

Improving molten regolith electrolysis with zirconia-based hollow anode technology

Supplementary Material

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Supplementary Material

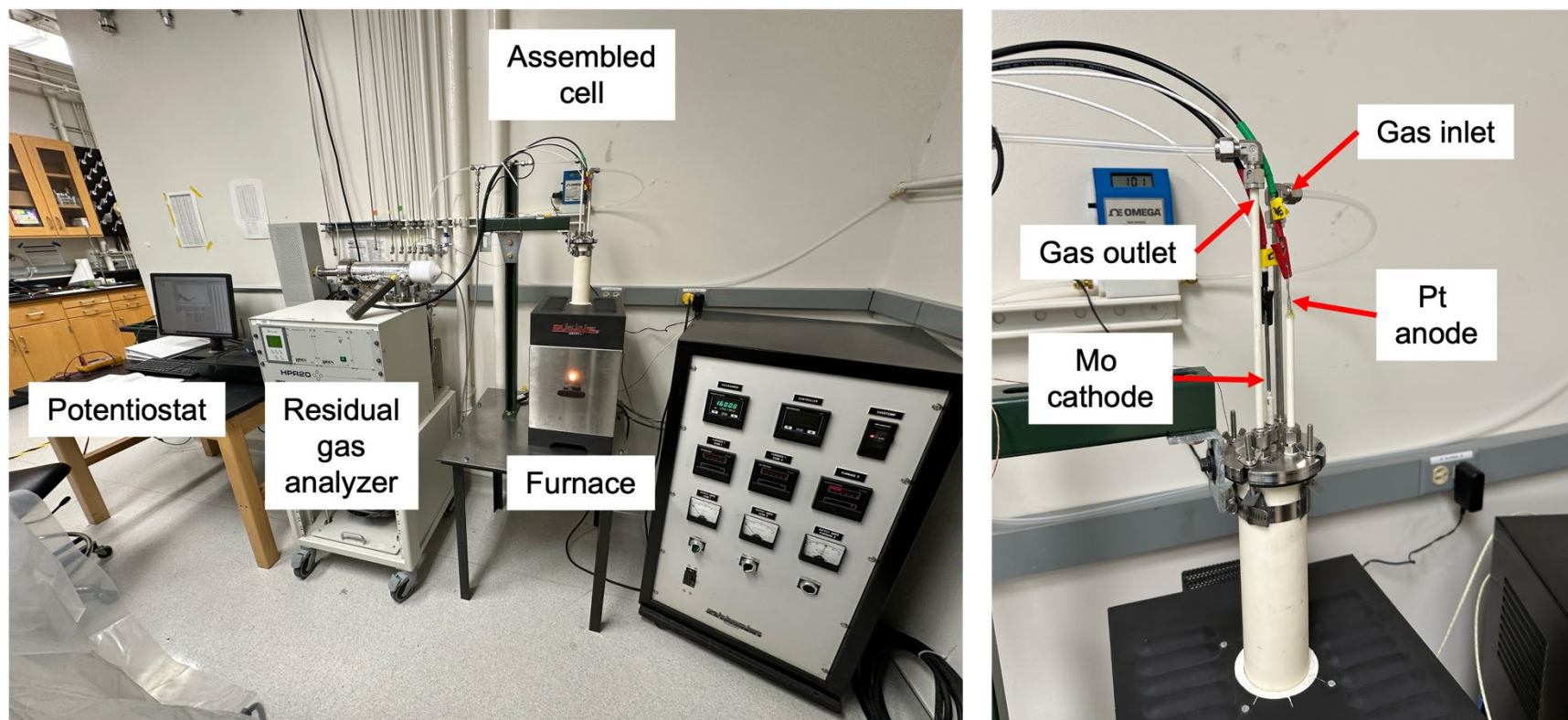


Figure S1: Labeled images of assembled electrolysis cell, gas/electrical feedthroughs, and supporting equipment during molten regolith electrolysis testing.

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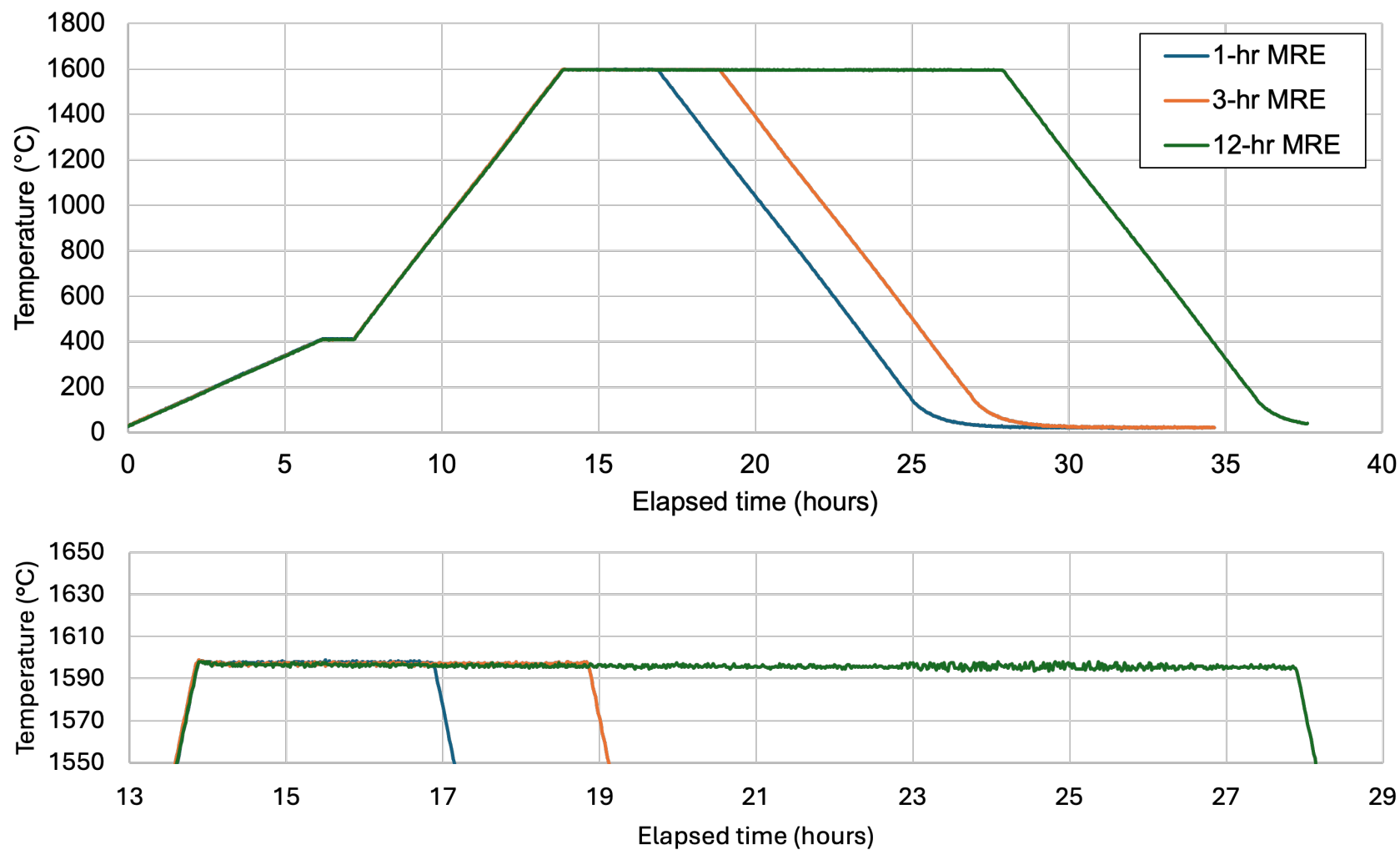
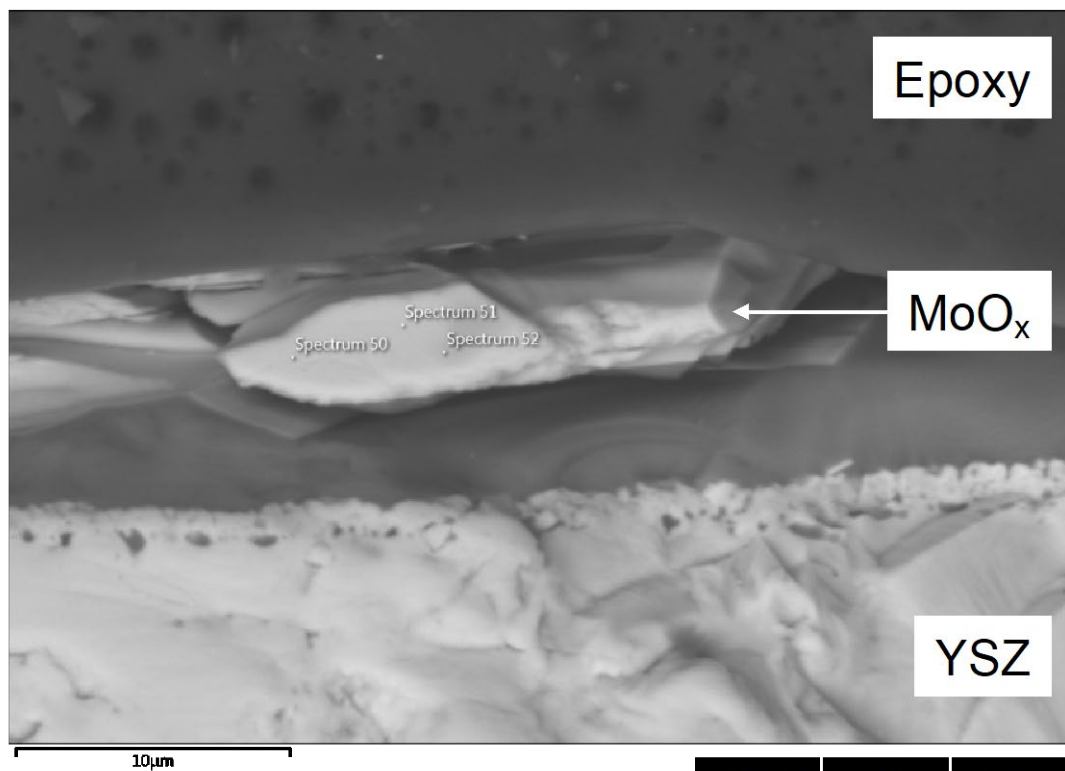


Figure S2: Thermal profile of all three electrolysis experiments from monitoring thermocouple in furnace. Top graph shows the entirety of the heating and cooling profiles. Bottom graph provides a detailed view of the dwell segment during which electrolysis is performed.

Supplementary Material

Backscattered electron image

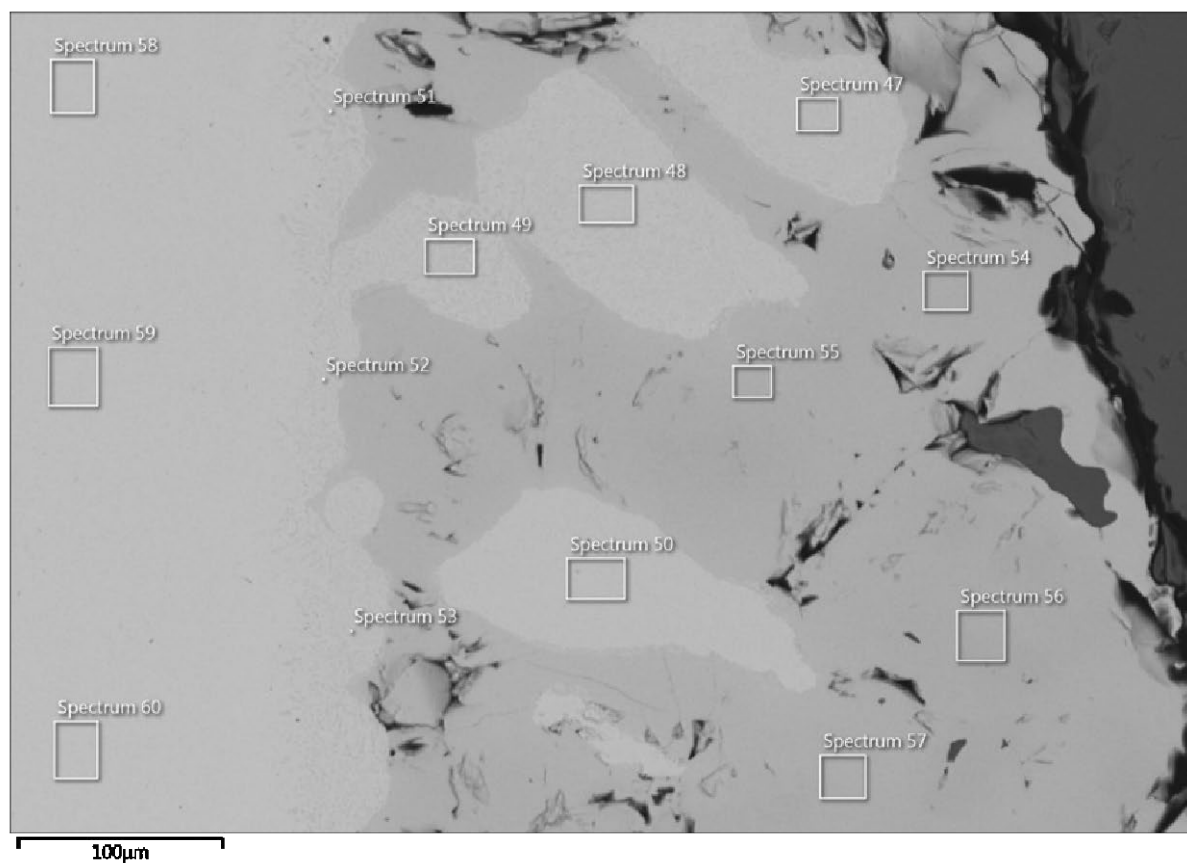


Site #	O	Mg	Al	Si	Ca	Fe	Mo
50	66.06	6.00	0.56	0.30	0.14	6.70	20.24
51	65.54	6.15	0.51	0.23	0.07	6.76	20.74
52	69.83	4.97	1.48	2.72	0.61	5.13	15.25

Figure S3: Quantitative EDS summary of Mo oxides observed on interior of YSZ after electrolysis experiments. Data taken from 3-hour electrolysis cell. All values are in at%.

Supplementary Material

Backscattered electron image



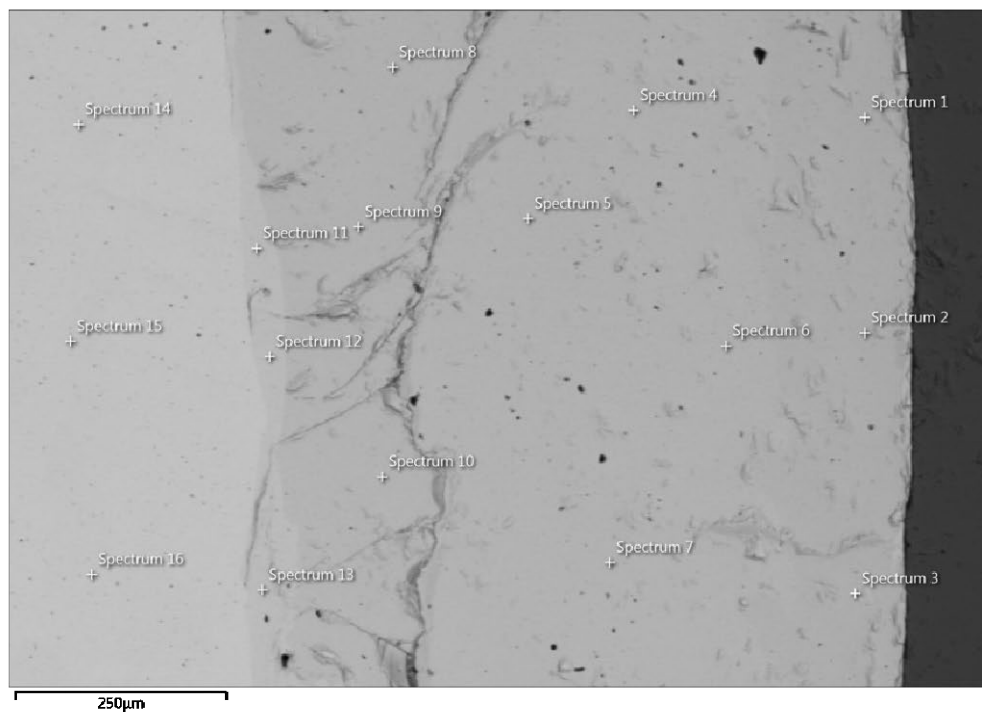
All values are in atomic %

Site #	Fe	Mo
47	19.11	80.89
48	17.57	82.43
49	17.81	82.19
50	18.09	81.91
51	8.52	91.48
52	8.79	91.21
53	36.47	63.53
54	58.07	41.93
55	57.63	42.37
56	62.95	37.05
57	58.85	41.15
58	0.00	100
59	0.07	99.93
60	0.01	99.99

Figure S4: Quantitative EDS summary of cathodic product region in 1-hour electrolysis cell (Figure 3). All values are in at%.

Supplementary Material

Backscattered electron image



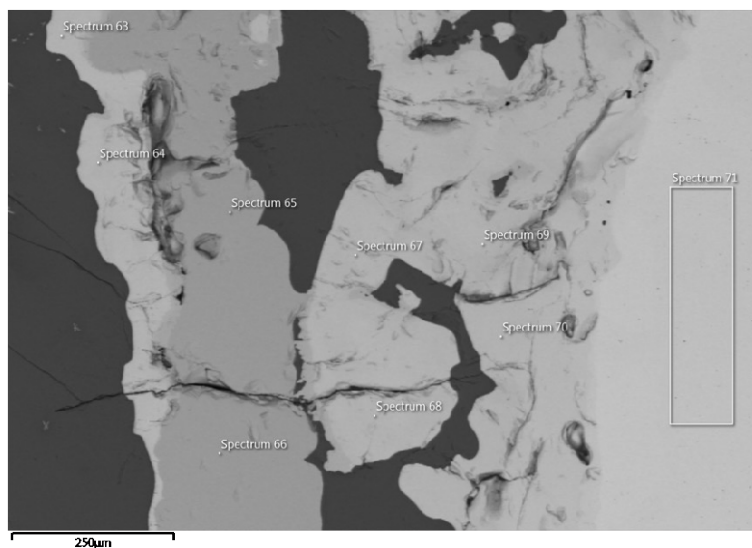
All values are in atomic %

Site #	Si	P	Fe	Mo
1	11.92	5.55	38.86	43.34
2	13.79	1.31	39.31	44.69
3	14.39	3.78	47.29	33.66
4	16.40	0.18	34.75	48.25
5	16.81	0.05	34.62	48.00
6	16.15	0.11	35.30	48.13
7	16.92	0.10	34.69	48.02
8	16.53	0.24	34.55	47.99
9	16.37	0.03	35.16	47.79
10	16.16	0.17	35.63	47.68
11	12.38	0.58	25.11	61.23
12	12.64	0.53	25.19	61.18
13	12.91	0.86	24.96	60.97
14	0.37	0.00	0.17	98.45
15	0.54	0.00	0.26	98.24
16	0.36	0.00	0.00	98.98

Figure S5: Quantitative EDS summary of cathodic product region in 3-hour electrolysis cell (Figure 4). All values are in at%.

Supplementary Material

Backscattered electron image



Site #	Si	P	Ti	Mn	Fe	Mo
63	37.16	0.13	4.87	0.36	6.61	50.87
64	36.29	0.29	4.42	0.49	13.36	45.15
65	65.34	0.00	0.07	0.03	0.00	34.56
66	65.24	0.00	0.05	0.08	0.11	34.52
67	37.75	0.00	4.09	0.29	5.24	52.64
68	37.45	0.04	6.48	0.37	4.91	50.75
69	37.34	0.00	2.74	0.40	6.08	53.45
70	37.23	0.12	4.92	0.32	5.52	51.90
71	0.36	-	-	-	-	99.64

All values are in atomic %

Figure S6: Quantitative EDS summary of cathodic product region in 12-hour electrolysis cell (Figure 5). All values are in at%.

Supplementary Material

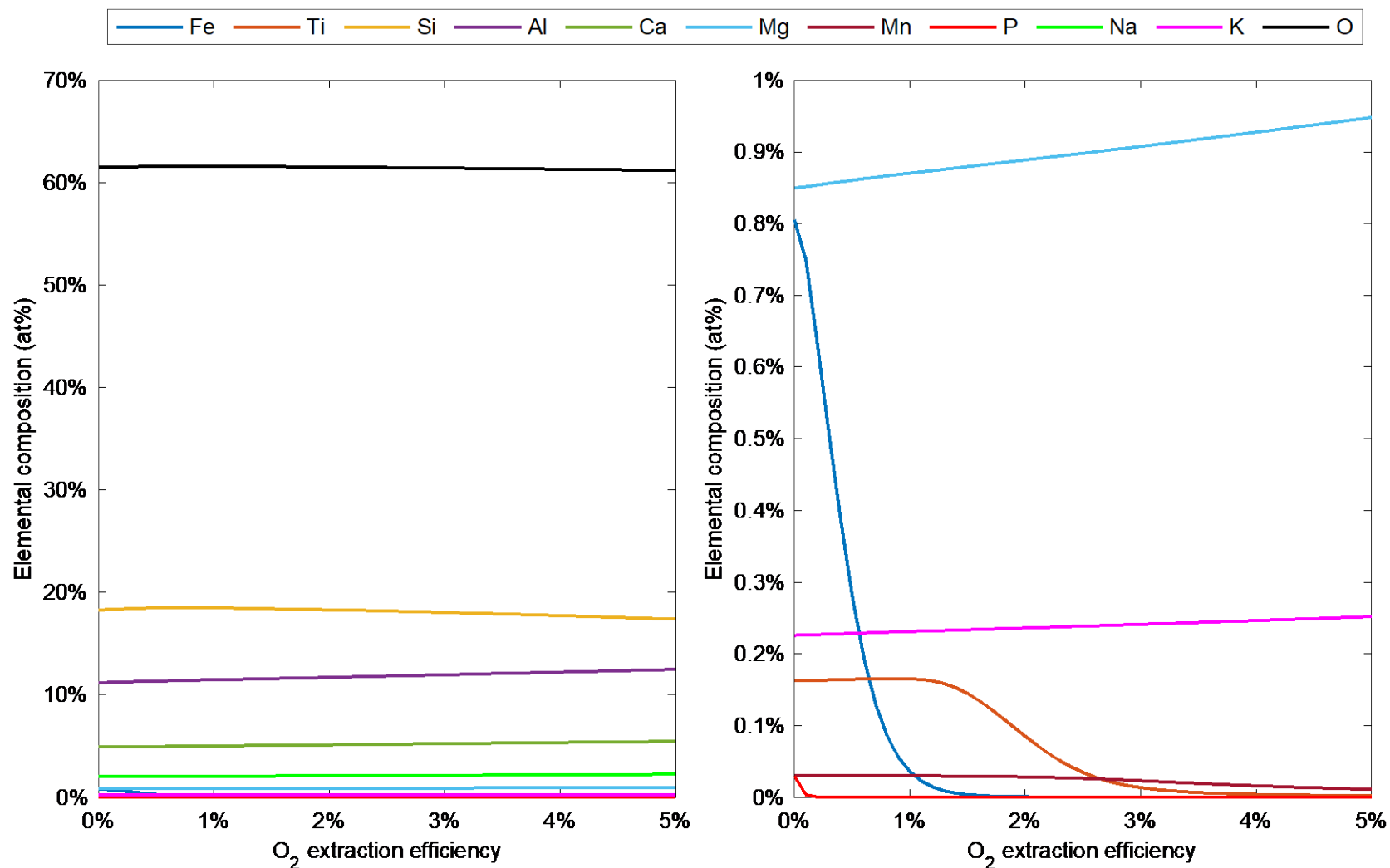


Figure S7: FactSage predictions of the remaining regolith composition (full (left) and expanded (right)) vs. O₂ extraction efficiency. Dashed vertical lines represent the O₂ extraction efficiency achieved in the 1-hour (0.4%), 3-hour (1.2%), and 12-hour (3.7%) electrolysis cells.

Supplementary Material

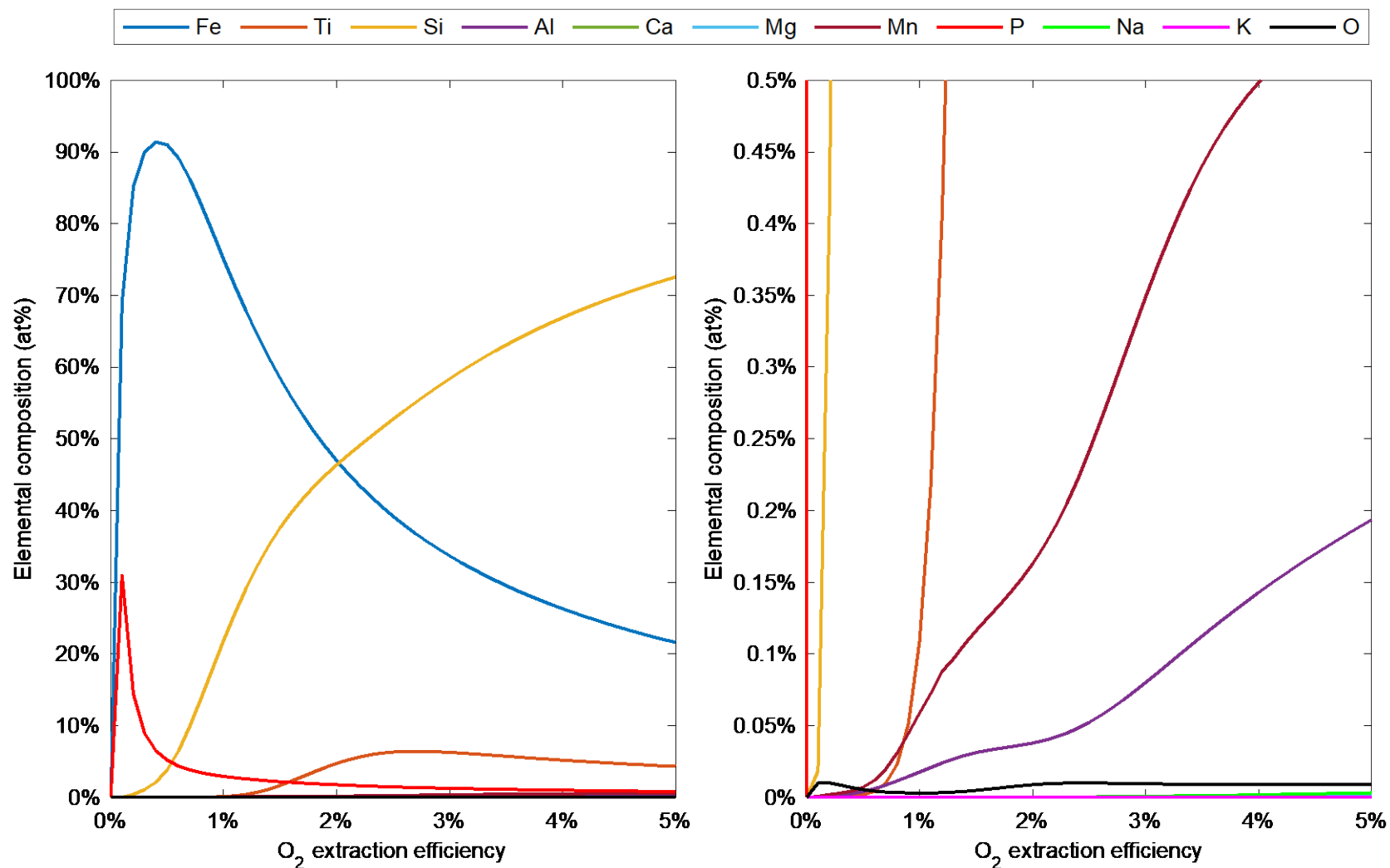


Figure S8: FactSage predictions of the cathodic product composition (full (left) and expanded (right)) vs. O₂ extraction efficiency. Dashed vertical lines represent the O₂ extraction efficiency achieved in the 1-hour (0.4%), 3-hour (1.2%), and 12-hour (3.7%) electrolysis cells.

Supplementary Material

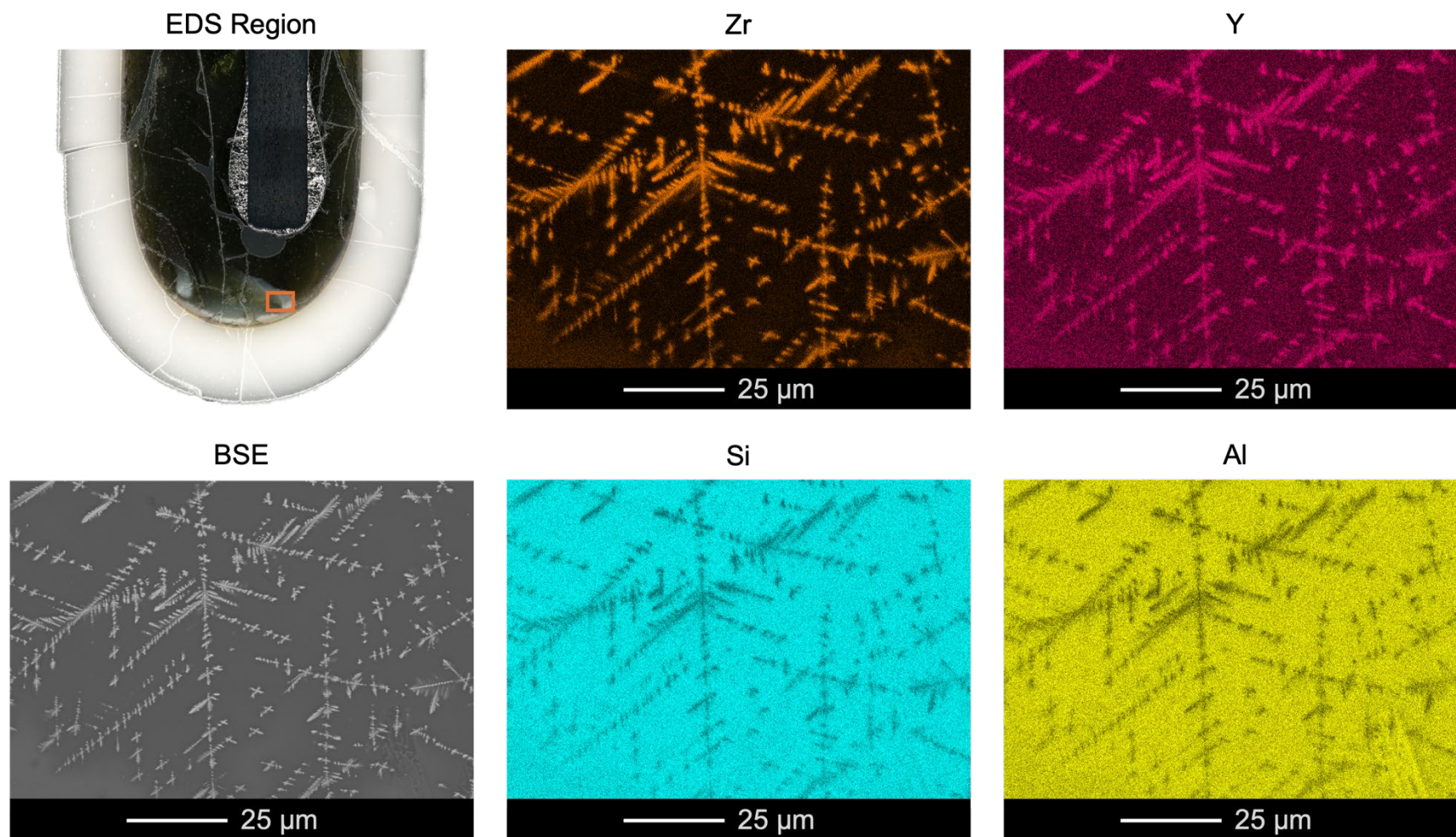


Figure S9: Backscattered electron (BSE) image and energy-dispersive X-ray spectroscopy (EDS) maps of YSZ particles at bottom of 1-hour electrolysis cell. EDS analysis area is denoted with the orange box in the optical microscope image.

Supplementary Material

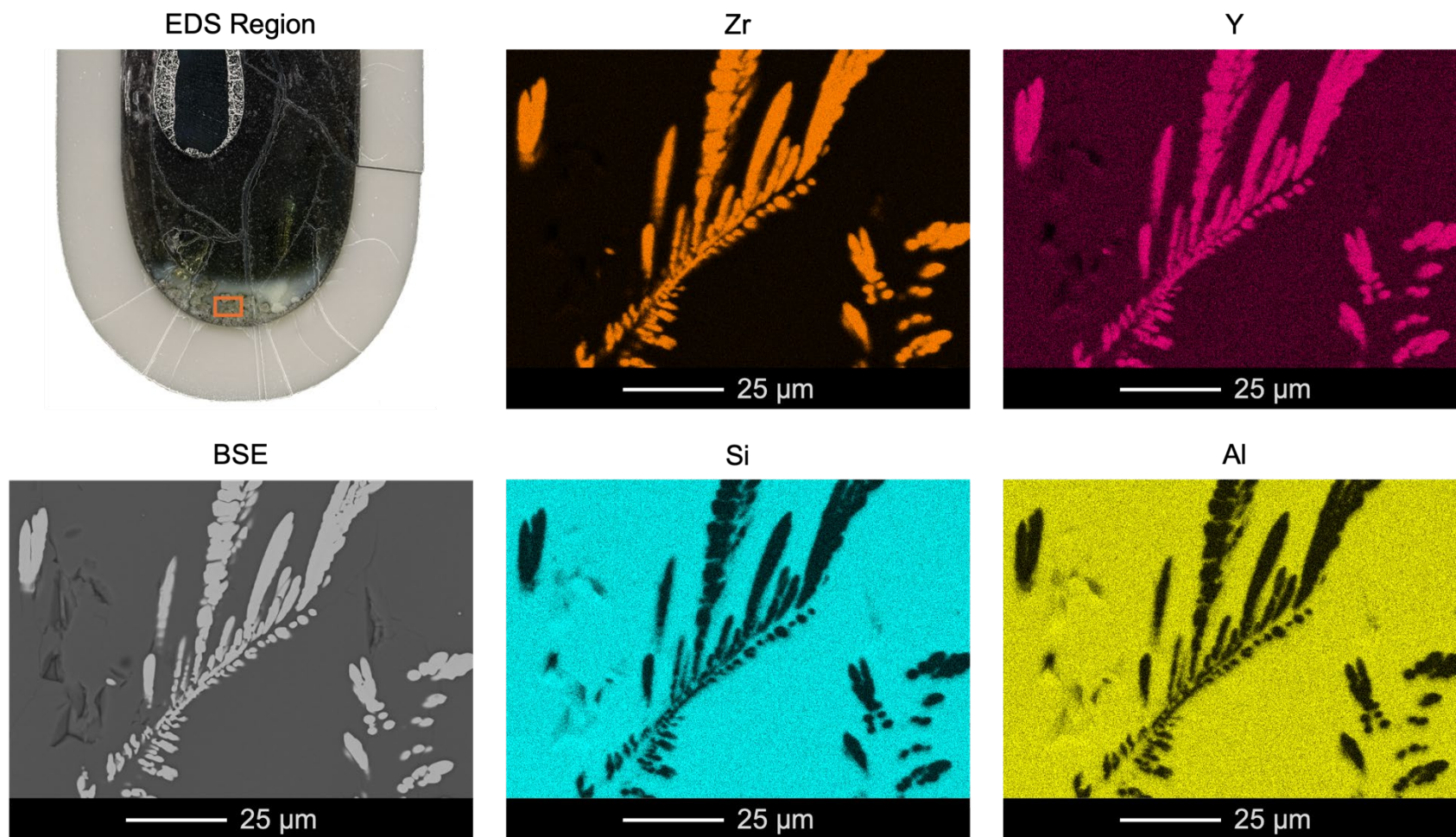


Figure S10: Backscattered electron (BSE) image and energy-dispersive X-ray spectroscopy (EDS) maps of YSZ particles at bottom of 3-hour electrolysis cell. EDS analysis area is denoted with the orange box in the optical microscope image.

Supplementary Material

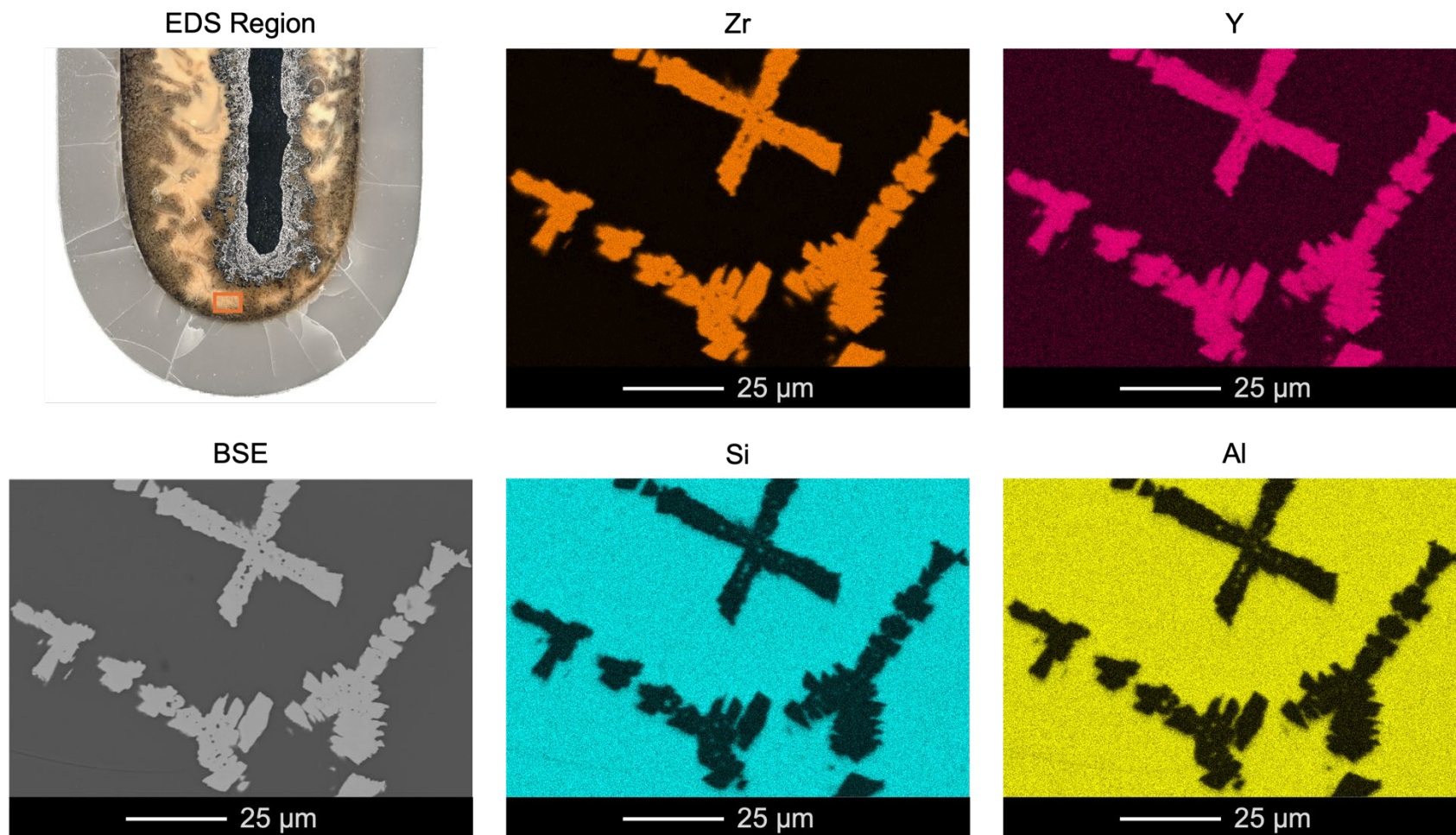


Figure S11: Backscattered electron (BSE) image and energy-dispersive X-ray spectroscopy (EDS) maps of YSZ particles at bottom of 12-hour electrolysis cell. EDS analysis area is denoted with the orange box in the optical microscope image.

Supplementary Material

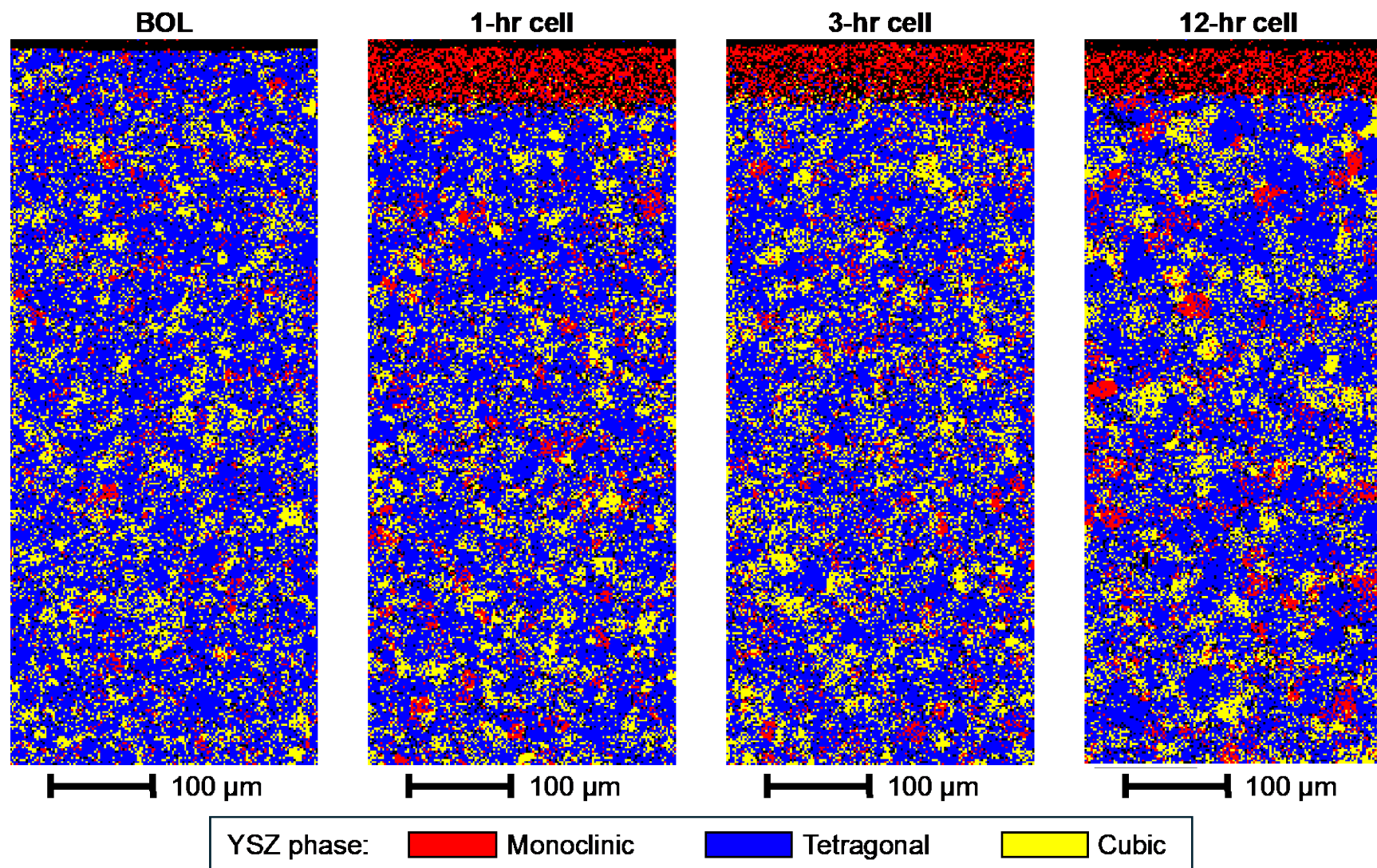


Figure S12: EBSD phase maps of beginning-of-life (BOL) YSZ and YSZ at molten regolith interface for the 1-hr, 3-hr and 12-hr electrolysis cells.