Electronic Supplementary Material (ESI) for Journal of Materials Chemistry A.

Supplementary Information

Next-generation Flexible Solid Oxide Fuel Cells with Highly Thermomechanical Stability

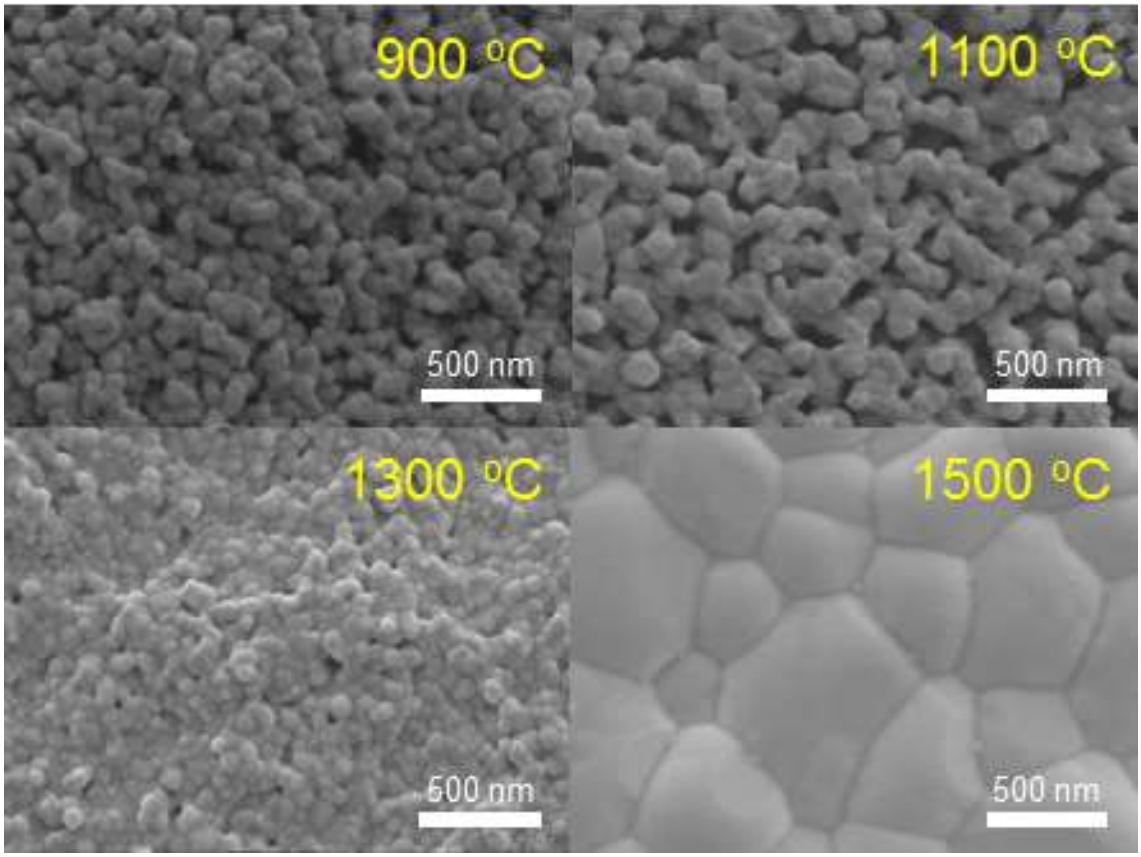
Ok Sung Jeon,[a] Ho Jung Hwang,[b] Oh Chan Kwon,[a] Jin Goo Lee*[c] and Yong Gun Shul*[a,b]

[a]Department of Chemical and Bio-molecular Engineering, Yonsei University, 134 Shinchon-dong Seodaemun-gu Seoul 120-749, Republic of Korea.

[b]Department of Graduate Program in New Energy and Battery Engineering, Yonsei University, 134 Shinchon-dong, Seodaemun-gu, Seoul 120-749, Republic of Korea.

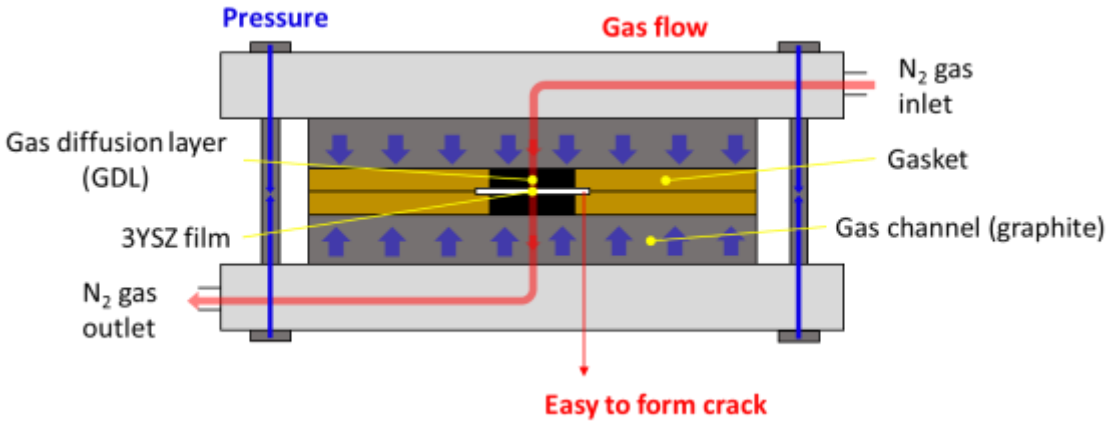
[c]School of chemistry, University of St Andrews, St Andrews, Fife KY16 9ST, UK
**Email - shulyg@yonsei.ac.kr*

Supplementary Figure 1. SEM micrographs of 3YSZ films with different sintering temperature.



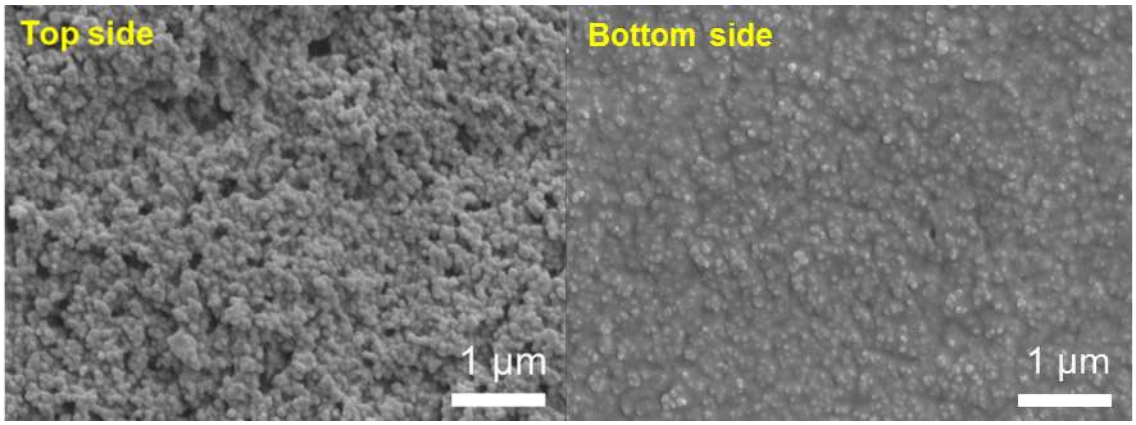
To figure out suitable sintering temperature, the 3YSZ films were fabricated by same process except the sintering temperature. It demonstrated that the electrolyte sintered at 1500 °C for 3h was adequate to be applied to SOFC electrolyte film without any optical holes.

Supplementary Figure 2. Scheme of gas permeability test system.



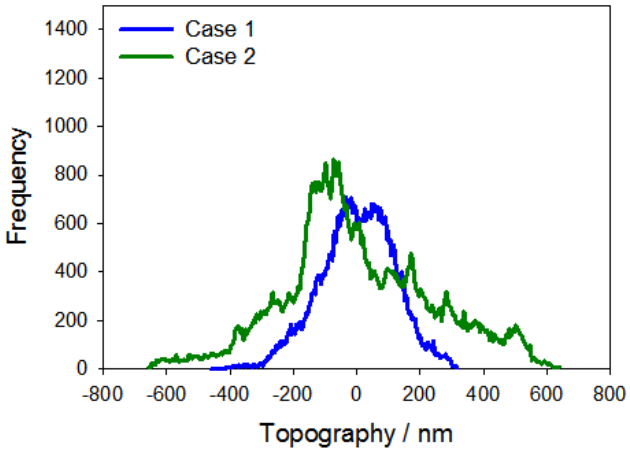
The 3YSZ film was located between two gas diffusion layers. In order to prevent to leak out from the gas permeability test system, it is required to tighten nuts severely. Through this step, pressure occurs at the whole area of 3YSZ film and it can form crack in the film which is mechanically weak.

Supplementary Figure 3. SEM micrographs of each side of as-prepared polymer mixed 3YSZ films.



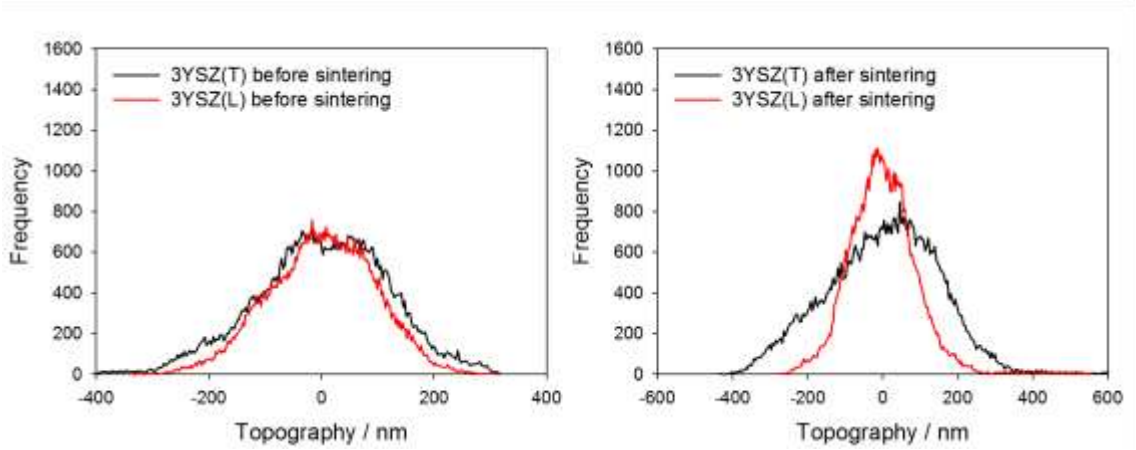
The top side of polymeric 3YSZ film was porous because of evaporation of solution in slurry. The bottom side of film had dense surface due to the ceramic nanoparticles which sank to the bottom of slurry by gravitational force.

Supplementary Figure 4. The roughness histograms of height at the film surface in case 1 and 2.



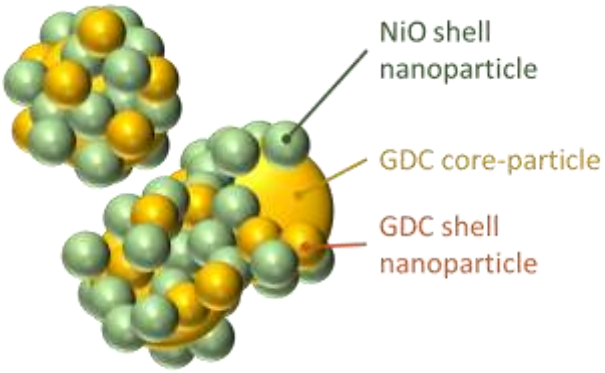
The film surface was rougher in case 2 that the top side of film located on zirconia plate facing upwards than in case 1 that the bottom side of film facing downwards.

Supplementary Figure 5. Tomography of 3YSZ films which had different grain size before and after sintering.



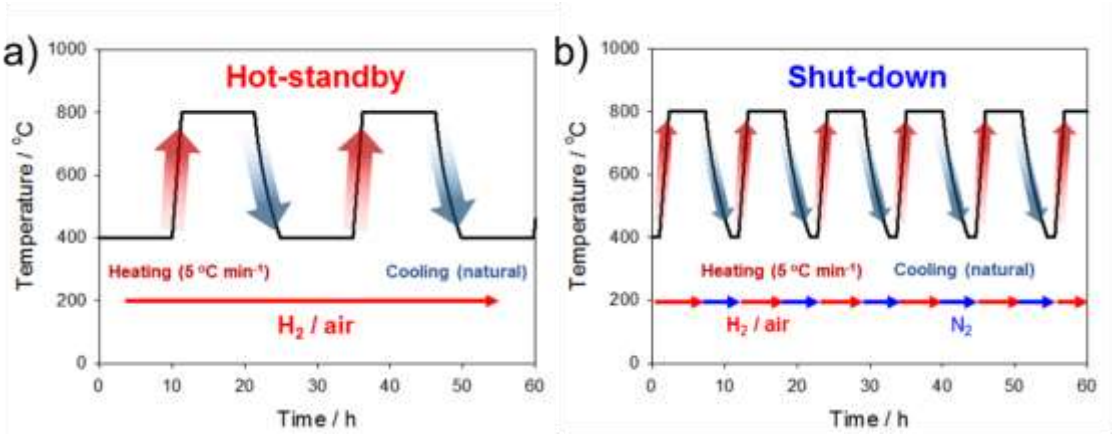
The surface roughness of the films fabricated by two different grain sized nanoparticles, 3YSZ(T) and 3YSZ(L), were detected by AFM. The roughness of 3YSZ(T) film and 3YSZ(L) film were approximately same before sintering. After sintering, the 3YSZ(T) film was slightly rougher than the 3YSZ(L) film.

Supplementary Figure 6. Scheme of core-shell-like nanocomposite anode material.



In our previous study, core-shell-like nanocomposite Ni-GDC was fabricated by Pechini method, which develops better connections between the electrolyte and the anode. In addition, it had positive effects on the distribution of Ni and GDC particles. The increase of number of anode particles attached to electrolyte by the core-shell-like nanocomposite significantly increased in triple phase boundary (TPB) sites and performance.[1]

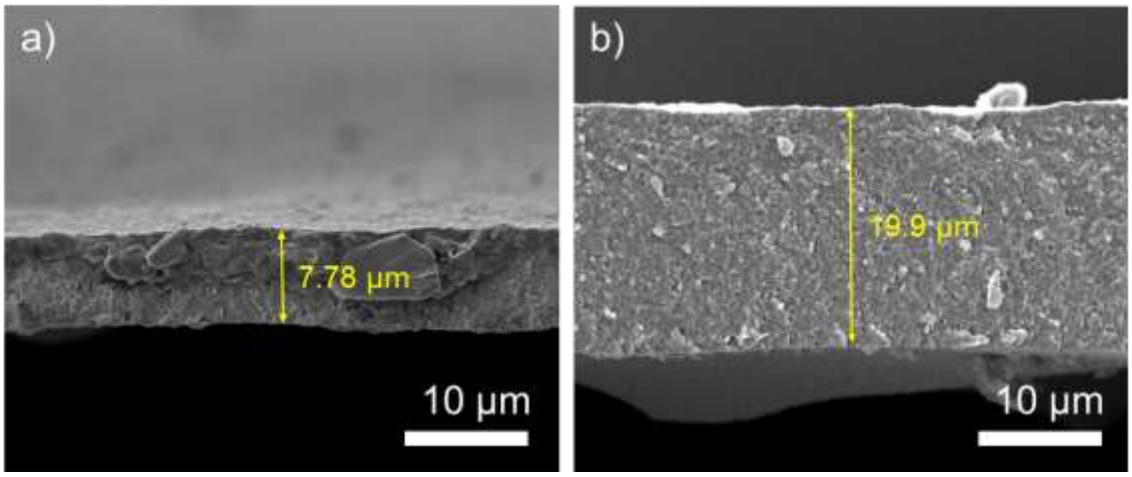
Supplementary Figure 7. Scheme of the hot-standby and shut-down protocols.



Hot-standby and shut-down protocols are composed of off-step and on-step under constant current density of 0.15 A cm^{-2}.

1) Hot-standby (Off-step) : lowering the temperature from 800 °C to 400 °C with natural cooling and maintaining at 400 °C for 10h in H_2/air feeding.
2) Hot-standby (On-step) : raising the temperature from 800 °C to 400 °C with 5 °C min^{-1} heating rate and maintaining at 800 °C for 10h in H_2/air feeding.
3) Shut-down (Off-step) : lowering the temperature from 800 °C to 400 °C with natural cooling and maintaining 400 °C for 1h in N_2 feeding
4) Shut-down (On-step) : raising the temperature from 800 °C to 400 °C with 5 °C min^{-1} heating rate and maintaining at 800 °C for 5h in H_2/air feeding.

Supplementary Figure 8. SEM micrographs of 3YSZ films fabricated by bar coater thickness of (a) 80 µm and (b) 160 µm.



Thickness of the 3YSZ films was fabricated by two different conditions which had only difference in thickness of the bar coater. It demonstrated that the film thickness depended on thickness of used bar coater for tape-casting.

Supplementary Table 1. Crystallographic characterization of powder according the amount of yttrium x (mol % Y_2O_3).

x / mol % Y_2O_3	Phase	Cell parameter / nm		c/a√2
3	T	a=3.607	c=5.189	1.0172
5	t’	a=3.622	c=5.158	1.0070
6	t’’	a=3.634	c=5.131	0.9984

Supplementary Table 2. Compositions of the 3YSZ electrolyte slurries.

Sample	Bar coater [μm]	3YSZ powder [g]	Grain size [nm]	Toluene/Ethyl alcohol [ml]	EFKA-4340 [ml]	Dibutyl-phthalate [ml]	Triton-X [ml]	Poly vinyl-butyral [g]
Slurry 1	80	40 (T)	17.17	50	1	2	1	6
Slurry 2	160	40 (T)	17.17	50	1	2	1	6
Slurry 3	80	40 (L)	5.05	50	1	2	1	6
Slurry 4	160	40 (L)	5.05	50	1	2	1	6

Supplementary reference

1 J. G. Lee, M. G. Park, S.-H. Hyun, Y. G. Shul, *Electrochim. Acta* **2014**, 129, 100-106