Morphological Evolution of Solid Oxide Fuel Cell in Operational Environment with X-ray Nano-tomography

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Solid oxide fuel cells (SOFCs) are promising systems to provide electricity at a large scale stationary power generation setting, typically larger than 100 kW. However, since the SOFC systems are required to operate at an elevated temperature of typically around 850°C or higher with high current density and for at least 40 thousands hours, their long-term degradation issues became pronounced. Specifically in one of the most promising anode materials, Ni-YSZ, the coarsening of Ni has attracted great attention for it attributes to the decrease in the cells' triple-phase-boundary (TPB) density and then the efficiency of the cells. It is therefore critical to precisely quantify the morphology evolution of the SOFCs while under a high-temperature environment to better investigate the degradation process.

The density of TPB, the active site in SOFC, along with other electrode morphological parameters important to fuel cell operation can only be quantified via three-dimensional (3D) probes. Both focused ion beam – scanning electron microscopy (FIB-SEM) and transmission X-ray microscopy (TXM) nano-tomography have recently provided unique path to quantify these electrochemical parameters. In the previous studies, different SOFCs are usually subjected to various amount of iso-thermal heat treatment to observe the degradation process at the various stages under the elevated temperature environment. As a result, when characterizing the morphological evolution as a function of annealing time and temperature, the sample variation could introduce the morphology difference. Therefore, one of the challenges of understanding the degradation process remains to be accurately quantifying the morphological parameters during the degradation process and therefore better establish reliable model to predict such a behavior.

In order to address the issue caused by the sample variations which also exists in the FIB-SEM serial sectioning method, we therefore conducted a serial experiments using TXM nano-tomography to continuously follow the morphological evolution of the same Ni-YSZ sample volume. The 3D electrochemical parameters were quantified and investigated from the very same sample volume during degradation. In addition to the coarsening of the internal Ni structure as reported previously, a very significant coarsening of Ni at the surface of the Ni-YSZ electrode material was observed, which can be seen from the comparison of Fig. 1 (Ni-YSZ before heat-treatment) and Fig. 2 (Ni-YSZ after heat-treatment). This phenomenon has not been recognized so far due to the sample preparation process. In previous studies, only the central location of the sample was observed. We will discuss the new discoveries and their impact.

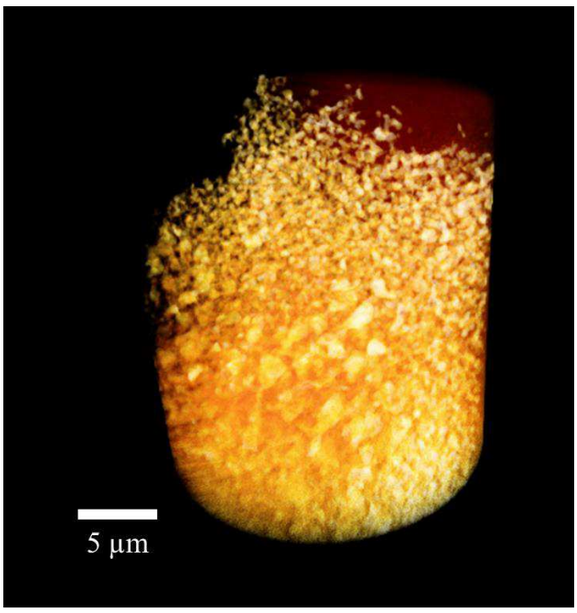

Fig. 1 – A 3D reconstruction of Ni-YSZ electrode before subjected to iso-thermal heat-treatment.

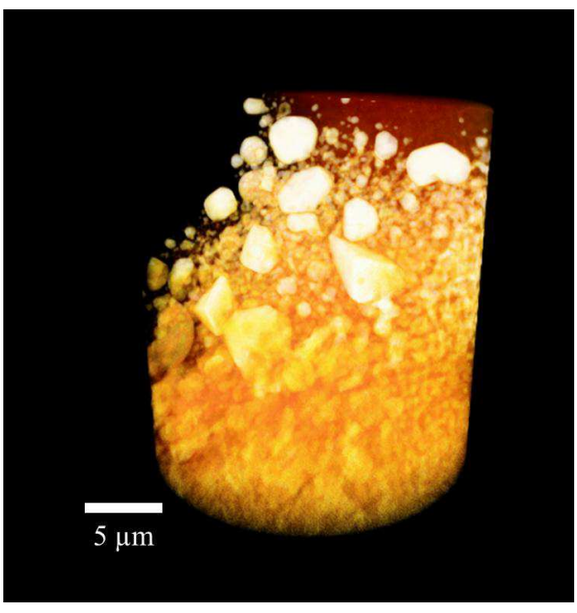

Fig. 2 – A 3D reconstruction of Ni-YSZ after 92 hours of iso-thermal heat treatment under reduction environment at 1050°C. Note that the free Ni particles near the surface coarsened much more significantly compared with the internal Ni structures where YSZ act as spatial constraints.