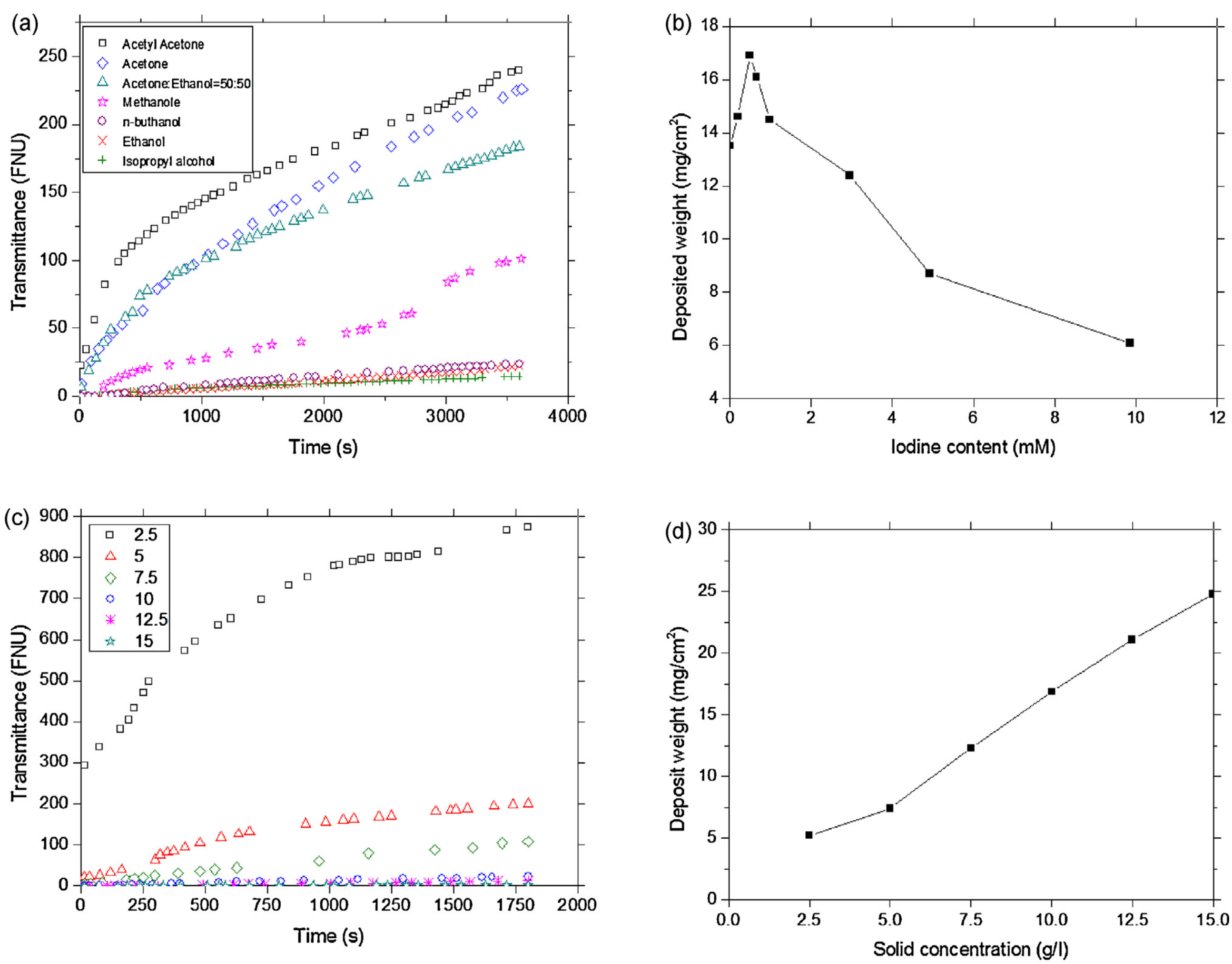

Fig. 1. Transmittance of 60NiO–40YSZ (wt.%) composite suspensions (10 mg/ml) and weight of the deposited coating after 3 min EPD and an applied voltage of 200 V. (a) Time-resolved sedimentation analysis shows the effect of various solvents on the stability of the suspensions. (b) Effect of iodine concentration in the solvent on the deposited weight. (c) Transmittance of the suspension and (d) deposited weight as a function of solid concentration in the suspension.