Cell Supply Chain Management and Surveillance Test Program

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The verification process is analyzed listed below as a fingerprint of each cell model: a)Incoming Quality Check, b)Electrical performance check with temperature and rate variables, c)X-ray tomography investigation to check defect, deformation, anomalies, especially in the safety risk areas, d)Destructive Physical Analysis checks and measures the electrode assembly (Jelly roll) alignment, overhang gaps among separator and electrodes, dimension, and internal short-circuit avoidance considerations, e)Analyze the dimension, composition, and materials of the separator and electrodes, f)Analyze electrode material, ratio, particle size and distribution, and g)electrolyte composition.

ECS Trans. 104, 109

ECS Transactions

Cell Supply Chain Management with Approval and Surveillance Program

Jaesik Chung[1]

ECS Transactions, Volume 104, Number 1

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Outline

Introduction

- Potential Changes of the Battery Failure Issues
- Counterfeit/Fake battery Issues
- Recalls of Lithium-ion Battery Products
- Note 7 battery issues and Root Cause Analysis Result
- 2006 Dell NBPC Recall, Root cause Analysis and Corrective Action
- Review the LiB cell Manufacturing Process
- Needs of System base Risk Assessment & Role of the test & Certification

Experimental – Smartphone vs Mobile Computing

Cell supply chain management with approval and surveillance program

Result and Discussion

Examples of each test procedure and test result analysis

Conclusion

1) Potential Changes of the Battery Failure Issues

1. Counterfeit/Fake battery Issues

2. Potential Changes

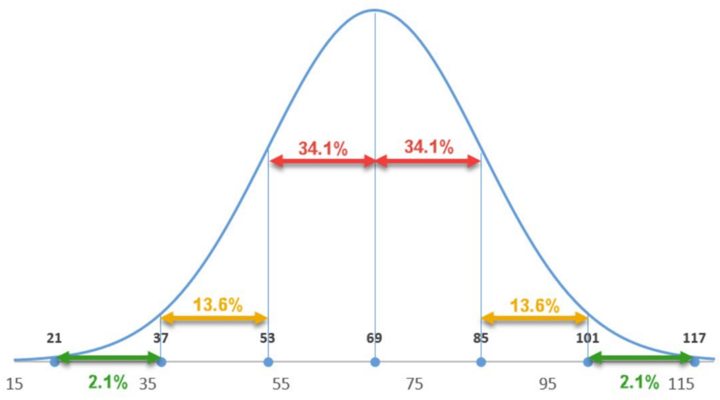
1) Changes of Materials

a) Electrode active materials: Chemical composition, purity of raw material,
manufacturing process/condition,
homogeneity of element in the material,
impurity level,
particle size and size distribution,

b) Conductivity Carbon: impurity level, grade, particle size and size distribution
c) Binder: impurity level, crystallinity and molecular weight of the polymers
d) Additives: impurity level, grade

2) Material selection guideline and IQC
3) Manufacturing process and required room conditions
4) Quality control process: minimize QC point, item, checking frequency
5) Internal approval process- model/lot: minimize test item/sample number, checking frequency.
6) Understand the Intrinsic property: thickness and spring-back
7) Formation, again and grading process:
Grade and screening: manufacturer risk vs customers risk, supply chain shortage, other issues.

Criteria of outlier cells
in the Screening process
- 6 Sigma and Normal Distribution



- Unknow/unproven changes
  - intentional vs unknown
- IQC , LQC, and OQC should check/block the unknown/unproven changes

*IQC: Incoming Quality Control
LQC: production Line Quality Control
OQC: Outgoing Quality Control

2) Counterfeit/Fake battery Issues

a) Counterfeit Materiel; Assuring Acquisition of Authentic and Conforming Materiel -SAE AS6174A

This SAE Standard standardizes practices to:
a) maximize availability of authentic materiel,
b) procure materiel from reliable sources,
c) assure authenticity and conformance of procured materiel, including methods such as certification, traceability, testing and inspection appropriate to the commodity/item in question,
d) control materiel identified as fraudulent/counterfeit,
e) report suspect or confirmed fraudulent/counterfeit materiel to other potential users and Authority Having Jurisdiction.

b) Counterfeit Electrical, Electronic, and Electromechanical (EEE) Parts; Avoidance, Detection, Mitigation, and Disposition - SAE AS5553C

This standard is for use by organizations that procure and/or integrate and/or repair EEE parts and/or assemblies containing such items, including maintenance, repair, and overhaul (MRO) organizations. The requirements of this standard are generic and intended to be applied/flowed down, as applicable, through the supply chain, to all organizations that procure EEE parts and/or assemblies, regardless of type, size, and product provided. The mitigation of counterfeit EEE parts in this standard is risk-based, and these mitigation steps will vary depending on the criticality of the application, desired performance, and reliability of the equipment/hardware. The requirements of this document are intended to be used in conjunction with a higher-level quality standard (e.g., AS/EN/JISQ9100, ISO-9001, ANSI/ASQC E4, ASME NQA-1, AS9120, AS9003, and ISO/TS 16949 or equivalent) and other quality management system documents. They are not intended to stand alone, supersede, or cancel requirements found in other quality management system documents, requirements imposed by contracting authorities, or applicable laws and regulations unless an authorized exemption/variance has been obtained. This document is not intended to make a legal determination of fraud, and appropriate legal counsel should be consulted for further action.

c) Foreign Object Damage (FOD) Prevention Program-Requirements for Aviation, Space, and Defense Organizations -SAE AS9146

This SAE standard defines FOD Prevention Program requirements for organizations that design, develop, and provide aviation, space, and defense products and services; and by organizations providing post-delivery support, including the provision of maintenance, spare parts, or materials for their own products and services.
It is emphasized that the requirements specified in this standard are complementary (not alternative) to customer, and applicable statutory and regulatory requirements. Should there be a conflict between the requirements of this standard and applicable statutory or regulatory requirements, the latter shall take precedence.

I E R&D C

3) Recalls of Lithium-ion Battery Products (2012-2017)

Consumer Product Safety Risk Management System (CPSRMS) searched incident reports from 1/1/12 to 7/24/17 using Narrative field search terms:

LI-ION/LITHIUM/POLYMER/BATTERY/CHARG

Results: > 25,000 incident reports; 483 primary product codes

CPSRMS Incident Data (2012-2017)

Product	# of Incidents
Computer battery or charger	3,000
Cell phone battery or charger	2,000
Power Banks (Portable USB charger)	400
Drones (under DOT)	200

Root Causes
- Battery Management System (BMS)
- Cell Design imperfection (Design/Material selection)
- Cell manufacturing quality control (QC)
- Lack of system integration (Charger-BMS-Cells)
- Non-Listed cells/systems

* Reference: Doug Lee, US CPSC at the Battery Show, Novi MI Sept.11 2017

49 Recalls (U.S.) of LiB - Powered Products

Product	# of Recalls	# Device
Hoverboard	11	502,200
Laptop	11	498,162
Tablet	2	83,000
Power Bank	4	211,325
Charger	3	684,007
Battery Backup	1	2500
Jump starter	2	14814
E-Bike	1	5000
UPS	1	2876
Cell Phone	1	1,920,927
Other*	9	289,692
Total	49	4,232,808

* Other products include baby monitor, gloves, hand warmers, RC car battery pack and wireless speakers

3-1) Lithium-ion Battery fire explosion incident summary

No.	Date	Accidents replay	Accident causes
1	March 2010	Two iPod Nano music players overheated and caught fire, Japan	Caused by overheated LIBs [105]
2	26 April 2010	Acer recalled 2700 laptop batteries, as Dell, Apple, Toshiba, Lenovo and Sony did in 2006	Potential overheating and fire hazards of LIBs [105]
3	11 April 2011	EV taxi caught fire, Hangzhou, China	Electrolyte burned due to short circuit
4	October 2013 to November 2013	6 Tesla Model S EV cars caught fire	Short circuit of the battery due to crash, self-ignition of the battery and so on
5	January 2013, January 2014	Three fire accidents of Boeing 747, happened in Boston America, Takamatsu, Tokyo Japan, respectively	Internal short circuit of the LIBs and the failure of the battery management system (BMS) [138–140]
6	April 2015	EV bus caught fire during charge, Shenzhen, China	Overcharge of the battery due to the failure of BMS
7	31 May 2016	The storage room of the LIB caught explosion, Jiangsu, China	Caused by the fully charged LIBs, maybe self-ignition
8	August 2016	Samsung Note 7 smart phone explosion	Space between the battery and other components was insufficient, causing short circuit
9	16 May 2017	Panasonic announced to recall over 270 thousand LIBs	Potential overheating and fire accidents
10	18 October 2017	EV car caught fire, Austria	The LIB of the car caught fire after crash
11	January 2018	Tesla Model S EV car self-ignited, China	Battery system self-ignited.
12	2 July 2018	4 MW/12 MWh energy storage system (ESS) caught fire and explosion, Korea	One LIB caught fire and propagated to over 3500 LIBs.
13	29 July 2018	Electric scooter caught fire and explosion during charging, China	Maybe overcharged.

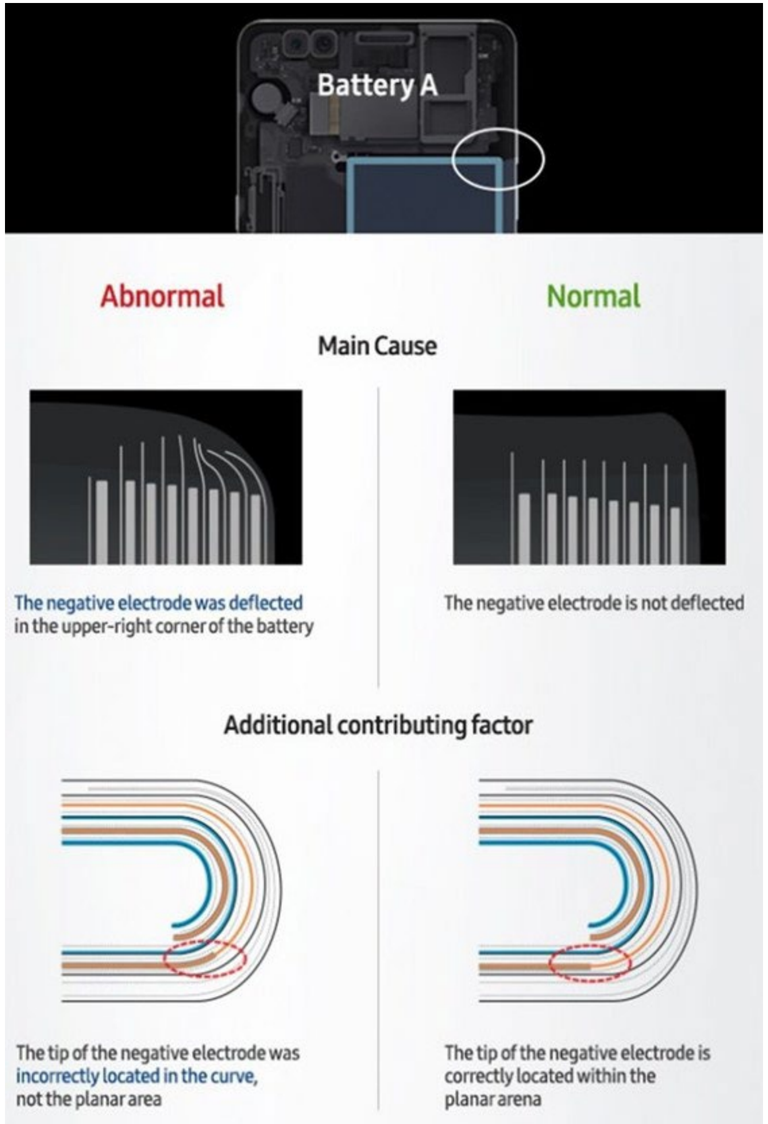
Ref. : Q. Wang, B. Mao and S.I. Stoliarov et al. / Progress in Energy and Combustion Science 73 (2019) 95–131

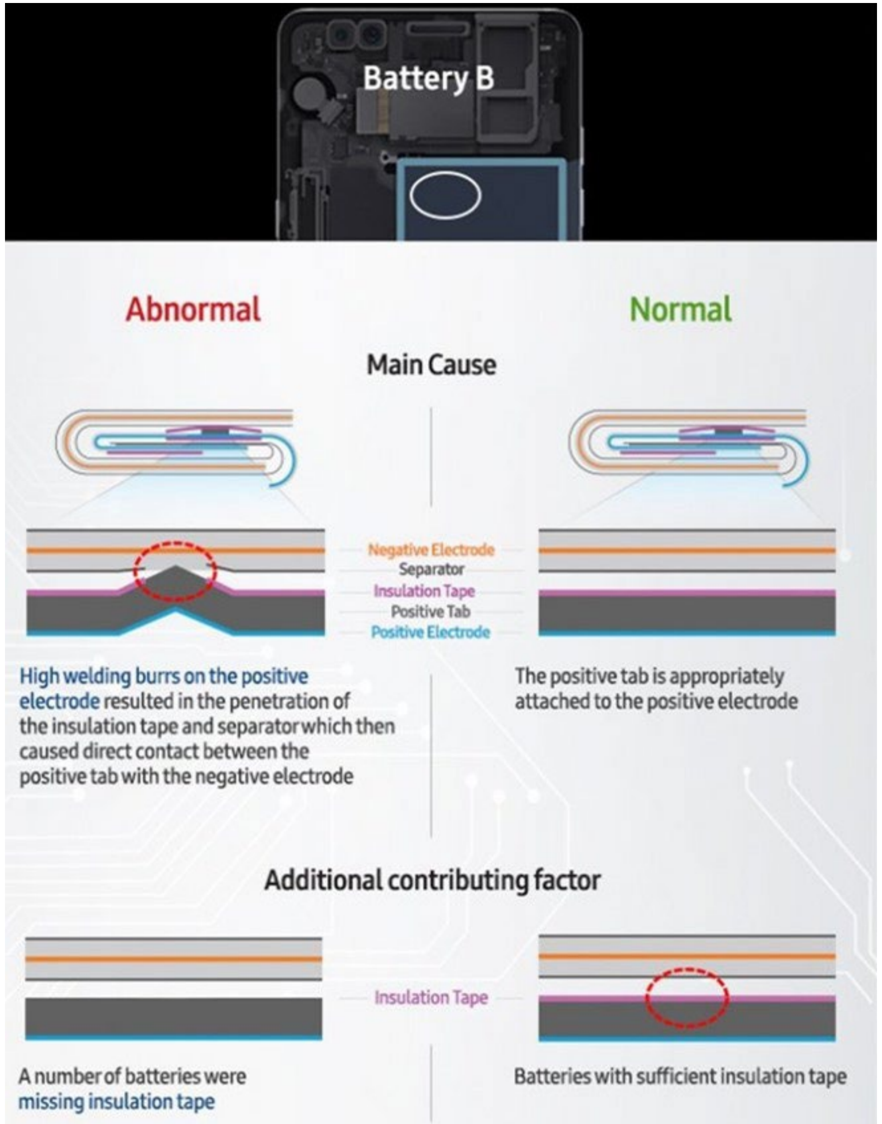
- ✓ Hyundai: recalled globally more than 74,000 Kona Evs - after 16 of them caught fire in South Korea, Canada and Europe in two years.
- ✓ GM: recalled - 68,677 EVs after five reported fires and two minor injuries-2017-2019 Chevrolet Bolt EVs
- ✓ Europe, Ford: recalled about 20,500 Kuga plug-in hybrid crossovers
- ✓ BMW, Volvo and others also have recalled EVs, including plug-in hybrid models, due to issues with battery systems.

Reference : Reuters, Nov. 17, 2020

4) Note 7 battery issues and Root Cause Analysis Result

Samsung hired 700 engineers to test out 200k devices and 30k batteries and engaged external investigators.





On 23 Jan 2017, Samsung Reported their failure investigation results. //https://www.youtube.com/watch?v=Iu18CykEH9o

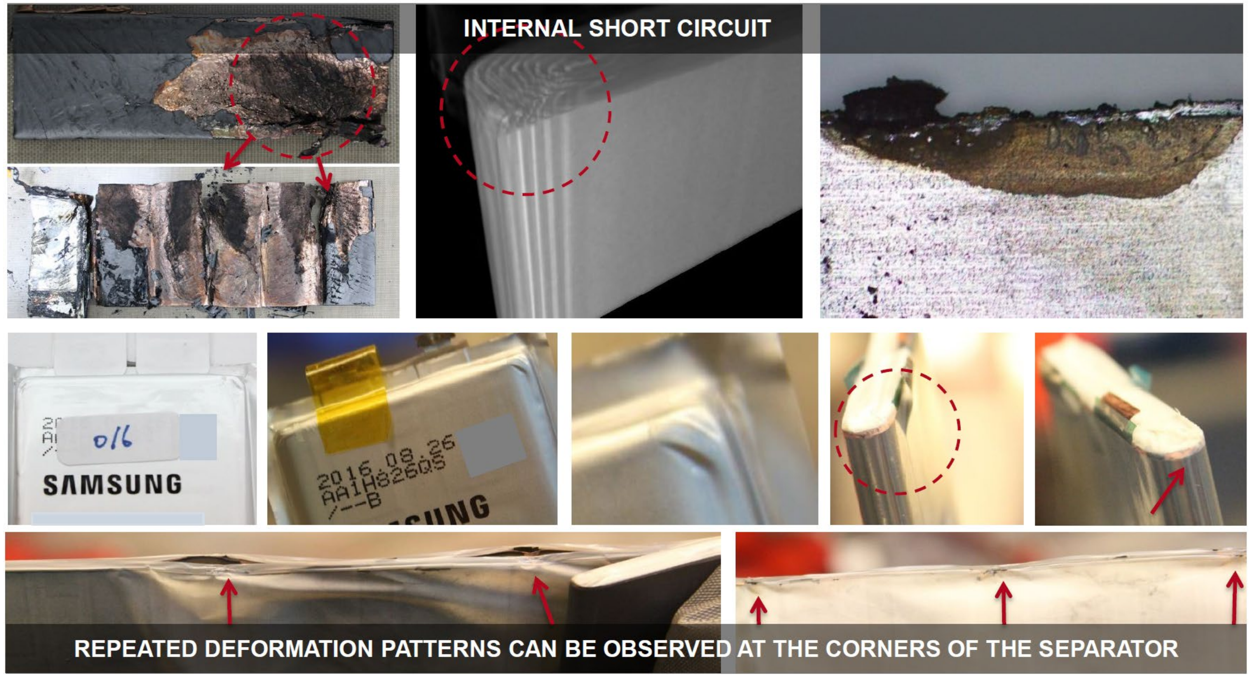
4-1) Note 7 battery issues and Root Cause Analysis Result

These issues can be filtering out during Formation/Aging/Grading process in the cell manufacturing.

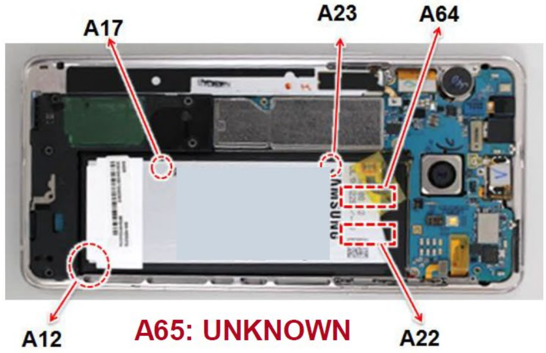
These issues can be filtering out during cell approval test inside the cell manufacturing factory.

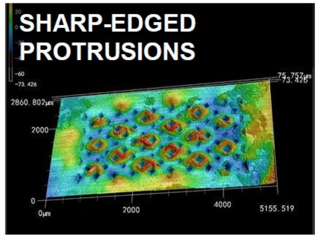
These issues can be filtering out during the Certification test; a) UN 38.3 Manual test, b) UL 1624/IEC62133-2, c) IEEE1725 Certification: many test items, and d) CTIA Certification Cell manufacturing Site Audit

Signs of ISC(internal short circuit) at the cell corner from 6 damaged devices



- Signs of internal short circuit (ISC) at different locations of the cells from 5 of the damaged devices
- Signs of ISC at the tab locations of swollen cells
- Missing insulation tape on the cathode of swollen cells
- Sharp-edged protrusions on the tab welding spots of swollen cells





On 23 Jan 2017, Samsung Reported their failure investigation results. //https://www.youtube.com/watch?v=Iu18CykEH9o

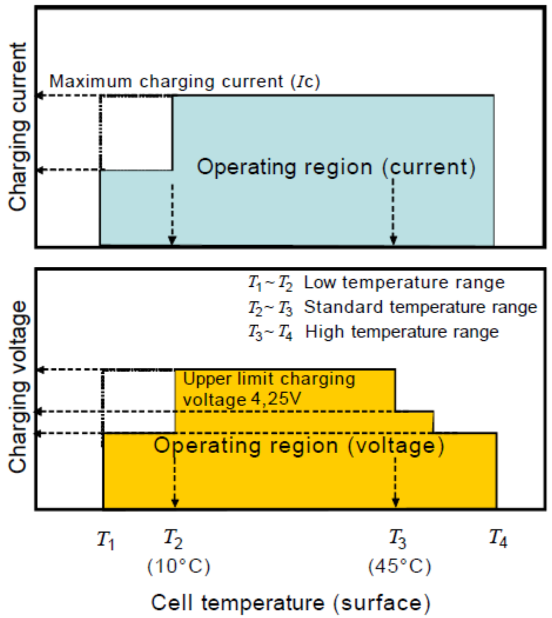
5) 2006 Dell NBPC Recall, Root cause Analysis and Corrective Action

Dell recalled over 4.6 M Set. /CA : Generate JIS C8714, Revise IEEE 1625 and start CTIA Certification.

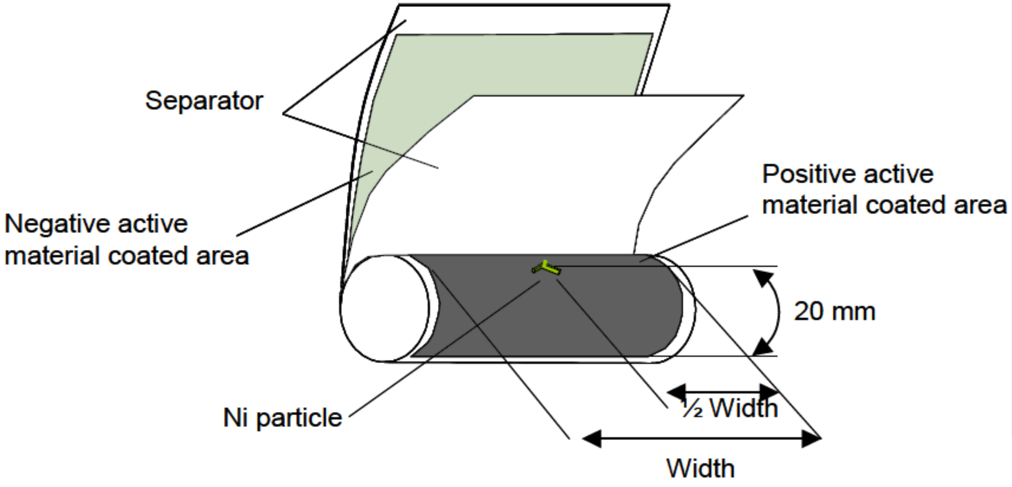



*** Cell/Pack were certified by UN DOT(IEC62281), IEC 62133, UL 1642/ 2054, National Standard**

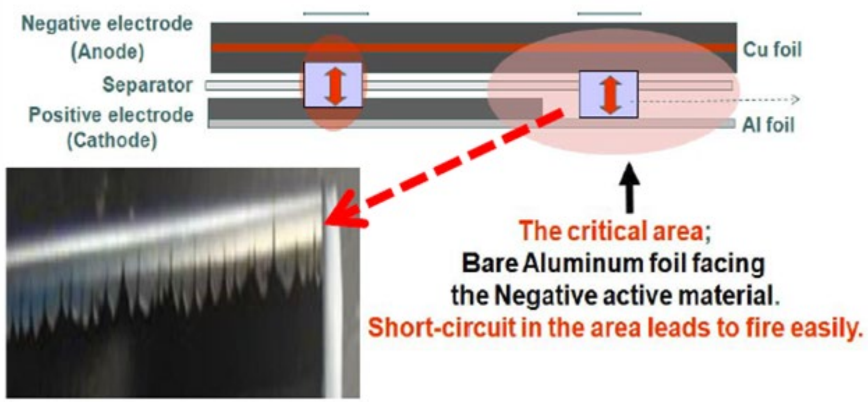
Schematic operating region of li-ion cell



Develop Forced Internal Short: JIS C 8714



Internal Short Avoidance :IEEE 1625/1725



6) Need Causal Analysis and Resolution (CAR)

- ✓ What is a Causal Analysis and Resolution? : A technique concentrates on identifying specific failures or defects, discovering root causes of those failures, and concluding with recommendations on how to eliminate those defects by implementing solutions that address the appropriate cause.

- ✓ How to maximize the effects of CAR ?

Cell Design & Manufacturing Check + Cell DPA & Material analysis + Manufacturing-site Audit program + Surveillance program

- ✓ Process of the Causal Analysis and Resolution

1) Select data for analysis: select all data/phenomena of the issues, defects or incidents for the CA analysis.
2) Perform causal analysis (CA):
   - Perform CA on the selected data /phenomena using root cause analysis techniques (-Pareto Analysis, -Fish Bone Diagram, etc.) & Failure mechanisms.
   - Identify the action plans to address the selected issues, defects or incidents in their current state (corrective action) and to avoid future occurrences (preventive action) based on the analysis results.
3) Implement selected action plans: - implement the Corrective and Preventive Action Plans.
   - Action plans help in addressing the root causes of analyzed issues/defects/incidents to prevent or reduce their occurrence/recurrences.
   - Action Plans are selected based on their scope and importance of the resolutions.
4) Evaluate the effect of implemented actions plan: evaluate the effect of the implemented action plans. study the remedial action plans of the same category of the issues/defects/incidents were implemented and analyze improvement between the current status and past status.
5) Record all data: record and documentation of all data used in the causal analysis and resolution.

* Reference : https://www.cmmiconsultantblog.com/cmmi-faqs/how-to-implement-causal-analysis-and-resolution

6-1) CAS and needs of System Base Risk Assessment & Role of the test & Certification

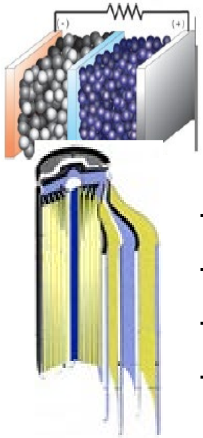
- Filter the potential or intrinsic risky (bad design/manufacturing, QC, impurities) cells out in advance with the cell failure and safety mechanism.
- Safety zone of the cell depends on the host system & use conditions.

Proposal : investigate the safety mechanism by System base Risk Assessment.

The Role of the test & Certification

Defects

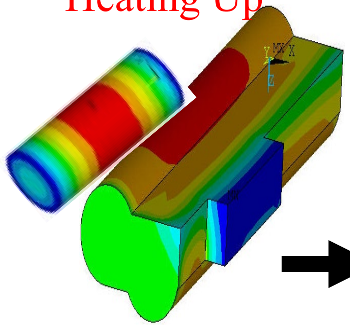
-Design Defect
-Manufacturing
-Material Def.
-Contamination
-Bad QC



Impacts; Trigger

-Electrical
-Mechanical
-Thermal
-Abuse/abnormal

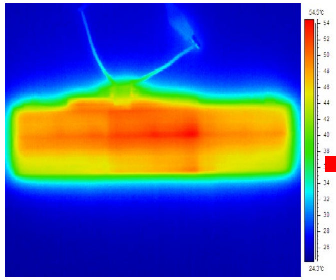
Heating Up



Heat Generation

Host System affect to Battery
User Environment
Abuse/Abnormal Condition

Heat Dissipation

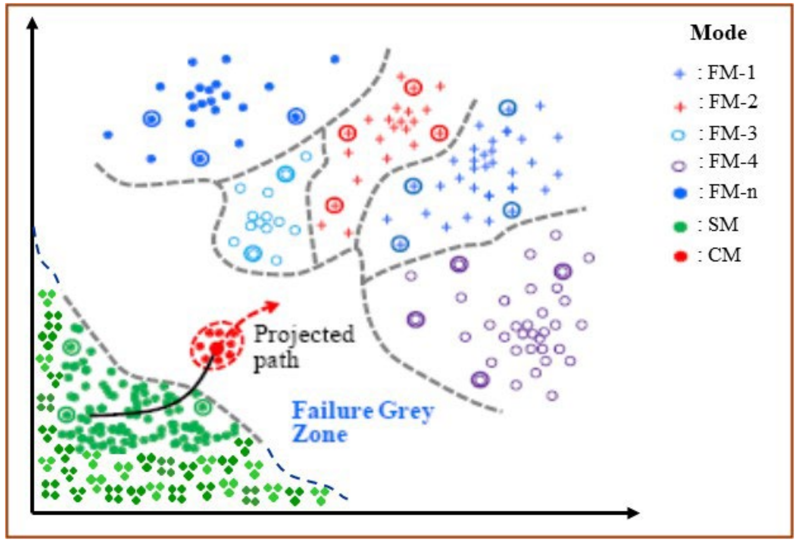


Thermal Management

Thermal Run-Away

Hg >> Hd

Hg: Heat generation
Hd: Heat dissipation



*Test and certification must filter the potential or intrinsic risky cells out in advance with the cell failure and safety mechanism.

* Safety zone of the cell depends on the host system & use conditions.

Reference: Jaesik Chung, **IEEE *Xplore*:** 24 Oct. 2013, - Energytech, 2013 **DOI:** 10.1109/EnergyTech.2013.6645308, **Development of a Li ion battery safety risk assessment tool**

6-1) CAS and review the LiB cell Manufacturing Process

-Manufacturing has long process and many kinds of materials which may have impurities➔ Black Box when not managed adequately

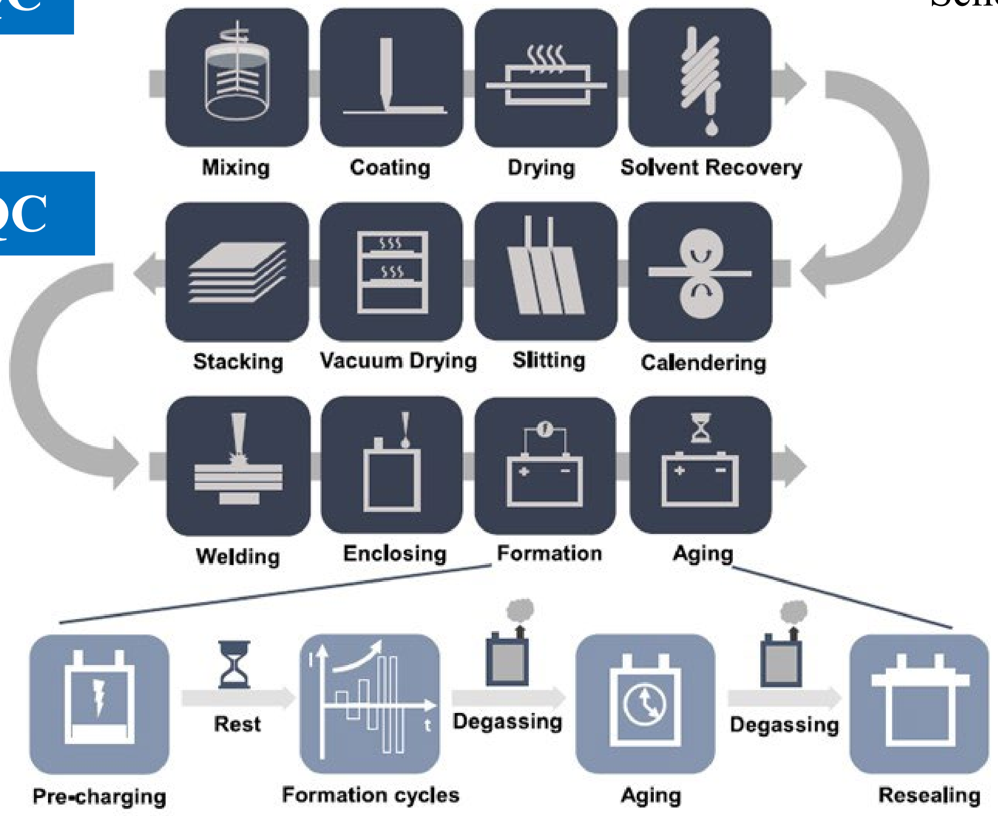
-Each machine/process has manufacturing Tolerance/Capacity affecting to quality/safety➔Black Box when not controlled adequately

-IQC, LQC, OQC, and internal approval processes are essential / Manufacturing considering Cell design is crucial.

*IQC: Incoming Quality control, LQC: production Line Quality Control, OQC: Outgoing Quality Control

IQC

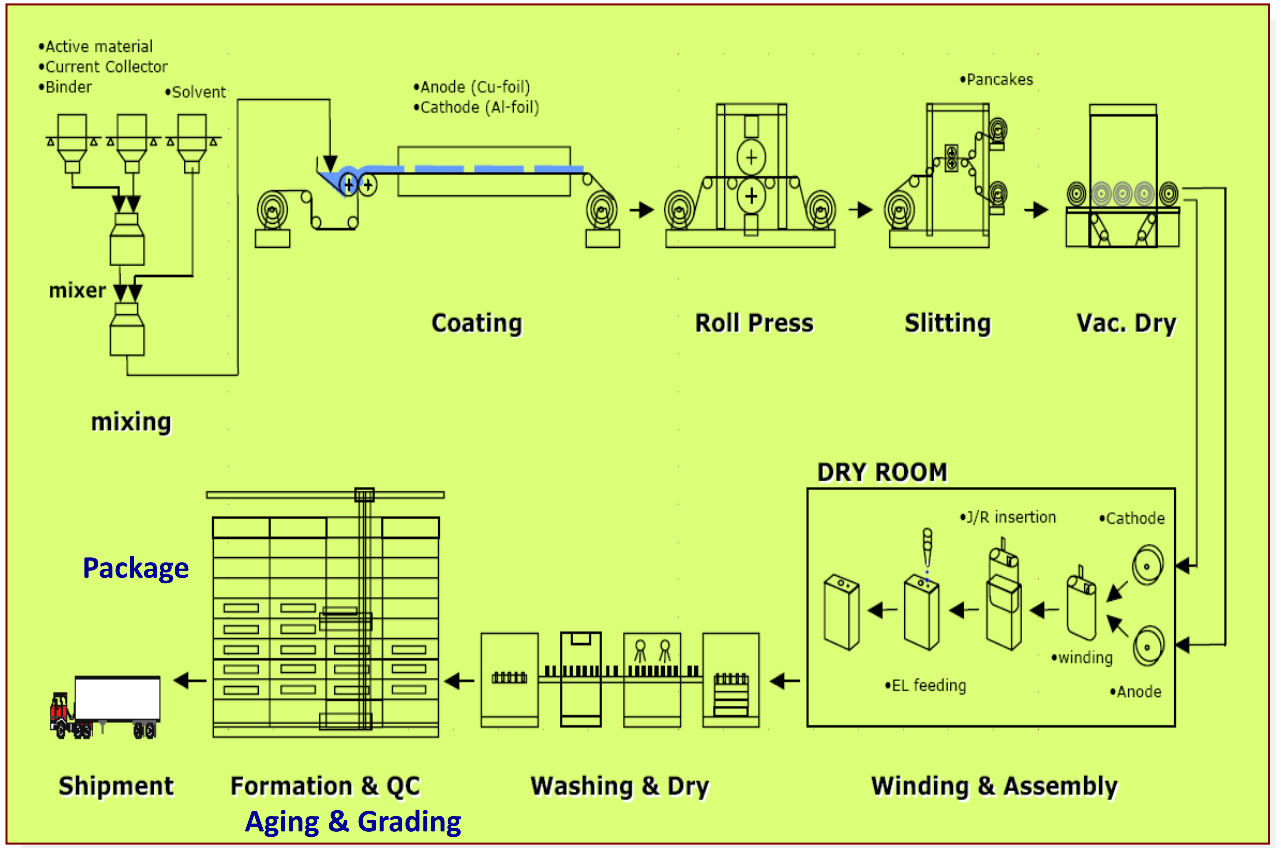
LQC



OQC

Ref. : Current and future lithium-ion battery manufacturing, Yangtao etal, iScience 24, 102332, April 23, 2021

Schematic of LIB manufacturing processes



*** Cell manufacturing site Audit Program***

Experimental

a) Cell models information

OEM Customers' Cell Supply Chain Management and Surveillance Test Program

- *Cell samples of the models were delivered with black marking covered.*

b) Experimental Equipment

- ✓ Cell teardown & measurement System : In-house designed system
- ✓ SEM-EDS : JEOL, model : JCM-7000 NeoScope™ Benchtop SEM-EDS
- ✓ Electron Microscopy: Nikon, NiNEXIV VMA-2520 CNC video measuring system
- ✓ Vision system with Software- In-house developed system with ImageJ software.

1. Concept of cell supply chain management and surveillance program

a) Purpose

- ✓ Generate a technical database of all the analysis results to create a fingerprint library of each cell lot.
- ✓ That enables OEMs can keep /manage its cell quality and supply chain consistency and monitor/manage any changes in the product by comparing cell characteristics among each cell lot through the database library.

b) Purposed Concepted

Conceptional introduction diagram of the Cell supply chain management with approval and surveillance program.

c) Application Category

Device System OEMs vs Cell Manufacturers

2. Evaluation Items to check the Potential Changes of a cell

Potential Changes of cell manufacturing : *intentional vs unknown*

1) Changes of Materials

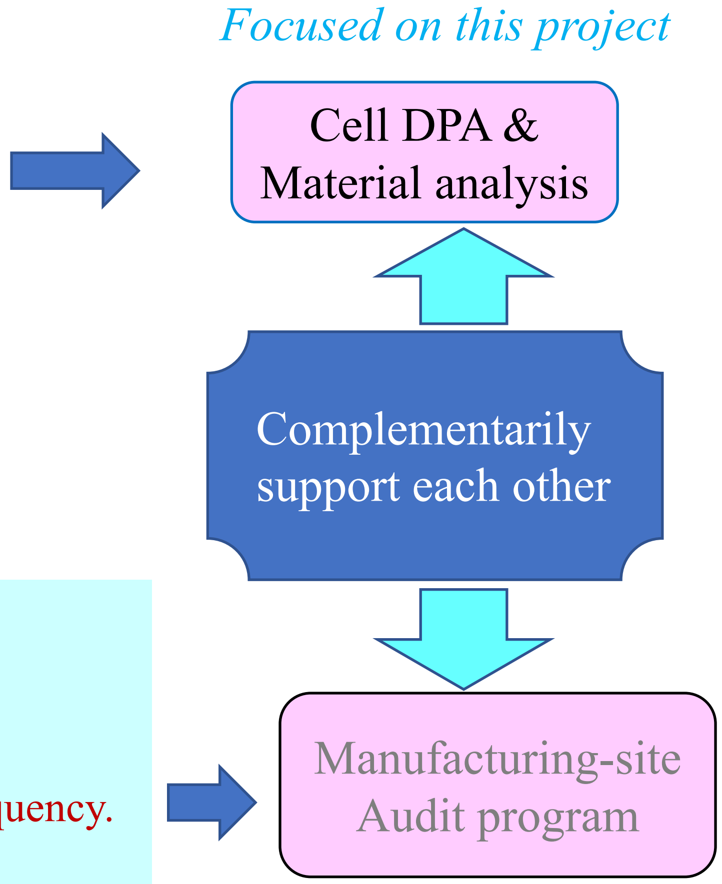
a) Electrode active materials - Chemical composition,
- Purity of raw material and impurity level
- Manufacturing process/condition
- Particle size and distribution
- Homogeneity of element in particle: NMC, MCA, MCMA

b) Conductivity Carbon : impurity level, grade, particle size and size distribution
c) Binder : impurity level, crystallinity and molecular weight of the polymers
d) Additives : impurity level, grade

2) Material selection guideline and IQC

3) Manufacturing process /requirement room conditions
4) Quality control process : minimize QC point, item, checking frequency
5) Internal approval process – model/lot : minimize test item/sample number, checking frequency.
6) Understand the Intrinsic property : thickness and spring-back

7) Formation, again and grading process: manufacturer risk vs customer risk
Grade and screening : manufacturer risk vs customers risk, supply chain shortage, other issues.



3. Test Items for fingerprint library

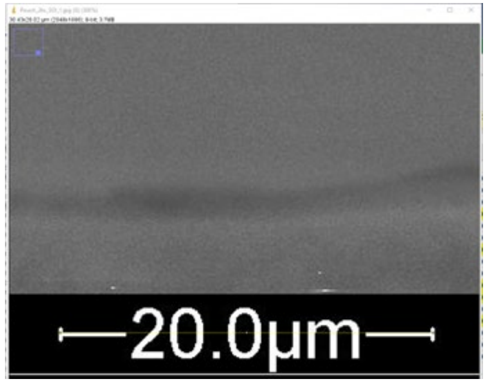
for the Cell supply chain management with approval and surveillance program

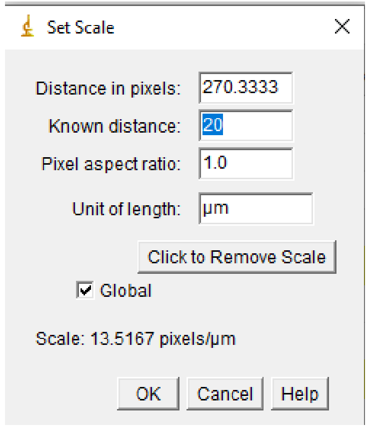
- ✓ Generate a technical database of all the analysis results to create a fingerprint library of each cell lot.
- ✓ That enables user can keep /manage its cell quality and supply chain consistency and monitor/manage any changes in the product by comparing cell characteristics among each cell lot through the database library.

	Test Item	Investigation method description	Key investigation factors
1	IQC Check	Visual inspection, OCV, AC-Imp., mass, dimension	Sample receiving status, Damage and anomaly
2	Cell Physical Geometry Check	X-ray investigation, EIS if any deformation	Risky area: 4 conners, Tab position, Damage and anomaly
3	Electrical Characteristics	Capacity, DCIR, EIS, Performance compression: Rate/Temp.	Rate and Temperature performance and DCIR, EIS
4	Electrode Assembly Alignment	Dimension, gap measure: Separator-Anode-Cathode	Electrode alignment, cell design/status, insulation mechanism
5	Dimension: Electrode-separator	Coated/uncoated area, Separator, Tab position/Insulation	Cell design/status, internal short avoidance design consideration
6	Thickness of components	Electrode, Separator-Ceramic coating, tab, insulation	Thickness, deformation, degradation, and anomaly
7	Electrode material and particle size	Electrode material, particle size/distribution by SEM-EDS	Change Electrode material, particle size/distribution, cross section
8	Electrode composition	Ratio of Active material/C.C/Binder/Additives by DT-TGA	Active material/C.C/Binder/Additives, Separator ceramic coating
9	Electrode press density	Anode and Cathode Press density by dimension and weight	Measure volume of electrode and thickness
10	Electrolyte composition Analysis	Electrolyte material composition: ICP-GC-Mass	ICP-GC-Mass results: m/z – abundance, Library search

4. Dimension Measurement - Analysis Equipment and Software

1) Known scale from the SEM image and convert it to pixels.



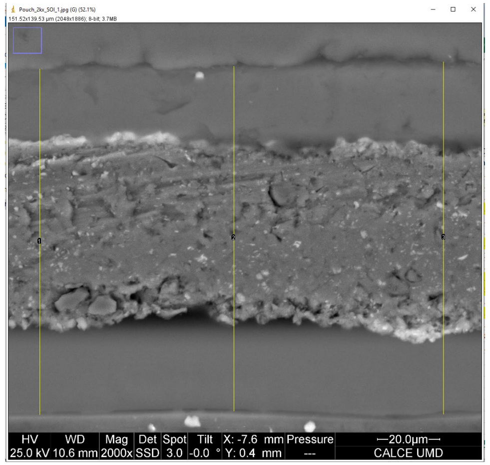


Thickness measurement and conversion process

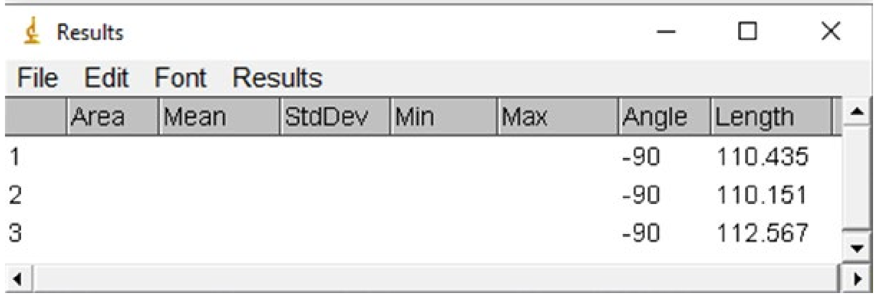
1) Use the scale provided in each image by the Oxford SEM software (*ISO 17025 accreditation*) and convert pixels into micrometer for those Image (scale reset for each image).
2) The image is uploaded, and the scale is set on the measurement software by zooming into the image scale with known distance (ex. 20um) and converting that into Pixels.

Ex) Overall Pouch Thickness is approximately 111 microns.

2) Example of conversion :SEM image to Pixels to thickness



3) Example of conversion to thickness.



	Area	Mean	StdDev	Min	Max	Angle	Length
1						-90	110.435
2						-90	110.151
3						-90	112.567

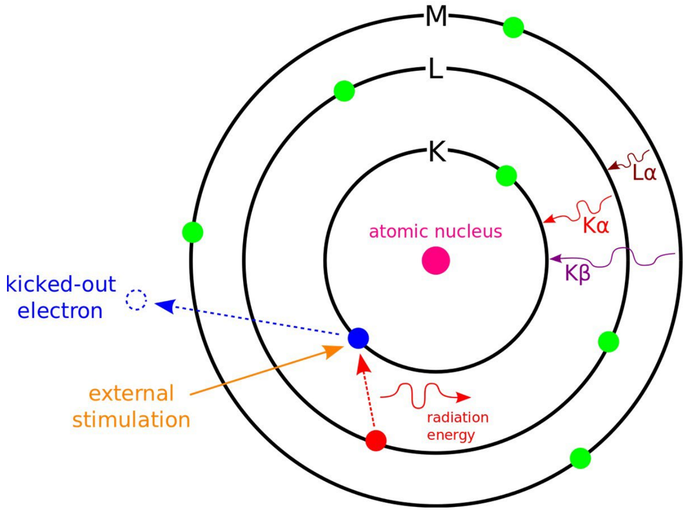
4) Dimension measure with Vision System

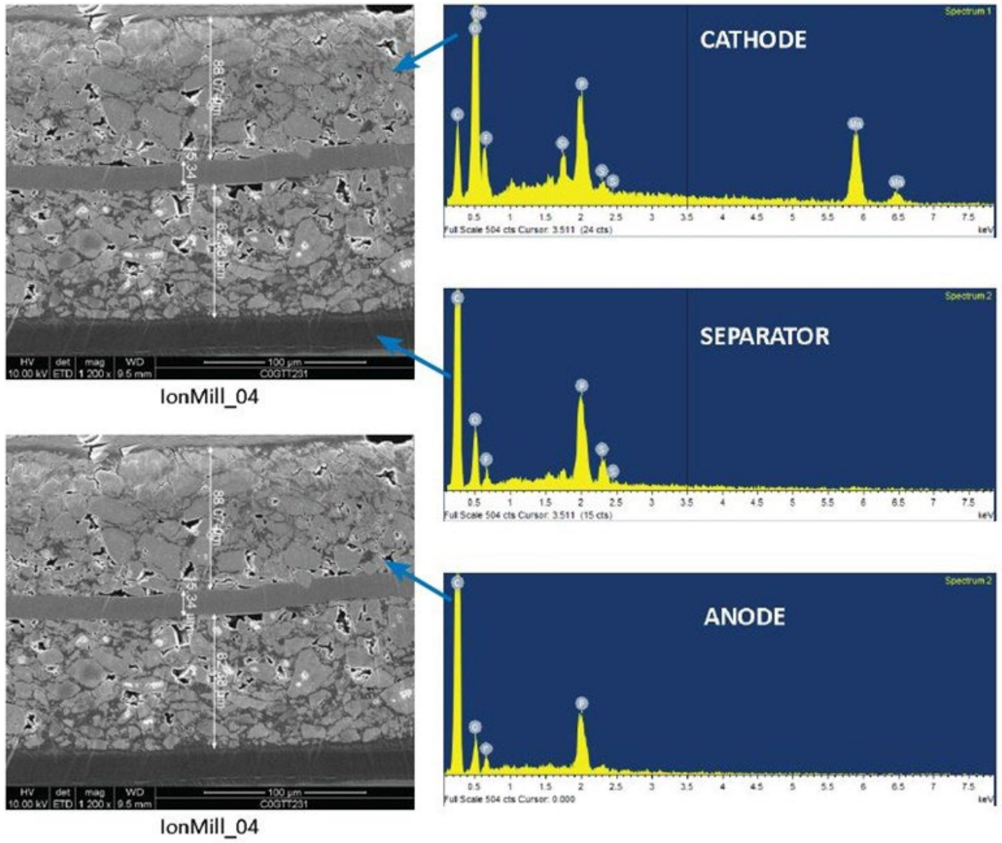
- ✓ **Nikon iNEXIV:** An Automatic CNC video measuring system with a minimum measurement calculation of 1 μm.
- ✓ **Vision system with Software-** In-house developed system.
- ✓ **ImageJ:** Used for macro measurements, inspired by NIH Image where it calculates a geometric measurement by pixel value statistics of user-defined selections.

5. Material analysis method by Elemental Mapping with EDS

- ❖ **EDS** (Energy-dispersive spectroscopy) is an analytical technique used for the elemental analysis or chemical characterization of a sample.
- ❖ EDS can be used to determine which chemical elements are present in a sample and to estimate their relative abundance.
- ❖ EDS technique can produce elemental distribution maps.
- ❖ The measured composition accuracy is affected by the nature of the sample. X-rays are generated by any atom in the sample that is sufficiently excited by the incoming beam.

Concept of EDS and an example of the SEM-EDS analysis for LiB cell components.

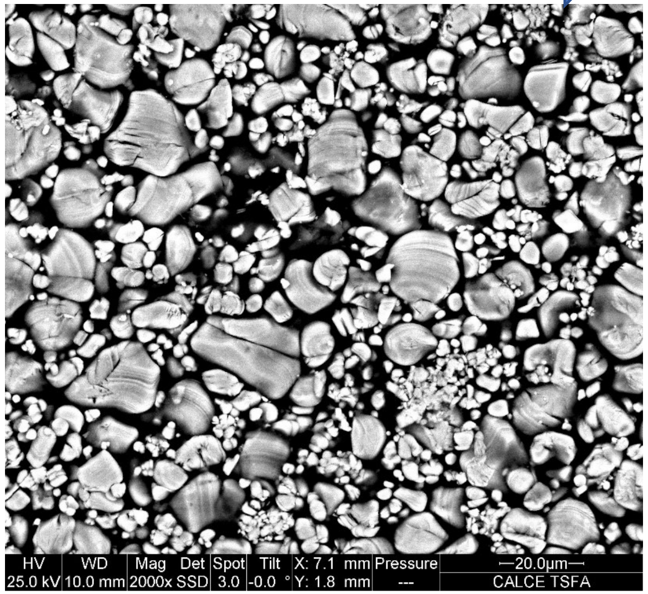


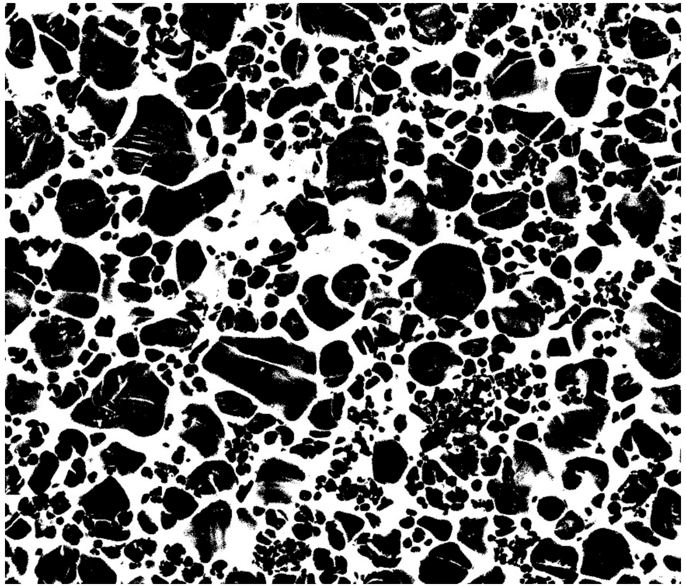


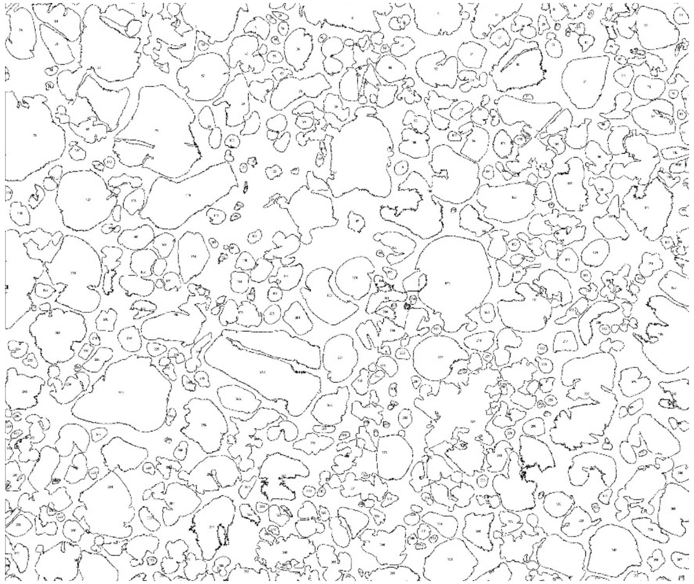
5. Particle Size & Distribution analysis method & process

SEM Image and Image-J picture software can convert and count the particle.
An example of the convert and calculation of the particles.

SEM Image → ***Particle Threshold in Image J*** → ***Particle(Size/number) Measurement***



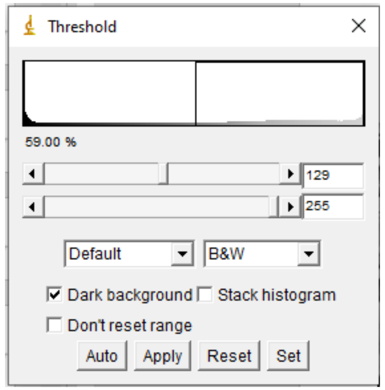


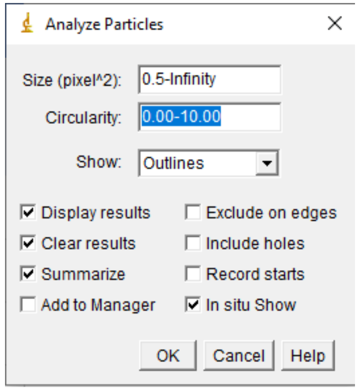


By setting a darkness threshold, Image J can estimate the number and size of particles present in the image as well as the area that they cover.

➔ well proven and accepted technology.
➔Reference : Particle Analysis - ImageJ

*Ion Milling Sample preparation technology is required to clean the sample surface out to investigate the SEM-EDS.

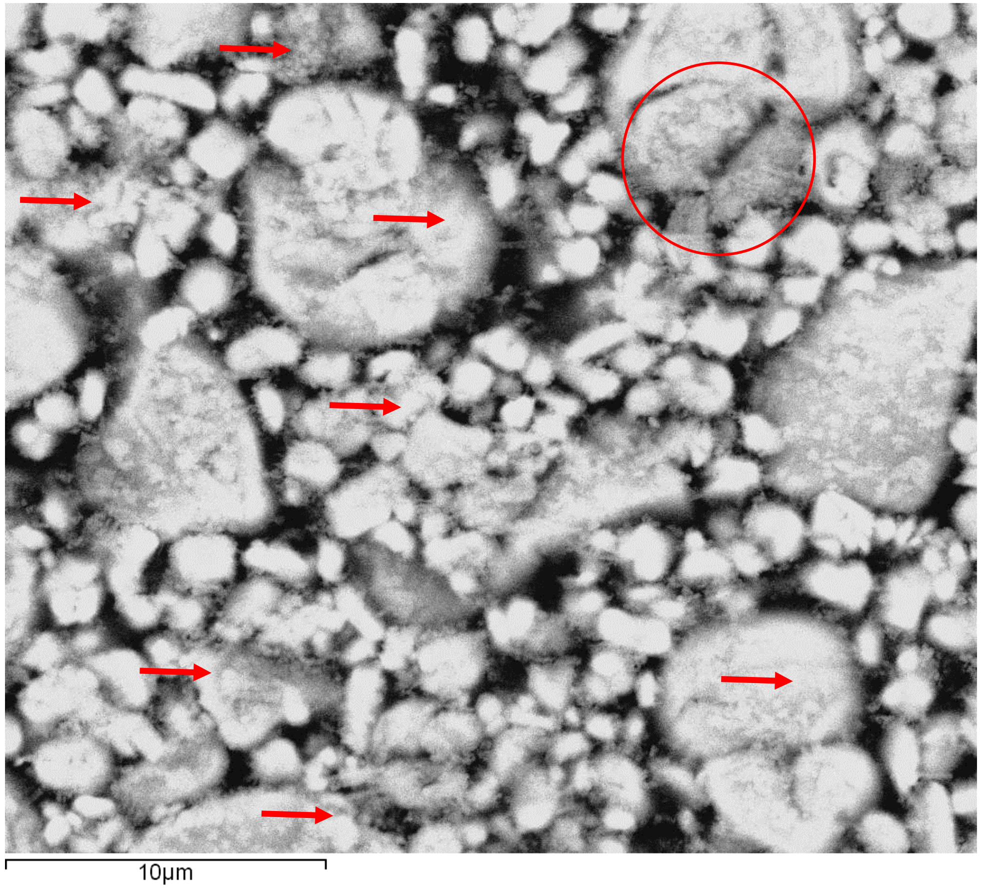




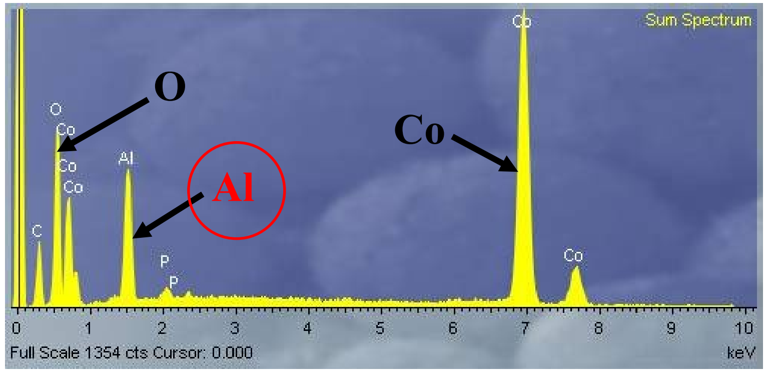
6. Enhance the accuracy of the SEM-EDS analysis results

EDS element mapping analyzed Co, C, and Al from the cathode electrode material.
Al_2O_3 particles of separator coated contaminated the surface of the cathode.
These particles obstruct the view of the $LiCoO_2$ particles and impede particle analysis.

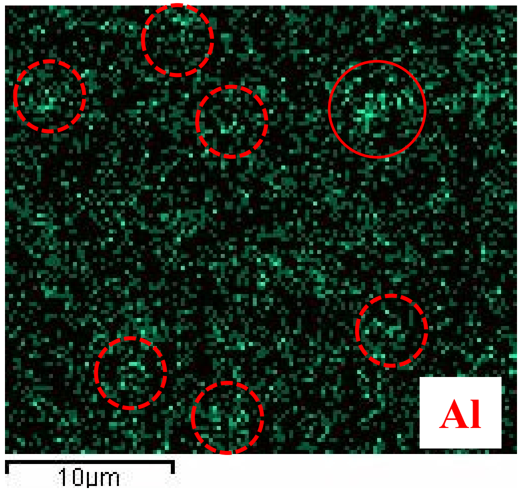
5000x



EDS



EDS element mapping



** The Ion-milling technology can help to clean up the contaminants,* Al_2O_3 *, from the electrode surface.*

* Al_2O_3 *particles detached from the separator surface contaminated the cathode surface.*

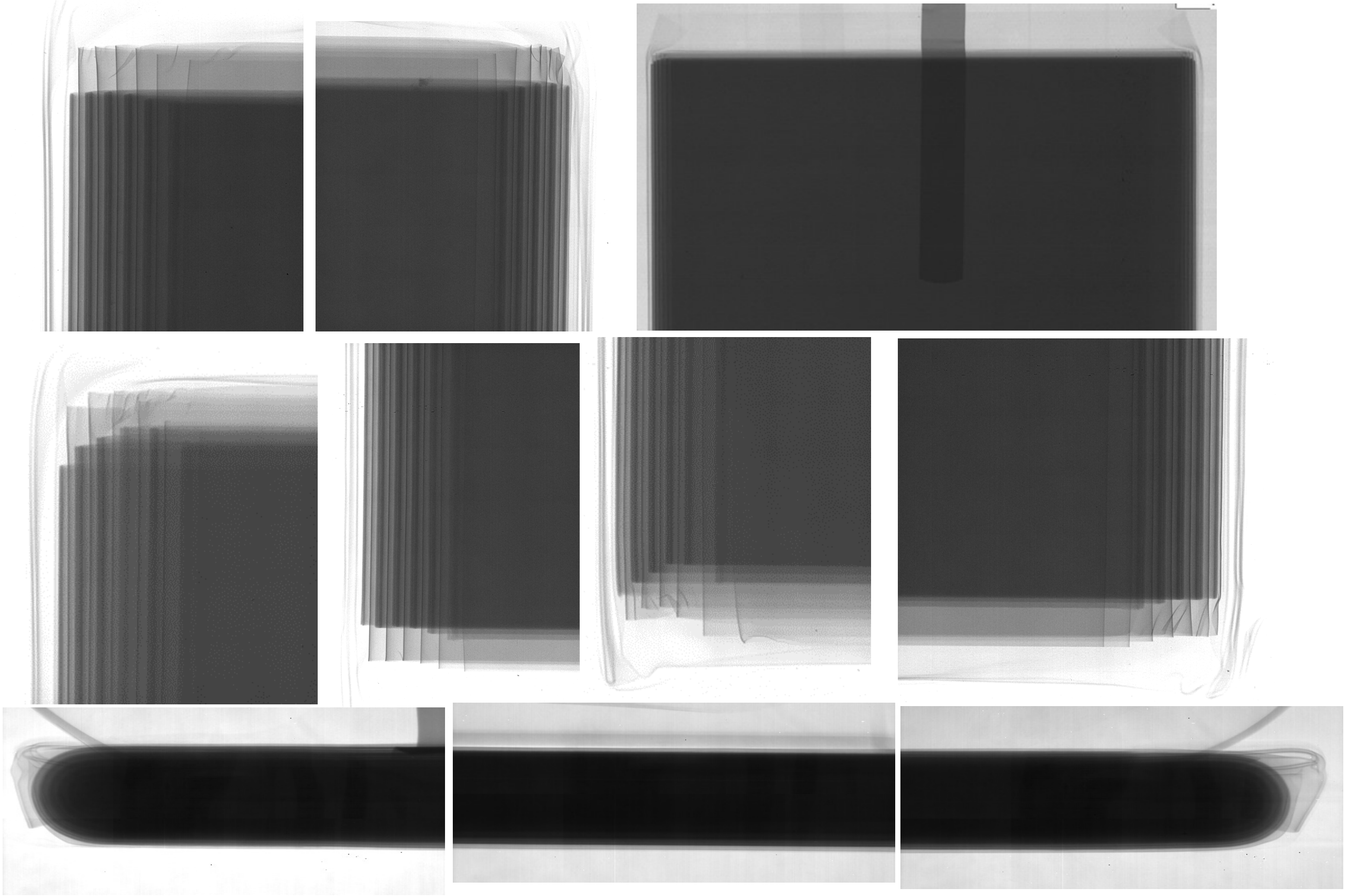
Results and Discussion

Test category and item can be changed according to the purpose of the projects or customers' request.

Test Category	Test Item	Result summary
IQC and Cell Physical Property Check process	IQC Physical Property Check - Visual Inspection, IQC, Dimension, EIS, Capacity, IR	Cell dimension and X-ray tomography results
Cell Characteristics evaluation	Electric Characteristics	Cell Electrical property as a fingerprint of the cell
	Thermal, and Mechanical behavior	Not include in this presentation
Geometry and dimension measurement	Check dimension and insulation mechanism	Example of dimension and insulation mechanism
	Alignment and gap measurement	Example of Alignment and gap measurement
Electrode Material Analysis	Anode/Cathode/Separator/other components	Example of Anode and Cathode
Thickness measurement	Electrodes: Anode/Cathode, Current Collectors: Cu/Al foil, Separator- Ceramic coatings Insulation Tapes and Pouch film	Not include in this presentation
	Anode/Separator/Cathode thickness and cross-section	Example of Anode/Separator/Cathode & Separator
Position of Tab/Welding/Insulate	Position of Tabs in Anode/Cathode	Not include in this presentation
	Welding and Insulate mechanism status	
Electrode Press Density	Experimental and calculation process	Ex. of Process of the Electrode Press Density calculation
Electrolyte Analysis	Electrolyte chemical composition	Example of Electrolyte chemical composition
Cell Dimension Changes	Electrode Dimension charge/discharge, aging	Example of Electrode/cell dimension changes
Safety considerations	Item can be selected by customers' request	Not include in this presentation
Manufacturing site Audit		Not include in this presentation

1) Example of the IQC and Cell Physical Property Check process

a) Example of the investigation of Cell safety risk area by X-ray tomography.



b) Cell dimension measurement

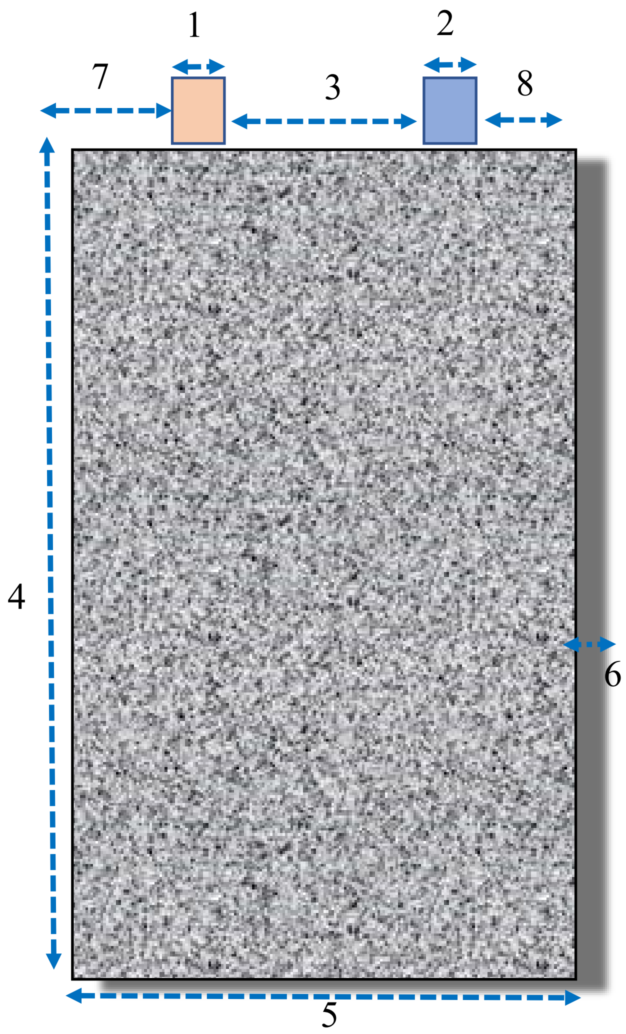
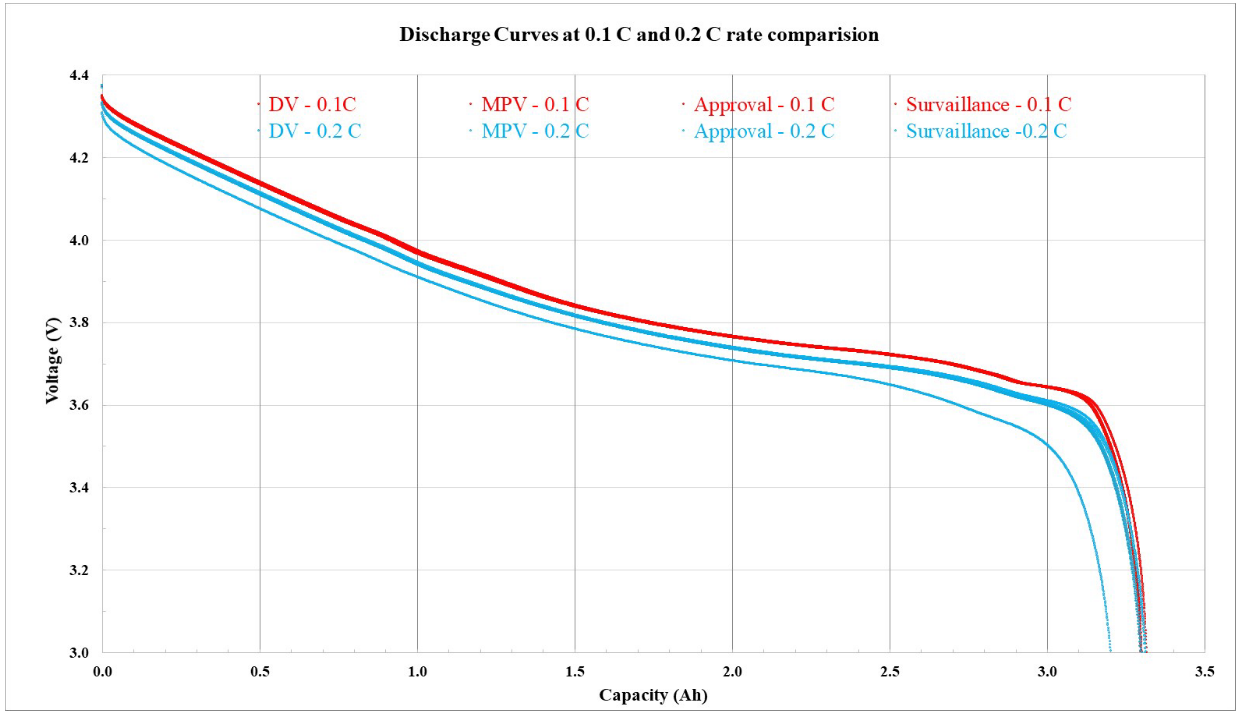


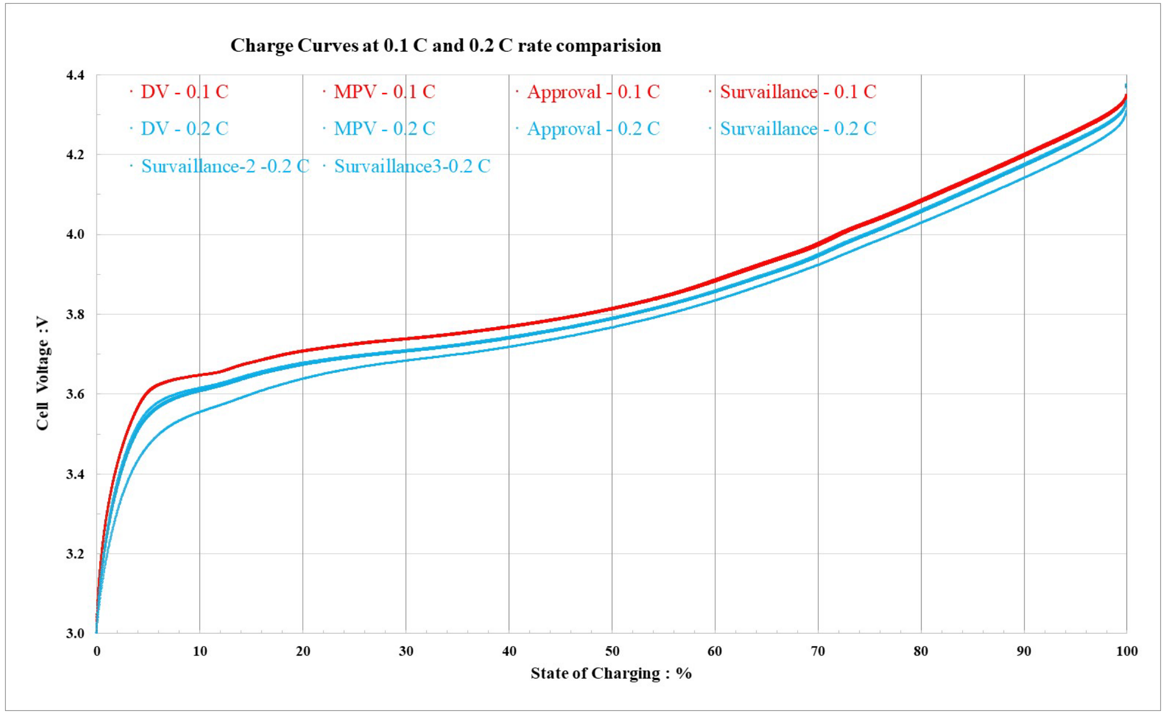
Figure 2. Conceptional introduction diagram of the Cell supply chain management with approval and surveillance program, a) Example of the investigation of Cell safety risk area by X-ray tomography, and b) Cell dimension measurement.

2) Example of Cell Characteristics evaluation: -Electric, - Thermal, and Mechanical behavior

* Electrical Characteristics evaluation

Cell rate performance comparison of each four manufacturing steps with 0.1 C and 0.2 C rate at room temperature condition.





* Rate Performance

dQ/dV plot : differential Capacity analysis of cell

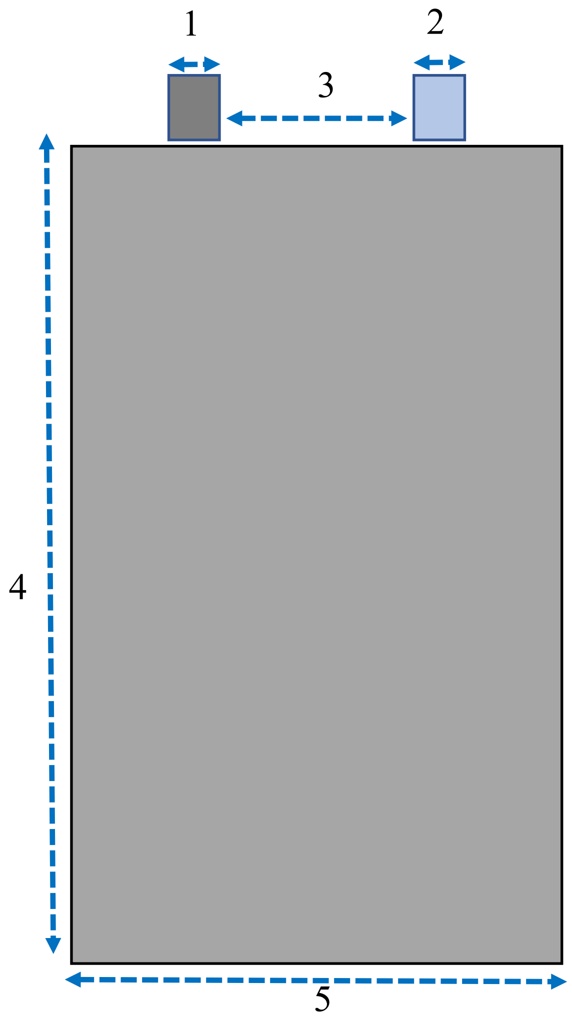
dV/dQ plot : differential Voltage analysis of cell

*Temperature behaviors.
- Operating temperature
- Safety : ARC

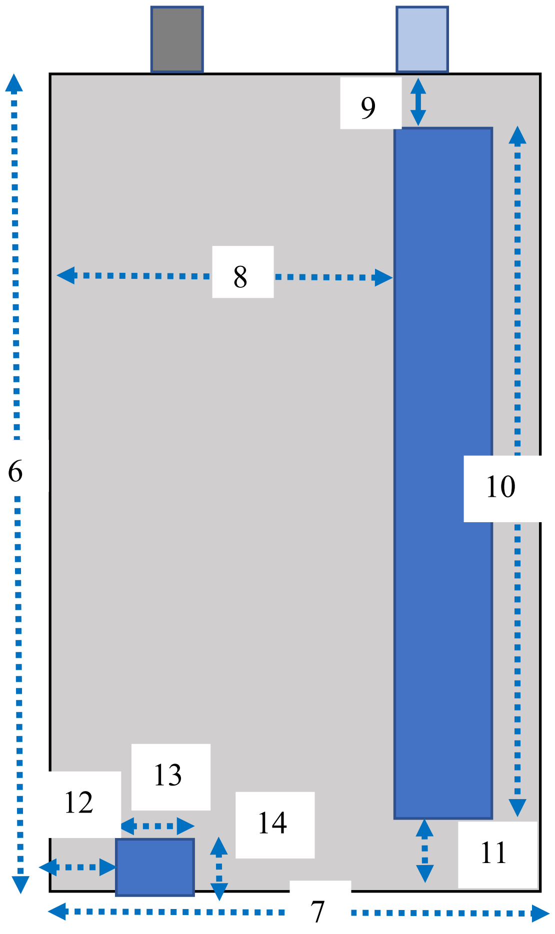
3) Example of the Electrode Assembly (Jelly Roll) dimension

Conceptional introduction diagram of the Cell Electrode Assembly, insulation tape, and an example of the management dimension management for the Cell supply chain management with approval and surveillance program. a) Schematic of the Electrode Assembly, b) Schematic of the Insulation Tape Position, and c) Example of the Electrode Assembly Measurement data.

a) Schematic: Electrode Assembly



b) Schematic of the Insulation Tape Position

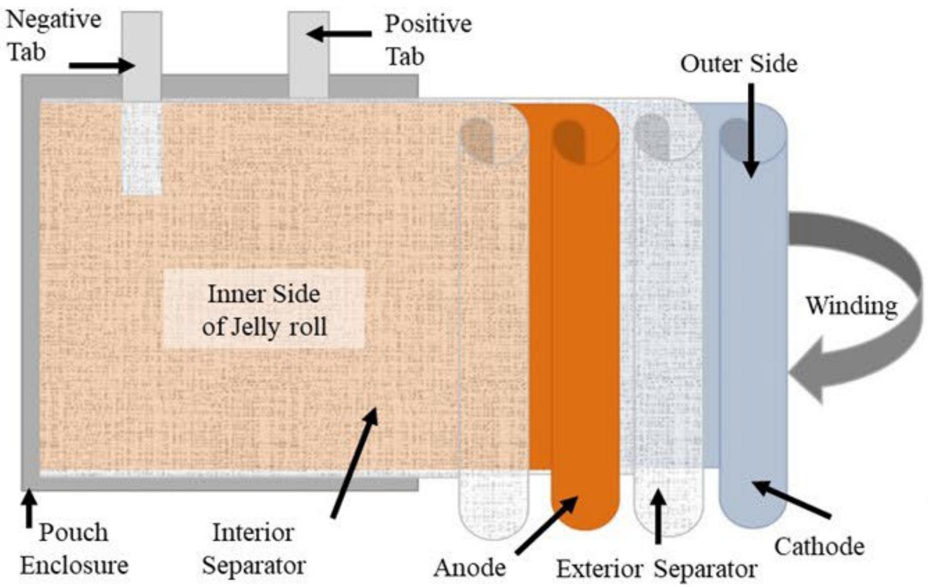


c) Example of the Electrode Assembly Measurement data : mm

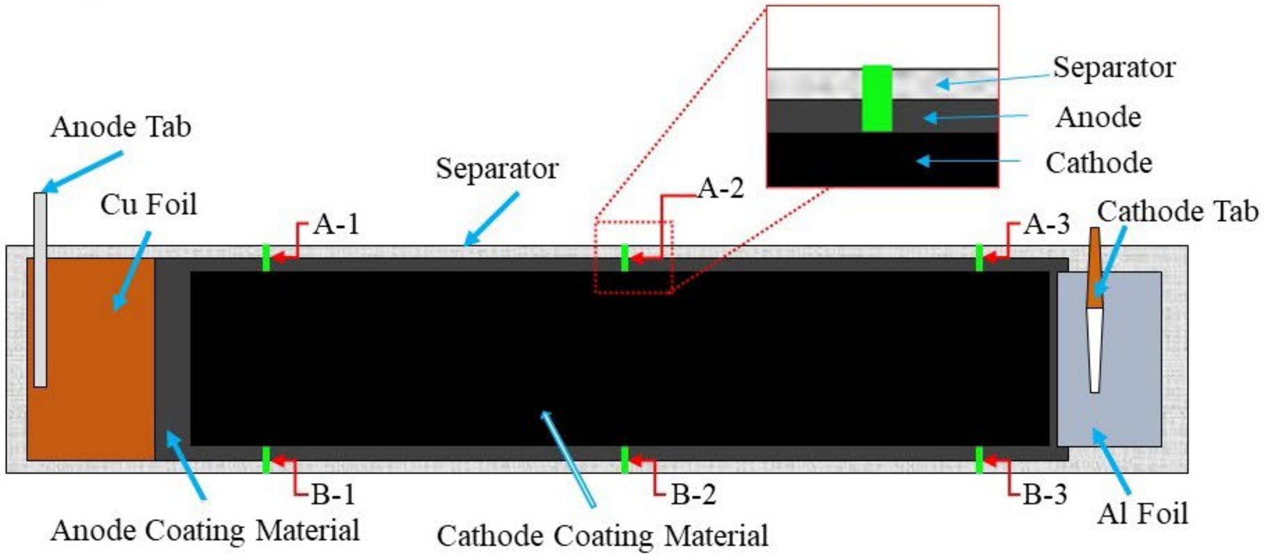
	DV	MPV	Approval	Surveillance
1	3.9	3.8	3.9	3.8
2	3.9	4.0	3.9	3.9
3	7.3	7.4	7.3	7.4
4	106.0	107.0	107.0	106.0
5	50.1	50.0	50.1	50.0
6	103.1	103.2	103.2	103.1
7	48.9	48.9	49.0	49.0
8	32.6	32.3	29.8	29.9
9	7.6	7.7	7.8	7.9
10	90.8	89.0	82.2	82.0
11	11.0	10.5	11.0	11.0
12	16.0	17.0	25.0	26.0
13	8.1	7.9	7.7	7.6
14	14.0	13.8	11.0	11.0

4) Example of the Alignment and Gap measurement - Separator-Anode-Cathode

a) Schematic of the Electrode Assembly Alignment Layout
Separator-Anode-Separator-Cathode



b) Schematic the concept of Electrode Alignment check and Gap measurement
Separator cover all area of Anode and Anode cover all area of Cathode



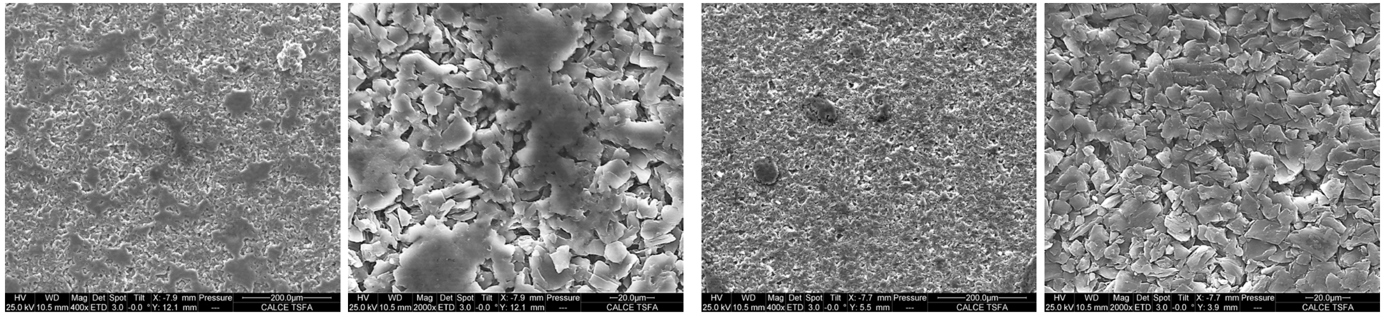
c) Gap measurement results among the Separator – Anode electrode – Cathode electrode

Distance the gap between Separator film and anode electrode : mm						
Cell	Top, Left	Top, Middle	Top, Right	Bottom, Left	Bottom, Middle	Bottom, Right
DV	1.246	0.840	0.698	0.863	0.627	0.953
MPV	0.978	0.636	0.703	0.527	0.607	0.567
Approval	1.251	0.649	1.114	0.725	1.023	0.685
Surveillance	1.004	0.918	0.798	0.734	0.753	0.860
Distance the gap between Anode and Cathode electrode : mm						
	Top, Left	Top, Middle	Top, Right	Bottom, Left	Bottom, Middle	Bottom, Right
DV	0.812	0.518	0.535	0.495	1.021	1.102
MPV	0.817	0.730	0.548	0.530	0.498	0.681
Approval	0.656	0.756	0.642	0.783	0.661	0.764
Surveillance	0.649	0.572	0.628	0.827	0.871	0.729

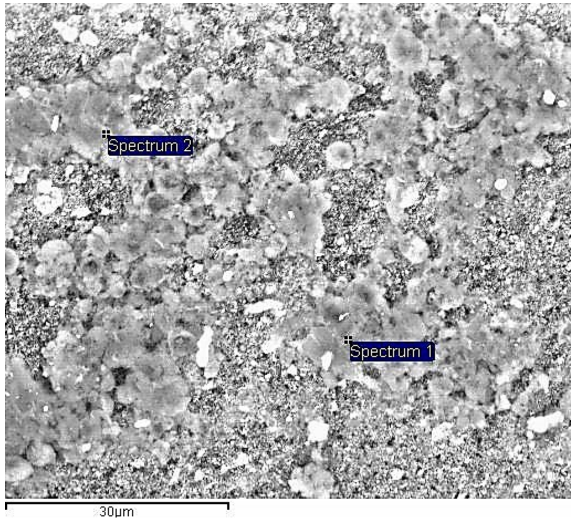
5) Example of the Electrode Material Analysis

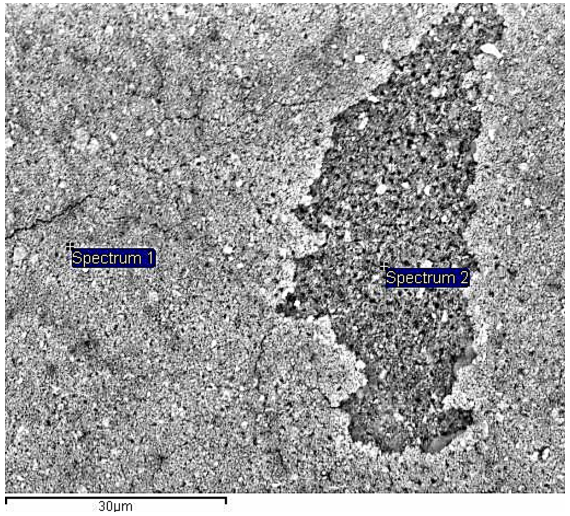
Anode surface and Materia analysis

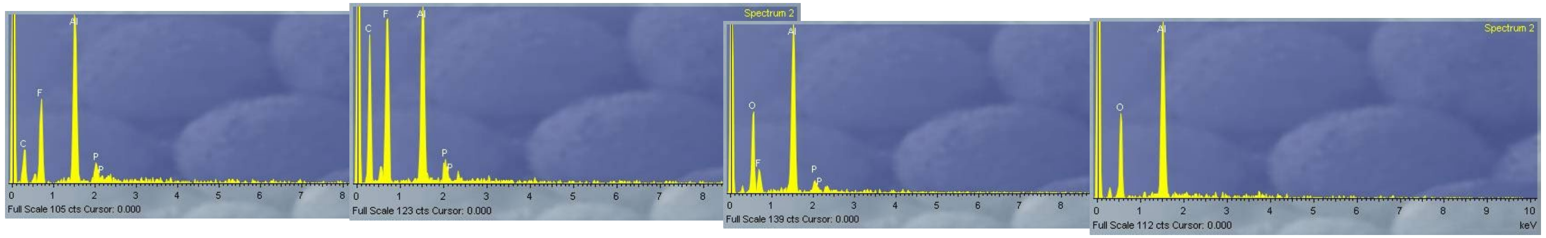
Step-1 Step-2



Separator surface and Materia analysis





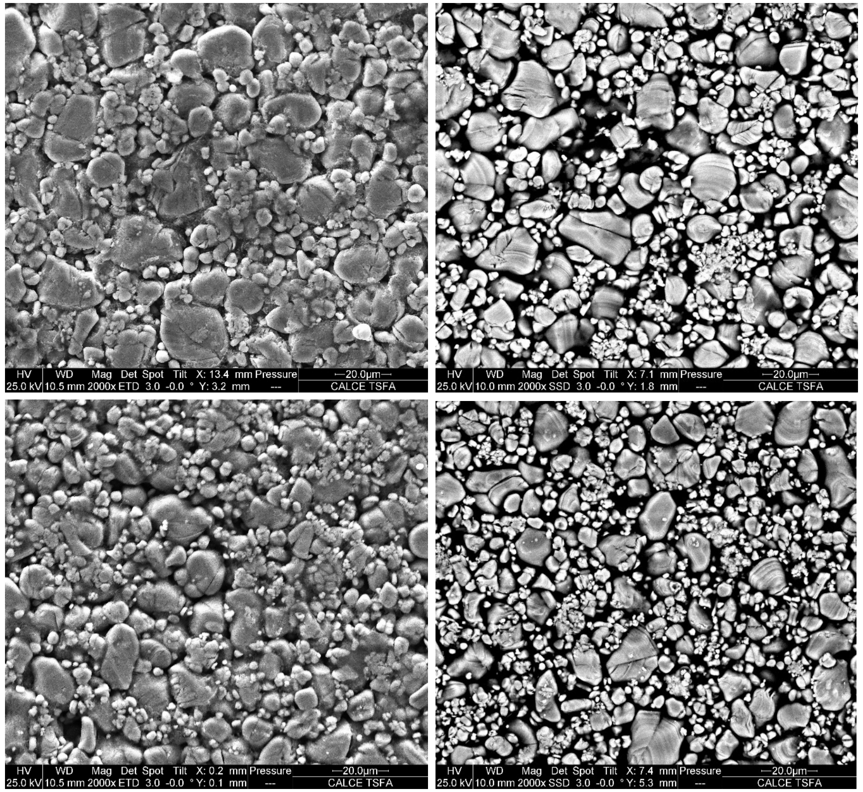


Cathode material Comparison between Step-1 & Step-2

Step-1 Step-2

Front

Back

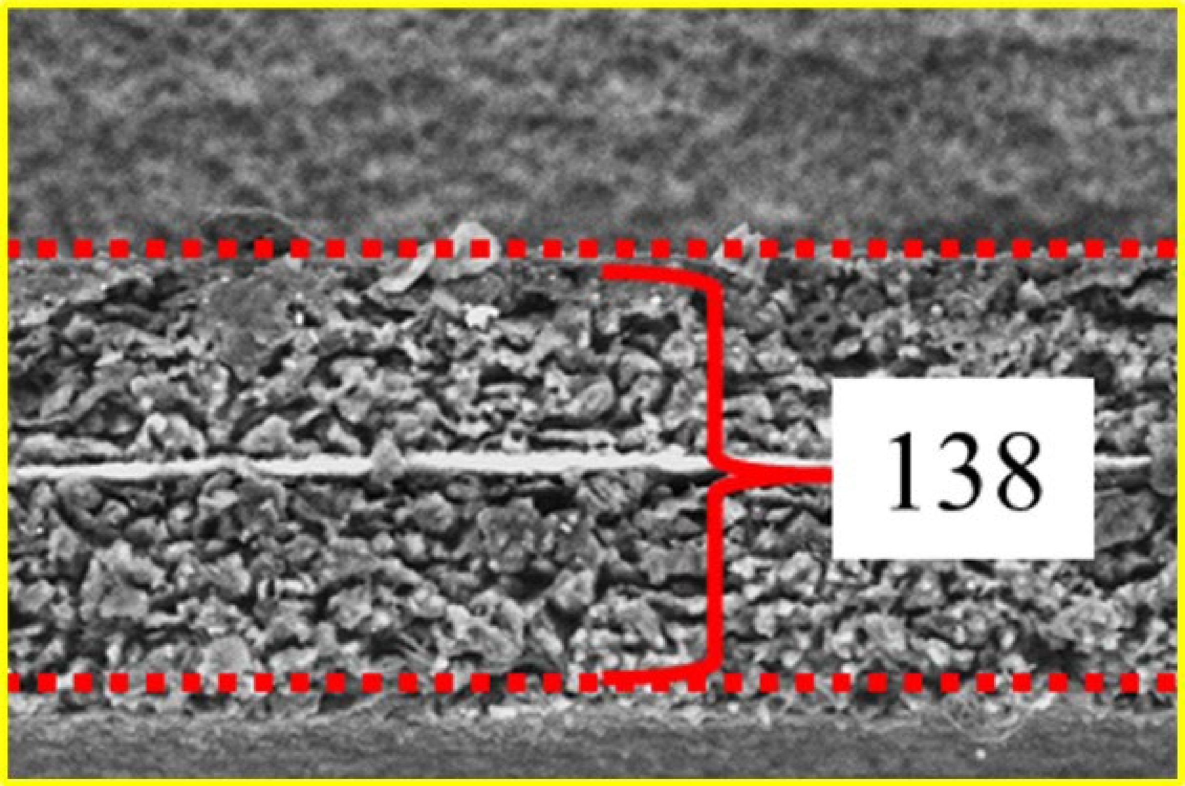


Comparison of cathode material characteristics between Step-1 and Step-2

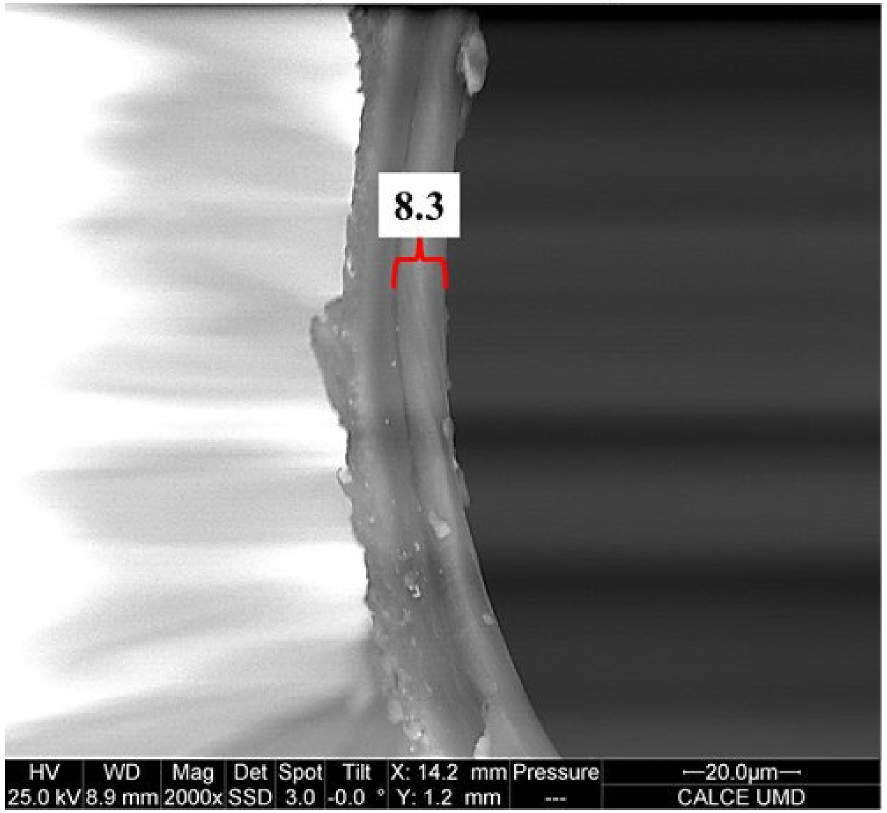
Property	Step-1	Step-2
Particle number	330 ~ 359	376 ~ 402
Average Particle size	23.1 ~ 25.2	25.8 ~ 29.1
% of particle in electrode	40.6 ~ 43.2	47.4 ~ 49.1

7) Example of the Thickness measurement- Electrode and separator

Example *of the* Electrode Thickness measurement



Example *of the* Separator Thickness measurement



Electrode Thickness Measurements (microns)

Electrode	Step-1	Step-2
Anode	138	138 - 150
Cathode	162	108 - 130

Separator Thickness Measurements (microns)

Electrode	Step-1	Step-2
Separator - 1	6 ~ 7	7 ~ 8
Separator - 2	7 ~ 8	8 ~9

8) Process of the Electrode Press Density calculation

1) Procedure

Cell DPA

Cut electrode with the Sample size

Washing electrode with DMC

Vacuum Dry

Measure Weight & Dimension

Remove electrode material from Current collector foil with electrode binder solvent.

Remove the electrode material with brush and Dry the foil

Measure Weight & Dimension of Current collector foil

Calculate the press density

2) Calculation Process

a) Electrode Press density

Weight of the electrode Material ÷ Volume of the electrode Material

b) Weight of the electrode and Volume of the electrode

Weight of electrode = Weight (Active material + Conductive Carbon + Binder + Current collector)
Volume of electrode = Volume (Active material + Conductive Carbon + Binder + Current collector)

c) Weight of the electrode Material and Volume of the electrode Material

Weight of electrode Material = Weight (electrode - Current collector)
Volume of electrode Material = Volume (electrode - Current collector)

d) Volume of the electrode Material and Current collector

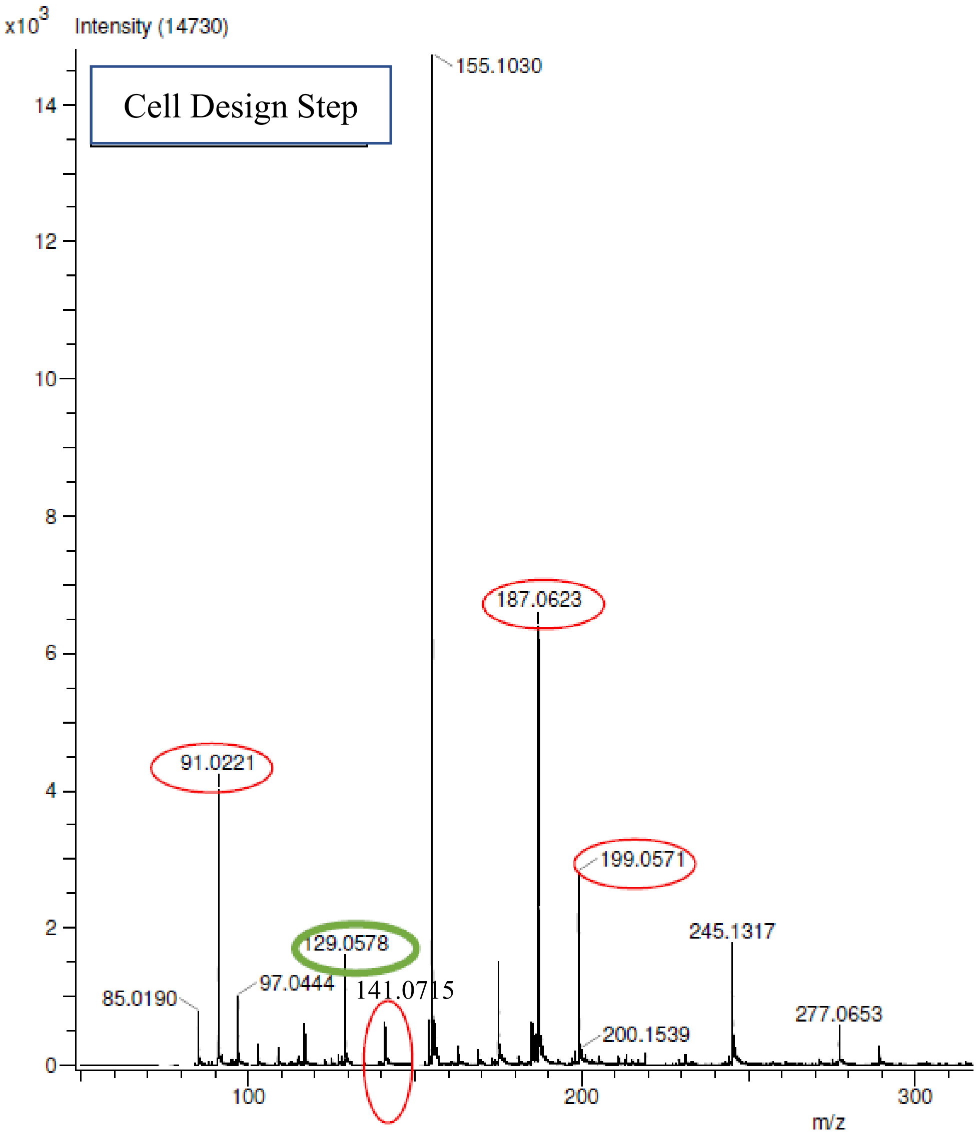
Volume of electrode Material = area (width x length) x thickness of electrode Material
Volume of electrode Current collector = area (width x length) x thickness of Current collector

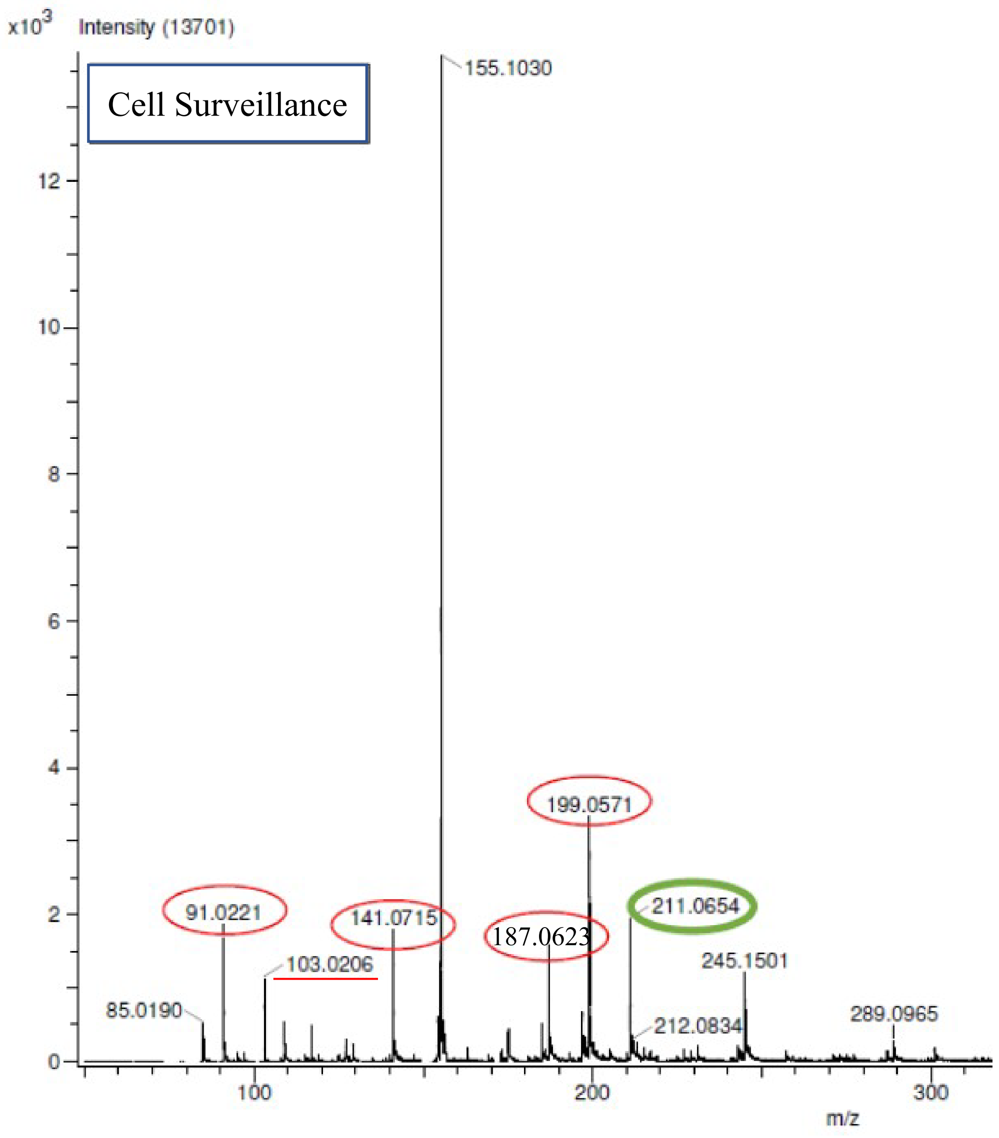
e) Thickness of the electrode Material and Current collector

Thickness of electrode Material = measured by SEM = (Electrode – Current collector) Thickness
Thickness of Current collector = measured by microscope

9) Example of the Electrolyte chemical composition Analysis

Examples of electrolyte analysis :two cell manufacturing steps. Comparison the main peak at m/z = 85 ~ 300area.

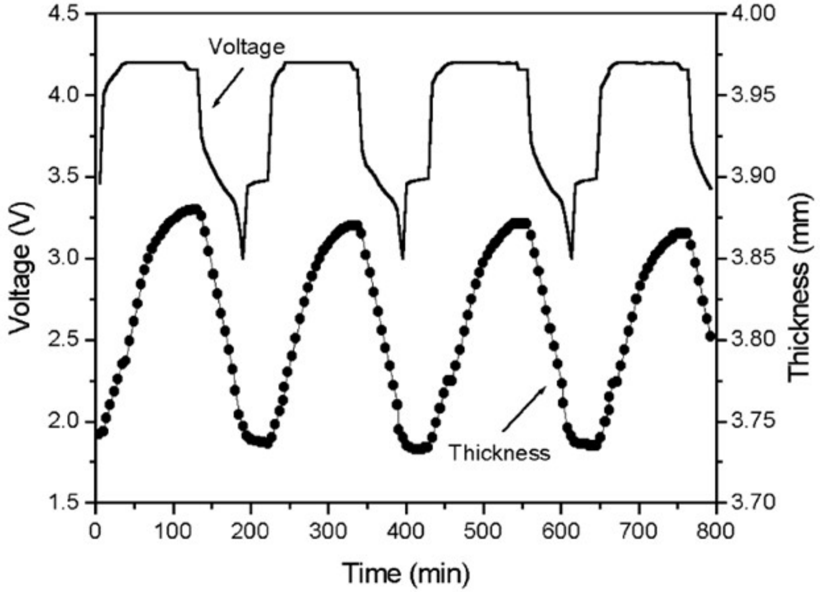




10) Dimension Changes by charge/Discharge, cell aging

Electrode/cell dimension changes during charge & discharge ➔ all factors must be fully understand & considered.

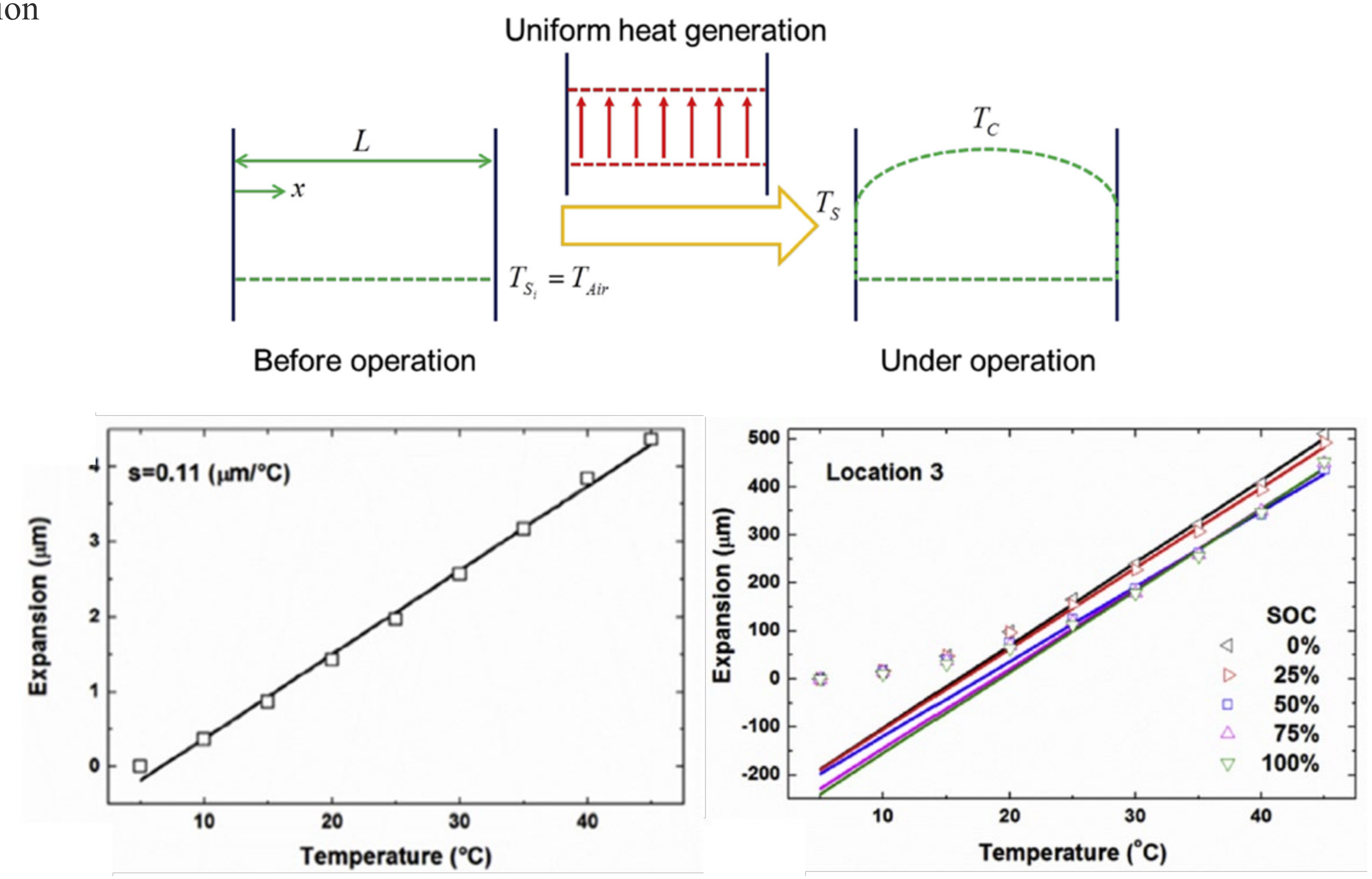
Battery dimensional changes occurring during cycles
-Expansion/contraction of host materials due to Li intercalation
-Electrode volume increase by irreversible reaction deposits
-Dead volume/pressure changes within cell



a) In situ thickness measurements of LiB cell during charge/discharge cycles

Ref.: J.H. Lee /J. of Power Sources 119–121 (2003) 833–837

Thermal expansion of the cell as the functions



Ref.: Journal of Power Sources 303(10):86-96 (2016)

Summary and Conclusion

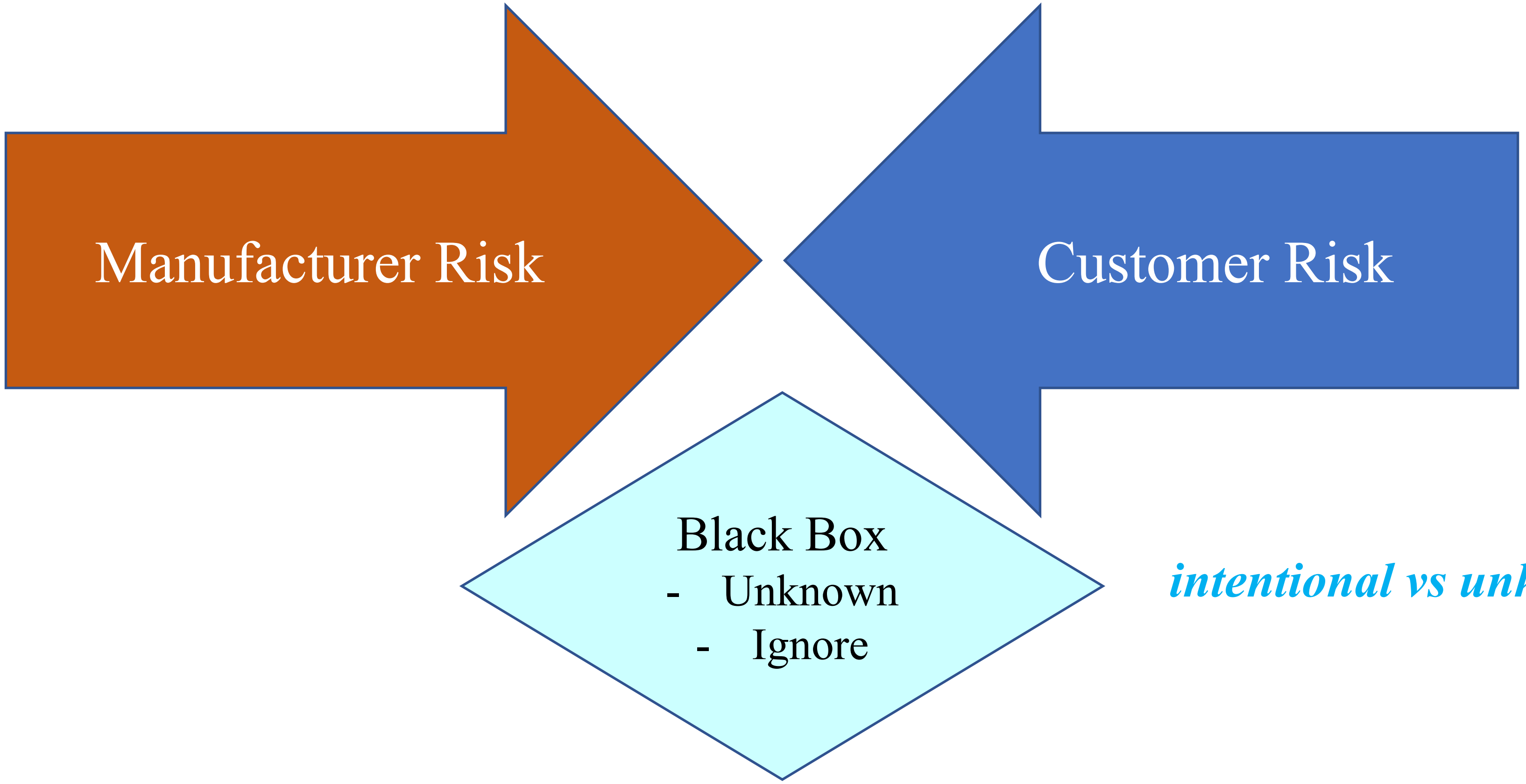
Generate a technical database of all the analysis results to create a fingerprint library of each cell lot.

That enables user can keep /manage its cell quality and supply chain consistency and monitor/manage any changes in the product by comparing cell characteristics among each cell lot through the database library.

Conceptional introduction diagram of the Cell supply chain management with approval and surveillance program.

➔ This program can apply for both Cell manufacturers and Devices OEMs.

Quality Risk Management (QRM) and Decision-making process



intentional vs unknown

Benefit of Cell Supply Chain Management & Surveillance Test Program

1. ***Generate a fingerprint of each cell model and lot: Performance and Safety & Reliability.***

2. ***Keep & manage the cell quality with high consistence****: supply chain system - material and cell.*

3. ***Monitor and control any changes in the cell and its material.***

4. ***Quick systematic response to quality complains and battery incidents.***

   - Causal Analysis and Resolution, - Root cause Analysis, - Corrective actions, - Recall decision.

5. ***Provide the solution for new model launching and verification of the new Chemistry/Material/Concept/Process of cell.***