Supplementary Information for

# Visualization of Structural Transformation of NiO/YSZ/BZY Nanocomposite Particles using in-situ Gas Environmental Transmission Electron Microscopy

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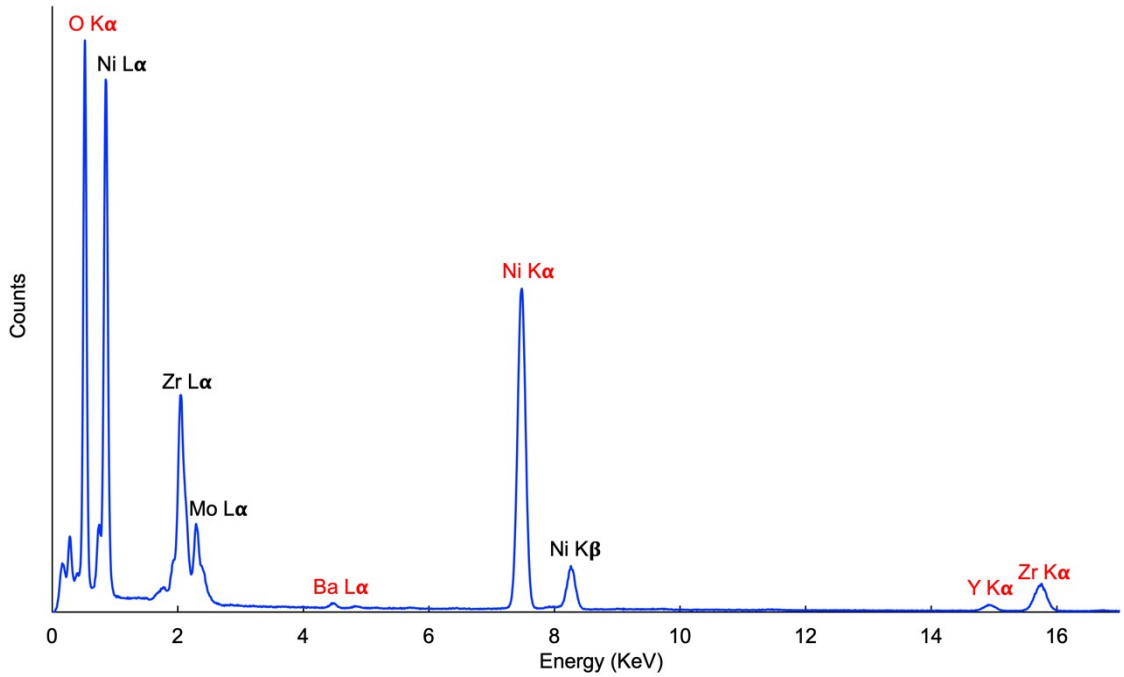



Figure S1. Energy-dispersive X-ray spectroscopy (EDS) spectrum obtained from the designated rectangular region, as indicated in Figure 2h. The red labels highlight the Zr K$\alpha$, Ni K$\alpha$, Y K$\alpha$, O K$\alpha$, and Ba L$\alpha$ peaks, which were used to generate the elemental maps presented in Figure 2c-2g. The presence of Mo L$\alpha$ peak is attributed to the Mo TEM gird.

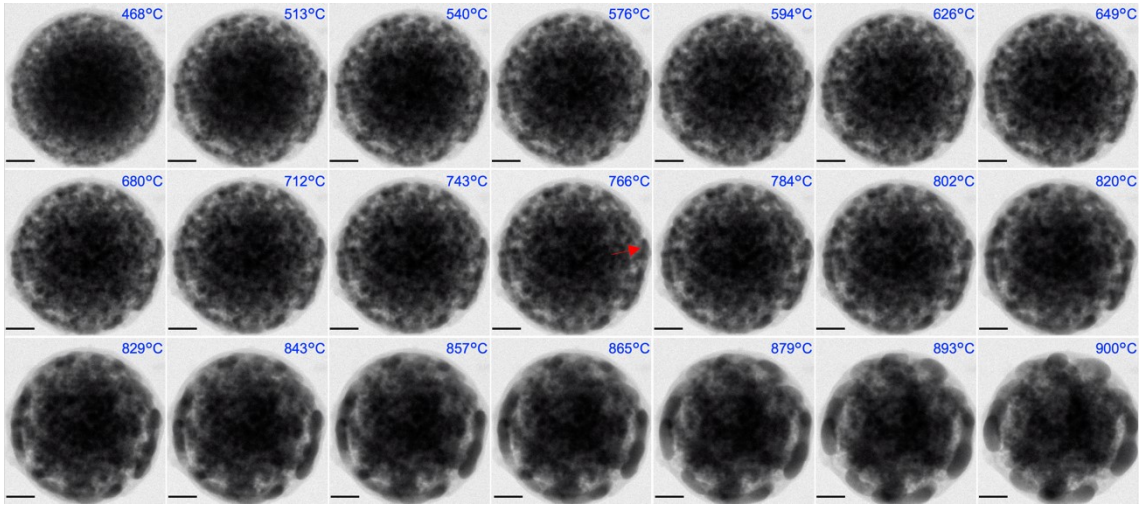
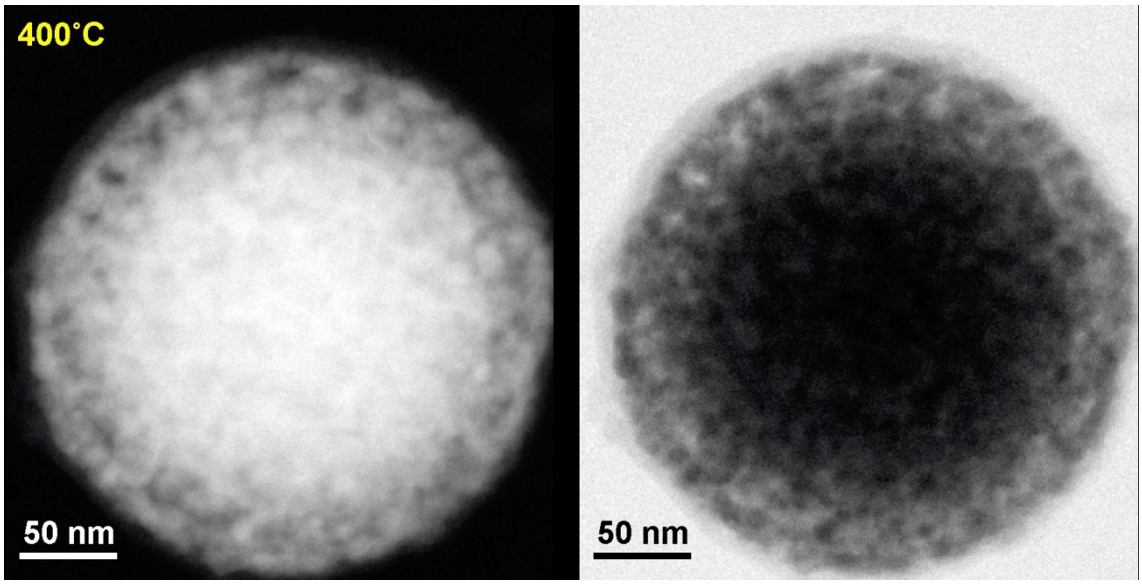



Figure S2. A series of ABF-STEM images of an isolated NiO/YSZ/BZY nanocomposite particle being heated from 400°C to 900°C in $H_2$ gas (the gas pressure is 1 atm). Gradually coarsening of primary particles on the outer surface of the composite particle can be obviously identified from 766°C. The scale bar is 50 nm.




Movie S3. HAADF-STEM (left) and ABF-STEM (right) images of the NiO/YSZ/BZY nanocomposite particle being heated from 400°C to 900°C in $H_2$ gas showing the continuous morphological changes.

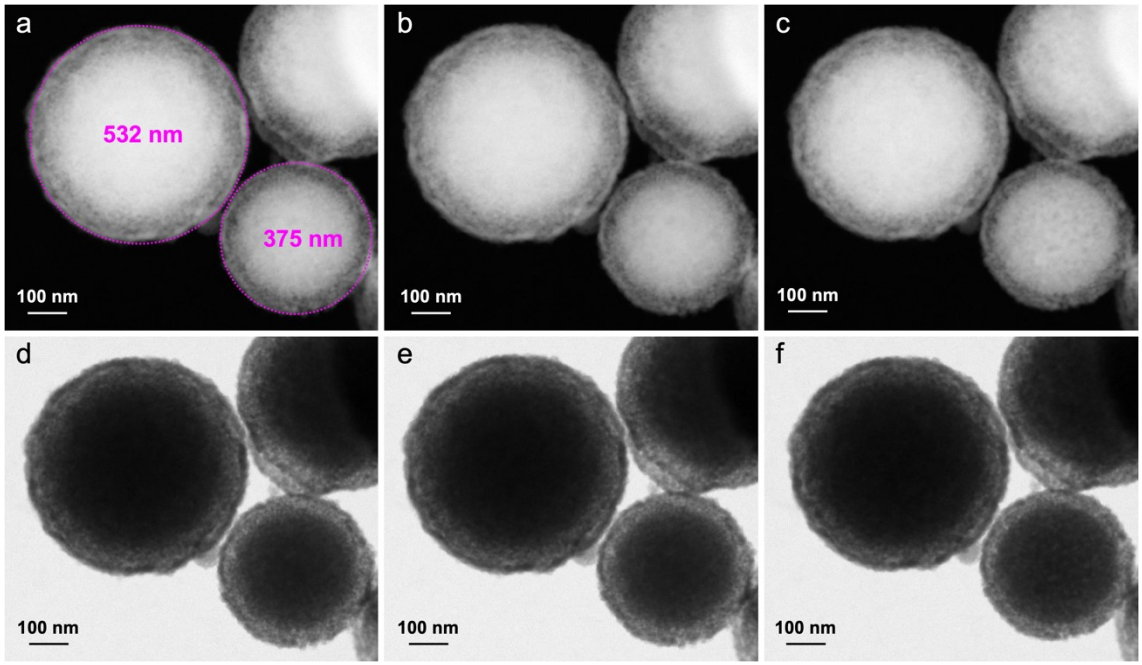



Figure S4. HAADF-STEM (a-c) and the corresponding ABF-STEM images (d-f) of NiO/YSZ/BZY nanocomposite particles heated in $N_2$ gas environment with a gas pressure of 1 atm. (a) and (d) 300°C; (b) and (e) 700°C; (c) and (f) 900°C.

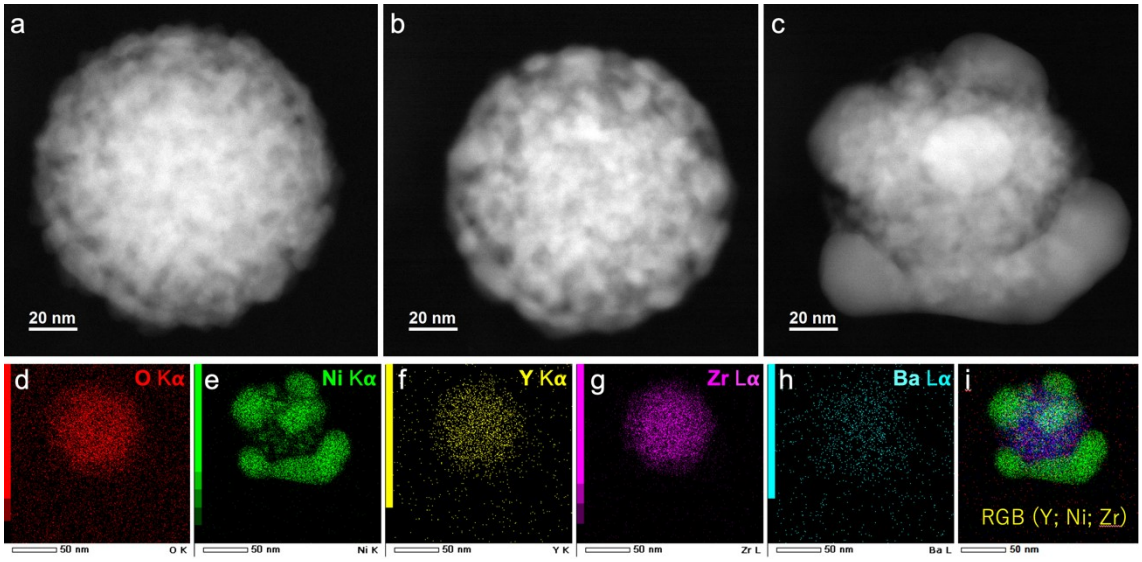
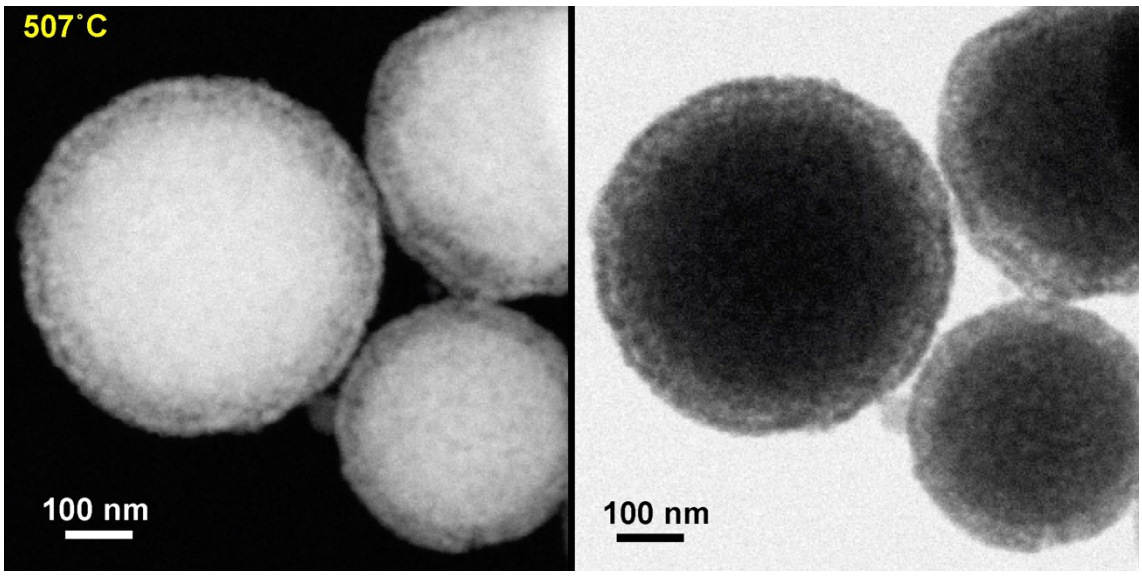



Figure S5. HAADF-STEM images of a NiO/YSZ/BZY nanocomposite particle heated to 400°C in air (a); 600°C in a mixed gas containing 96% $N_2$ with 4% $H_2$ (b); and 800°C in a mixed gas containing 96% $N_2$ with 4% $H_2$ (c) with all the gas pressures are of 1 atm. (d)-(i) EDS elemental maps of the particle heated to 800°C in a mixed gas containing 96% $N_2$ with 4% $H_2$, (d) O K$\alpha$ map; (e) Ni K$\alpha$ map; (f) Y K$\alpha$ map; (g) Zr L$\alpha$ map; (h) Ba L$\alpha$ map; and (i) Overlay of Y, Ni and Zr with Y in red, Ni in green, and Zr in green, showing the original outermost NiO particles were reduced to Ni nanoparticles.




Movie S6. HAADF-STEM (left) and ABF-STEM (right) images of the NiO/YSZ/BZY nanocomposite particles being heated from 400°C to 900°C in $H_2$ gas showing the migrating of Ni atoms along the external surfaces, and eventually congregating at the grain boundary triple point where the NiO/YSZ/BZY nanocomposite particles had formed.