Electronic Supplementary Material (ESI) for Energy & Environmental Science


**Supplementary Information**

# An Intermediate-Temperature Solid Oxide Fuel Cell with Electrospun Nanofiber Cathode

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**Impedance spectra fitting:**

An L-$R_0$-$R_H$/$CPE_H$-$R_L$/$CPE_L$ circuit was used to fit the impedance spectra[1-2]. *L* is the inductor from the long lead wires between the cells and the instrument. $R_0$ represents the total resistance from the electrolyte and the contact. Two depressed semi arcs were observed for LSCF NF and LSCF20GDC cells, and the characteristic frequencies for these two arcs are at $10^3$ and $10^1$ Hz range. Therefore the first set of R-CPE is named $R_H$-$CPE_H$ to represent the high frequency arc and the second set of R-CPE is named $R_L$-$CPE_L$ to represent the low frequency arc. CPE is the constant phase element. The same circuit was also used to fit the LSCF50GDC cell.

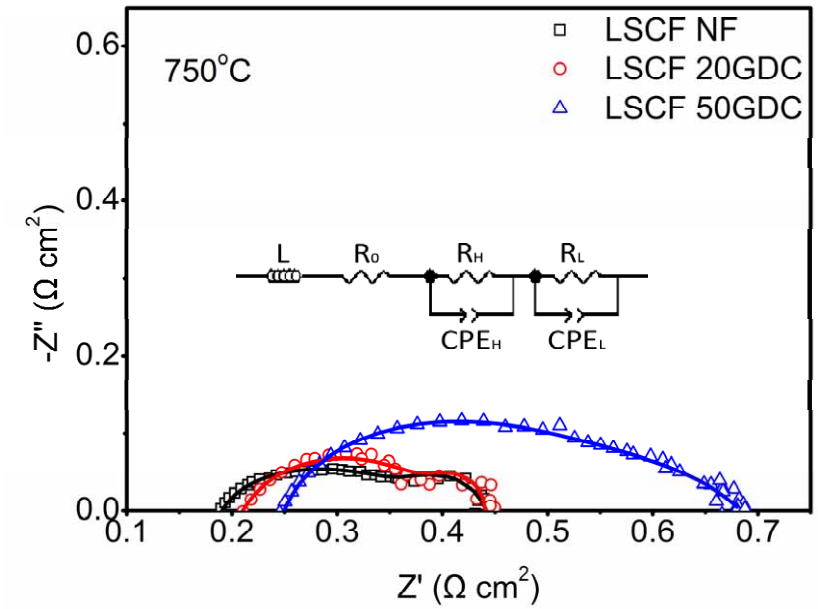


**Figure S1**. Impedance spectra of the cells taken at 750°C, the open symbols are measured data and the solid lines are the fitting curves. The insert is the equivalent circuit used to fit the spectra

| **Cell No.** | ***L* (*H*)** | ***$R_o$* (*Ωcm²*)** | ***$R_H$* (*Ωcm²*)** | ***$Y_H$* (*S cm⁻² sⁿ*)** | ***$R_L$* (*Ω cm²*)** | ***$Y_L$* (*S cm⁻² sⁿ*)** |
|---|---|---|---|---|---|---|
| **LSCFNF** | 4.232E-7 | 0.192 | 0.223 | $Y_0$=0.048 n=0.561 | 0.042 | $Y_0$=0.184 n=0.977 |
| **LSCF20GDC** | 5.835E-7 | 0.204 | 0.235 | $Y_0$=7.8E-3 n=0.733 | 0.027 | $Y_0$=0.237 n=0.948 |
| **LSCF50GDC** | 9.078E-7 | 0.237 | 0.276 | $Y_0$=6.9E-3 n=0.767 | 0.183 | $Y_0$=0.221 n=0.599 |

**Table S1**. Parameters derived from the equivalent circuit fitting for different cells at 750°C. The admittance of a constant phase element (CPE) is defined as $Y_{CPE}=Y_0 (j\omega)^n$, in which $Y_0$ is the pseudo-admittance, $\omega$ is the radius speed and *n* is the exponent constant.[2]

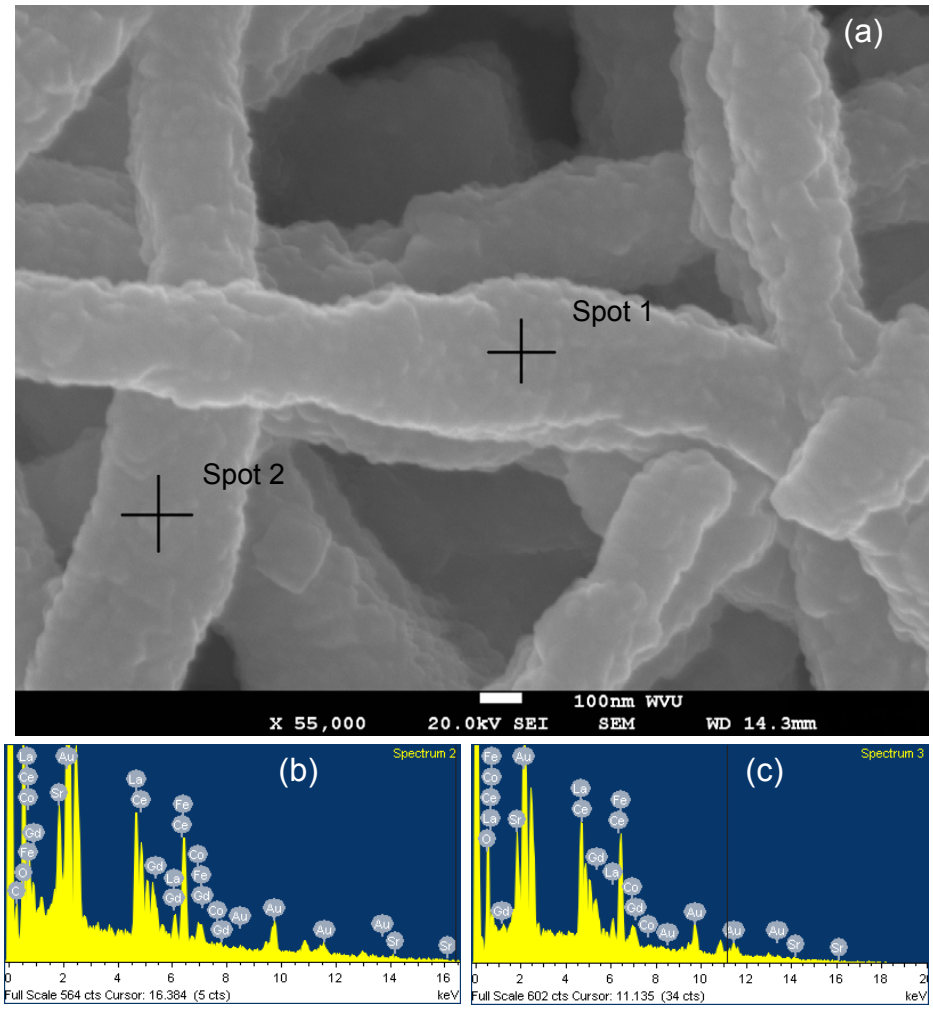


**Figure S2**. (a) SEM image of the LSCF20GDC cathode showing small particles on the nanofiber surface; (b) and (c) EDX spectra taken from different locations (spot 1 and spot 2, respectively), confirming the presence of Ce and Gd on the fiber surface.

| Spot 1 | Element | Weight % | Atomic % | Spot 2 | Element | Weight % | Atomic % |
|---|---|---|---|---|---|---|---|
| | C K | 2.76 | 15.33 | | C K | 4.18 | 19.42 |
| | O K | 11.48 | 44.81 | | O K | 13.08 | 45.59 |
| | Fe K | 7.99 | 8.94 | | Fe K | 7.33 | 7.32 |
| | Co K | 1.80 | 1.91 | | Co K | 1.96 | 1.85 |
| | Sr L | 3.17 | 2.26 | | Sr L | 2.29 | 1.73 |
| | La L | 13.48 | 6.06 | | La L | 12.27 | 4.93 |
| | Ce L | 19.10 | 7.51 | | Ce L | 16.32 | 6.70 |
| | Gd L | 5.55 | 2.20 | | Gd L | 5.61 | 1.99 |
| | Au M | 34.67 | 10.99 | | Au M | 36.97 | 10.47 |
| | Totals | 100.00 | | | Totals | 100.00 | |

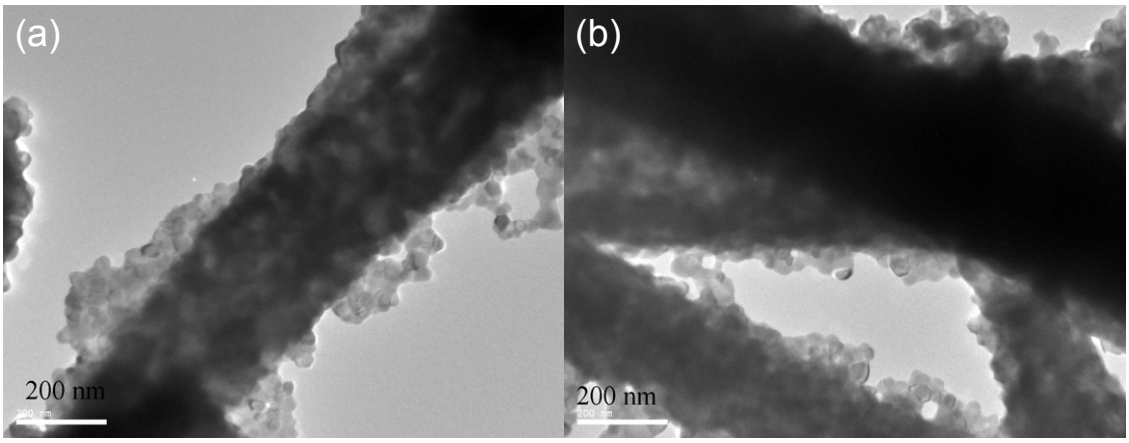


**Figure S3** TEM image of the LSCF20GDC cathode. GDC nanoparticles can be clearly observed on the nanofibers surface; (a) and (b) were taken from different spots

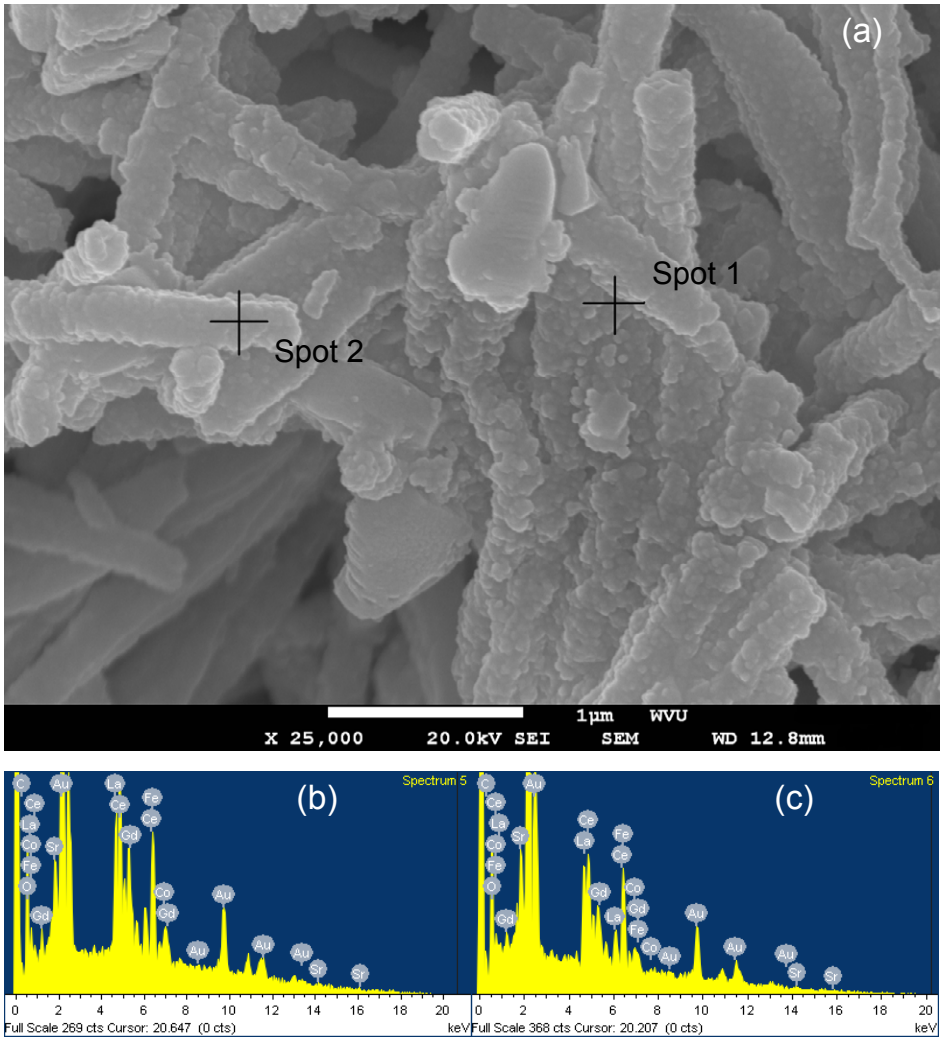


**Figure S4**. (a) SEM image of the LSCF50GDC cathode, showing that the nanofibers were broken and surrounded by GDC aggregates; (b) and (c) EDX spectra taken from different locations (spot 1 and spot 2, respectively), which has confirmed the presence of Ce and Gd in the matrix. The Ce and Gd relative ratios are higher in spot 1 than that in spot 2, which indicates the nanofibers intersections were filled with GDC.

| **Spot 1** | Element | wt% | at% | **Spot 2** | Element | wt% | at% |
|---|---|---|---|---|---|---|---|
| | O K | 11.07 | 49.88 | | O K | 14.94 | 54.34 |
| | Fe K | 10.29 | 12.43 | | Fe K | 12.20 | 13.21 |
| | Co K | 2.61 | 2.99 | | Co K | 3.27 | 3.96 |
| | Sr L | 6.24 | 4.80 | | Sr L | 7.66 | 5.02 |
| | La L | 18.37 | 8.92 | | La L | 20.37 | 8.99 |
| | Ce L | 17.70 | 8.52 | | Ce L | 8.82 | 3.94 |
| | Gd L | 3.89 | 2.24 | | Gd L | 2.03 | 0.94 |
| | Au M | 29.85 | 10.22 | | Au M | 30.69 | 9.60 |
| | Total | 100.00 | | | Total | 100.00 | |

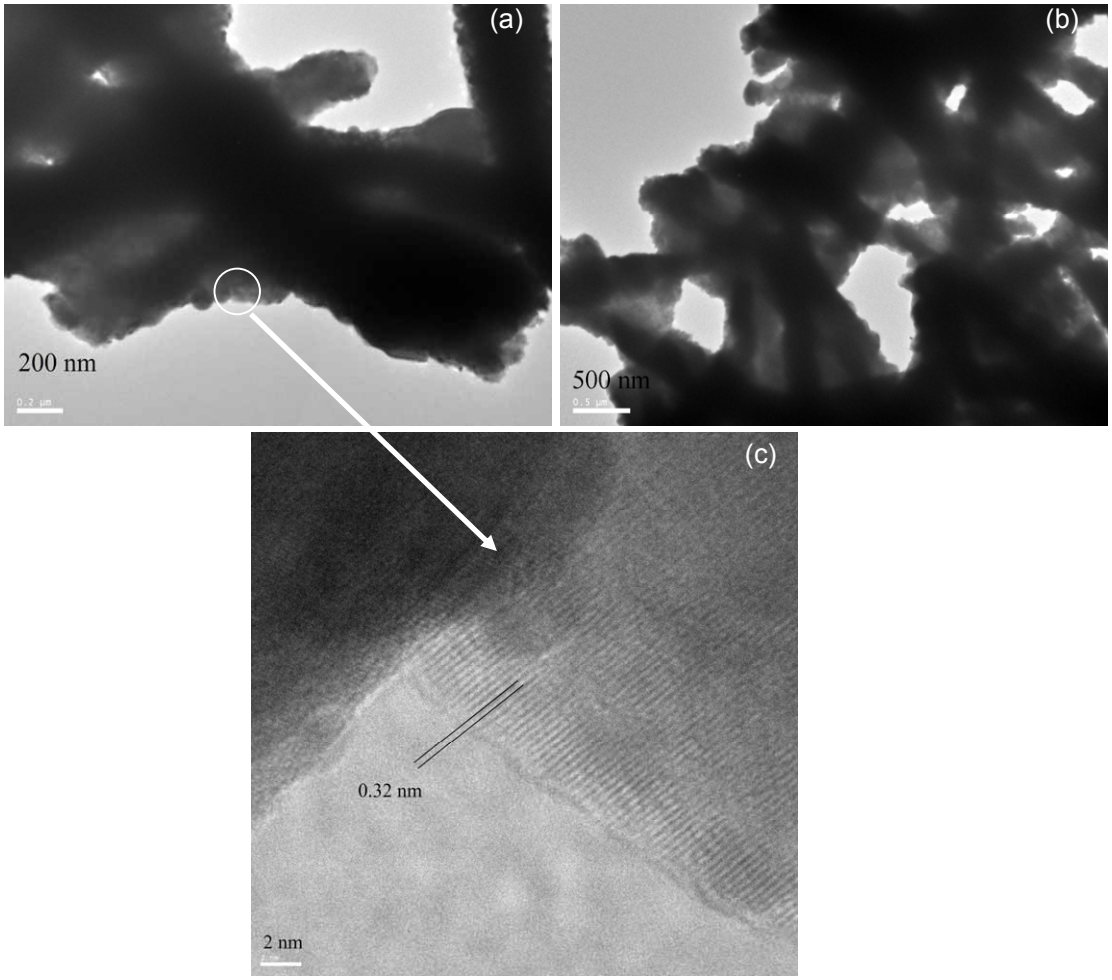


**Figure S5**. (a) and (b) TEM images of the LSCF50GDC cathode, showing the nanofibers are embedded in the GDC matrix. (c) HRTEM image taken from the spot labeled in (a), showing the interface between GDC and LSCF. The lattice spacing of the GDC is 0.32 nm, which is consistent to $CeO_2$ (111) facet[3].

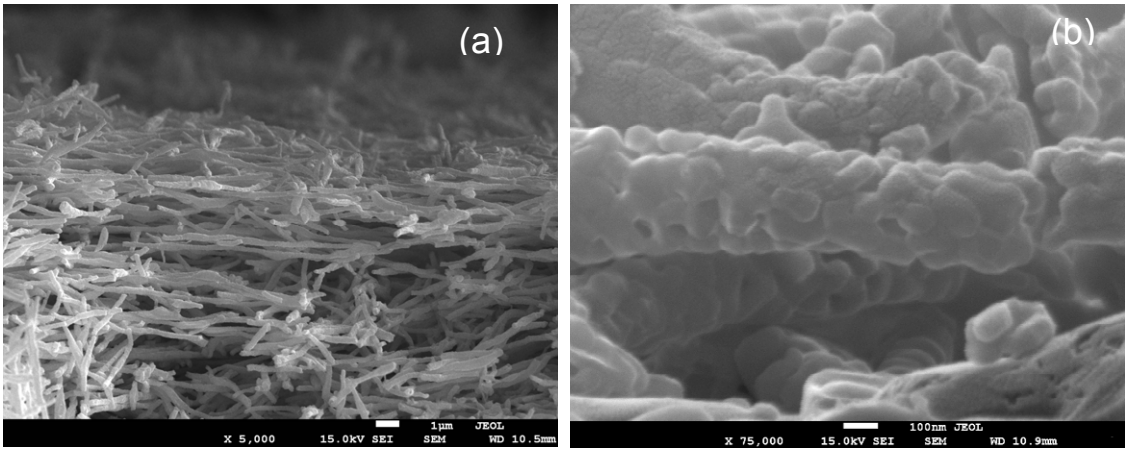


**Figure S6**. (a) SEM image of the cross section of the LSCF NF cathode after 200 hours of stability testing; (b) nanofibers close to the cathode/electrolyte interface after 200 hours of stability testing

**References:**

1. J. M. Haag, B. D. Madsen, S.A. Barnett, and K. R. Poeppelmeiera, *Electrochem. Solid-State Lett.* 2008, **11**, B51-B53.
2. S. W. Lee, N. Miller, M. Staruch, K. Gerdes, M. Jain and A. Manivannan, *Electrochim. Acta*, 2011, **56**, 9904–9909.
3. Q. Yuan, H. H. Duan, L. L Li, L.D. Sun, Y. W. Zhang and C.H. Yan, *Journal of Colloid and Interface Science* 2009, **335**, 151–167.