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Stability of Nickel in Ni/Zirconia Electrodes at High Steam Concentrations

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This paper discusses stability of the Ni/yttria-stabilized zirconia (YSZ) electrodes used in high temperature electrochemical devices, solid oxide fuel cells and solid oxide electrolyzers in the presence of high steam partial pressures. Despite stabilization with ceramics, sintering of metal nickel crystallites is likely to be accelerated by steam. Because the exchange current density is directly related to the nickel particle size, coarsening would lead to aging of the electrochemical device.

In this study, Ni/YSZ electrodes were exposed to high humidity levels corresponding to 90% fuel utilization in a controlled gas-tight environment at 800, 900 and 1000^{o}C for 1000-5000 hours. Microstructure analysis was performed using scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS). A set of 10 elemental maps was collected per condition (Figure 1) and analyzed using Image J^{TM} software to determine the average Ni particle size and standard deviation. For comparison, similar data sets and analyses were performed for samples tested with 3% steam.

A typical histogram of Ni particle sizes after exposures to 3% and 52% steam at 1000^{o}C for 3000 hours is given in Figure 2. The maximum in the Ni particle size shifted to higher values, indicating the Ni particle growth from 0-0.2 mm^2 with 3% steam to 0.6-0.8 mm^2 with 52% steam. The largest single particle in the 3% steam group was 4.9 mm^2, while the largest in the 52% steam was 10.7 mm^2. The *t* - test that compares one variable between two groups was used to compute the P value and statistical significance. No changes in the Ni particle size in all tests conducted with 3% steam were detected (Figure 3). The changes in the Ni particle size after exposures to 52-53% steam at 900^{o}C became statistically significant in 3000 hours. At 1000^{o}C and high steam content Ni particle growth was statistically significant at all times tested. No significant growth was detected at 800°C.

The nickel particle growth at the triple-phase boundary is expected to result in decreased electrochemical performance through decreases in the exchange current density. To predict the lifetime of an electrochemical device as a function of time, temperature, and steam content, a coarsening model was correlated with the polarization loss data.

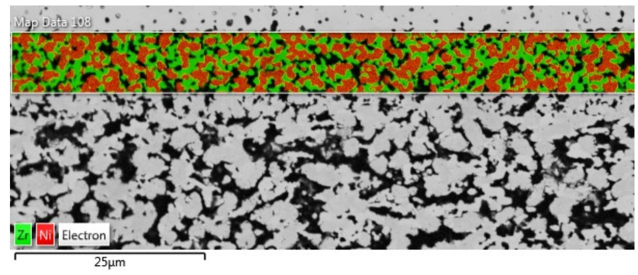

Figure 1. EDS layered image of the active anode. Nickel is shown in red, zirconia is shown in green and pores are back.

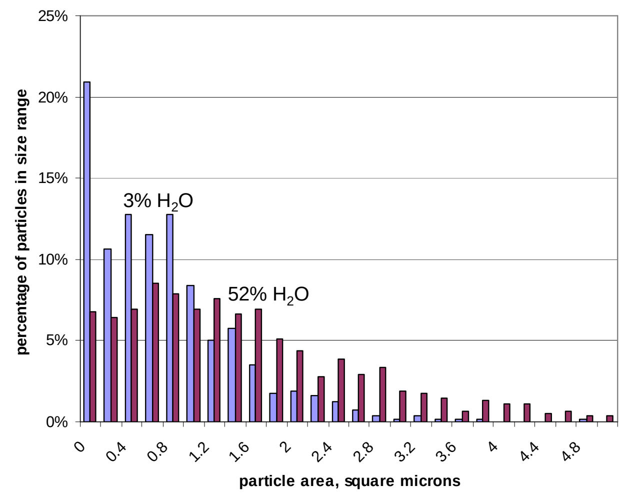

Figure 2. Histogram of Ni particle sizes in the active electrochemical layer for 1000°C, 3000 hours.

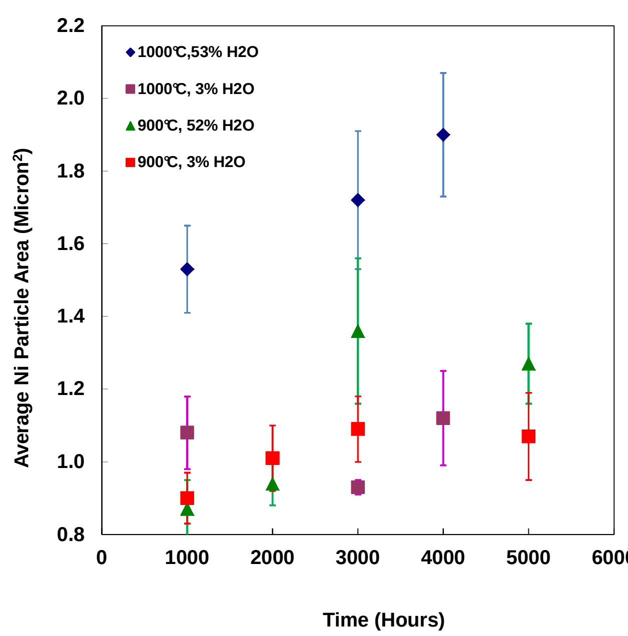

Figure 3. Changes in average Ni particle size in the active anode after exposures to 3 or 52-53% steam content at 900 and 1000^{o}C.