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# Supplementary Information

# Chemically and mechanically stable dual-phase membrane with high oxygen permeation flux

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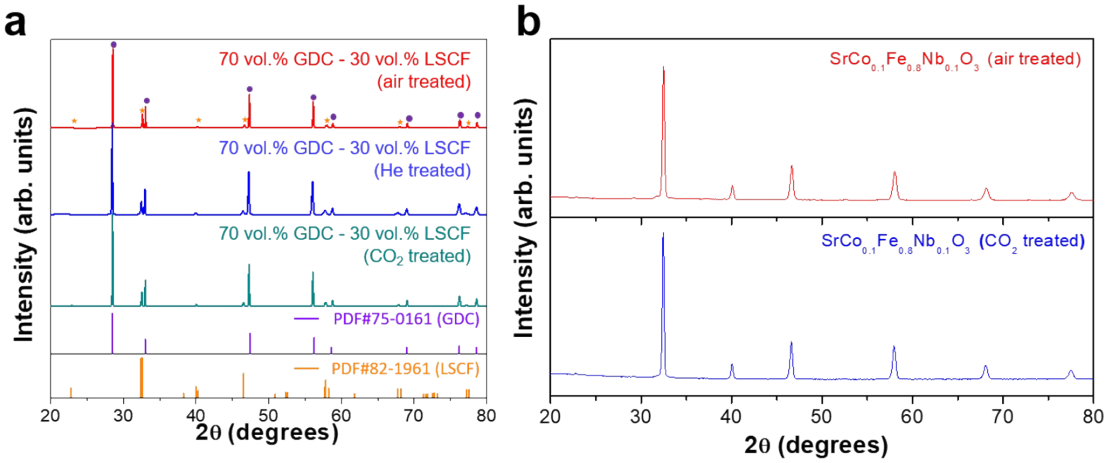


**Fig. S1** XRD patterns of GDC/LSCF and SCFN. a) XRD patterns of GDC/LSCF after the aging under operating conditions (air, He, $CO_2$) at 850 °C for 50 h. b) XRD patterns of SCFN before and after aging under air and $CO_2$ at 850 °C for 50 h.

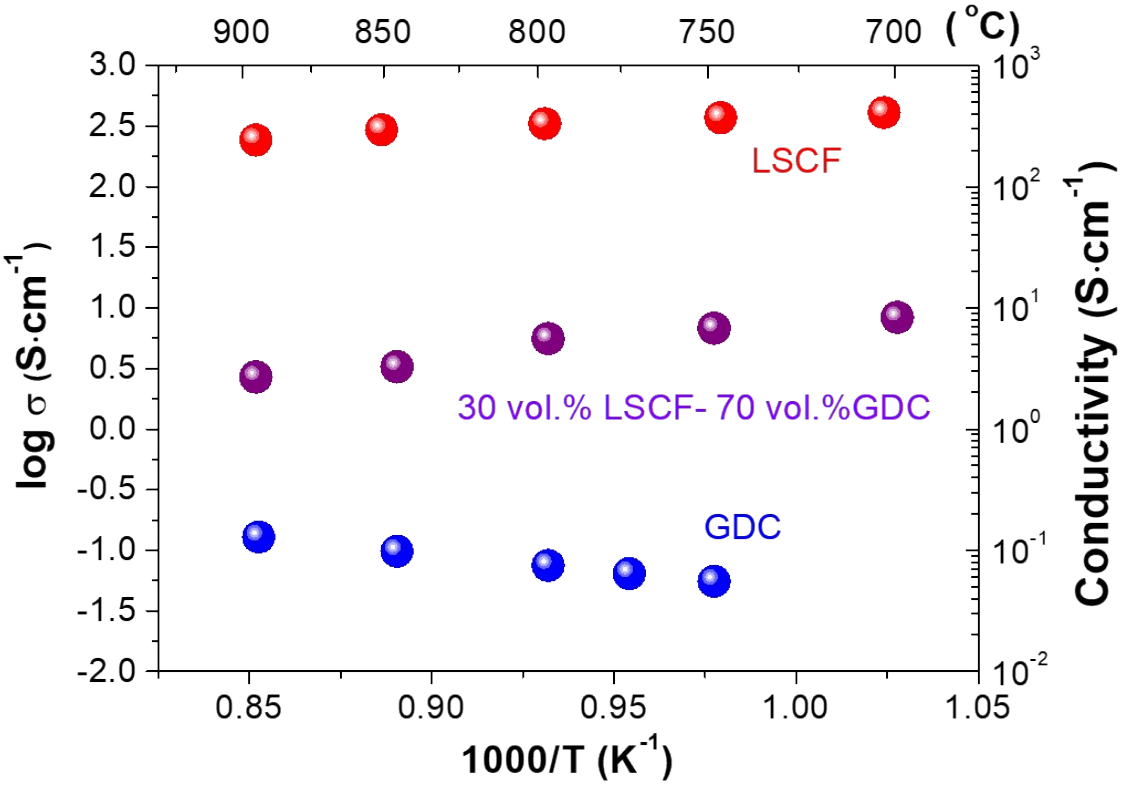


**Fig. S2** Electrical conductivities of LSCF, GDC, and GDC/LSCF (70 vol.% GDC/30 vol.% LSCF)

In order to obtain the optimized oxygen flux, it is desirable to design the dual-phase membrane with two continuously distributed phases: an ionic-conducting phase and an electronic-conducting phase. In the previous our study, 20 vol.% of LSCF guaranteed electrical percolation in the GDC/LSCF membrane. However, in this study, to ensure the electronic conduction, the content of LSCF phase was increased to 30 vol.%. As shown in Supplementary Information (Fig. S2), the LSCF, GDC, and GDC/LSCF composite represent the conductivities of 242, 0.129, and 2.69 $S \cdot cm^{-1}$ at 900 °C. Considering that the electrical conductivity of GDC/LSCF (2.69 S·cm-1 at 900 °C) is more than 20 times larger than that of GDC (0.129 S·cm-1 at 900 °C), it can be confirmed that 30 vol.% of LSCF is certainly electronically percolated to GDC phase.

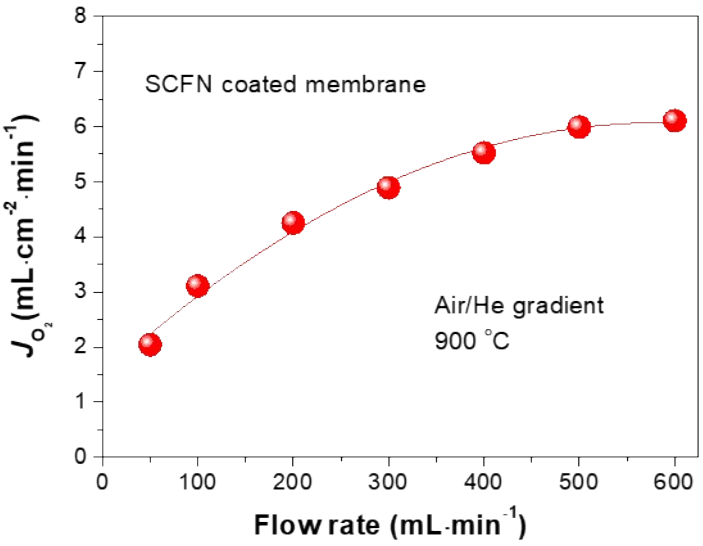


**Fig. S3** Oxygen permeation flux of the SCFN-coated membrane as a function of the gas flow rate.