Supporting Information

Beyond the Slurry: Architecting Binder-Free Tin Anodes for High-Energy Lithium-Ion Batteries — A Review

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Supplement information S1.

Calculation Methods for Gravimetric and Volumetric capacities

In this study, both gravimetric and volumetric capacities were calculated at the electrode level, explicitly accounting for all electrode components, including active materials, inactive components, and the current collector. This approach enables a fair and practical comparison of different anode architectures reported in the literature.

Electrode-Level Capacity Relationships

The relationship between gravimetric capacity and volumetric capacity at the electrode level is expressed as:

$$Gravimetric\ Capacity\left(\frac{mAh}{g_{electrode}}\right) * Density\left(\frac{g_{electrode}}{cm^3}\right) = Volumetric\ capacity\left(\frac{mAh}{cm^3}\right) = \frac{Areal\ Capacity\left(\frac{mAh}{cm^2}\right)}{Anode\ thickness\ (cm)} \quad (1)$$

where the electrode thickness and density include contributions from all components of the electrode.

Electrode Thickness

The electrode thickness (cm) corresponds to the total thickness of all electrode components. If substrate information was not explicitly reported in the original reference, a copper current collector with a thickness of 10 μm was assumed.

Electrode-Level Density Calculation

The electrode-level density was estimated using the rule-of-mixtures method, based on the reported material composition for alloy or composite foils.

For Sn or Sn-based composite materials deposited on a substrate, the density was calculated using the reported deposition parameters (mass, thickness, and electrode area), according to:

$$Density\left(\frac{g_{electrode}}{cm^3}\right) = \frac{mass\ loading\left(\frac{g_{electrode}}{cm^2}\right)}{Anode\ thickness\ (cm)} \quad (2)$$

Specific Capacity at the Electrode Level

The specific capacity at the electrode level was calculated using the reported deposited mass, electrode thickness, and geometric area:

$$Gravimetric\ Capacity\left(\frac{mAh}{g_{electrode}}\right) = \frac{Areal\ Capacity\left(\frac{mAh}{cm^2}\right)}{mass\ loading\left(\frac{g_{electrode}}{cm^2}\right)} = \frac{Active\ Gravimetric\ Capacity\left(\frac{mAh}{g_{active\ material}}\right) x\ Active\ material\ loading\left(\frac{g_{active\ material}}{cm^2}\right)}{mass\ loading\left(\frac{g_{electrode}}{cm^2}\right)} \quad (3)$$

When specific capacity values were reported relative to the cathode (e.g., mAh g^{-1} of cathode), the corresponding areal capacity was first obtained by multiplying the reported specific capacity by the cathode mass loading (mg cm^{-2}). If the anode and cathode areas

differed, the smaller electrode area was used for all capacity calculations to ensure consistency.

Mass Loading Definition

The electrode-level mass loading ($g_{electrode}$ cm^{-2}) includes the total mass of all electrode components, including active material, inactive material, and the current collector. If substrate information was not provided, a 10 μm-thick copper current collector was assumed.

Material Densities

The densities of Sn-based anode materials were calculated using the rule-of-mixtures approach. The elemental densities used in this work are listed below: Cu = 8.96 g cm^{-3}, Sn = 7.287 g cm^{-3}, Ni = 8.9 g cm^{-3}, Ti = 4.506 g cm^{-3}, Co = 8.86 g cm^{-3}, Zn = 7.134 g cm^{-3}, Sb = 6.68 g cm^{-3}.

Table S1 Summary of Electrode-Level Performance of Sn-Based Anodes. Superscript numbers next to material names indicate reference numbers cited in the main text. The area (cm^2) refers to the geometric area of the tested sample. The thickness (cm) represents the total thickness of all electrode components. The mass loading (mg cm^{-2}) includes all components of the electrode. Both gravimetric (mAh g^{-1}) and volumetric (mAh cm^{-3}) capacities were calculated at the electrode level, considering all components. When a formation cycle was employed, the values from the initial formation cycle were used. Number-of- cycle life ("N_{80}") is defined as the number of cycles at which the charge capacity/delithiation capacity (half-cell) or discharge capacity (full cell) decreases to 80% of its initial value. If the 80% capacity retention threshold is not reached within the reported cycling window, the last available cycle is taken as the "N_{max}"; these are right-

censored endpoints (limited by reporting length) and do not imply 80% retention. In the cell configuration, the half cell with Li electrode (Li denotes lithium metal)), LLI is limited lithium inventory test in half-cell,[59] the full cell with cathodes electrodes in which LFP is $LiFePO_4$; NCM523, NCM811, and NMC622 refer to $Li(Ni_xCo_yMn_z)O_2$ cathode materials with molar ratios of 5:2:3, 8:1:1, and 6:2:2, respectively. "N/A" indicates information not available or not specified in the original reference. The references cited in this table have been listed in the article's reference list.

Sample	Substrate	Area (cm^2)	Thickness cm	Mass loading ($mg\ cm^{-2}$)	Density ($mg\ cm^{-3}$)	Cell configuration (Cutoff)	Capacity at 1st cycle		N_{80}	N_{max}
							Gravimetric ($mAh\ g^{-1}$)	Volumetric ($mAh\ cm^{-3}$)		
Graphite[11]	Cu foil	1.54	0.0072	0.01887	2.621	Li (0.005-1.5V)	179.73	471.04	-	100
10Sn-C[53]	Ni foam	0.785	0.0075	0.01234	1.645	Li (0.01-2V)	414.59	682	95	-
15Sn-C[53]	Ni foam	0.785	0.0075	0.01459	1.945	Li (0.01-2V)	533.16	1037	72	-
20Sn-C[53]	Ni foam	0.785	0.0075	0.01759	2.345	Li (0.01-2V)	576.55	1352	48	-
Cu-Sn-3[54]	Cu foam	1.1304	0.0500	0.00320	0.064	Li (0.01-3V)	684.49	43.78	-	200
Sn-Cu[72]	Cu foil	1	0.0011	0.00961	8.73	Li (0.1-1.25V)	30.15	263.28	-	80
33Sn-Al[92]	Cu foil	1	0.0015	0.0096	6.4	Li	40.13	256.85	2	-

						(0.05-1.25V)				
66Sn-Al[92]	Cu foil	1	0.0015	0.00946	6.31	Li	22.20	140	2	-
						(0.05-1.25V)				
Sn-Ni_PEO[112]	Cu foil	0.785	0.0018	0.00928	5.156	Li	34.59	178.31	200	-
						(0.01-2V)				
Sn-Ni_6h[112]	Cu foil	0.785	0.0018	0.00928	5.156	Li	34.31	176.89	9	-
						(0.01-2V)				
Sn-Co[117]	Cu foil	0.785	0.0102	0.09113	8.93	Li	2.61	23.33	-	75
						(0.05-2V)				
TNA-Sn[131]	Ti foil	1.54	0.0302	0.13597	4.508	Li	28.03	5.66	3	-
						(0-2.7V)				
TNA-Sn180[131]	Ti foil	1.54	0.03016	0.13597	4.508	Li	42.29	8.54	10	-
						(0-2.7V)				
Sn-C-500[55]	Carbon	0.79	0.0125	0.00330	0.264	Li	1002.2	264.58	-	200
						(0.01-3V)				
Sn-C-600[55]	Carbon	0.79	0.0125	0.00330	0.264	Li	800.9	211.44	200	-
						(0.01-3V)				
CoSn-CNT[58]	CNT	1.1304	0.0433	0.00204	0.047	Li	431	20.26	-	450
						(0.01-3V)				
Sn-C[74]	CNF	1	0.0040	0.00200	0.5	Li	691	345.5	7	-
						(0.01-2V)				
Sn-rGO-650[96]	rGO	1.1304	0.0070	0.00088	0.125	Li	755	94.38	50	-

						(0.005-2.0V)				
Sn-rGO-800[96]	rGO	1.1304	0.0070	0.00088	0.125	Li (0.005-2.0V)	300	37.5	50	-
Sn-C[98]	Carbon fibers	0.785	0.0014	0.00100	0.699	Li (0.01-3V)	785	548.95	-	500
Sn-CNF-0[132]	CNF	1.1304	0.0041	0.00133	0.326	Li (0.01-3V)	800	260.98	3	-
Sn-CNF-2[132]	CNF	1.1304	0.0035	0.00133	0.375	Li (0.01-3V)	890.5	334.33	4	-
CF-Sn-C[133]	CNF	N/A	0.0100	0.00280	0.28	Li (0.001-3V)	863	241.64	31	-
0.3CNTSn[31]	Sn foil	1.1304	0.0020	0.01450	7.248	Li (LLI: 2 mAh cm^{-2}, 1.5V)	26.21	190	-	200
0.6CNTSn[31]	Sn foil	1.1304	0.0020	0.01442	7.209	Li (LLI: 2 mAh cm^{-2}, 1.5V)	31.90	230	-	200
1.2CNTSn[31]	Sn foil	1.1304	0.0020	0.01427	7.133	Li (LLI: 2 mAh cm^{-2}, 1.5V)	51.87	370	-	72
1.8CNTSn[31]	Sn foil	1.1304	0.0020	0.01412	7.058	Li (LLI: 2 mAh cm^{-2}, 1.5V)	55.97	395	-	66
2.2CNTSn[31]	Sn foil	1.1304	0.0020	0.01402	7.009	Li	62.06	435	1	-

						(LLI: 2 mAh cm^{-2}, 1.5V)				
CRSn[31]	Sn foil	1.1304	0.0020	0.01458	7.287	Li	17.84	130	-	200
						(LLI: 2 mAh cm^{-2}, 1.5V)				
CRSnZn[32]	Sn foil	1.1304	0.0020	0.01444	7.220	Li	69.95	509.70	-	100
						(LLI: 2 mAh cm^{-2}, 1.5V)				
ARBA1[32]	Sn foil	1.1304	0.0020	0.01444	7.220	Li	72.46	528.00	-	100
						(LLI: 2 mAh cm^{-2}, 1.5V)				
NCF[59]	Sn foil	1.1304	0.0020	0.01506	7.528	Li	183.4	1380.68	37	-
						(LLI: 225 mAh g^{-1}, 1.5V)				
Pewter[59]	Sn foil	1.1304	0.0020	0.01452	7.259	Li	175.3	1272.45	30	-
						(LLI: 225 mAh g^{-1}, 1.5V)				
Sn-Hg[60]	Sn foil	N/A	0.0081	0.06367	7.861	LFP_12mg cm^{-2}	22.77	179.01	-	200
						(1.8-2.4V)				
Bio-Sn[66]	Sn foil	0.785	0.0030	0.02181	7.27	NCM811_23.4mg cm^{-2}	142.14	1033.33	-	110
						(2.8-4.2V)				
3DIP-Sn[67]	Sn foil	N/A	0.0088	0.05346	6.075	LFP_1.8 mg cm^{-2}	4.63	28.15	460	-
						(2.0-3.7V)				
3DIP-Sn[67]	Sn foil	N/A	0.0088	0.05346	6.075	LFP_7.1 mg cm^{-2}	19.12	116.18	380	-

						(2.0-3.7V)				
CRSZ-25P[68]	Sn foil	1.1304	0.0020	0.01083	5.415	Li (LLI: 2 mAh cm^{-2}, 1.5V)	129.27	700	64	-
CRSZ-45P[68]	Sn foil	1.1304	0.0020	0.00794	3.971	Li (LLI: 2 mAh cm^{-2}, 1.5V)	200.83	797.5	60	-
Sn-Zn[106]	Sn foil	0.785	0.0045	0.03261	7.246	Li (0.3-1V)	232.09	1681.84	57	-
Foil-25[107]	Sn foil	0.785	0.0025	0.01812	7.246	Li (0.3-1V)	292.13	2116.89	32	-
Foil-45[107]	Sn foil	0.785	0.0045	0.03261	7.246	Li (0.3-1V)	223.42	1618.99	50	-
Foil-55[107]	Sn foil	0.785	0.0055	0.03986	7.246	Li (0.3-1V)	76	550.72	72	-