Energy Materials

Supplementary Material

High-voltage flat-tubular segment-in-series SOFCs: strategic design of an $SrZrO_3$ insulation layer

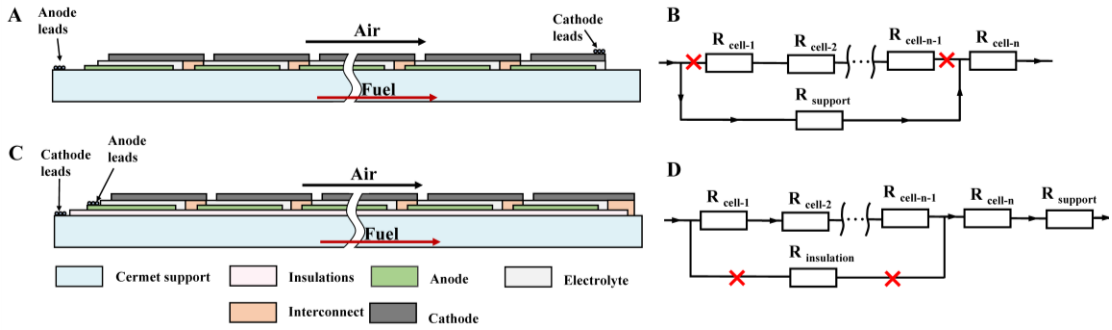
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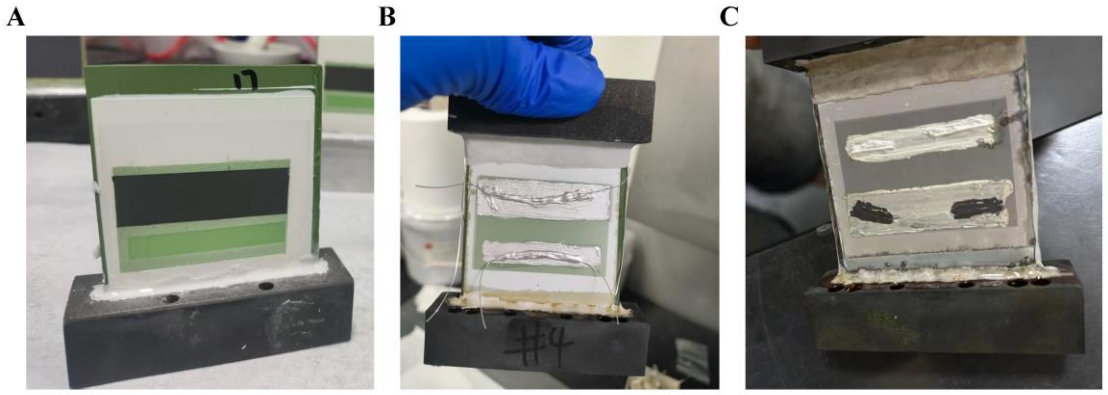
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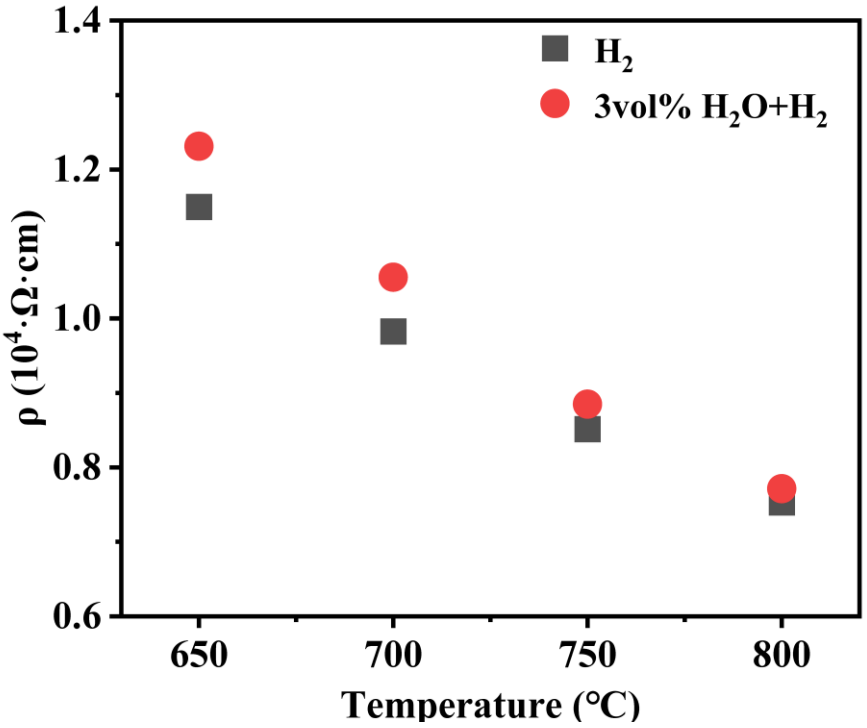
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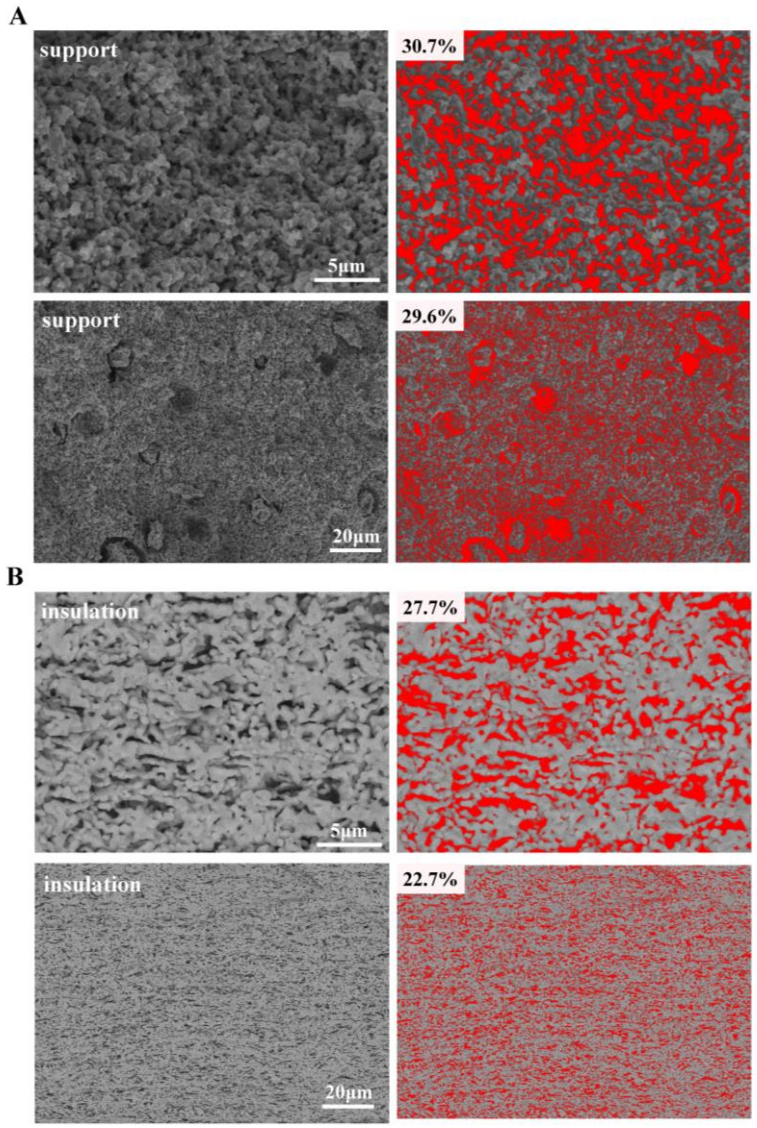
Supplementary Figure 1. Influence of the insulating layer on the performance of FT-SIS-SOFCs and the corresponding equivalent circuits. (A) FT-SIS-SOFC without an insulating layer; (B) Equivalent circuit without an insulating layer; (C) FT-SIS-SOFC with an insulating layer and (D) Equivalent circuit with an insulating layer.



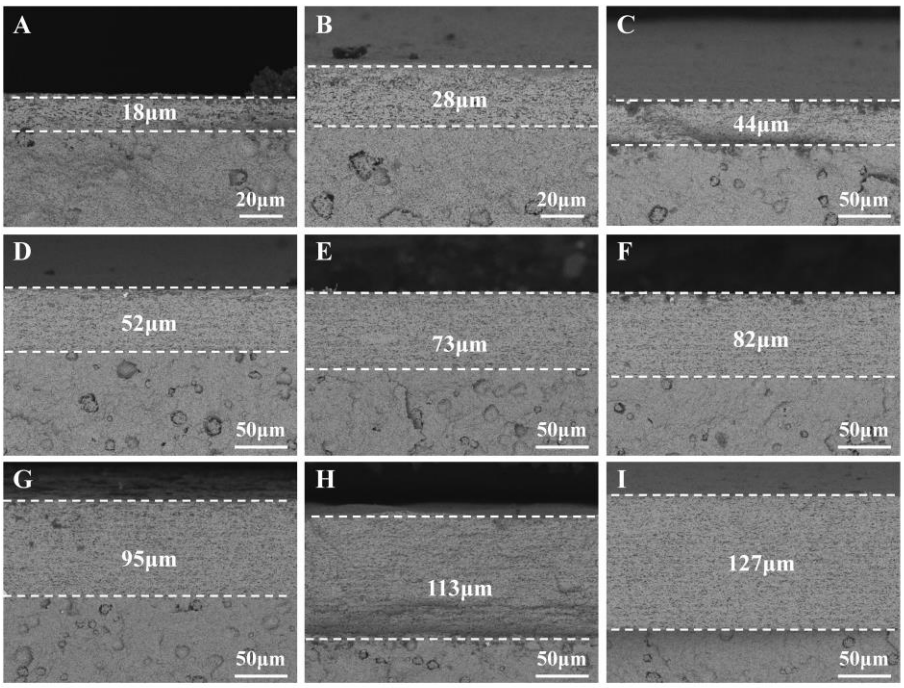
Supplementary Figure 2. Physical images of the single cell, photograph taken by the authors. (A) Before testing; (B) Lead connection and sealing and (C) After testing.



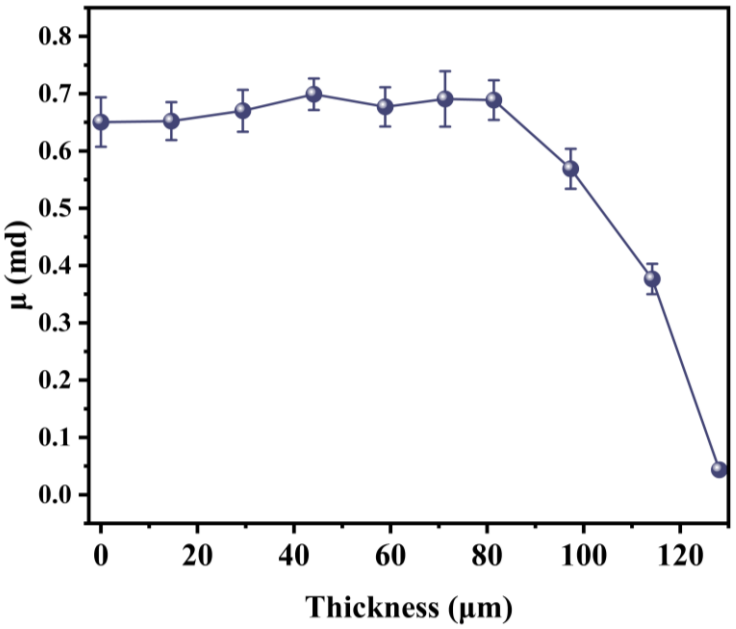
Supplementary Figure 3. Electrical resistivity of the previously reduced SZO specimen measured under dry H_2 and humidified H_2 containing 3 vol.% H_2O at 650 – 800 ℃.



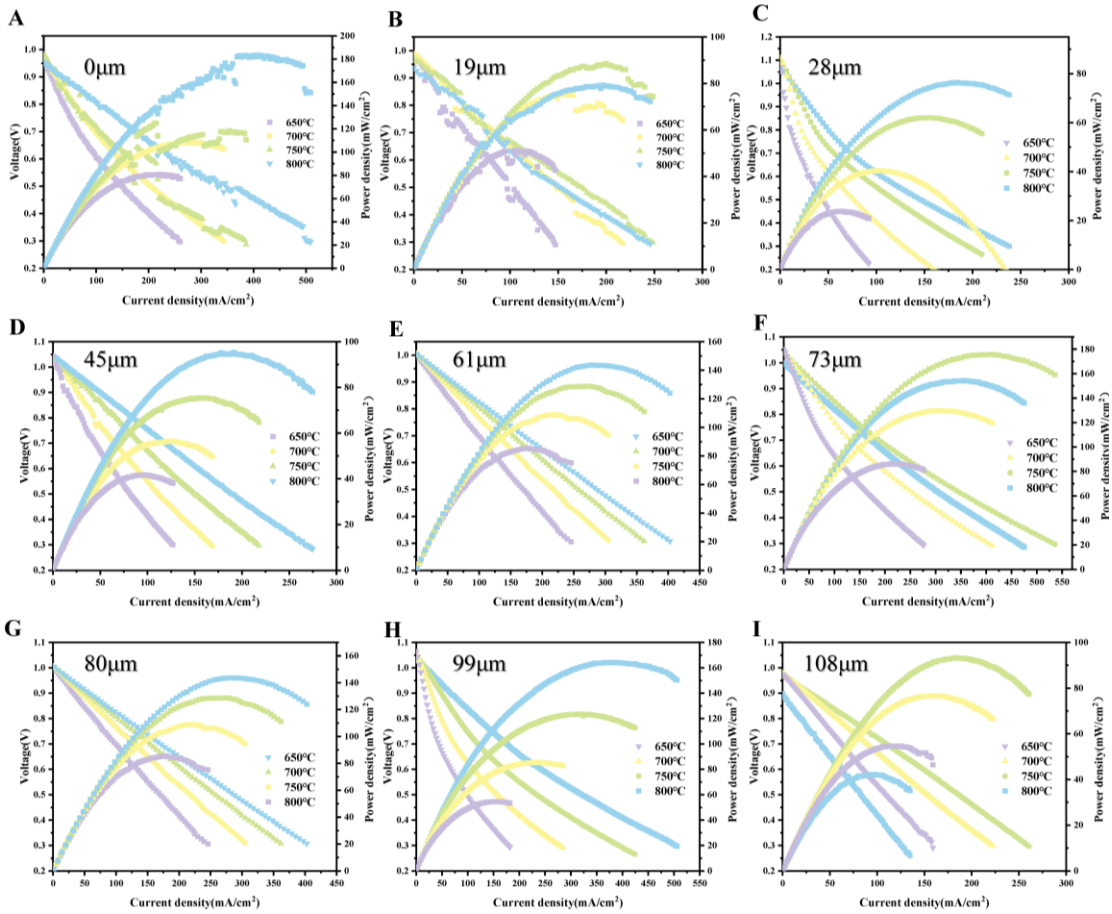
Supplementary Figure 4. Cross-sectional SEM micrographs and corresponding ImageJ-based porosity analysis of the porous layers after co-sintering at 1350 ℃ and subsequent reduction. (A) Cermet support imaged at two magnifications;(B) SZO insulating layer imaged at two magnifications.



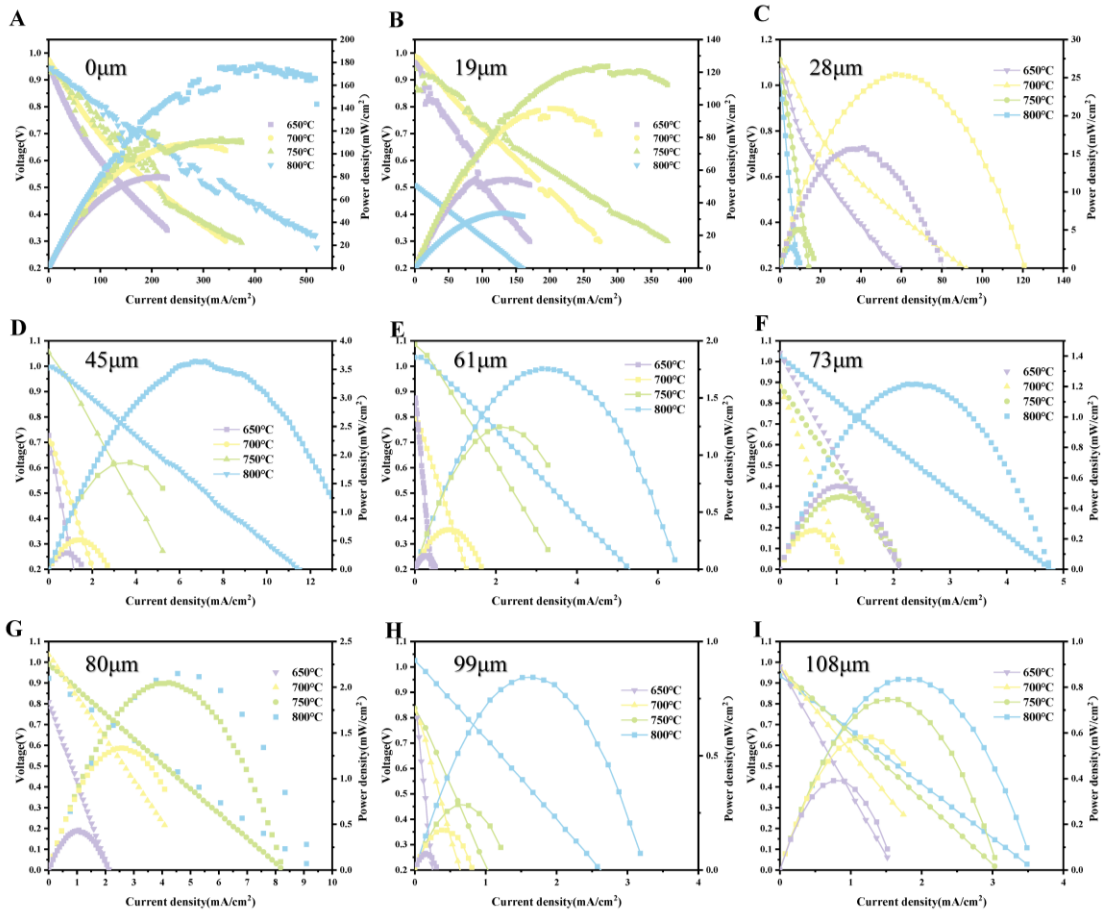
Supplementary Figure 5. Cross-sectional SEM images of the support/SZO specimens used for gas permeability measurements with different SZO insulating layer thicknesses: (A) 18 μm; (B) 28 μm; (C) 44 μm; (D) 52 μm; (E) 73 μm; (F) 82 μm; (G) 95 μm; (H) 113 μm; (I) 127 μm.



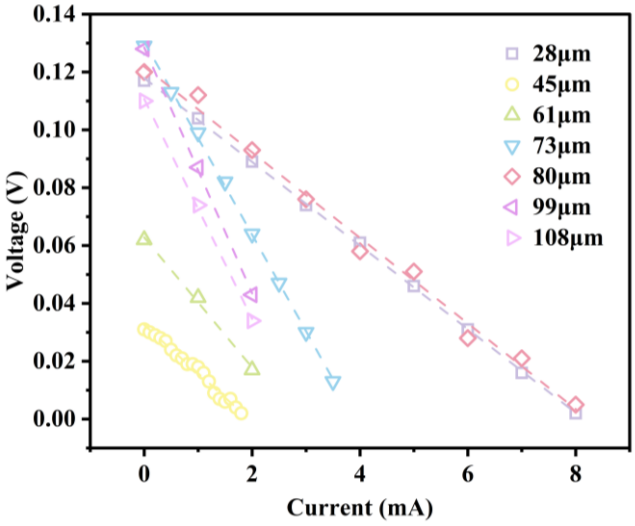
Supplementary Figure 6. Apparent gas permeability of the cermet support/SZO composite as a function of SZO insulating layer thickness.



Supplementary Figure 7. Output performance of single cells with different SZO thicknesses under the A–C configuration. (A) 0 μm; (B) 19 μm; (C) 28 μm; (D) 45 μm; (E) 61 μm; (F) 73 μm; (G) 80 μm; (H) 99 μm and (I) 108 μm.



Supplementary Figure 8. Output performance of single cells with different SZO thicknesses under the S–C configuration. (A) 0 μm; (B) 19 μm; (C) 28 μm; (D) 45 μm; (E) 61 μm; (F) 73 μm; (G) 80 μm; (H) 99 μm and (I) 108 μm.

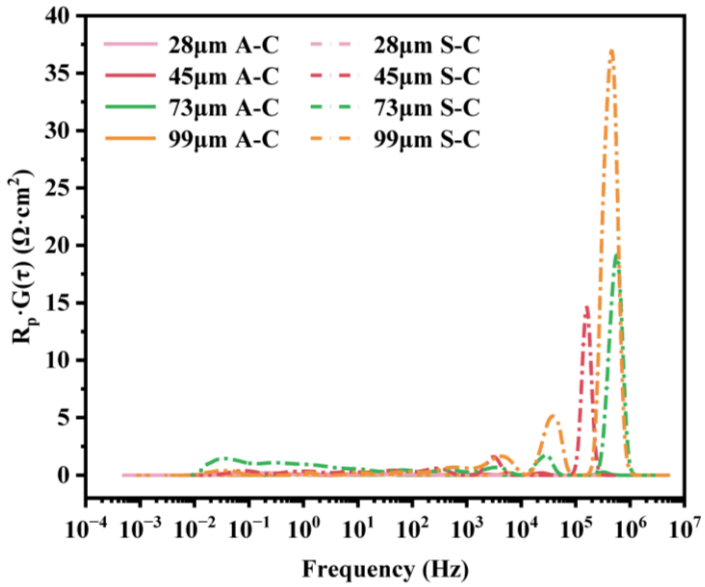


Supplementary Figure 9. Current-voltage (I-V) characteristics measured between the functional anode and the conductive support at 800 °C under the independent S–A diagnostic configuration with the cathode electrically floating.

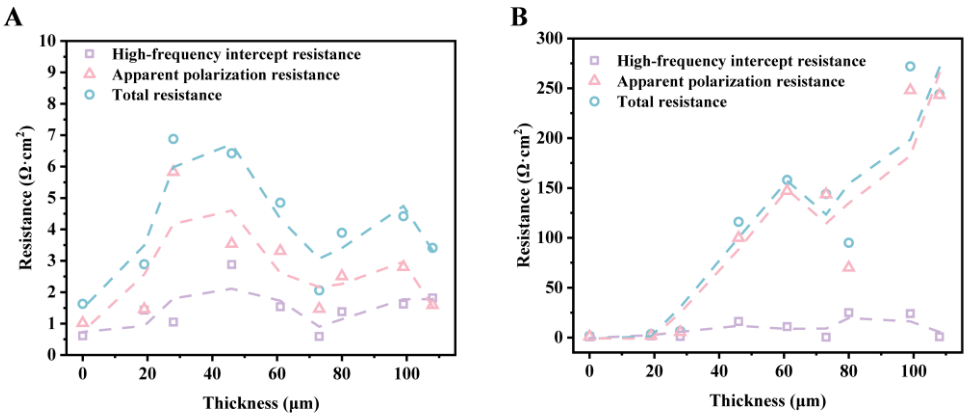
Supplementary Table 1. Linear fitting parameters of the A–S direct-current polarization curves measured at 800 ℃

Thickness (μm)	$R_{S\text{-}A}$ (Ω)	R^2
28	14.5	0.99977
45	16.7	0.9831
61	22.5	0.9959
73	33.4	0.99918
80	14.8	0.99263
99	42.5	0.99958
108	38	0.99908

$R_{S\text{-}A}$ is the apparent resistance of the A–S pathway obtained from linear fitting of the direct-current polarization curve. A larger $R_{S\text{-}A}$ corresponds to a weaker A–S direct-current-carrying coupling.



Supplementary Figure 10. The A-C and S-C DRT responses at representative SZO thicknesses.



Supplementary Figure 11. Apparent impedance contributions of single cells with different SZO insulating-layer thicknesses under the A–C and S-C configurations at 800 ℃. (A) A–C configuration; (B)S–C configuration at 800 ℃.

Supplementary Table 2. Open-circuit potentials measured under the three lead configurations at 800 ℃ for cells with different SZO thicknesses. The calculated value $V_{S-C} - V_{A-C}$ is compared with the directly measured V_{S-A} to evaluate the internal consistency of the three-node potential relationship. The voltage difference ΔV represents the deviation between the measured and calculated values

Thickness (μm)	$V_{A–C}$ (V)	$V_{S–C}$ (V)	$V_{S–A}$ (V)	$V_{S–C} - V_{A–C}$ (V)	ΔV (V)
28	1.063	1.176	0.117	0.113	0.004
45	0.985	1	0.031	0.015	0.016
61	1.024	1.035	0.06	0.011	0.049
73	0.999	1.159	0.129	0.16	-0.031
80	0.959	1.072	0.12	0.113	0.007
99	1.038	1.131	0.128	0.093	0.035
108	0.898	1.054	0.11	0.156	-0.046

$V_{A–C}$, $V_{S–C}$ and $V_{S–A}$ denote the open-circuit potentials measured between the corresponding electrode pairs. The calculated quantity $V_{S–C} - V_{A–C}$ is obtained using the cathode as the common reference. $\Delta V = V_{S–A} - (V_{S–C} - V_{A–C})$ represents the deviation between the measured and calculated S–A potential differences.