Supplementary Materials

The supplementary materials include Fig. S1 and Fig. S2, which present FE-SEM images of the cross-sections of dense sintered $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3-\delta}$ (LSCF6428) and $Pr_4Ni_3O_{10+\delta}$ (PNO) samples, both showing minimal porosity. Details regarding the testing rigs, or, in simpler terms, setups used to investigate oxygen exchange kinetics, oxygen permeation, and long-term performance are outlined in the supplementary materials. Supplementary Fig. S3 illustrates the ECR measurement setup, Fig. S4 shows the oxygen permeation setup, and Fig. S5 depicts the PIE measurement setup. These figures provide a clear depiction of the setup components and their operation. Fig. S6 illustrates the critical length (L_c) in µm of PNO and LSCF6428. Additionally, XRD analysis was conducted on the fractionated PNO powders before and after the pulse isotopic exchange (PIE) measurements to confirm phase purity and assess material degradation. The analysis, presented in supplementary Fig. S7 and Fig. S8, revealed no evidence of degradation during the PIE measurements.

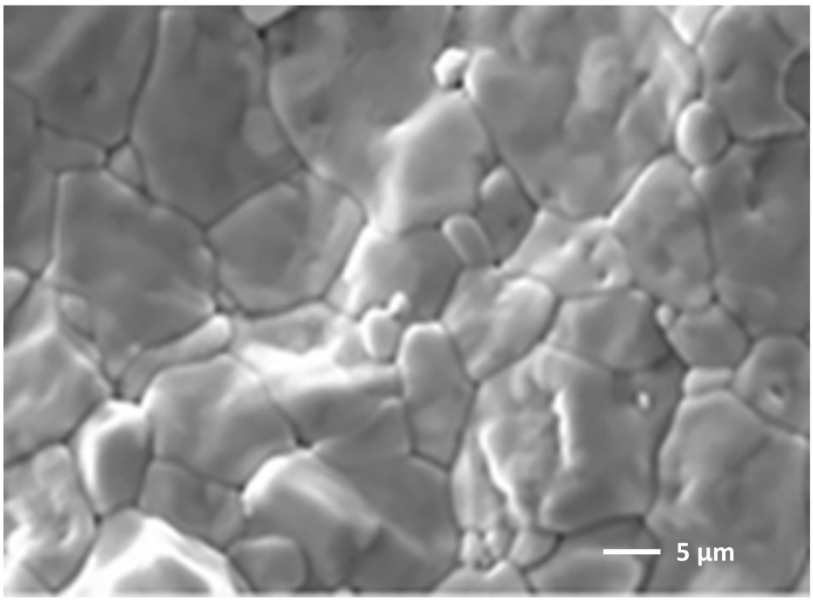

Fig. S1 FE-SEM image of the cross-section of dense $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3-\delta}$ (LSCF6428) sample, sintered at 1200 °C.

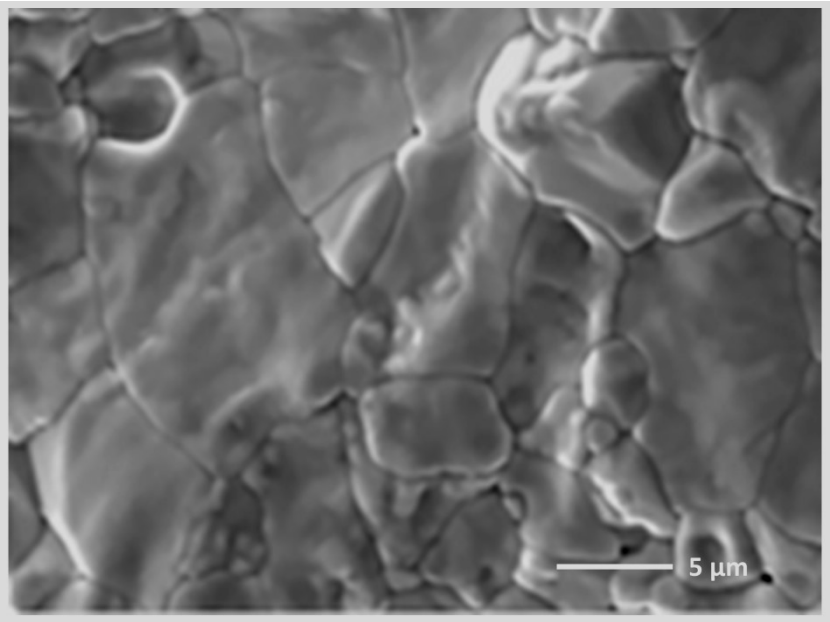

Fig. S2 FE-SEM image of the cross-section of dense $Pr_4Ni_3O_{10+\delta}$ (PNO) sample, sintered at 1000 ^oC.

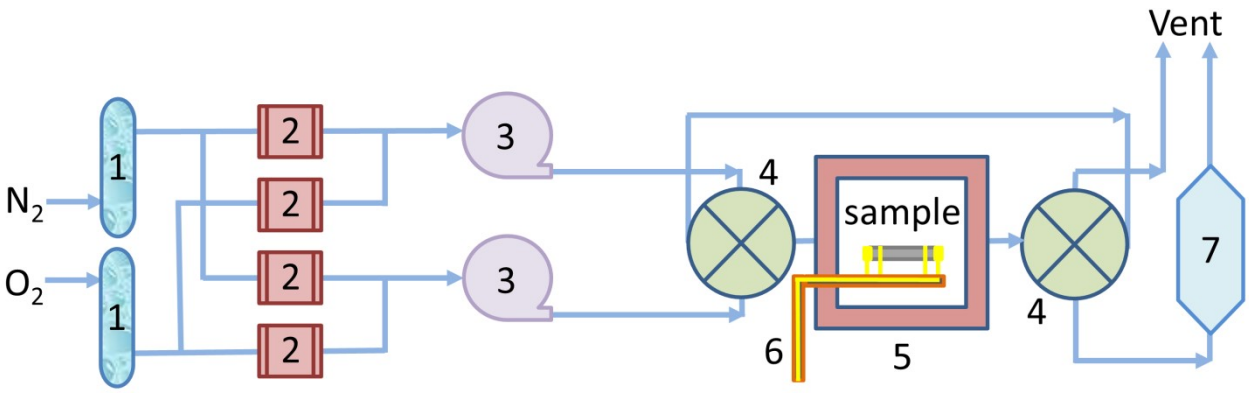

Fig. S3 Schematics of the ECR set-up, illustrating the following components: (1) Moisture filter, (2) Mass flow controller, (3) Oxygen pump, (4) Multi-way valve, (5) Sample furnace, (6) Electrical contacts of the sample, (7) Oxygen sensor.

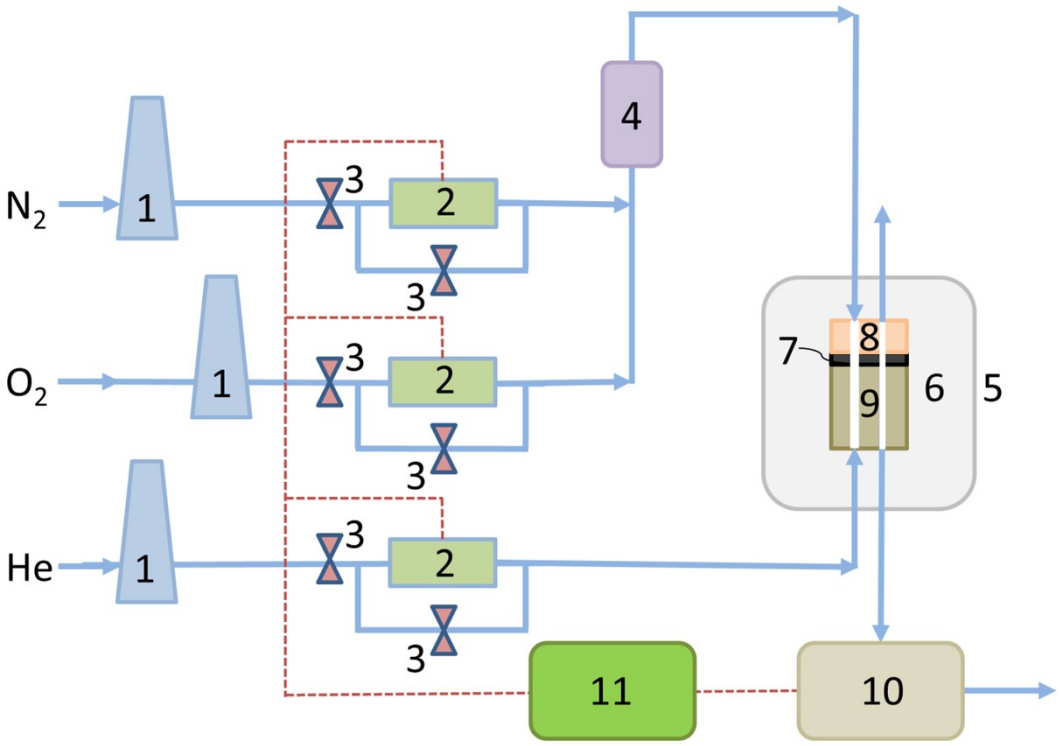

Fig. S4 Schematics of the oxygen permeation set-up, illustrating the following components: (1) Chrompack gas filter, (2) Mass flow controller, (3) Valve, (4) Mixing chamber, (5) Electric furnace, (6) ProboStat Cell, (7) Membrane, (8) Feed side, (9) Sweep side (10) Gas chromatography and oxygen sensor, and (11) computerized control system.

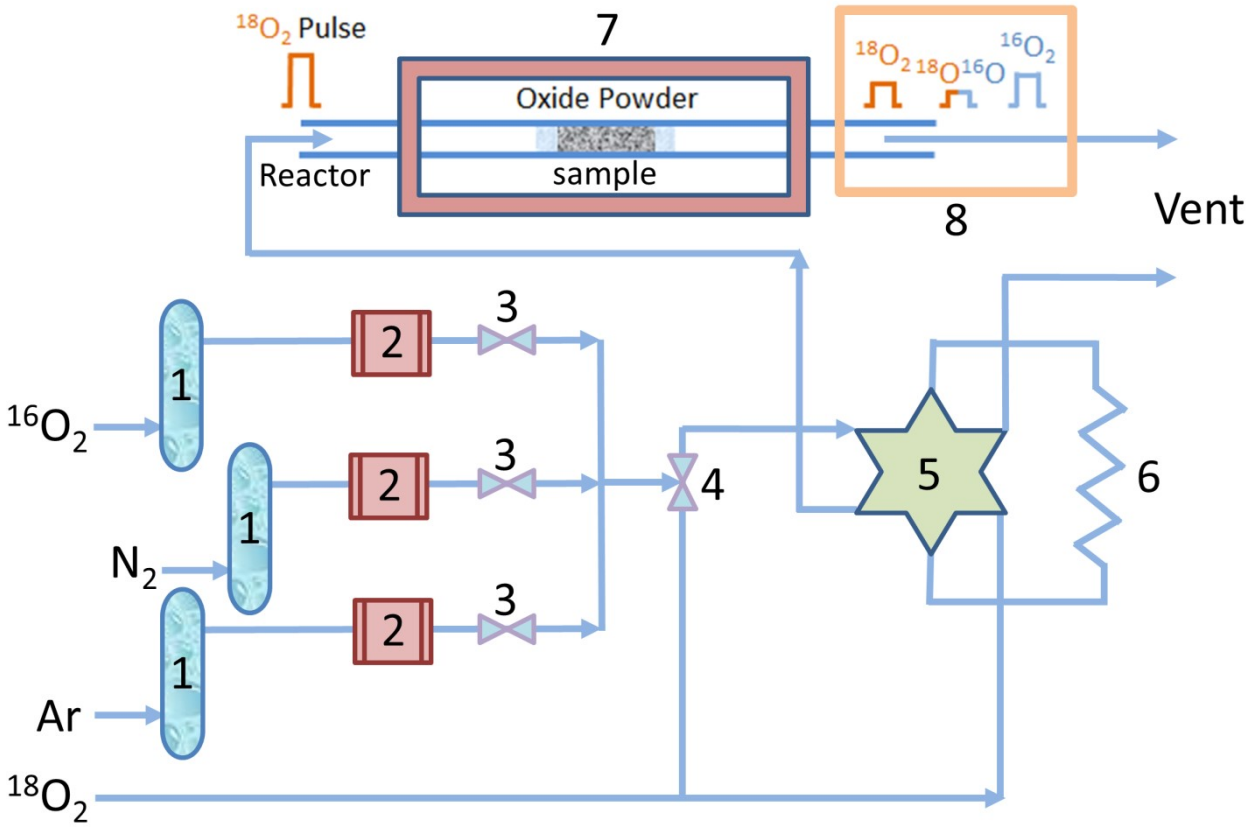

Fig. S5 Schematics of the pulse isotopic exchange (PIE) set-up, illustrating the following components: (1) Moisture filter, (2) Mass flow controller, (3) Valve, (4) 3-Way valve, (5) Multiple-way valve, (6) $^{18}O_2$ sample loop, (7) Reactor loaded with packed bed inside the furnace, and (8) Mass spectrometer.

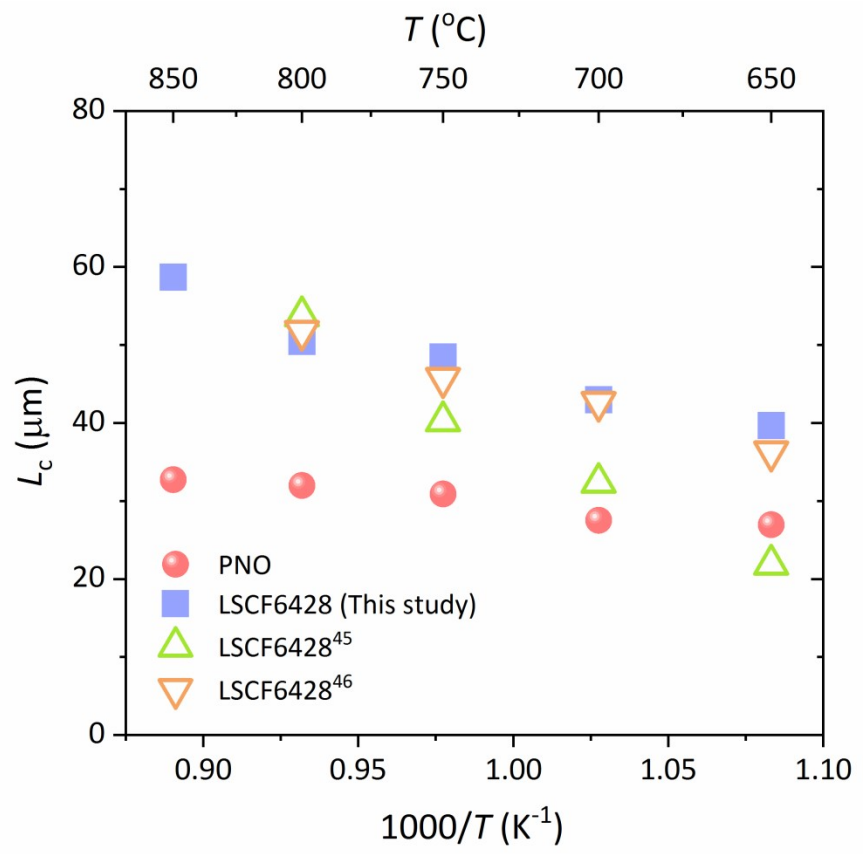

Fig. S6 Critical length (L_c) versus temperature plot for PNO and LSCF6428.

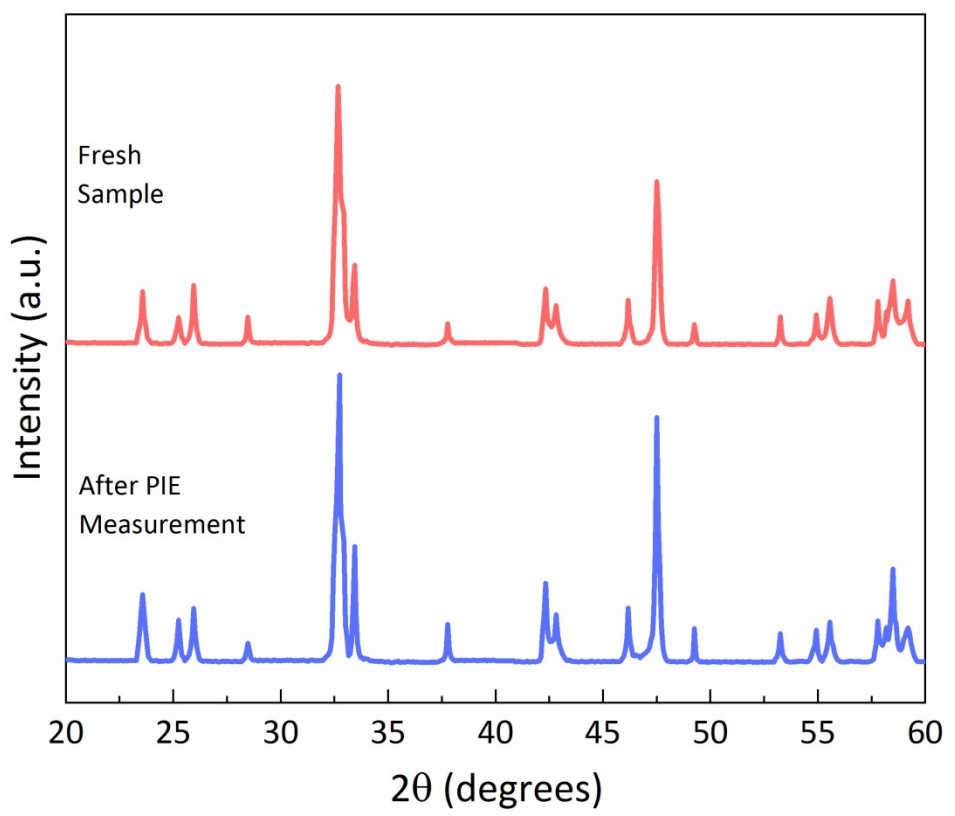

Fig. S7 Comparison of XRD analysis before and after the temperature dependence PIE measurement on the $Pr_4Ni_3O_{10+\delta}$ (PNO) fractionated powder.

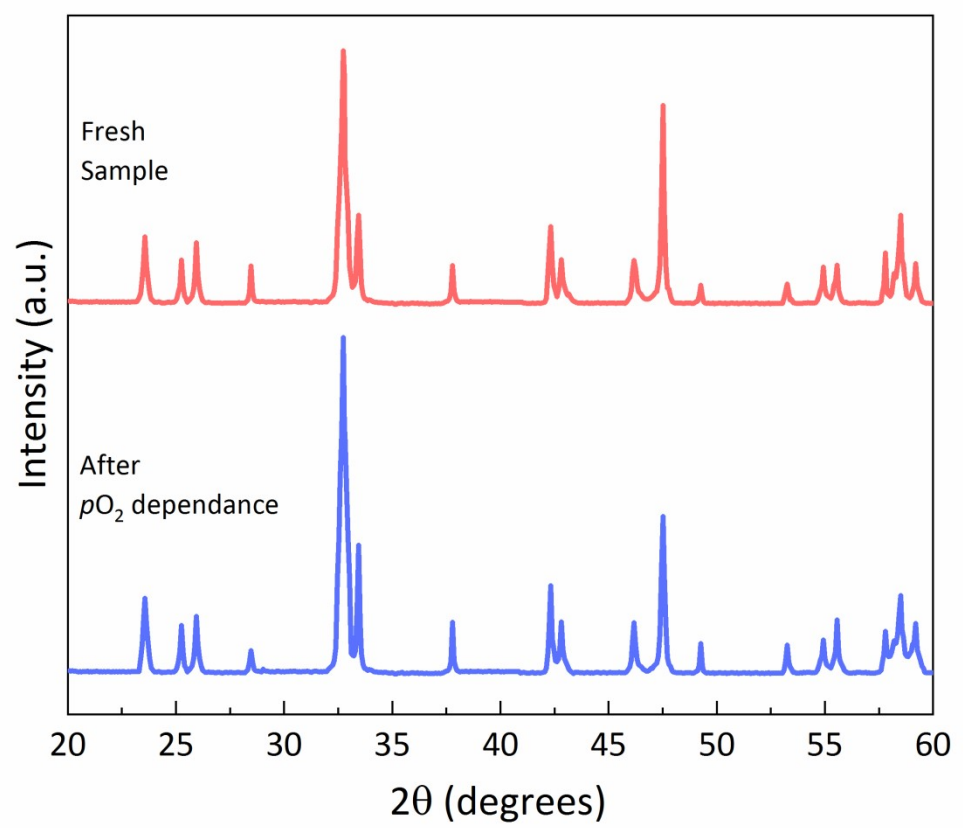

Fig. S8 Comparison of XRD analysis before and after the pO_2 dependence PIE measurement on the $Pr_4Ni_3O_{10+\delta}$ (PNO) fractionated powder.