Supplementary Information (SI) for Chemical Society Reviews.

Supplementary Information

A comprehensive understanding on the anionic redox chemistry of high-voltage cathode materials for high-energy-density lithium-ion batteries

Qingyuan Li[a,‡], Dong Zhou[b,‡], Mihai Chu[c], Zhongqing Liu[d], Liangtao Yang[e], Wei Wu[e], De Ning[e], Wenyuan Li[a], Xingbo Liu[a], Jie Li[c,*], Stefano Passerini[f,h,*] and Jun Wang[g,*]

[a]Benjamin M. Statler College of Engineering & Mineral Resources, West Virginia University, Morgantown, WV, 26506, USA

[b]School of Advanced Energy, Shenzhen Campus of Sun Yat-sen University, Shenzhen, 518107, P. R. China

[c]Department of Energy, Politecnico di Milano, Via Lambruschini 4, Milano, 20156, Italy

[d]Sodium Innovation Material Technology (SIMT) Co., Ltd., Wuxi, 214142, P. R. China

[e]Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences, Shenzhen, 518055, P. R. China

[f]Austrian Institute of Technology (AIT), Center for Transport Technologies, Giefinggasse 2, Wien, 1210, Austria

[g]School of Innovation and Entrepreneurship, Southern University of Science and Technology, Shenzhen, 518055, P. R. China

[h]Karlsruhe Institute of Technology (KIT), Helmholtz Institute Ulm (HIU), Helmholtzstr. 11, Ulm, 89081, Germany

*Corresponding authors.

E-mail addresses: E-mail: jie1.li@polimi.it (J. Li); stefano.passerini@ait.ac.at (S. Passerini); wangj9@sustech.edu.cn (J. Wang).

[‡]These authors contributed equally to this work.

Table S1 Effects of different coating materials and thicknesses on the electrochemical performance of Li-rich oxides.[1]

Material	Coating layer	Coating thickness (nm)	Cutoff voltage (V)	1 C (mA g^{-1})	IDC[a] (mAh g^{-1}) / ICE[b](%) / Rate (C)	DC[c] before cycling (mAh g^{-1}) / Cycle number/Retention (%) / Rate (C)	Ref.
$Li_{1.2}Mn_{0.6}Ni_{0.2}O_2$	MnO_x	20	4.8	200	298.1/90.2/1	298.1/33/88.2/1	2
$Li_{1.2}Mn_{0.567}Ni_{0.167}Co_{0.066}O_2$	MnO_2	5	4.8	200	299/88/0.025	280/50/90.3/0.1	3
$Li_{1.2}Ni_{0.18}Co_{0.04}Mn_{0.58}O_2$	MnO_2	10	4.8	200	294.4/88.8/0.1	294.4/80/87.8/0.1	4
$Li_{1.2}Ni_{0.15}Mn_{0.55}Co_{0.1}O_2$	MnO_2	-	4.8	260	226.0/83/0.1	222.6/50/94/0.2	5
$Li_{1.2}Mn_{0.54}Co_{0.13}Ni_{0.13}O_2$	MnO_2	10-50	4.8	250	239.1/83.9/0.05	181.5/100/88.2/0.5	6
$0.5Li_2MnO_3{\cdot}0.5LiNi_{0.44}Mn_{0.32}Co_{0.24}O_2$	Li_2MnO_3	3	4.8	250	292.7/88.9/0.1	231.9/100/94.1/1	7
$Li_{1.2}Mn_{0.54}Co_{0.13}Ni_{0.13}O_2$	Li_2MnO_3	10	4.8	200	292.7/88.7/0.1	231.9/100/94.1/1	8
$Li_{1.2}Mn_{0.54}Co_{0.13}Ni_{0.13}O_2$	Li_2MnO_3	5	4.8	300	291.8/76.4/0.1	197/100/76.9/1	9
$Li_{1.2}Mn_{0.54}Co_{0.13}Ni_{0.13}O_2$	$Li_4Mn_5O_{12}$	14	4.7	250	276/–/0.05	276/300/83.1/0.2	10
$Li_{1.2}Mn_{0.6}Ni_{0.2}O_2$	$Li_4Mn_5O_{12}$	5	4.8	200	267.3/96.4/0.1	232/300/80/0.5	11
$Li_{1.2}Mn_{0.54}Co_{0.13}Ni_{0.13}O_2$	V_2O_5	6	4.8	250	279.5/87.8/0.1	279.5/50/96.3/0.1	12
$Li_{1.18}Co_{0.15}Ni_{0.15}Mn_{0.52}O_2$	Li_3VO_4	5	4.8	200	276.4/87.7/0.2	126.2/100/78.6/5	13
$Li_{1.2}Mn_{0.6}Ni_{0.2}O_2$	$Li_{\delta}V_2O_5$	5	4.8	200	–/87.7/0.1	198/50/91.4/1	14
$Li_{1.17}Ni_{0.17}Co_{0.10}Mn_{0.56}O_2$	LiV_3O_8	2-5	4.6	250	252.9/93.7/0.05	231.5/100/94.3/0.05	15
$Li_{1.2}Mn_{0.54}Co_{0.13}Ni_{0.13}O_2$	LiV_3O_8	2.5	4.8	250	265.9/–/0.1	–/50/87.6/1	16
$Li_{1.2}Mn_{0.54}Co_{0.13}Ni_{0.13}O_2$	$LiVO_3$	3	4.8	250	–78.6/0.1	–/400/84/1	17
$0.4Li_{4/3}Mn_{2/3}O_2{\cdot}0.6LiNi_{1/3}Co_{1/3}Mn_{1/3}O_2$	Co_3O_4	3-5	4.8	200	279.1/84.99/0.1	197.4/80/94.1/0.5	18
$Li_{1.2}Mn_{0.534}Co_{0.133}Ni_{0.133}O_2$	Co_3O_4	15	4.8	300	271/79/0.1	253.3/80/73.3/0.2	19
$Li_{1.2}Mn_{0.54}Co_{0.13}Ni_{0.13}O_2$	$LiFePO_4$	-	4.8	250	279/94/0.1	237/100/96/1	20
$Li_{1.12}Ni_{0.18}Co_{0.07}Mn_{0.57}O_2$	$Li_3V_{1.5}Al_{0.5}(PO_4)_3$	5-10	4.8	250	279/93/0.1	228/100/96/1	21
$Li_{1.2}Mn_{0.54}Co_{0.13}Ni_{0.13}O_2$	$Li_4V_2Mn(PO_4)_4$	50	4.8	250	300/84.2/0.05	196.1/200/78.1/1	22
$Li_{1.2}Mn_{0.533}Ni_{0.267}O_2$	Li_xCoPO_4	5	4.9	250	–	–/500/80.06/1	23
$Li_{1.2}Mn_{0.54}Co_{0.13}Ni_{0.13}O_2$	$La_{1-x}Sr_xMnO_{3-y}$	5-8	4.75	260	243.5/80/0.1	202/200/94/1	24
$Li_{1.2}Mn_{0.54}Co_{0.13}Ni_{0.13}O_2$	$La_2Li_{0.5}Co_{0.5}O_4$	16	4.8	250	270.5/81.5/0.1	204.2/200/82.6/1	25
$Li_{1.2}Mn_{0.54}Co_{0.13}Ni_{0.13}O_2$	$Li_7La_3Zr_2O_{12}$	10	4.8	–	246.2/78.1/0.1	246.2/100/86.3/0.1	26
$Li_{1.2}Mn_{0.54}Co_{0.13}Ni_{0.13}O_2$	$Li_{6.25}La_3Zr_2Al_{0.25}O_{12}$	-	4.8	200	282.4/85.6/0.1	190.7/300/95.7/1	27
$Li_{1.2}Mn_{0.54}Co_{0.13}Ni_{0.13}O_2$	$Li_{0.5}La_{0.5}TiO_3$	4	4.8	–	261.6/86.4/0.12	226.5/100/–/0.12	28
$Li_{1.2}Mn_{0.54}Co_{0.13}Ni_{0.13}O_2$	Li_2MoO_4	20	4.8	250	257.31/77.79/0.1	–/100/81.85%/1	29
$Li_{1.2}Mn_{0.6}Ni_{0.2}O_2$	$LiNi_{0.5}Mn_{1.5}O_4$	2	4.8	250	261/80/0.1	236/100/99.6%/0.5	30

$Li_{1.2}Mn_{0.54}Co_{0.13}Ni_{0.13}O_2$	$LiMn_{1.4}Ni_{0.5}Mo_{0.1}O_4$	10	4.8	250	300/–/0.1	265/120/75/1	31
$Li_{1.2}Mn_{0.56}Ni_{0.16}Co_{0.08}O_2$	Al_2O_3	5	4.8	200	293.4/82.2/0.1	261.8/100/89.2/0.5	32
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	MgO	5-10	4.8	200	260.8/78.0/0.1	243.1/100/96.4/1	33
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	ZrO_2	-	4.8	–	308.5/95.4/0.1	291.5/170/68.7/0.2	34
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	TiO_2	6	4.8	300	254.6/82.4/0.2	194.9/100/79.6/1	35
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	CeO_2	2	4.8	–	282.2/68.0/0.1	255.0/300/80.4/0.5	36
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	$MgAl_2O_4$	6	4.8	250	252.0/80.1/0.1	226.1/200/78.1/1	37
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	$NiFe_2O_4$	15	4.75	260	259.8/87.2/0.1	232.5/200/91.8/1	38
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	$La_{0.9}Sr_{0.1}CoO_3$	6	4.8	250	247.0/78.6/0.05	162.5/400/80.0/1	39
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	AlF_3	5-7	4.8	300	283.3/88.3/0.1	187.1/200/84.4/1	40
$Li_{1.19}Mn_{0.57}Ni_{0.16}Co_{0.08}O_2$	AlF_3	-	4.6	200	240.6/96.3/0.1	199.0/100/85.9/0.5	41
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	MgF_2	-	4.8	–	282.6/87.2/0.05	256.0/200/80.0/0.5	42
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	FeF_3	5-15	4.8	250	280.0/80.0/0.1	190.0/100/95.0/0.5	43
$Li_{1.18}Mn_{0.52}Ni_{0.15}Co_{0.15}O_2$	BiOF	3	–	200	292.0/92.0/0.2	292.0/100/92.0/0.2	44
$Li_{1.2}Fe_{0.1}Ni_{0.15}Mn_{0.55}O_2$	$AlPO_4$	8	4.8	200	267.2/78.9/0.2	296.4/50/74.4/0.1	45
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	$FePO_4$	2-3	4.8	250	280.4/86.4/0.1	268.4/100/86.8/0.2	46
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	$LaPO_4$	4-6	4.8	200	283.4/89.3/0.1	249.8/200/83.2/1	47
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	$CePO_4$	20	4.6	200	275.3/84.6/0.05	242.5/300/86.9/0.5	48
$Li_{1.2}Mn_{0.56}Ni_{0.16}Co_{0.08}O_2$	$La(PO_3)_3$	6.9	4.8	230	286.1/–/0.05	227.4/100/94.2/0.1	49
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	PAA	10	4.8	250	244.0/80.0/0.1	220/100/97.7/0.4	50
$Li_{1.2}Mn_{0.6}Ni_{0.2}O_2$	PANI	-	4.6	–	262.0/75.8/0.1	262.0/50/93.0/0.1	51
$Li_{1.1}Mn_{0.67}Ni_{0.23}O_2$	PPy	10	4.8	200	–	200.0/200/96.0/0.1	52
$Li_{1.13}Mn_{0.463}Ni_{0.203}Co_{0.203}O_2$	FPI	15	4.8	135	248.0/73/0.2	248.0/50/94.0/0.2	53
$Li_{1.17}Mn_{0.56}Ni_{0.175}Co_{0.095}O_2$	PEDOT/PSS	5-8	4.6	–	265.0/89.8/0.05	220.0/50/67.3/1	54
$0.4Li_2MnO_3\cdot 0.6LiNi_{1/3}Co_{1/3}Mn_{1/3}O_2$	Graphene oxide	2-3	4.6	200	247.0/99.5/0.1	227.0/100/78.0/1	55
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	Graphene oxide	5	4.8	250	313.0/110.2/0.05	268.0/50/75.0/0.2	56
$Li_{1.2}Mn_{0.6}Ni_{0.2}O_2$	SiO_2	2	4.8	200	271.0/73.8/0.1	238.3/50/～100/0.2	57
$Li_{1.2}Mn_{0.6}Ni_{0.2}O_2$	B-Ni	1-3	4.8	250	248.3/86.7/0.	207.0/400/91.1/1	58

	complexes				2		
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	Potassium Prussian blue	3-4	4.8	200	281.7/85.69/0.1	229.1/100/77.2/0.5	59
$Li_{1.17}Ni_{0.20}Co_{0.05}Mn_{0.58}O_2$	Mn-MOFs	2-3	4.8	300	323.8/91.1/0.1	323.8/100/87.7/0.1	60
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	Al_2O_3/AlF_3	-	4.8	250	240.0/83.8/0.05	147.0/200/84.0/1	61
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	CaF_2/Graphite	100	4.8	—	269.6/71.5/0.1	215.2/150/90.0/0.5	62
$Li_{1.2}Mn_{0.54}Ni_{0.13}Co_{0.13}O_2$	Al_2O_3/PPy	-	4.8	250	281.4/80.4/0.1	230.0/100/90.7/1	63
$Li_{1.2}Mn_{0.585}Ni_{0.185}Fe_{0.03}O_2$	$AlPO_4/Li_3PO_4$	4	4.8	200	260.7/85.0/0.1	233.5/200/74.8/0.2	64

[a]IDC represents initial discharge capacity; [b]ICE represents initial Coulombic efficiency; [c]DC represents discharge capacity.

Table S2 Effects of different coating materials and thicknesses on electrochemical performance in LCO oxides.

Material	Coating layer	Coating thickness (nm)	1 C (mA g^{-1})	Cutoff voltage (V)	Cyclability (capacity retention-cycles-rate)	Rate capability (mAh g^{-1} rates)	Ref.
LCO	Al_2O_3	20	-	4.5	98.6%-200-2C	163-2C	[65]
	$LiMgPO_4$	5-10	-	4.65	71.76%-200-1C	120.8-5C	[66]
	$Mg_3(PO_4)_2$	15	274	4.6	79%-1000-1C	168-5C	[67]
	$LiCoPO_4$	7	180	4.5	89.5%-50-1C	189-1C	[68]
	Li_3PO_4	30-40	274	4.6	96.7%-100-0.1C	133.7-5C	[69]
	Li_3PO_4 and Mg^{2+} Y^{3+} doping	10	274	4.6	79.2-300-0.5C	109.6-10C	[70]
	$LiZr_2(PO_4)_3$	-	274	4.55	72.2%-100-0.5C	90-5C	[71]
	$AlPO_4$-5 zeolite	10	-	4.6	90%-200-1C	108-10C	[72]
	$Li_{1.5}Al_{0.5}Ti_{1.5}(PO_4)_3$	22	274		97.6%-100-0.5C	150-5C	[73]
	$LiAlO_2$	3	270	4.7	85.8%-300-1C	128-10 C	[74]
	TiO_2	4.2	-	4.6	92%-50-0.5C	190.9-3C	[75]
	La-Y-O composite	5	140	4.6	94.4%-300-1C	145.3-20C	[76]
	LiF	1	-	4.6	92%-1000-3C	141-10C	[77]
	LiF	2.25	274	4.6	80.5-700-0.5C	124.9-3 C	[78]
	Li_3PO_4/CoP	15	274	4.6	80.9%-200-0.5C	74.8-10 C	[79]
	Li_2TiO_3	10	220	4.6	80.5%-400-1C	112-10 C	[80]
	Co_3O_4@$Li_{6.4}La_3Zr_{1.4}Ta_{0.6}O_{12}$	10-15	160	4.2	70.4%-300-2C	110-5C	[81]
	Li_2ZrF_6	6-13	-	4.5	80.5%-1500-70 mA g^{-1}	96.2-700 mA g^{-1}	[82]
	LiF&$Li_xB_yO_z$	2	200	4.6	81.7%-300-2C	151.3-5C	[83]
	La_2O_3-ZrO_2	9	140	4.5	90.3%-200-1C	165.6-10C	[84]
	$Li_xPO_yF_z$	5-10	-	4.6	82.9%-500-1C	120.9-5C	[85]
	Mg^{2+}, F^- doping and PO_4^{3-} coating	2-5	274	4.7	81%-200-1C	113.5-10C	[86]

Table S3 Comparative analysis of W, Zr and Nb element doping modifications in LCO.

Doping Element	Key Mechanisms	Benefits	Challenges
Tungsten (W)	• Improves structural stability by increasing interlayer spacing and reducing particle size. • Enhances Li^+ diffusion kinetics.	• High electrochemical performance. • Improved cycle life.	• Potential for WO_3 impacting Li^+ diffusion. • Precise control of W doping concentration is crucial.
Zirconium (Zr)	• Suppresses O oxidation and Co reduction. • Enhances crystal structural stability. • Promotes Li^+ diffusion.	• Improved rate capability. • Enhanced thermal stability.	• May require careful optimization of Zr doping levels to avoid detrimental effects.
Niobium (Nb)	• Enhances structural stability through strong Nb-O bonds. • Lowers charge transfer resistance. • Promotes Li^+ diffusion. • Improves electronic conductivity. • Stabilizes CEI.	• Enhanced rate capability. • Improved cycling stability.	• Potential for Nb to induce phase transformations if not carefully controlled.

Table S4 Effects of different coating materials and thicknesses on electrochemical performance in Ni-rich oxides.[87]

Material	Coating layer	Coating thickness (nm)	1 C (mA g^{-1})	Cutoff voltage (V)	Rate performance (RT)[a)] current-capacity / mAh g^{-1}	Cycling performance (RT) current-cycles-capacity retention	Ref.
SC[b)] $LiNi_{0.6}Co_{0.1}Mn_{0.3}O_2$	$LiBO_2$ with B doping	10-30	180	4.5	5C-138 (RT); 1C-195.8 (45°C)	5C-1000-70.75%	88
SC $LiNi_{0.83}Co_{0.11}Mn_{0.06}O_2$	Li_3BO_3 with Zr doping	5	–	4.6	-	1C-200–83.9%	89
SC NCM622[c)]	$LiBO_2$-B_2O_3	15	175	4.5/4.7	1C-160.8 (4.5 V); 1C-167.4 (4.7 V)	1C-200-88.5% (4.5 V); 1C-200-80% (4.7 V)	90
NCM811[d)]	$LiAlO_2$	3	–	4.5	5 C-165	5C-200-64.5%-	91
NCM622	$LiAlO_2$&GO	5-7	200	4.5	10C-100.4	1C-200-88%;	92
NCM622	N-doped $LiAlO_2$	2	210	4.5	10C-154	1C-450-87.0%	93
NCM622	$LiAlO_2$	1	250	4.5/4.7	3C-142 (4.5V); 3C-115 (4.7V)	0.2C-350-75.7% (4.5 V)	94
NCM811	Li_5AlO_4&$LiAlO_2$	23	280	4.5	10-137.2	1C-50-83.9%	95
NCM622	$LiAlO_2$/LiF&AlF_3	6	–	4.5	10C-155.3	1C-200-93.01%	96
SC NCM622	Li–Si–O	8	180	4.5	1C-183.9	1C-100-90.6%	97
NCM622	$LiAlO_2$/$Si_{1-x}AlxO_2$	7	–	4.5	10C-153.4	5C-500-78.5%	98
NCM811	β-$LiAlSiO_4$	15	180	4.5	-	1C-100-83.4% (25°C); 1C-100-86.5% (55°C)	99
NMC622	Li_2TiO_3&PO_4^{3-} doping	5	–	4.5	5C-167.2; 10C-157.8	1C-800-77.4%	100
NCM622	TiO_x and $Li_xTi_yO_z$	<5	180	4.6	–	1C-100-67%	101
NCM811	Li_2MnO_3	6.6-14.1	200	4.6	–	1C-100-90.6%	102
NCM622	Li_8ZrO_6 and Li_2ZrO_3	12.5	175	4.5	5C-176.5	1C-100-91.1%	103
NMC622	Li_xZr_yO	2.2	180	4.5	5C-91; 7C-50	3C-100-68%	104
NCM622	ZrO_2	5	180	4.5	10C-112.7	0.5C-100-82.5%; 2C-100-79%	105
NCM622	$Li_{6.1}La_3Al_{0.3}Zr_2O_{12}$	6-12	200	4.5	2C-165.5	2C-100-84.6%; 10C-100-54.7%	106
NCM811	Nb doping & $LiNbO_3$	7	180	4.5	-	1C-200-80.5%	107
NCM811	Li_2MoO_4	3-4	200	4.5	-	1C-100-98.1% (4.5V, 55°C)	108
NCM811	Li_2SnO_3	4-5	250	4.5	5C-150	0.2C-100-99%	109
NCM622	Li_2SnO_3&Sn^{4+} gradient doping	5	195	4.5	5C-136.2	1C-100-88.31%	110
NCM811	$Li_x WO_y$	5	210	4.5	5C-165.5 (RT)	1C-100-88.4%; 1C-100-49.6%	111
NCM811	Li_3PO_4	10	200	4.5	10C-148.8	1C-100-88.4%	112
NCM811	Li_3PO_4	13.6	–	4.8	1C-90	1C-300-80%	113

NCM811	$Li_n(TM)_mPO_4$ (TM = Ni, Co, and Mn)	4-6	200	4.5	10C-140 (25°C)	1C-300-80.36% (25°C); 1C-200-61.22% (55°C)	114
$LiNi_{0.87}Co_{0.1}Al_{0.03}O_2$	Li_2O-BPO_4	10	200	4.7	-	1C-100-76.2%	115
NCM622	$Li_{1.4}Al_{0.4}Ti_{1.6}(PO_4)_3$	-	190	4.5	10C-152.6	1C-100-90.9%	116
SC $LiNi_{0.6}Co_{0.1}Mn_{0.3}O_2$	$Li_{1.5}Al_{0.5}Ge_{1.5}P_3O_{12}$	2	–	4.6	10C-112.4 (4.4V, 55°C)	5C-500-81.8(4.6V, RT)	117
SC-NCM811	$Li_{1.5}Al_{0.5}Ge_{1.5}(PO_4)_3$	15	–	4.5	5C-175	0.2C-100-94.5%; 1C-400-83.1%	118
NCM811	$Li_{1.5}Al_{0.5}Zr_{1.5}(PO_4)_3$	4	200	4.5	–	1C-200-84.8%	119
$LiNi_{0.90}Co_{0.05}Mn_{0.05}O_2$	Li_4TeO_5	4	200	4.5	5C-184.8	1C-200-82.12%	120
NCM811	TiO_2	-	200	4.5	10C-135	1C-200-88.5%	121
$LiNi_{0.83}Co_{0.11}Mn_{0.06}O_2$	Li_2WO_4	5-10	200	4.5	10C-172	1C-150-98.1%	122

a) RT (Room Temperature); b) SC (Single Crystal); c) NCM622 ($LiNi_{0.6}Mn_{0.2}Co_{0.2}O_2$); d) NCM811 ($LiNi_{0.8}Mn_{0.1}Co_{0.1}O_2$).

References

1. Q. Wang, L. Liu, H. Li, G. Yang, A. N. Alodhayb and J. Ma, *J. Mater. Sci. Technol.*, 2025, **207**, 274-294.
2. F. Wu, N. Li, Y. Su, H. Lu, L. Zhang, R. An, Z. Wang, L. Bao and S. Chen, *J. Mater. Chem.*, 2012, **22**, 1489-1497.
3. S. Guo, H. Yu, P. Liu, X. Liu, D. Li, M. Chen, M. Ishida and H. Zhou, *J. Mater. Chem. A*, 2014, **2**, 4422-4428.
4. Y. Jin, Y. Xu, X. Sun, L. Xiong and S. Mao, *Appl. Surf. Sci.*, 2016, **384**, 125-134.
5. D. Yu, P. Zhu, C. Hu, X. Huang, K. Tang and J. Wang, *J. Phys. Chem. Lett.*, 2023, **14**, 10959-10966.
6. Z. Li, P. Yang, Z. Zheng, Q. Pan, Y. Liu, Y. Li and J. Xuan, *Micromachines*, 2021, **12**, 1410.
7. S. Kim, W. Cho, X. Zhang, Y. Oshima and J. W. Choi, *Nat. Commun.*, 2016, **7**, 13598.
8. Y. Xie, S. Chen, W. Yang, H. Zou, Z. Lin and J. zhou, *J. Alloys Compd.*, 2019, **772**, 230-239.
9. Y. Li, J. Zhang, R. Hong and N. Liu, *Ind. Eng. Chem. Res.*, 2022, **61**, 1133-1139.
10. X. D. Zhang, J. L. Shi, J. Y. Liang, Y. X. Yin, J. N. Zhang, X. Q. Yu and Y. G. Guo, *Adv. Mater.*, 2018, **30**, 1801751.
11. W. Zhu, Z. Tai, C. Shu, S. Chong, S. Guo, L. Ji, Y. Chen and Y. Liu, *J. Mater. Chem. A*, 2020, **8**, 7991-8001.
12. H. He, L. Zan and Y. Zhang, *J. Alloys Compd.*, 2016, **680**, 95-104.
13. Q. Fu, F. Du, X. Bian, Y. Wang, X. Yan, Y. Zhang, K. Zhu, G. Chen, C. Wang and Y. Wei, *J. Mater. Chem. A*, 2014, **2**, 7555-7562.
14. S.-X. Liao, C.-H. Shen, Y.-J. Zhong, W.-H. Yan, X.-X. Shi, S.-S. Pei, X. Guo, B.-H. Zhong, X.-L. Wang and H. Liu, *RSC Adv.*, 2014, **4**, 56273-56278.
15. H. Meng, L. Li, J. Liu, X. Han, W. Zhang, X. Liu and Q. Xu, *J. Alloys Compd.*, 2017, **690**, 256-266.
16. C.-S. Xu, H.-T. Yu, C.-F. Guo, Y. Xie, N. Ren, T.-F. Yi and G.-X. Zhang, *Ionics*, 2019, **25**, 4567-4576.
17. Y. Qu, W. Tang, H. Liu, C. Li, L. Zou, Z. Chen, Z. Yang, J. Su and W. Zhang, *Ind. Eng. Chem. Res.*, 2023, **62**, 10467-10476.
18. Y. Jin, Y. Xu, L. Xiong, X. Sun, L. Li and L. Li, *Solid State Ionics*, 2017, **310**, 62-70.
19. Y. Li, H. Huang, J. Yu, Y. Xia, C. Liang, Y. Gan, J. Zhang and W. Zhang, *J. Alloys Compd.*, 2019, **783**, 349-356.
20. B. Seteni, N. Rapulenyane, J. C. Ngila, S. Mpelane and H. Luo, *J. Power Sources*, 2017, **353**, 210-220.
21. K. Shi, K. Liang, J. Zheng and Y. Qiu, *Appl. Surf. Sci.*, 2019, **483**, 1-9.
22. S.-q. Yang, P.-b. Wang, H.-x. Wei, L.-b. Tang, X.-h. Zhang, Z.-j. He, Y.-j. Li, H. Tong and J.-c. Zheng, *Nano Energy*, 2019, **63**, 103889.
23. G. Zhou, D. Zhang, Y. Zhang, W. Wang, T. Uchiyama, C. Zhang, Y. Uchimoto and W. Wei, *ACS Appl. Mater. Interfaces*, 2023, **15**, 19055-19065.
24. S. Hu, Y. Li, Y. Chen, J. Peng, T. Zhou, W. K. Pang, C. Didier, V. K. Peterson, H. Wang, Q. Li and Z. Guo, *Adv. Energy Mater.*, 2019, **9**, 1901795.
25. X. Deng, M. Li, Z. Ma and X. Wang, *Nano Res.*, 2023, **16**, 10634-10643.
26. C. Shen, Y. Liu, W. Li, X. Liu, J. Xie, J. Jiang, Y. Jiang, B. Zhao and J. Zhang, *J. Colloid Interface Sci.*, 2022, **615**, 1-9.
27. Y. Wei, J. Cheng, D. Li, Y. Li, Z. Zeng, H. Liu, H. Zhang, F. Ji, X. Geng, J. Lu and L. Ci, *Adv. Funct. Mater.*, 2023, **33**, 2214775.
28. H. Zhang, T. Yang, Y. Han, D. Song, X. Shi, L. Zhang and L. Bie, *J. Power Sources*, 2017, **364**, 272-279.
29. S. Zhang, Y. Ye, Z. Chen, Q. Lai, T. Liu, Q. Wang and S. Yuan, *Materials*, 2023, **16**, 5655.
30. X. Ding, L.-N. Xiao, Y.-X. Li, Z.-F. Tang, J.-W. Wan, Z.-Y. Wen and C.-H. Chen, *J. Power Sources*,

2018, **390**, 13-19.
31. F. Wu, N. Li, Y. Su, H. Shou, L. Bao, W. Yang, L. Zhang, R. An and S. Chen, *Adv. Mater.*, 2013, **25**, 3722-3726.
32. T. Wang, Z. Huang, M. Cai and S. Shi, *Mater. Lett.*, 2020, **279**, 128479.
33. S. J. Shi, J. P. Tu, Y. Y. Tang, X. Y. Liu, Y. Q. Zhang, X. L. Wang and C. D. Gu, *Electrochim. Acta*, 2013, **88**, 671-679.
34. S. Dong, X. He, Q. Xu, L. Ma, C. Hai and Y. Zhou, *Langmuir*, 2023, **39**, 7723-7730.
35. X. Ran, J. Tao, Z. Chen, Z. Yan, Y. Yang, J. Li, Y. Lin and Z. Huang, *Electrochim. Acta*, 2020, **353**, 135959.
36. B. Wang, L. Lu, Y. Hu, L. Chen and H. Jiang, *New J. Chem.*, 2023, **47**, 2173-2176.
37. M. Li, X. Deng, Z. Wang, K. Liu, Z. Ma, J. Wang and X. Wang, *Appl. Surf. Sci.*, 2022, **592**, 153328.
38. J. Peng, Y. Li, Z. Chen, G. Liang, S. Hu, T. Zhou, F. Zheng, Q. Pan, H. Wang, Q. Li, J. Liu and Z. Guo, *ACS Nano*, 2021, **15**, 11607-11618.
39. Y. Lei, Y. Elias, Y. Han, D. Xiao, J. Lu, J. Ni, Y. Zhang, C. Zhang, D. Aurbach and Q. Xiao, *ACS Appl. Mater. Interfaces*, 2022, **14**, 49709-49718.
40. J. Zhang, D. Zhang, Z. Wang, F. Zheng, R. Zhong and R. Hong, *J. Mater. Sci.*, 2023, **58**, 4525-4540.
41. Y.-K. Sun, M.-J. Lee, C. S. Yoon, J. Hassoun, K. Amine and B. Scrosati, *Adv. Mater.*, 2012, **24**, 1192-1196.
42. K. Yang, B. Niu, Y. Liu, J. Zhong and J. Li, *Int. J. Electrochem. Sci.*, 2019, **14**, 3139-3152.
43. C.-D. Li, J. Xu, J.-S. Xia, W. Liu, X. Xiong and Z.-A. Zheng, *Solid State Ionics*, 2016, **292**, 75-82.
44. X. Bian, Q. Fu, Q. Pang, Y. Gao, Y. Wei, B. Zou, F. Du and G. Chen, *ACS Appl. Mater. Interfaces*, 2016, **8**, 3308-3318.
45. F. Wu, X. Zhang, T. Zhao, L. Li, M. Xie and R. Chen, *ACS Appl. Mater. Interfaces*, 2015, **7**, 3773-3781.
46. J. He, Z. Bai, X. Huang, Z. Zhang, L. Lu and J. Li, *J. Solid State Electrochem.*, 2023, **27**, 171-182.
47. X. Zhang, X. Xie, R. Yu, J. Zhou, Y. Huang, S. Cao, Y. Wang, K. Tang, C. Wu and X. Wang, *ACS Appl. Energy Mater.*, 2019, **2**, 3532-3541.
48. F. Meng, H. Guo, Z. Wang, X. Li and Y. Deng, *Ionics*, 2020, **26**, 2117-2127.
49. M. Zhou, J. Zhao, X. Wang, J. Shen, W. Tang, Y. Deng and R. Liu, *Chin. Chem. Lett.*, 2023, **34**, 107793.
50. J. Yang, P. Li, F. Zhong, X. Feng, W. Chen, X. Ai, H. Yang, D. Xia and Y. Cao, *Adv. Energy Mater.*, 2020, **10**, 1904264.
51. L. Sun, X. Yi, C. Shi, X. Ren, Y. Gao, Y. Li and P. Zhang, *Int. J. Electrochem. Sci.*, 2017, **12**, 4756-4767.
52. P. Vahdatkhah, S. Khatiboleslam Sadrnezhaad and O. Voznyy, *J. Electroanal. Chem.*, 2022, **914**, 116317.
53. H. Q. Pham, G. Kim, H. M. Jung and S.-W. Song, *Adv. Funct. Mater.*, 2018, **28**, 1704690.
54. J. Lee and W. Choi, *J. Electrochem. Soc.*, 2015, **162**, A743.
55. P. Oh, M. Ko, S. Myeong, Y. Kim and J. Cho, *Adv. Energy Mater.*, 2014, **4**, 1400631.
56. B. Song, M. O. Lai, Z. Liu, H. Liu and L. Lu, *J. Mater. Chem. A*, 2013, **1**, 9954-9965.
57. Y. Zhao, Z. Lv, T. Xu and J. Li, *J. Alloys Compd.*, 2017, **715**, 105-111.
58. W. Guo, Y. Zhang, L. Lin, Y. Liu, M. Fan, G. Gao, S. Wang, B. Sa, J. Lin, Q. Luo, B. Qu, L. Wang, J. Shi, Q. Xie and D.-L. Peng, *Small*, 2023, **19**, 2300175.
59. Z. Xu, L. Ci, Y. Yuan, X. Nie, J. Li, J. Cheng, Q. Sun, Y. Zhang, G. Han, G. Min and J. Lu, *Nano Energy*, 2020, **75**, 104942.
60. Q.-Q. Qiao, G.-R. Li, Y.-L. Wang and X.-P. Gao, *J. Mater. Chem. A*, 2016, **4**, 4440-4447.
61. H. Yu, Y. Gao and X. Liang, *J. Electrochem. Soc.*, 2019, **166**, A2021.
62. M. Li, H. Wang, L. Zhao, F. Zhang and D. He, *J. Solid State Chem.*, 2019, **272**, 38-46.

63. Y. Bei, Y. Zhang, Y. Li, Y. Song, L. Liu, J. Ma and J. Liu, *J. Alloys Compd.*, 2022, **928**, 167140.
64. Y. Wang, W. Yu, L. Zhao, A. Wu, A. Li, X. Dong and H. Huang, *Electrochim. Acta*, 2023, **462**, 142664.
65. F. Zhao, Y. Tang, J. Wang, J. Tian, H. Ge and B. Wang, *Electrochim. Acta*, 2015, **174**, 384-390.
66. J. Zhong, W. Zhao, M. Zhang, Z.-W. Yin, Z. Zhuo, S. Zhang, M. Zhang, F. Pan, B. Zhang and Z. Lin, *Small*, 2023, **19**, 2300802.
67. S.-D. Zhang, M.-Y. Qi, S. Guo, Y.-G. Sun, T.-T. Wu, H.-S. Zhang, S.-Q. Lu, F. Meng, Q. Zhang, L. Gu, Z. Zhao, Z. Peng, H. Jin, H. Ji, Y.-R. Lu, T.-S. Chan, R. Duan and A.-M. Cao, *Energy Storage Mater.*, 2023, **57**, 289-298.
68. H. Lee, M. G. Kim and J. Cho, *Electrochemistry Communications*, 2007, **9**, 149-154.
69. Y. Li, M. Zan, P. Chen, Y. Huang, X. Xu, C. Zhang, Z. Cai, X. Yu and H. Li, *ACS Appl. Mater. Interfaces*, 2023, **15**, 51262-51273.
70. W. Sun, J. Yang, W. Shi, H. Zheng, Y. Cheng and X. Xu, *ACS Appl. Energy Mater.*, 2024, **7**, 6585-6597.
71. X. Zhang, B. Peng, L. Zhao, G. Wan, F. Wang, S. Zeng, H. Zhang, J. Ding and G. Zhang, *ACS Appl. Mater. Interfaces*, 2022, **14**, 16204-16213.
72. Z. Lin, Y. Ying, Z. Xu, G. Chen, X. Gong, Z. Wang, D. Guan, L. Zhao, M. Yang, K. Fan, T. Liu, H. Li, H. Zhang, H. Li, X. Zhang, Y. Zhu, Z. Lu, Z. Shao, P. Hou and H. Huang, *Energy Environ. Sci.*, 2025, **18**, 334-346.
73. Y. Li, H. Pan, L. Gan, M. Zan, Y. Huang, B. Wang, B. Deng, T. Wang, X. Yu, B. Wang, H. Li and X. Huang, *Energy Storage Mater.*, 2024, **67**, 103290.
74. J. Yao, Y. Li, T. Xiong, Y. Fan, L. Zhao, X. Cheng, Y. Tian, L. Li, Y. Li and W. Zhang, *Angew. Chem. Int. Ed.*, 2024, **136**, e202407898.
75. L. Xu, S. Cheng, H. Niu and Z. Wang, *Electrochim. Acta*, 2024, **478**, 143862.
76. Y. Zhao, W. Zeng, S. Su, J. Wu, J. Ke, Y. Sun and X. Lin, *ACS Appl. Mater. Interfaces*, 2024, **16**, 60448-60457.
77. Z. Bi, Z. Yi, L. Zhang, G. Wang, A. Zhang, S. Liao, Q. Zhao, Z. Peng, L. Song, Y. Wang, Z. Zhao, S. Wei, W. Zhao, X. Shi, M. Li, N. Ta, J. Mi, S. Li, P. Das, Y. Cui, C. Chen, F. Pan and Z.-S. Wu, *Energy Environ. Sci.*, 2024, **17**, 2765-2775.
78. Q. Ding, Z. Jiang, K. Chen, H. Li, J. Shi, X. Ai and D. Xia, *Carbon Energy*, 2024, e602.
79. Z. Liu, M. Han, S. Zhang, H. Li, X. Wu, Z. Fu, H. Zhang, G. Wang and Y. Zhang, *Adv. Mater.*, 2024, **36**, 2404188.
80. L. Gao, F. Li, G. Zeng, X. Jin, Z. Li and C. Wang, *Adv. Funct. Mater.*, **n/a**, 2416338.
81. Y. Leng, S. Dong, Y. Sun, L. Ma, J. Li, H. Feng, C. Hai and Y. Zhou, *Langmuir*, 2024, **40**, 6295-6303.
82. X. Zhou, C.-Y. Chang, D. Yu, K. Zhang, Z. Li, S.-K. Jiang, Y. Zhu, Y. Xia, B. J. Hwang and Y. Wang, *Nat. Commun.*, 2025, **16**, 112.
83. J.-K. Liu, G.-D. Bai, Z.-W. Yin, L. Deng, W.-J. Sun, Z. Wang, G.-Y. Bai, Y.-X. Luo, Z.-L. Jin, Y. Zhou, J.-T. Li and S.-G. Sun, *Chem. Commun.*, 2025, DOI: 10.1039/D4CC05449K.
84. Y. Zhao, W. Zeng, S. Qin, S. Su, J. Wu, J. Ke, Y. Sun, K. Liu and X. Lin, *J. Alloys Compd.*, 2024, **989**, 174377.
85. Z. Meng, H. Wang, Y. Wang, H. Zhang, Q. Xiang, Y. Zheng, H. Yuan, J. Huang, T. Fan and Y. Min, *J. Alloys Compd.*, 2024, **1005**, 176087.
86. X. Li, J. Lyu, F. Du, K. Wang, M. Tian, X. Zhang, S.-W. Yang, Z. Hao, J. Zheng and G. Q. Xu, *Nano Energy*, 2025, **133**, 110496.
87. Y. Shao, J. Xu, A. Amardeep, Y. Xia, X. Meng, J. Liu and S. Liao, *Small Methods*, 2024, **8**, e2400256.
88. S. Gao, B. Shi, J. Liu, L. Wang, C. Zhou, C. Guo, J. Zhang and W. Li, *ACS Sustainable Chem. Eng.*, 2021, **9**, 5322-5333.
89. J. Shen, B. Zhang, X. He, B. Xiao, Z. Xiao, X. Li and X. Ou, *J. Colloid Interface Sci.*, 2023, **629**,

388-398.
90. W. Wang, L. Wu, Z. Li, K. Huang, Z. Chen, C. Lv, H. Dou and X. Zhang, *Chemelectrochem*, 2021, **8**, 2014-2021.
91. G. Ding, F. Yan, Z. Zhu, J. Chen, Z. Hu, G. Li, J. Liu, L. Gao, W. Jiang and F. sun, *Ceram. Int.*, 2022, **48**, 5714-5723.
92. Y. Li, C. Yu, C. Xu, W. Liu, M. Dang, H. Jin, W. Li and J. Zhang, *Ionics*, 2021, **27**, 3239-3249.
93. Q. Li, G. Yang, Y. Chu, C. Tan, Q. Pan, F. Zheng, Y. Li, S. Hu, Y. Huang and H. Wang, *Electrochim. Acta*, 2021, **372**, 137882.
94. W. Liu, X. Li, D. Xiong, Y. Hao, J. Li, H. Kou, B. Yan, D. Li, S. Lu, A. Koo, K. Adair and X. Sun, *Nano Energy*, 2018, **44**, 111-120.
95. J. Wu, X. Tan, J. Zhang, L. Guo, Y. Jiang, S. Liu, T. Zhao, Y. Liu, J. Ren, H. Wang, X. Kang and W. Chu, *Energy Technol.*, 2019, **7**, 209-215.
96. H. Wang, Y. Chu, Q. Pan, G. Yang, A. Lai, Z. Liu, F. Zheng, S. Hu, Y. Huang and Q. Li, *Electrochim. Acta*, 2021, **366**, 137476.
97. G. Li, L. You, Y. Wen, C. Zhang, B. Huang, B. Chu, J.-H. Wu, T. Huang and A. Yu, *ACS Appl. Mater. Interfaces*, 2021, **13**, 10952-10963.
98. H. Wang, Y. Chu, Q. Pan, C. Tan, Y. Shi, Y. Li, S. Hu, F. Zheng, Y. Huang and Q. Li, *ACS Sustainable Chem. Eng.*, 2021, **9**, 8951-8961.
99. X. Zhang, G. Hu, Y. Cao, Z. Peng, W. Wang, C. Tan, Y. Wang and K. Du, *Electrochim. Acta*, 2021, **383**, 138297.
100. G. Yang, K. Pan, F. Lai, Z. Wang, Y. Chu, S. Yang, J. Han, H. Wang, X. Zhang and Q. Li, *Chem. Eng. J.*, 2021, **421**, 129964.
101. Z. Ahaliabadeh, V. Miikkulainen, M. Mäntymäki, S. Mousavihashemi, J. Lahtinen, Y. Lide, H. Jiang, K. Mizohata, T. Kankaanpää and T. Kallio, *ACS Appl. Mater. Interfaces*, 2021, **13**, 42773-42790.
102. Y. Xie, F. Guo and Y. Zhang, *Appl. Surf. Sci.*, 2022, **595**, 153479.
103. Z. Shao, Y. Liu, Y. Chen, Z. Yu and J. Li, *Ionics*, 2020, **26**, 1173-1180.
104. Y. Liu, X. Wang, S. K. Ghosh, M. Zou, H. Zhou, X. Xiao and X. Meng, *Dalton Trans.*, 2022, **51**, 2737-2749.
105. L. Yao, F. Liang, J. Jin, B. V. R. Chowdari, J. Yang and Z. Wen, *Chem. Eng. J.*, 2020, **389**, 124403.
106. Z. Cheng, F. Lv, N. Xu, Y. Liu, H. Xie, M. Wu, Y. Ma, Y. Zhang and L. Chen, *Appl. Surf. Sci.*, 2020, **524**, 146556.
107. F. Zhao, X. Li, Y. Yan, M. Su, L. Liang, P. Nie, L. Hou, L. Chang and C. Yuan, *J. Power Sources*, 2022, **524**, 231035.
108. L. Musuvadhi Babulal, C. C. Yang, S.-h. Wu, W.-C. Chien, R. Jose and S. Jessie Lue, *Chem. Eng. J.*, 2021, **413**, 127150.
109. W. Liu, X. Li, Y. Hao, H. Maleki Kheimeh Sari, J. Qin, W. Xiao, X. Wang, H. Yang, W. Li, L. Kou, Z. Tian, L. Shao, C. Zhang and J. Zhang, *ACS Appl. Energy Mater.*, 2020, **3**, 3242-3252.
110. L. Wang, J. Liang, X. Zhang, S. Li, T. Wang, F. Ma, J. Han, Y. Huang and Q. Li, *Nanoscale*, 2021, **13**, 4670-4677.
111. Z. Zhu, A. Gao, Y. Liang, F. Yi, T. Meng, J. Ling, J. Hao and D. Shu, *ACS Sustainable Chem. Eng.*, 2022, **10**, 50-60.
112. P. Zou, Z. Lin, M. Fan, F. Wang, Y. Liu and X. Xiong, *Appl. Surf. Sci.*, 2020, **504**, 144506.
113. H. Gupta, S. K. Singh, N. Srivastava, D. Meghnani, R. K. Tiwari, R. Mishra, A. Patel, A. Tiwari, A. L. Saroj and R. K. Singh, *ACS Appl. Energy Mater.*, 2021, **4**, 13878-13889.
114. Y. Li, L. Cui, C. Tan, X. Fan, Q. Pan, Y. Chu, S. Hu, F. Zheng, H. Wang and Q. Li, *Chem. Eng. J.*, 2022, **430**, 132985.
115. S. Jamil, Q. Ran, L. Yang, Y. Huang, S. Cao, X. Yang and X. Wang, *Chem. Eng. J.*, 2021, **407**, 126442.
116. Y. Wang, B.-N. Liu, G. Zhou, K.-H. Nie, J.-N. Zhang, X.-Q. Yu and H. Li, *Chin. Phys. B*, 2019, **28**,

068202.
117. Y.-D. Huang, H.-X. Wei, P.-Y. Li, Y.-H. Luo, Q. Wen, D.-H. Le, Z.-J. He, H.-Y. Wang, Y.-G. Tang, C. Yan, J. Mao, K.-H. Dai, X.-H. Zhang and J.-C. Zheng, *J. Energy Chem.*, 2022, **75**, 301-309.
118. M. Liu, J. Zhou, T. Cheng, Z. Feng, Y. Qin and B. Guo, *ACS Appl. Energy Mater.*, 2022, **5**, 9181-9188.
119. Z. Wang, H. Zhong and G. Song, *J. Alloys Compd.*, 2020, **849**, 156467.
120. R. Wang, Y. Zhang, Z. Li, L. Wu, J. Chen, X. Liu, H. Hu, H. Ding, S. Cao, Q. Wei and X. Wang, *J. Energy Chem.*, 2025, **101**, 630-640.
121. Q. Fan, Z. Chen, W. Ma and Z. Shi, *Appl. Mater. Today*, 2025, **42**, 102559.
122. C. Li, J. Liu, Y. Su, J. Dong, H. Zhang, M. Wang, Y. Guan, K. Yan, N. Liu, Y. Lu, N. Li, Y. Su, F. Wu and L. Chen, *Energy Storage Mater.*, 2025, **74**, 103893.