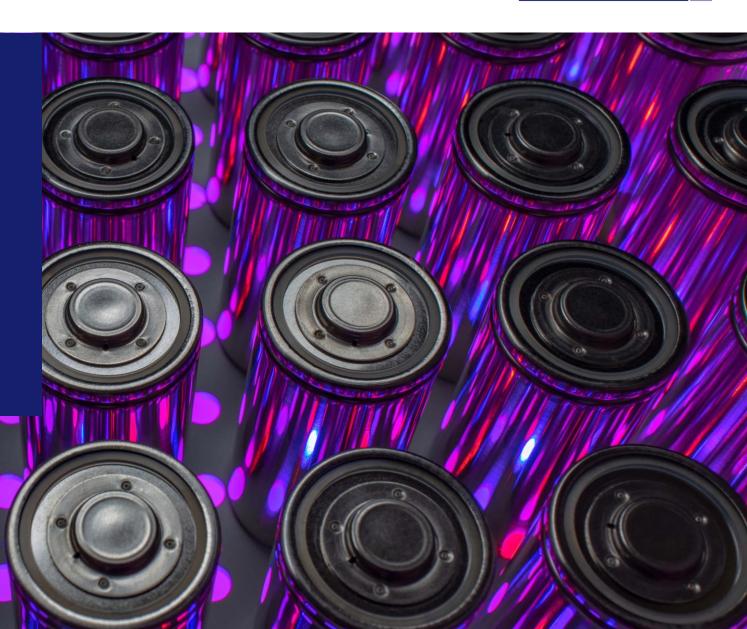


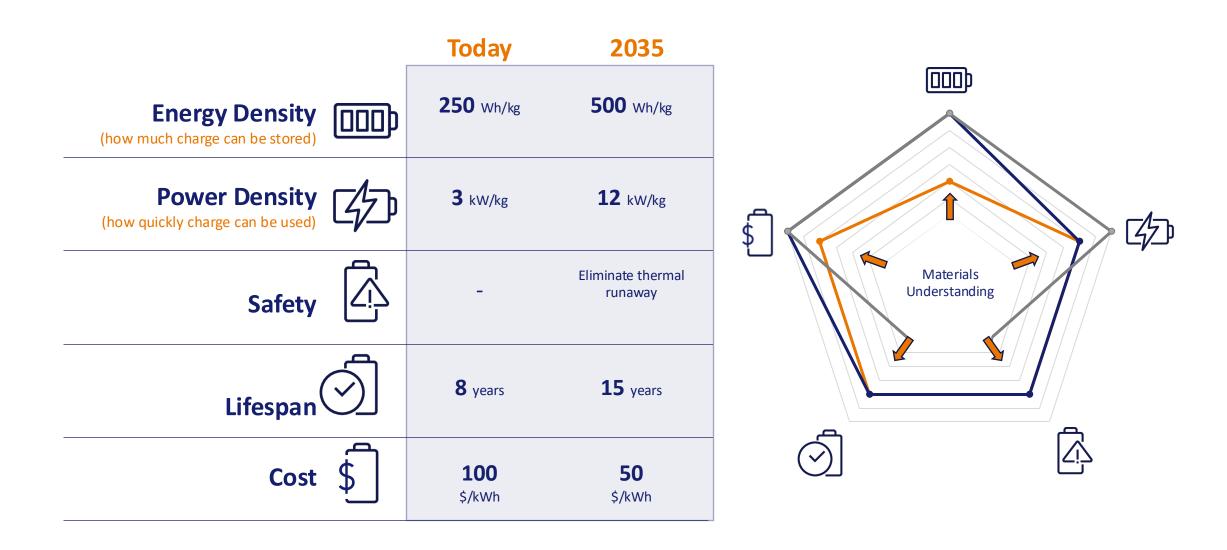
Solutions for Battery Materials Analysis

Enabling your battery development through materials understanding



Desirable battery properties





Enabling battery development through materials understanding





Solutions for Materials Understanding



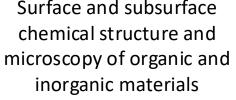


Analysis of structure, chemical and physiochemical properties in liquids and solids



3D characterisation of surface nanoscale structure, mechanical and electrical properties







Nano scale elemental and structural characterisation and classification of key materials using SEM

Correlative microscopy solutions include Raman Imaging and Scanning Electron Microscopy (RISE)



									_		
			Electroly	te Characterisat	ion	Techniques	Prop	erty	_		
		\cap	Concentr	ation and purity		NMR		\$ 6	0		
			Ionic con	c conductivity		NMR	(J)				
		V	Breakdov	wn & degradatio	n	NMR		Ø \$			
			Impact or	n electrode SEI	formation	AFM	Ó		_		
				¢ €			↓ [↓]				
				ANODE	ELECTROLY						
Anode Characterisation	Techniques	Prope	rty	888	J:** -	vi, coo		Cathode Cha	racterisation	Techniques	Property
Lithium content	SEM, Raman			888	* * *	*		Particle size		EDS	□ ↓ ⑦
Interfacial roughness	AFM	(¢)	Ā		***	* * • •	+	Chemical cor	nsistency	EDS, Raman	☞ 4 ⊅ ⊙]
Carbon material quality	Raman	000) (\$Þ ⊙]	888	* ~ -*	*		Powder purit	ý	EDS	[] [] [] []
Characterise SEI formation	AFM	(¢)	Ø 4	888	* * }]	* • •		Cycling effec	t on chemistry	Raman, RISE	<u>()</u> 💷 🖗
-				\$3		R · · · · · · · · · · · · · · · · · · ·	2			+	
Ī			Separator	r Characterisatio	on	Techniques	Prop	erty	-		
			Structure	deterioration du	uring cycling	Raman, RISE	Ó	Ā			
			Nanoscale	e structure		AFM	000)		-		
			Porosity 8	& permeability		NMR	000)				



									_		
			Electroly	te Characterisa	ition	Techniques	Prop	erty	_		
		\cap	Concentration and purity			NMR	000)	\$ 🛆	0		
			lonic con	nductivity wn & degradation		NMR	(d)				
		V°°	Breakdow			NMR	Ā	Ø \$			
			Impact or	n electrode SEI	formation	AFM	Ó				
				↑ e ANOD	E ELECTROLY				_		
Anode Characterisation	Techniques	Prope	rty	338	3 1.+1 -	• • •		Cathode Cha	racterisation	Techniques	Property
Lithium content	SEM, Raman	000)		88				Particle size		EDS	□□□ 4 🖓 ⊙
Interfacial roughness	AFM	(¢)	Ā		***	* * ° §		Chemical cor	sistency	EDS, Raman	☞ 4 ⊅ ⊙]
Carbon material quality	Raman		(j) (j)	338	* * *	*		Powder purit	у	EDS	[] [] [] []
Characterise SEI formation	AFM	(¢)	Í	88	◎ ★ •★ } □	J * * •	200	Cycling effect	t on chemistry	Raman, RISE	<u> (</u>
-				33	SEPARATO	R	992			+	
			Separator	[•] Characterisati	on	Techniques	Prop	erty			
			Structure	deterioration o	luring cycling	Raman, RISE	Ó	Ā			
			Nanoscale	e structure		AFM	000)		•		
			Porosity 8	& permeability		NMR	000)				



Electrolyte Characterisation Techniques Property Concentration and purity NMR Concentration Concentration Innact on electrole SEI formation AFM S S Interfacial roughness AFM S S Carbon material quality Raman Concentration during cycling Froperty Structure deterioration during cycling Raman, RISE S Concentration Structure deterioration during cycling Raman, RISE S Concentration Nanocale structure AFM S Concentration Property Nanocale structure AFM S Concentration Property Nanocale structure AFM S Concentration Property Nanocale structure AFM S Concentration Concentration Structure deterioration AFM S Concentration Concentration Concentration Concentration AFM S Concentration Concentration Concentration Concentration Concentration Concentration SEM Concentratid Concentration Concentra										_		
Inoic conductivity NMR Image: Conductivity Image: Conductivity NMR Image: Conductivity Image: Conduc				Electrolyte (Characterisatio	on	Techniques	Prop	erty	_		
Breakdown & degradation NMR Impact on electrode SEI formation AFM Impact on electrode SEI formation AFM Impact on electrode SEI formation AFM Anode Characterisation Techniques Property Lithium content SEM, Raman Impact on electrode SEI formation FelectroLVTE Cathode Characterisation Techniques Property Interfacial roughness AFM Impact on Education Impact on Educ			\cap	Concentratio	on and purity		NMR	000)	\$] 🖾	0		
Impact on electrode SEI formation AFM Impact on electrode SEI formation AFM Anode Characterisation Techniques Property Lithium content SEM, Raman Impact on electrode SEI formation Techniques Property Lithium content SEM, Raman Impact on electrode SEI formation AFM Impact on electrode SEI formation Impact on electrode SEI formation Techniques Property Carbon material quality Raman Impact of electroacterisation Impact of electroacterise Impact of electroacterisation Imp				Ionic conduc	ctivity		NMR	(¢)				
Impact on electrode SEI formation AFM Impact on electrode SEI formation AFM Anode Characterisation Techniques Property Lithium content SEM, Raman Impact on electrode SEI formation Techniques Property Lithium content SEM, Raman Impact on electrode SEI formation AFM Impact on electrode SEI formation Impact on electrode SEI formation Techniques Property Carbon material quality Raman Impact of electroacterisation Impact of electroacterise Impact of electroacterisation Imp			Ų Ū	Breakdown a	& degradation	I	NMR		Ø \$	Ű,		
Anode Characterisation Techniques Property Lithium content SEM, Raman Interfacial roughness AFM Image: Carbon material quality Raman Image: Carbon material quality Raman, RISE Image: Carbon material quality EDS Image: Carbon material quality Raman, RISE Image: Carbon material quality Raman, RISE Image: Carbon material quality Raman, RISE Image: Carbon material quality EDS Image: Carbon material quality Raman, RISE Image: Carbon material quality Image: Carbon material quality Raman, RI				Impact on el	Impact on electrode SEI formation					_		
Anode Characterisation Techniques Property Lithium content SEM, Raman Importantian SEM, Raman Importantian Property Interfacial roughness AFM Importantian Importantiantian Importantian </td <td></td> <td></td> <td></td> <td></td> <td>↑ e ANODE</td> <td>¥¥.</td> <td></td> <td>) f</td> <td></td> <td></td> <td></td> <td></td>					↑ e ANODE	¥¥.) f				
Lithium content SEM, Raman Interfacial roughness AFM Image: Carbon material quality Raman Image: Carbon material quality EDS Image: Carbon material quality Image: Carbon material quality EDS Image: Carbon material quality Image: Carbon material quality EDS Image: Carbon material quality					888	, · · · · ·	me esso					
Interfacial roughness AFM Image: Construction of the structure deterioration during cycling AFM Image: Construction of the structure of	Anode Characterisation	Techniques	-	rty	000		b b		Cathode Cha	racterisation	Techniques	Property
Carbon material quality Raman Image: Carbon material quality Raman Image: Carbon material quality Raman Image: Carbon material quality Powder purity EDS Image: Carbon material quality Characterise SEI formation AFM Image: Carbon material quality	Lithium content	SEM, Raman			888	× L.	* * · · · · · · · · · · · · · · · · · ·		Particle size		EDS	
Carbon material quality Raman Imp <t< td=""><td>Interfacial roughness</td><td>AFM</td><td>Þ</td><td>Ā (-</td><td></td><td>**</td><td>**</td><td></td><td>Chemical cor</td><td>nsistency</td><td>EDS, Raman</td><td>෩ ්⊅ ා</td></t<>	Interfacial roughness	AFM	Þ	Ā (-		**	**		Chemical cor	nsistency	EDS, Raman	෩ ්⊅ ා
- Separator Characterisation Techniques Property Structure deterioration during cycling Raman, RISE Structure deterioration during cycling AFM	Carbon material quality	Raman		4 ③	888	* ~ ->	K. * 8555		Powder puri	ty	EDS	▲
Separator Characterisation Techniques Property Structure deterioration during cycling Raman, RISE Image: Compared and the second and the	Characterise SEI formation	AFM	(¢)		888	* * }	J * • • • •		Cycling effect	t on chemistry	Raman, RISE	<u> (</u>
Structure deterioration during cycling Raman, RISE Im Im <thim< th=""> Im Im</thim<>	-				555		or or				+	
Nanoscale structure AFM 🔟 🕼 🚽	Ī			Separator Ch	naracterisation	า	Techniques	Prop	erty	•		
Nanoscale structure AFM 🔟 🕼 🚽				Structure det	terioration du	ring cycling	Raman, RISE	Ó	Ā			
Porosity & permeability NMR 🔟 🗘 🛆				Nanoscale st	ructure		AFM	000)		-		
				Porosity & pe	ermeability		NMR	000)				

How clean is my electrode precursor material?



Cu



Identification of metallic contaminant introduced during the mining and subsequent manufacturing of Li-ion batteries can cause short circuits AZtecBattery provides high speed automated software analyses of EDS spectra identifying and classifying elements in contaminants and their morphology

Quantifying levels of unwanted Fe, Cu, and other metallic contaminants in manufacturing plant filters identified stainless steel pipes as the source and now enables ongoing QC monitoring



								-		
			Electrolyte Charact	terisation	Technique	S Property		_		
		0	Concentration and	purity	NMR	00	▣ \$] [Å	0		
			Ionic conductivity	nductivity		5	Þ			
		ŴŬ	Breakdown & degra	adation	NMR		\$ Ø \$	U U		
			Impact on electrod	e SEI formation	AFM	Ś		_		
			¢		W~	∫∳		-	Ļ	
				ANODE ELEC	CTROLYTE C	ATHODE				
Anode Characterisation	Techniques	Proper	ty	×.	j.	****	Cathode Cha	racterisation	Techniques	Property
Lithium content	SEM, Raman		E		* * *	6666	Particle size		EDS	IIII (⊅ ⊙]
Interfacial roughness	AFM	(¢)	6			••••• (+)	Chemical con	sistency	EDS, Raman	☞ ∽ ⊘
Carbon material quality	Raman	000 (4 ① 〔	**	-*.,*		Powder purit	Ý	EDS	[Å ⊙] §]
Characterise SEI formation	AFM	(¢)	Ĵ 🖞	** *	· · * •		Cycling effect	on chemistry	Raman, RISE	oj 💷 🖧
-			E	SEF	A PARATOR	2002			+	
T			Separator Characte	risation	Techniqu	es Pro	operty			
			Structure deteriora	tion during cycling	Raman, R	ISE 📀				
			Nanoscale structure	2	AFM	00		4		
			Porosity & permeab	bility	NMR	00				

Does my separator degrade during cycling?





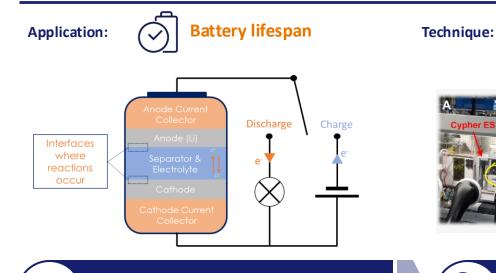
Separator polymers undergo molecular deterioration with cycling. Changes in separator composition and their ability to suppress dendrite growth affect the performance of Li-ion batteries. Raman Imaging Scanning Electron Microscopy (RISE) maps high resolution microstructure, chemical and elemental composition and atomic/molecular bonding to understand separators and electrodes before and after cycling The outer uniaxial polypropylene layers of the separator deteriorate, appearing as biaxial in the cycled battery. These structural changes can be correlated to observed cell performance degradation

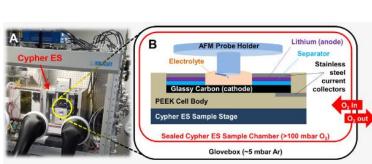


								_		
			Electrolyte Characterisatio	n	Techniques	Prop	erty	_		
		0	Concentration and purity		NMR		\$] 🕼	0		
			Ionic conductivity		NMR	Þ				
		V°°	Breakdown & degradation		NMR		Ø] \$]			
			Impact on electrode SEI fo	rmation	AFM	\bigcirc		_		
			<u>↑</u>			14				
			ANODE	ELECTROLYT		e				
Anode Characterisation	Techniques	Proper	ty See	J. * *	· . · · ·		Cathode Cha	racterisation	Techniques	Property
Lithium content	SEM, Raman	000)	888	* * *	*		Particle size		EDS	₽
Interfacial roughness	AFM	(¢)		*	**	+	Chemical con	sistency	EDS, Raman	☞ ∽
Carbon material quality	Raman	000 (4) ③ ~ ~	* ~ -*	*		Powder purit	y	EDS	[] [] [] []
Characterise SEI formation	AFM			* * 1 = =	* • •		Cycling effect	t on chemistry	Raman, RISE) m
-			\$\$		• ~ *****				+	
T			Separator Characterisation	Techniques	Property					
			Structure deterioration duri	ng cycling	Raman, RISE	Ø	Â			
		_	Nanoscale structure		AFM			•		
			Porosity & permeability		NMR					

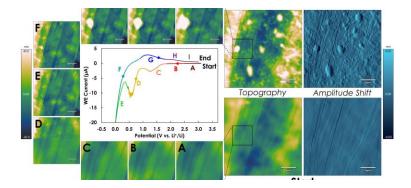
How does my SEI form?







AFM



The Problem

Formation of a stable anode Solid Electrolyte Interphase (SEI) is critical for reliable battery performance. During cycling this SEI can degrade deteriorating capacity, or ultimately form dendrites which cause short circuits. The Analysis

Using a Cypher AFM an integrated electrochemical cell inside a glove box, the anode surface morphology is imaged during the charge and discharge cycle.



The Solution

As the SEI forms on different electrode designs, AFM quantifies its uniformity. One electrode undergoes unwanted blistering at high charge potentials as intercalated water molecules split. Roughness increases dramatically during cycling.



									_		
			Electroly	te Characterisat	ion	Techniques	Prop	erty			
		0	Concentr	ation and purity		NMR	000)	\$ 6	0		
			Ionic con	nductivity		NMR	(J)	I			
		V	Breakdov	wn & degradatio	n	NMR		Ø]\$]			
			Impact o	n electrode SEI f	formation	AFM	Ó		_		
				€ ANODE		TE CATHODE					
Anode Characterisation	Techniques	Proper	rty		J.*.	ver or		Cathode Cha	racterisation	Techniques	Property
Lithium content	SEM, Raman			88	* * *	*		Particle size		EDS	
Interfacial roughness	AFM	(¢)	Ā		***	* * • •	+	Chemical cor	nsistency	EDS, Raman	☞ 4 ⊙
Carbon material quality	Raman	000 (\$Þ ⊙]	888	* ~ -*	* 888		Powder purit	ý	EDS	[] [] []
Characterise SEI formation	AFM	(J)	<u> </u>	888	* * }]	* • • • • • • • • • • • • • • • • • • •		Cycling effect	t on chemistry	Raman, RISE	<u> ()</u>
-				\$33		R · · · · · · · · · · · · · · · · · · ·				+	
T			Separator	r Characterisatio	n	Techniques	Prop	erty	-		
			Structure	deterioration du	iring cycling	Raman, RISE	Ó	Â			
			Nanoscale	e structure		AFM	000)		4		
			Porosity &	& permeability		NMR	000)				

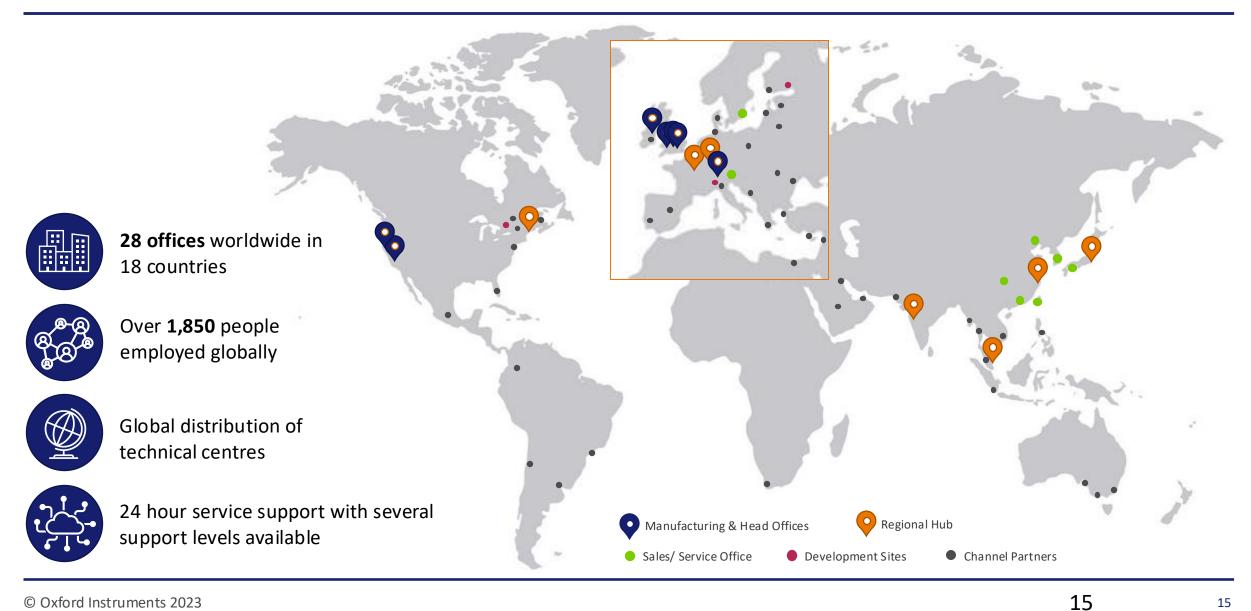
Enabling battery development through materials understanding





Global Footprint







Oxford Instruments can help battery development with a broad variety of techniques.

- Of which only a small number has been showcased here:
 - Electrolyte property optimisation
 - QA/QC (cathode precursor powders, electrolyte)
 - Analysis of separator degradation with cycling
 - Imaging and monitoring of SEI formation
- We can also help with:
 - Failure analysis (electrodes, electrolyte, full battery, failure mechanisms)
 - Materials research (formulation testing, new materials development, light and trace element analysis, high resolution analysis)
 - Recycling (black mass analysis)
 - Correlative microscopy



inclusive · innovative · trusted · purposeful

oxinst.com