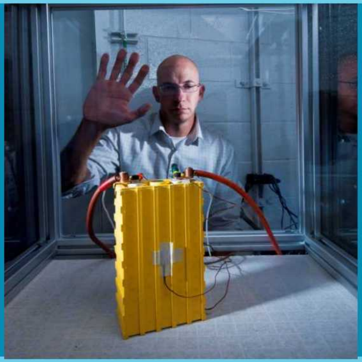
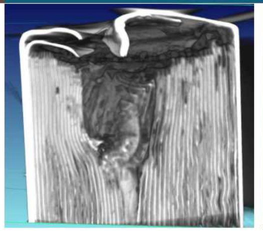
SAND2019-0291PE

Battery Abuse Laboratory Operations





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Outline

- **Introduction**
  - ✓Power Sources Technology Group
  - ✓BATLab capabilities
  - ✓Current BATLab projects
- **Determination of Battery Stability Through Advanced Diagnostics**
- **Ex-Situ Analysis of Abused Cells**
- **Future Work**
- **Acknowledgements**

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Power Sources Technology Group (2540)

- Mission: Advance power source technologies to meet present/future energy needs
- Research, design, & develop power sources for NNSA, DOD, DOE, DOT, and commercial applications
- Cradle-to-grave research
- Production of thermal batteries, thermoelectrics, lithium primary/secondary batteries, novel battery chemistries, component & materials surveillance, and battery abuse testing

Battery Abuse Testing Laboratory (BATLab) Capabilities

Comprehensive abuse testing platforms for determining safety and reliability of cells & battery packs (from Wh to kWh)

- Customers: DOD, DOE, DOT, NNSA, & private companies

<u>Mechanical abuse</u>

- Penetration
- Crush
- Immersion

<u>Electrical abuse</u>

- Overvoltage/overcharge
- Short Circuit
- Overdischarge/voltage reversal

<u>Thermal abuse</u>

- Excessive temperatures
- Thermal propagation
- Calorimetry

Current Laboratory Projects

- Determination of Battery State of Stability Through Advanced Diagnostics
- Impact of Initiation Methods on Propagating Thermal Runaway in Li-ion Batteries
- Mitigation of Failure Propagation in Multi-Cell Lithium Ion Batteries
- Li-ion Battery Propagation Trigger Technique Development (Laser)
- XFC - Extreme Fast Charge Project

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How do you know if a potentially abused battery is unsafe or unstable?

2013 Boeing Dreamliner Battery Fires, FAA Grounds Fleet

Voltage and temperature are often lagging indicators of a battery failure.

By the time a measurable trend is detected, it may be too late to arrest a catastrophic thermal runaway.

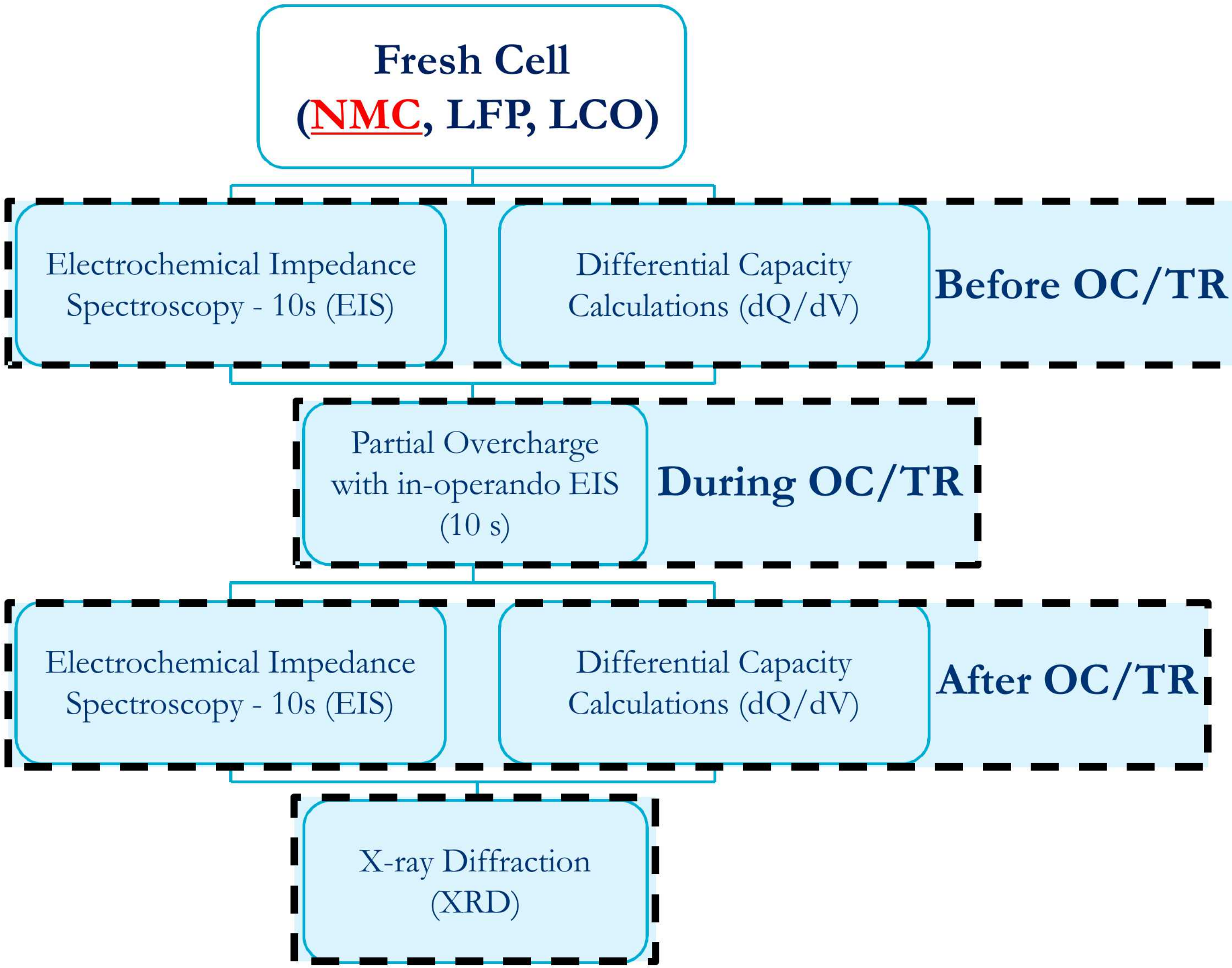
Batteries may also be unstable due to previous exposure to abusive conditions, but show little sign of problems during initial monitoring.

Tested Cells

10 Ah NMC Cells

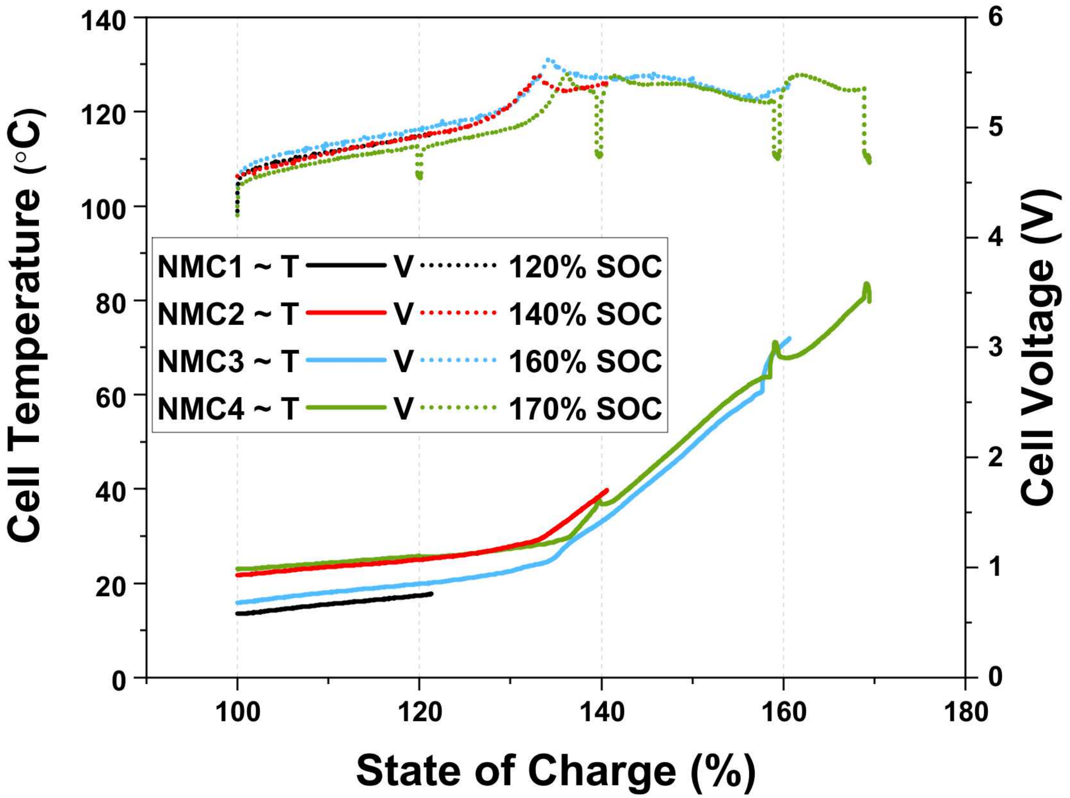
Nominal Voltage	**3.7 V**
Nominal Capacity	10 Ah
Charge Current	Standard 0.2C (1C max.)
Charge cut-off V	4.2 V
Discharge Current	Standard 0.2C (5C max.)
Discharge cut-off V	2.75 V
Dimensions	141.2 mm x 91.0 mm x 9.2 mm (LxWxH)
Weight	240 g

Methodology and Approach



OC/TR – Overcharge/Thermal Ramp

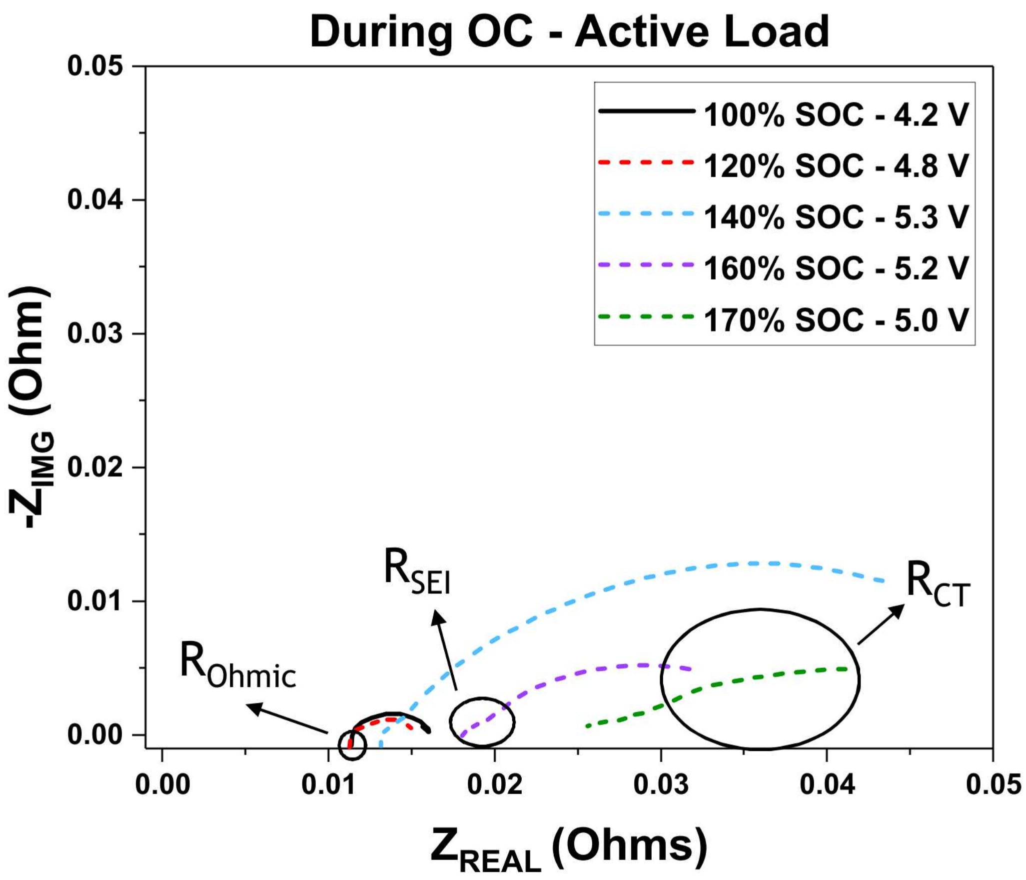
Overcharge Effects to Cell Temperature and Voltage

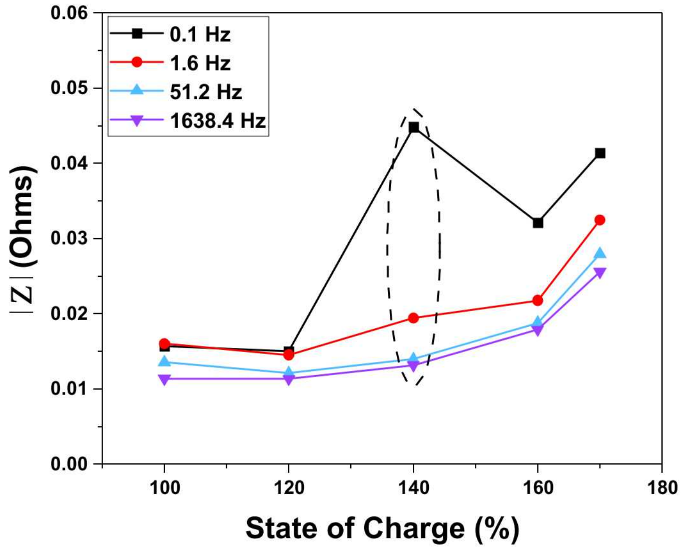


Four individual cells, NMC1, NMC2, NMC3 and NMC4, are overcharged to 120%, 140%, 160%, and 170% SOC, respectively.

	Initial T (°C)	Max. T (°C)	ΔT (°C)
NMC1-120%	13.5	17.7	4.2
NMC2-140%	21.7	39.8	18.1
NMC3-160%	15.9	71.9	56.0
NMC4-170%	23.0	83.5	60.5

NMC4 - 170% SOC: In-operando EIS

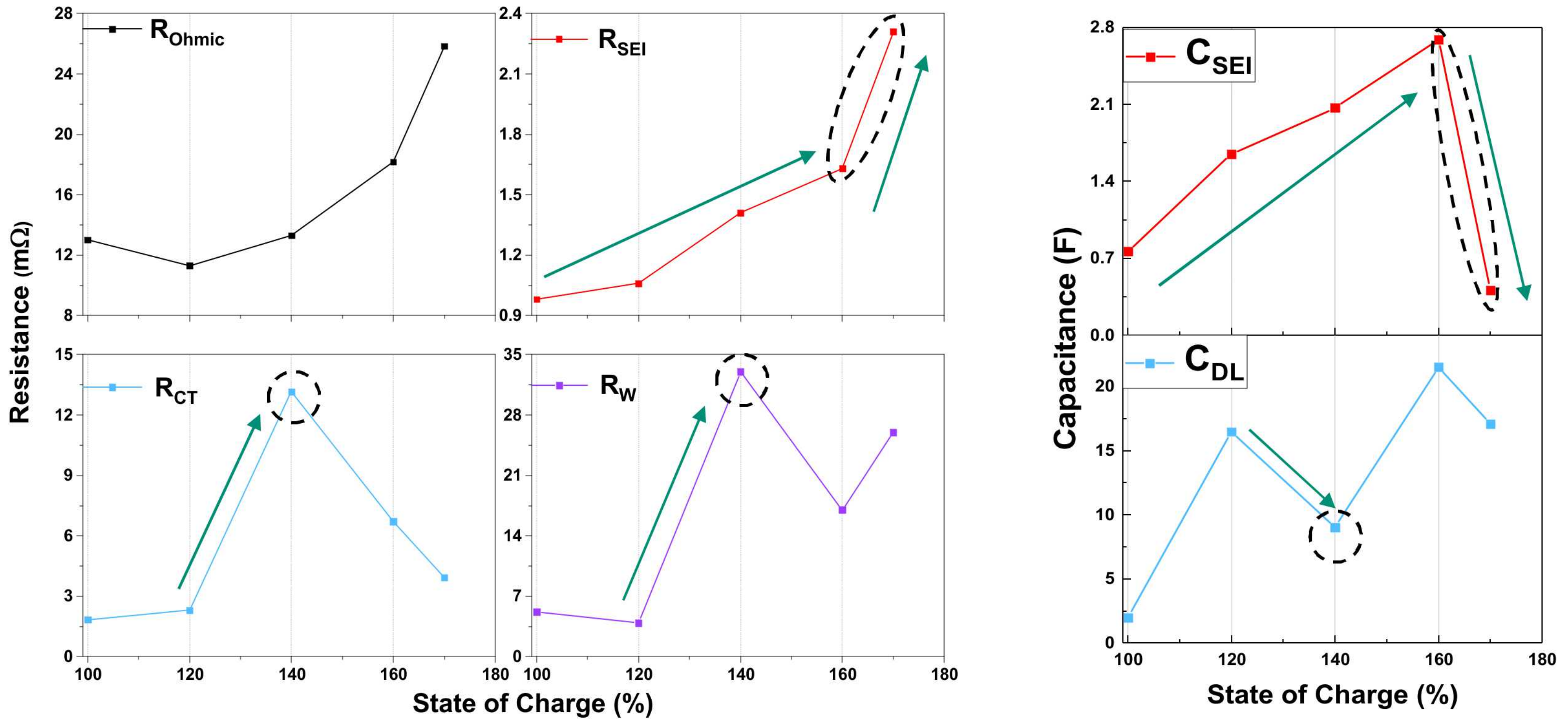


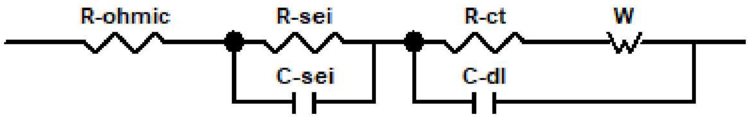


$$|Z| = \sqrt{Z_{REAL}^2 + Z_{IMG}^2}$$

- R_{ohmic} increase at higher states of charge above 120% SOC. The change is associated with conductivity loss within the cell components.

NMC4 - 170% SOC: In-operando EIS

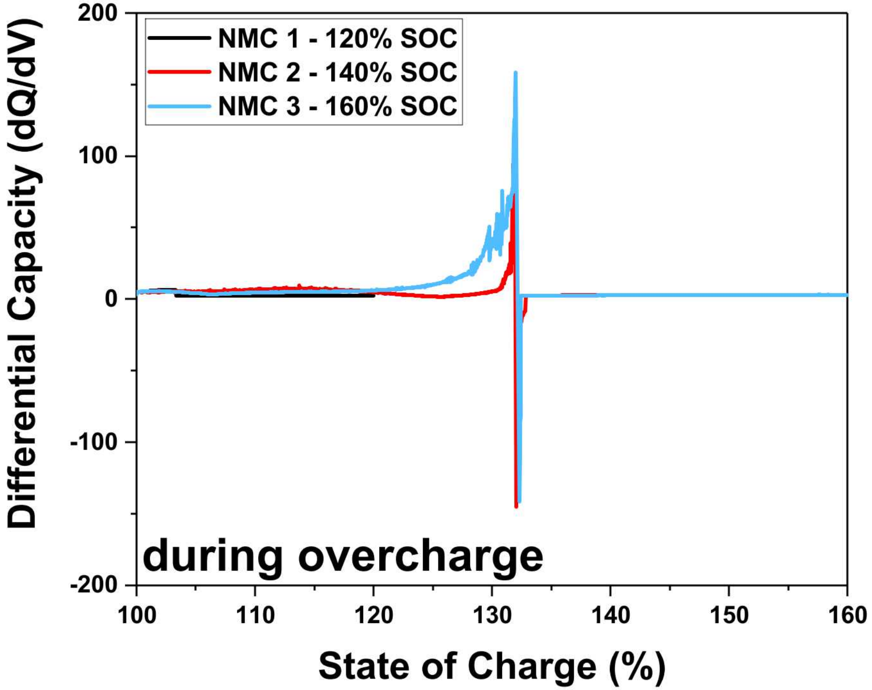


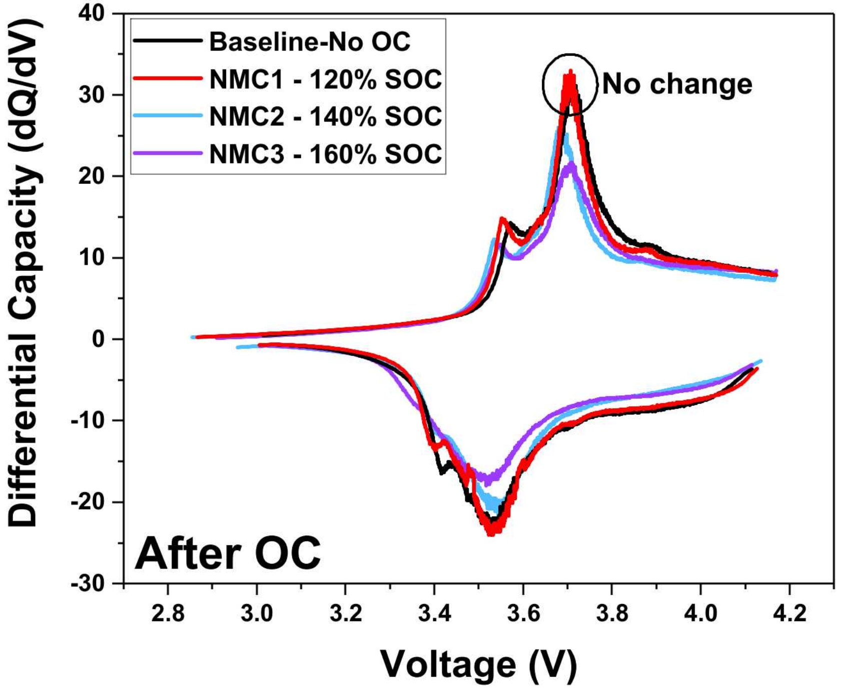


Equivalent Circuit

- The R_{SEI} slightly increased after each level of overcharge as well as the C_{SEI}, which could indicate a growth in the SEI layer.
- The R_{CT} significantly increased after 140% SOC and subsequently decreased for high SOC's.

Differential Capacity (dQ/dV)





- The differential capacity for NMC1 (120% SOC) exhibits no change in the redox processes of the cell.
- NMC2 and NMC3 presented a decreased dQ/dV, characteristic of loss of active material.
- The dQ/dV calculated during the OC procedure identified a redox reaction between 130-135% SOC.

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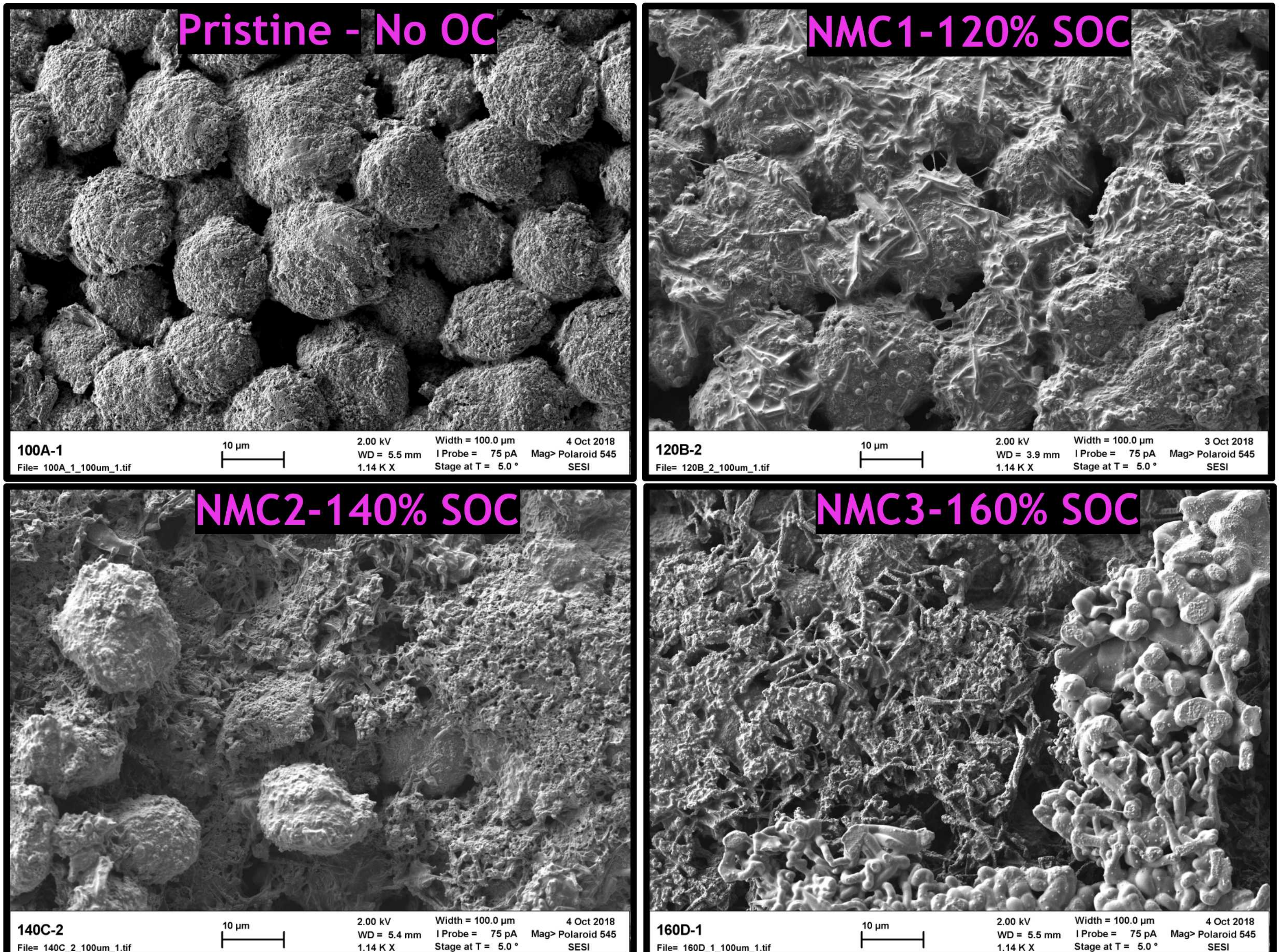
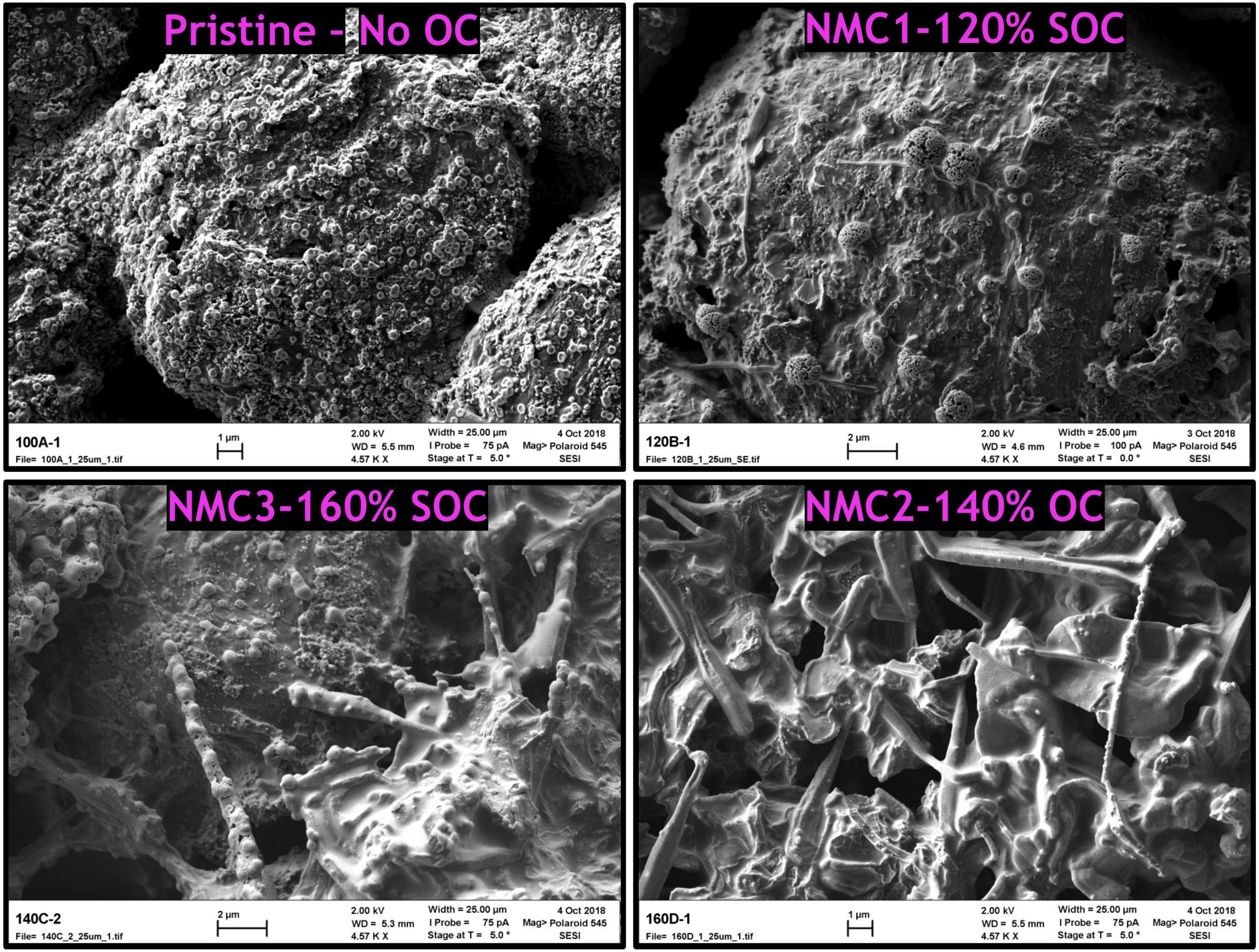
Disassembly Images

Microstructural Changes in Anode (100µm lense)



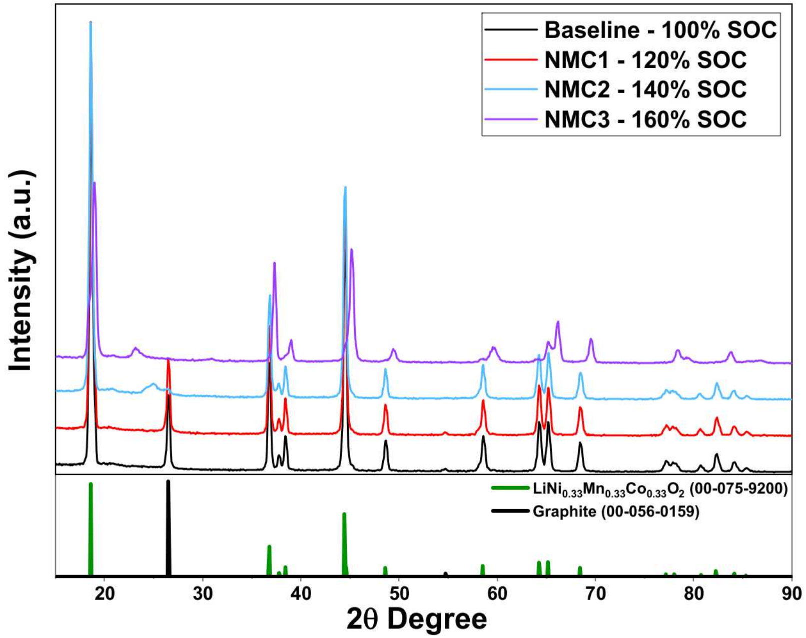
SEM – Amy Allen and Barry Ritchey (2555)

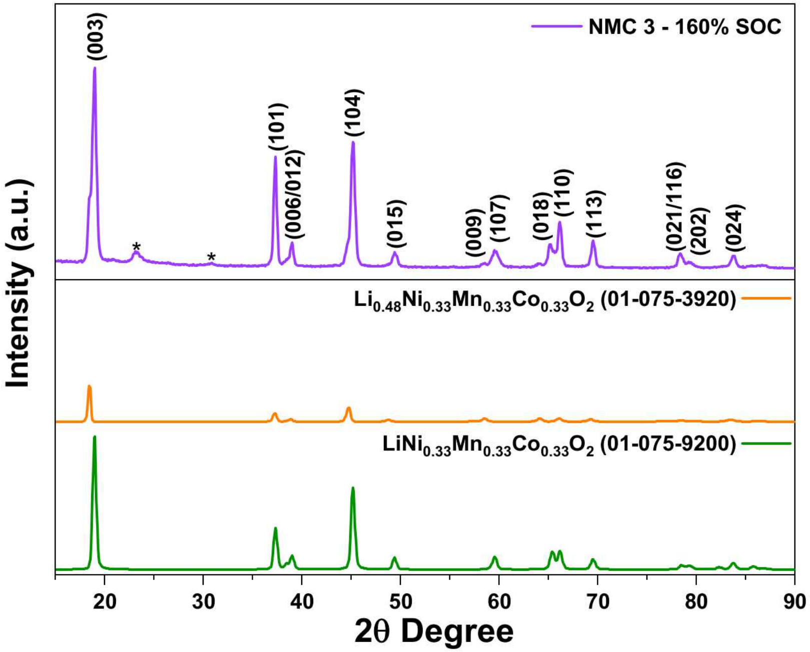
Microstructural Changes in Anode (25μm lense)



SEM – Amy Allen and Barry Ritchey (2555)

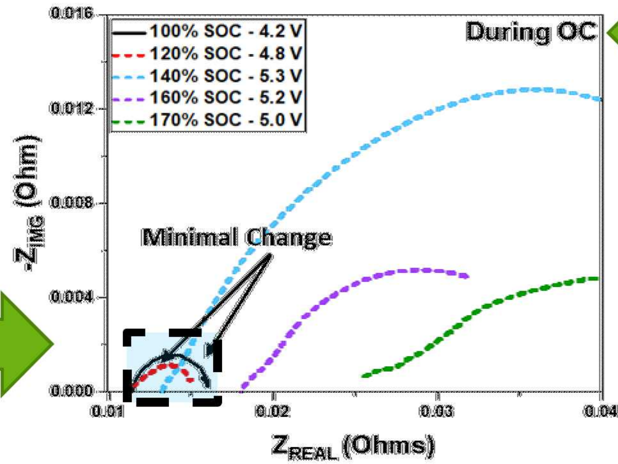
X-ray Diffraction (XRD): Cathode



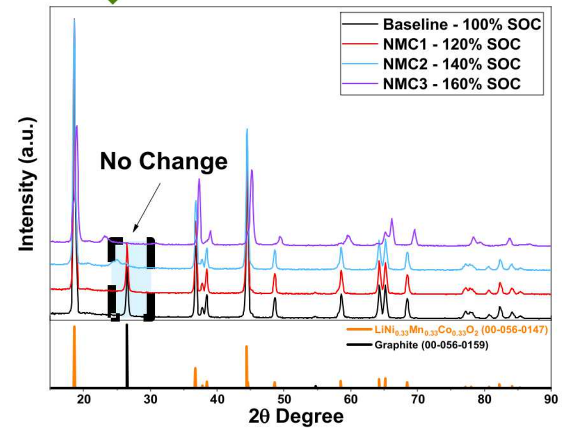


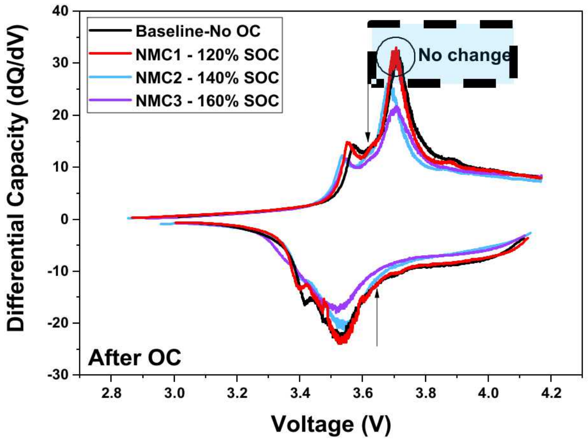
- XRD diffractograms of the cathode revealed significant changes for SOC's > 140%.
- NMC3 (160% SOC) diffraction peaks were shifted to higher degree values, indicating a general shrinkage of the lattice.
- Rietveld refinement for NMC3 (160% SOC) based on lithiated vs. delithiated NMC, presented a combination of phases with 86% lithiated NMC and 14% delithiated NMC, suggesting a decomposition of the cathode and loss of lithium inventory.

Electrochemical Impedance Spectroscopy during overcharge procedure



X-ray Diffraction (Cathode)

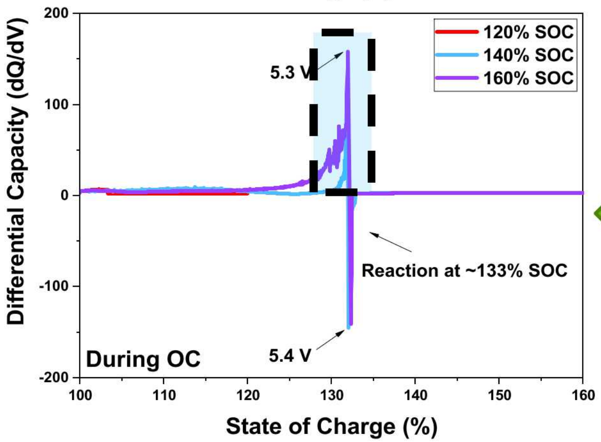


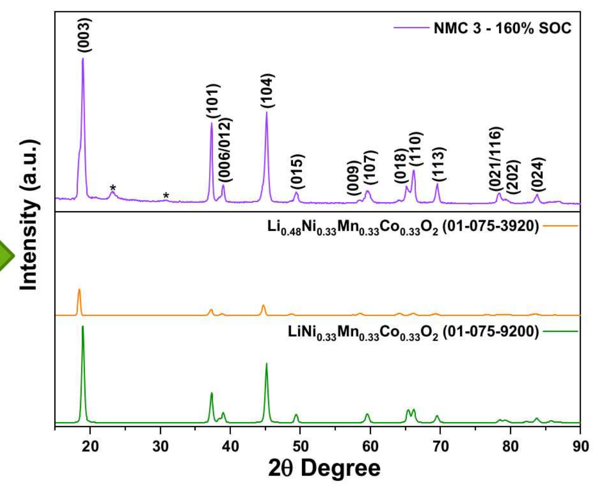


Differential capacity of the cell during & after overcharge

Rietveld Refinement for 160% SOC

Phase	% (+/- 5%)
Lithiated NMC	86
Delithiated NMC	14





Harvested from NMC3 – 160%SOC

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Acknowledgements

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