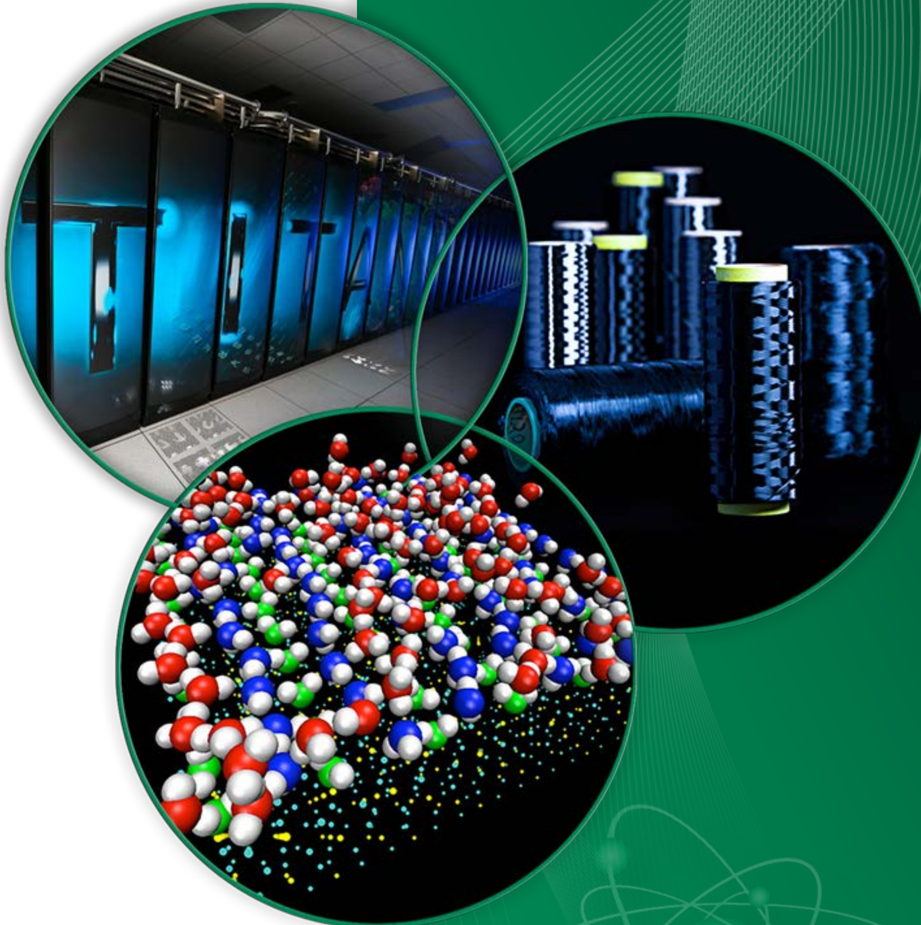
Electrode Coating Defect Analysis and Processing NDE for High-Energy Lithium-Ion Batteries



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ES165

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Overview

Timeline

- Project Start: 10/1/14
- Project End: 9/30/19
- Percent Complete: 10%

Barriers

- Barriers addressed
  - By 2020, further reduce EV battery cost to $125/kWh.
    - Materials processing cost reduction and electrode quality control (QC) enhancement.
  - Achieve deep discharge cycling target of 750-1000 cycles for EVs (2020).

Budget

- Total project funding
  - $9050k
- $1475k in FY15

Partners

- Interactions/Collaborations
  - Equipment Suppliers: Frontier Industrial Technology, Keyence, FLIR
  - Battery Manufacturers: XALT Energy, Navitas Systems
  - Materials Suppliers: TODA America, Superior Graphite
  - National Laboratories: ANL, NREL
- Project Lead: ORNL

Relevance & Objectives

- Main Objective: To reduce the amount of scrap electrode by at least 75% and the associated amount ***assembled into finished cells***.
  - Reduce lithium ion battery system cost by implementing in-line NDE and electrode QC.
  - Quantification of effects of different defect types on rate performance and cell lifetime.
  - Identify manufacturing defects and their relation to cell failure.
  - Implement materials characterization to investigate the cell failure mechanism(s).
  - Collaborate with battery makers for QC technology development.
  - IR thermography for electrode coating defects (agglomerates, pinholes, blisters, divots, metal particles, etc.).
- Relevance to Barriers and Targets
  - Implementation of critical QC methods to reduce scrap rate by ***creating feedback loops*** (by 2020, reduce EV battery cost to $125/kWh).
  - Quantification of various defect effects on cycle life (to achieve 750-1000 cycles for EVs by 2020).

Project Milestones

Status	SMART Milestones	Description
1/2015 ✓	FY15 Milestone	Develop methods to generate different electrode coating defects such as pinholes, blisters, large agglomerates, divots, and metal particle contaminants for evaluation in full coin cell test matrix.
6/2015 ✓	FY15 Milestone	Obtain comprehensive, statistically representative full coin cell capacity data on different types of electrode coating defects to determine which type of defects cause cell failures or substandard performance.
6/2015	FY15 Milestone On Schedule	Produce defect-free ABR baseline electrode coatings, made via aqueous processing, as confirmed by laser thickness measurement and IR thermography techniques; demonstrate comparable rate performance and cycle life for 50 0.2C/-0.2C cycles and 150 1C/-2C cycles with electrode coating lengths of at least 200 ft.
6/2016	FY16 Milestone On Schedule	Quantify long-term capacity fade (1000 1C/-2C cycles) for at least three different types of anode and cathode coating defects in full 1-Ah pouch cells and publish findings (i.e. transfer technology to domestic LIB manufacturers).
9/2016	FY16 Milestone On Schedule	Verify performance of an optimally configured active IR thermography system using ABR baseline anodes and cathodes with known thickness, porosity, and bulk density differences on the ORNL slot-die coating line

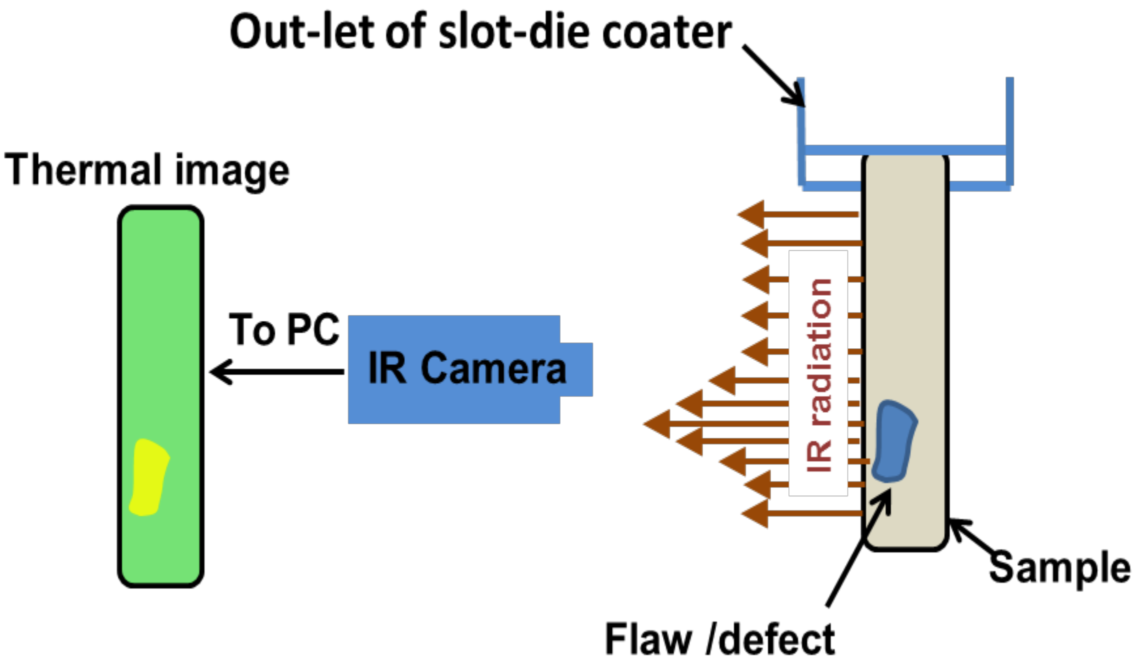
Project Approach

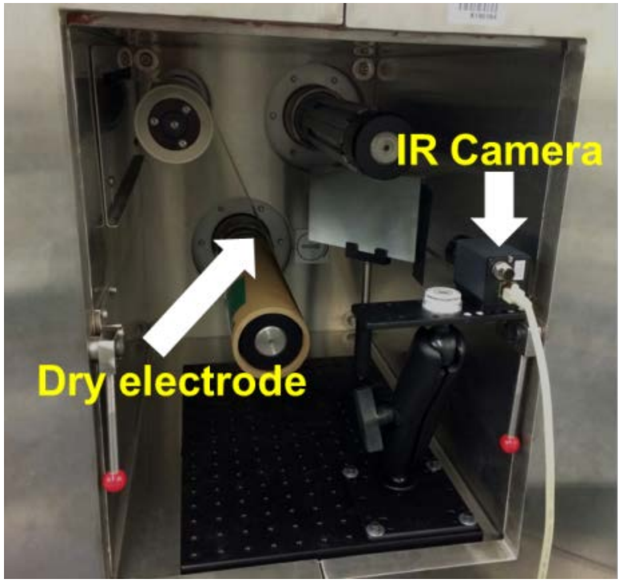
- **Problems to be addressed:**
  - Excessive scrap rates of electrodes and lack of ability to detect coating defects prior to formation cycling; novel, low-cost methods of NDE and QC are required.
  - Conventional electrode QC involves inspection only with optical CCD camera, which may miss many subtle, but important, defects.
  - Effects of different types of defects on cell rate performance and cycle life must be quantified to help determine which coating defects must be identified in the first place.
- **Overall technical approach and strategy:**
  1. Continue identification and demonstration of efficacy of in-line QC techniques utilized in other industries (plastics, textiles, ceramic coatings, photovoltaics, etc.) on ORNL pilot coating equipment.
  2. Correlate in-line NDE and QC methods with systematic cell performance data of various defect types (i.e. identify defects and test electrodes with these defects in coin and pouch cells).
  3. Quantify defect effects on cell performance (power, energy and lifetime).
  4. Employ advanced materials characterization techniques to devise cell failure mechanism(s) associated with defects.
- **Verify cost savings metrics for electrode scrap reduction with industry partner.**
  - How is electrode scrap related to cell acceptance rate and pack production costs?

Technical Accomplishments – Executive Summary (FY15 Q1-2)

- Developed methods to generate different electrode coating defects such as pinholes, blisters, large agglomerates, divots, and metal particle contaminants for evaluation in full coin-cell test matrix.
- Obtained comprehensive, statistically representative full coin-cell data on different types of electrode coating defects to determine which types of defects cause cell failures or substandard performance (rate performance ***and*** capacity fade).
- Investigated and correlated IR thermography electrode QC data with full coin-cell statistical data.
- Obtained microstructural information for understanding cell failure mechanism(s) associated with electrode defects.

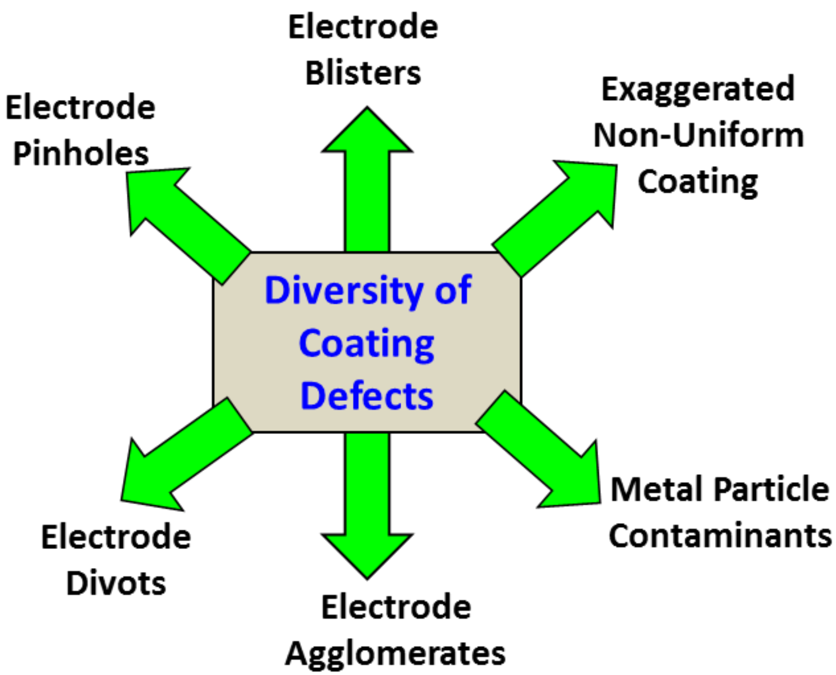
Technical Accomplishments – IR camera Installation on Slot-Die Coater

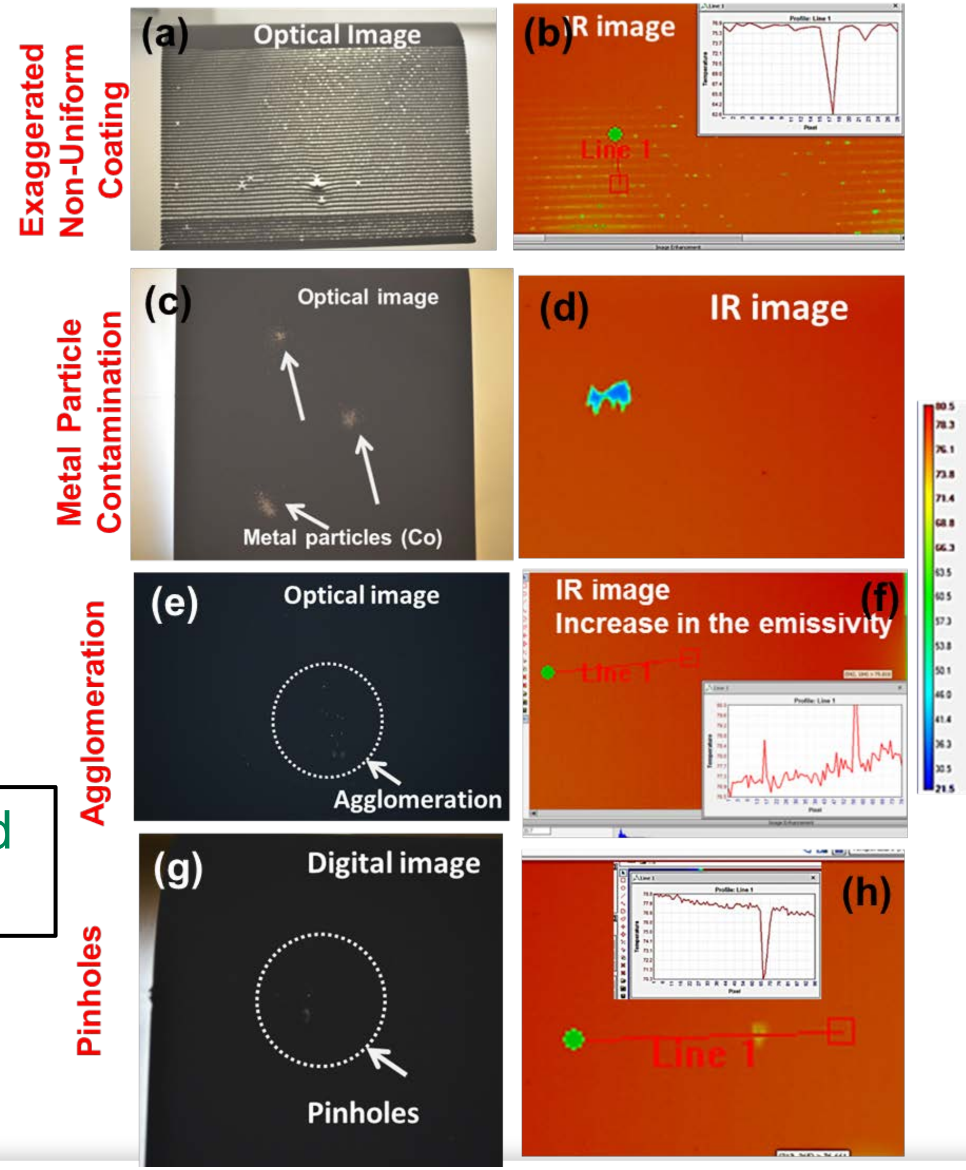




Monitor temperature profile of dried electrodes detecting any potential defects such as divots, pinholes, agglomerates, etc.

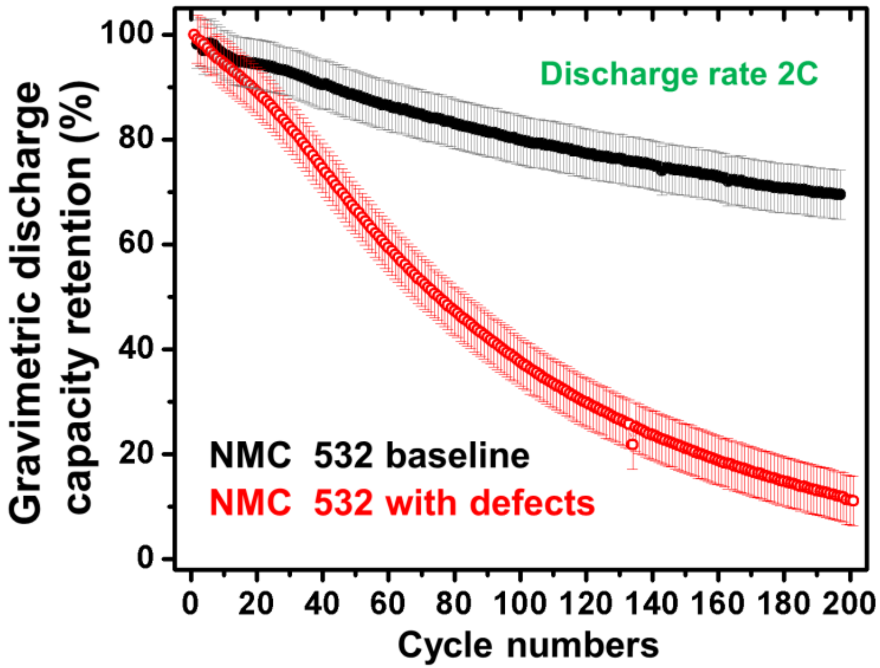
Technical Accomplishments – Systematic Study of Electrode Coating Defects

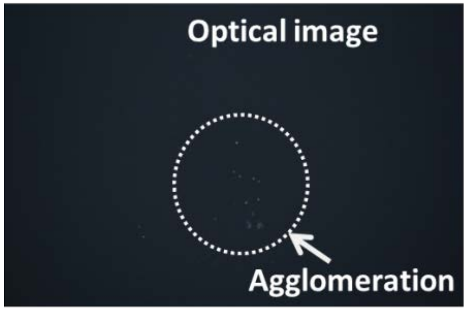


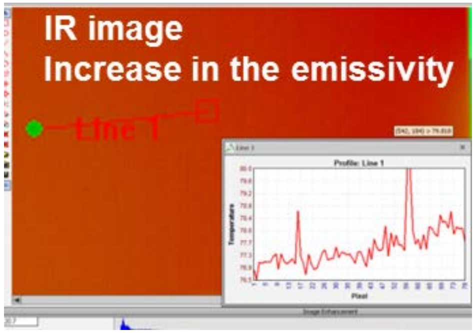


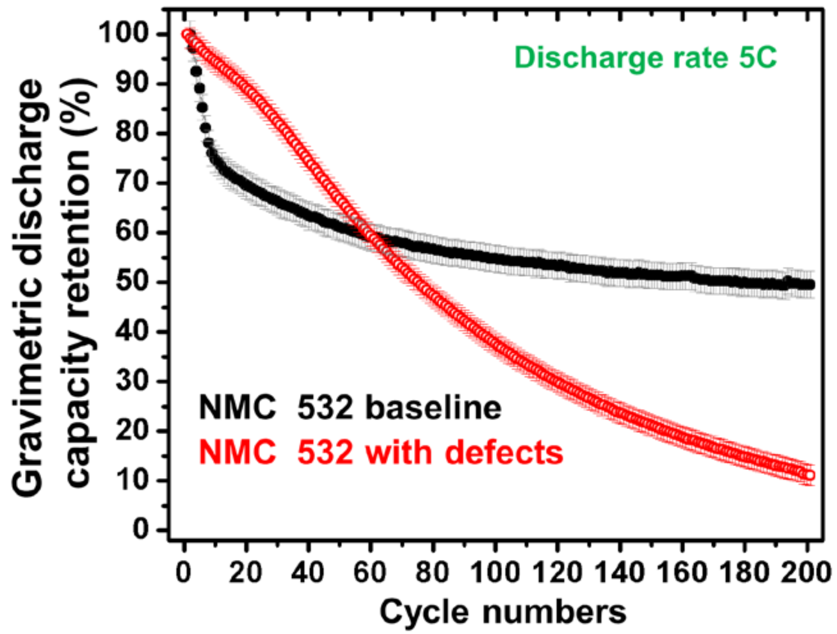
6 types of defects are being studied to determine relative importance.

Technical Accomplishments – Effect of Cathode Coating Agglomerates on Discharge Capacity





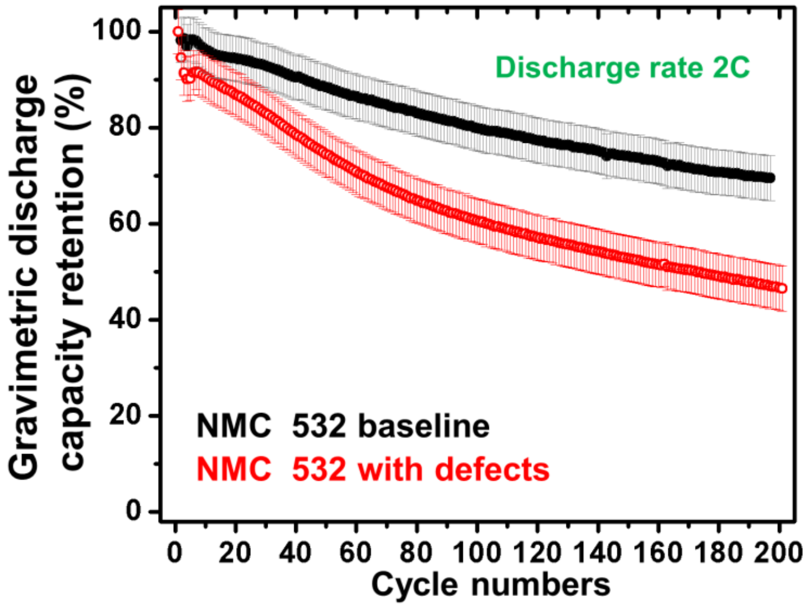


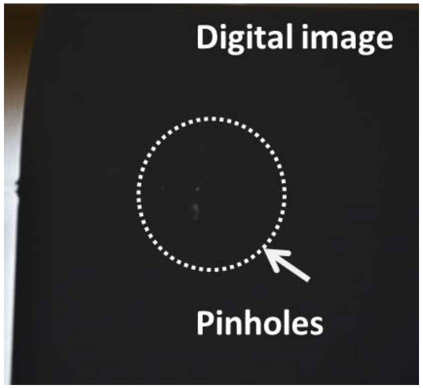


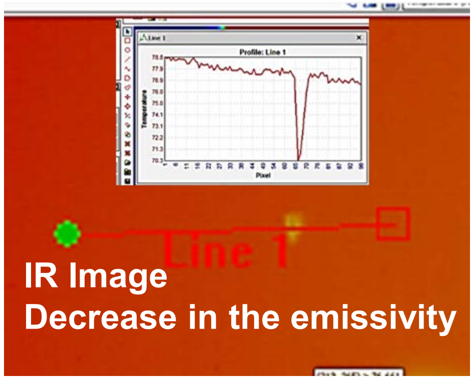
11% and 14% capacity retention after 200 cycles at 2C and 5C discharge rate in case of defective electrodes

Effect of agglomerates on capacity fade is prohibitive.

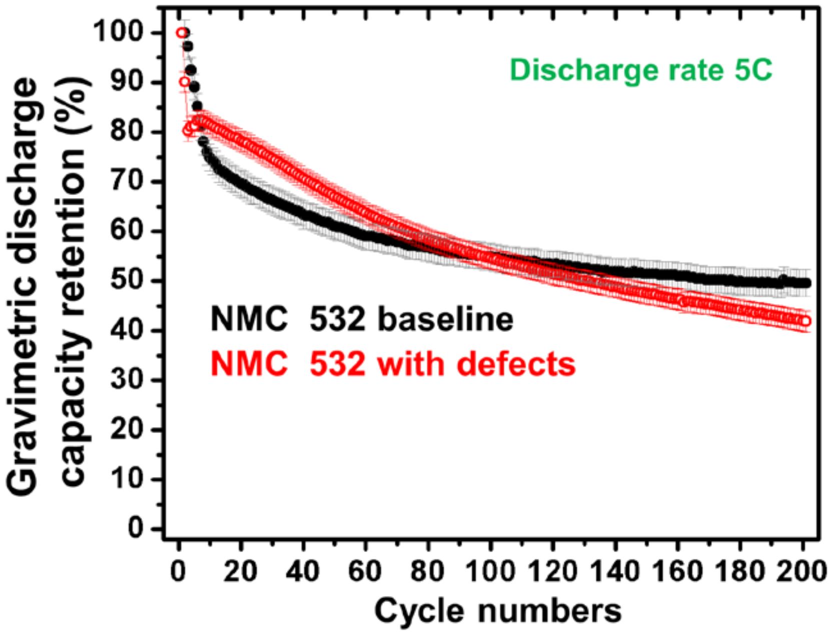
Technical Accomplishments – Effect of Electrode Pinholes on Discharged Capacity



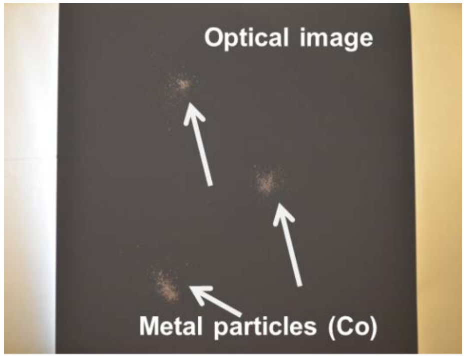


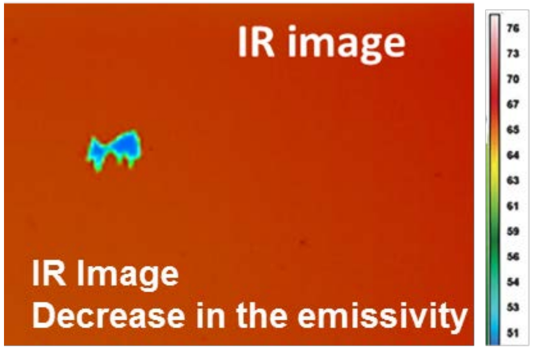


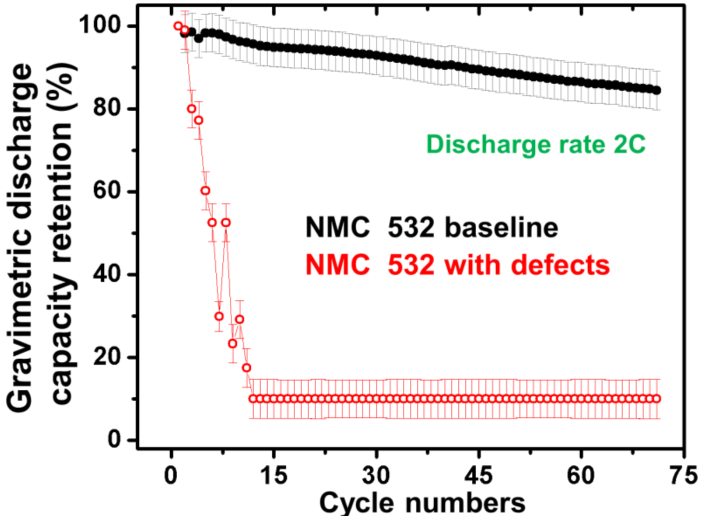
Effect of pinholes on capacity fade is significant; however, it is much less severe than that of agglomerates.



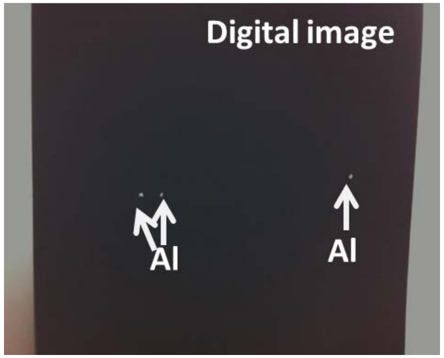
Technical Accomplishments – Effect of Metal Particle (Co Powder and Al foil) Contaminants Is Detrimental

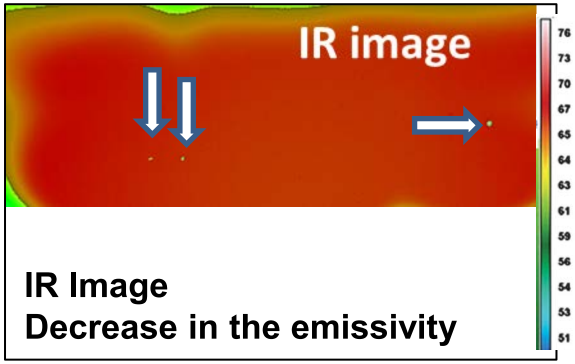


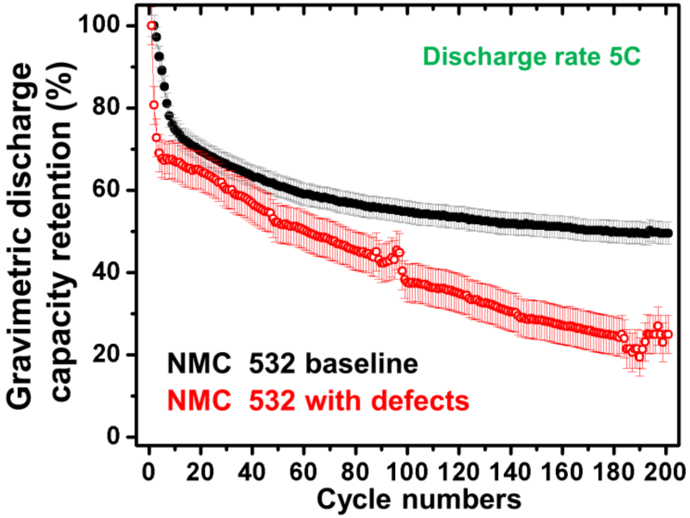




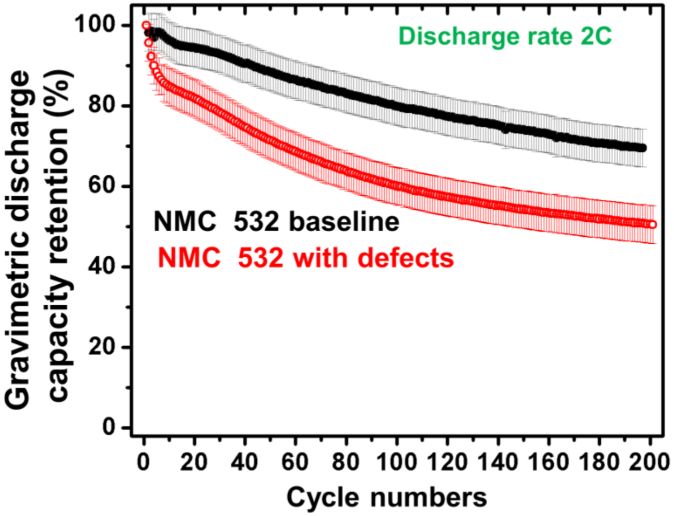
Capacity fade is also deleteriously affected by Co particle contaminants and Al foil contaminants.

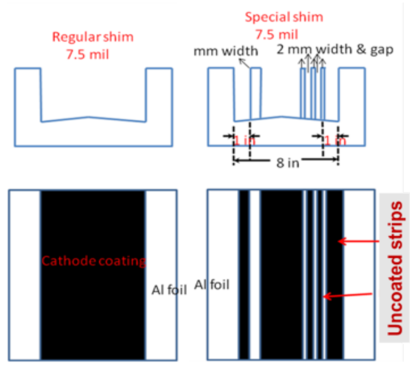


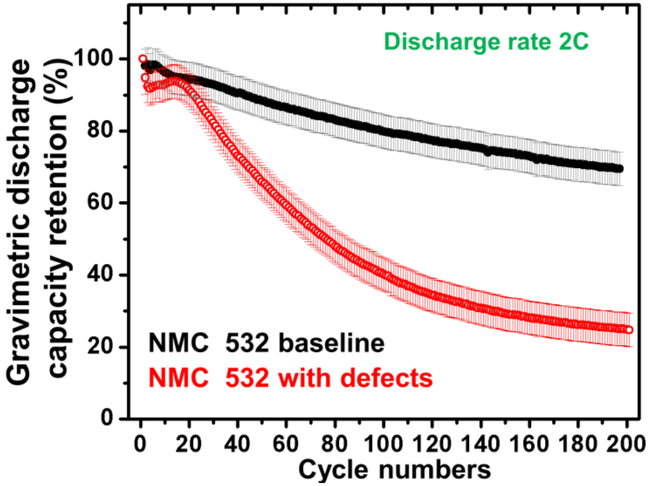


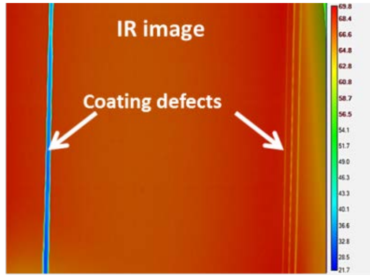


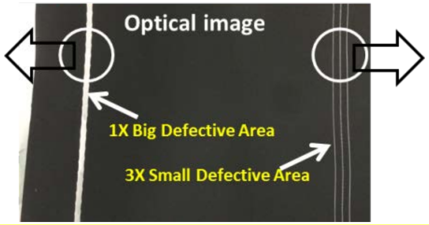
Technical Accomplishments – Specific Design of Experiments to Explain Observations Related to Missing Coating

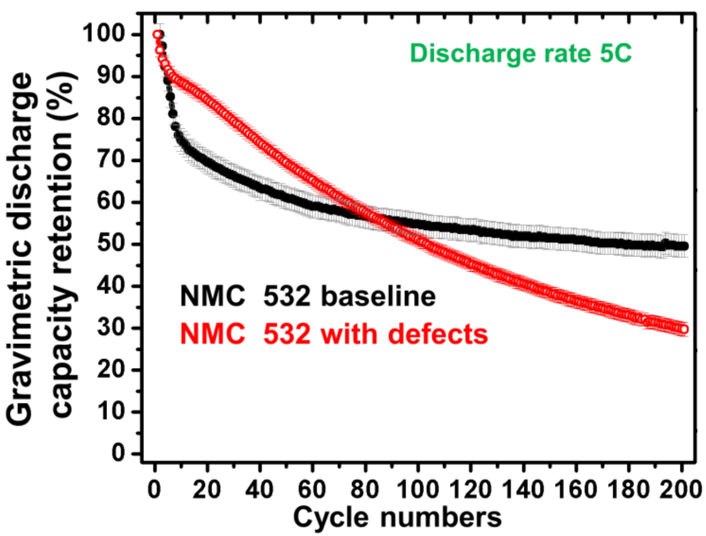


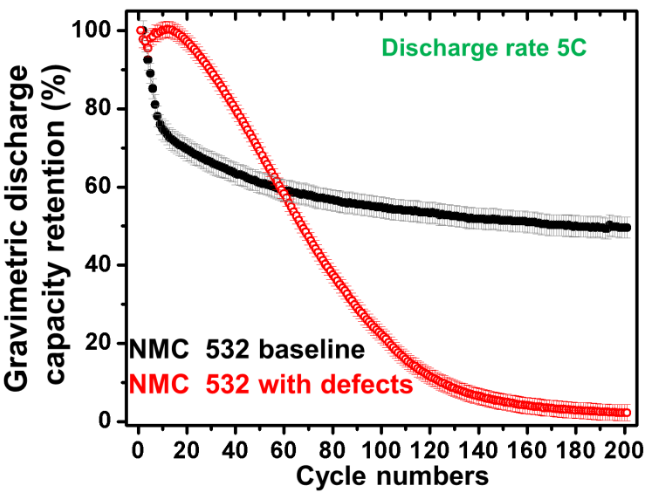






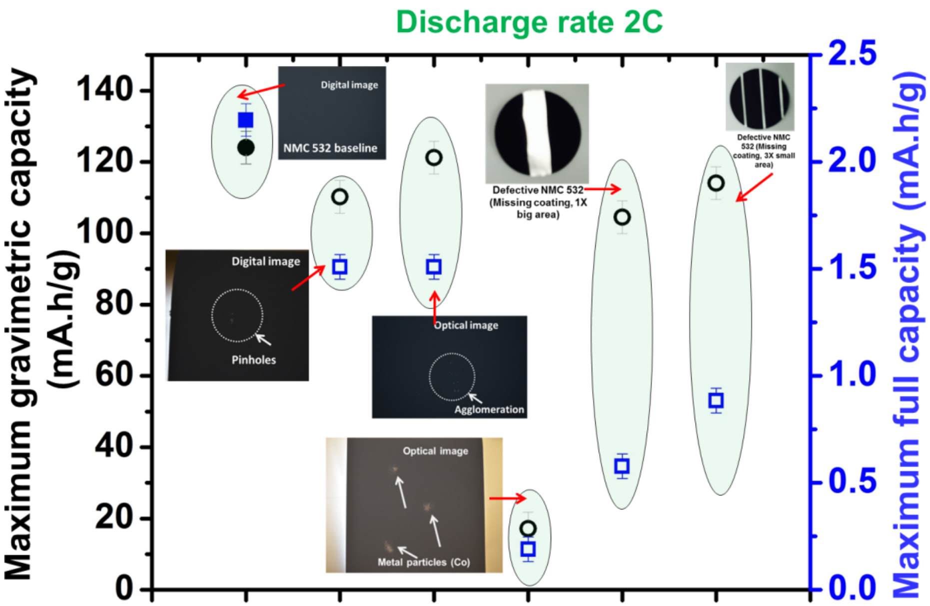


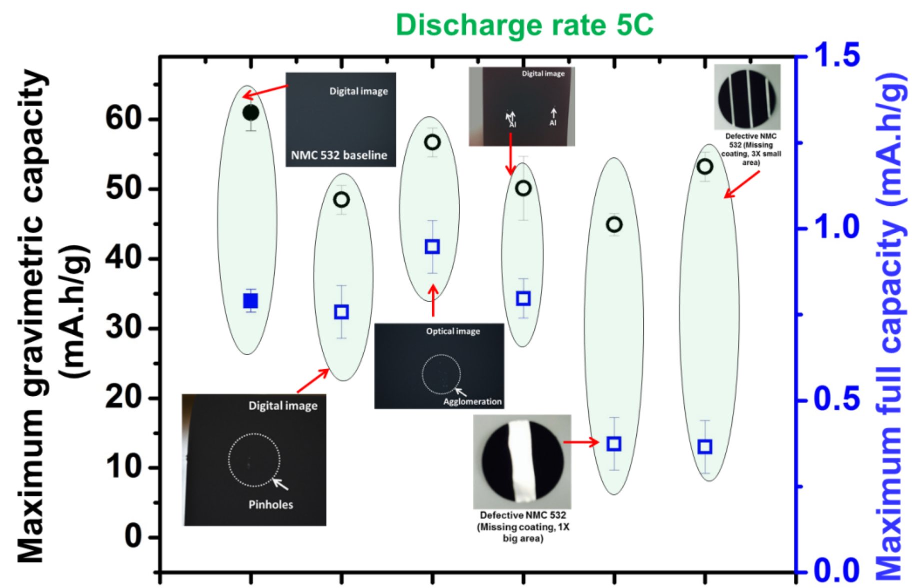




Capacity fade is more significant in the case of 3× smaller defective areas (more interfaces between coated and uncoated regions).

Technical Accomplishments – Comparison the gravimetric and full capacity from defective electrodes and baseline non-defective NMC 532

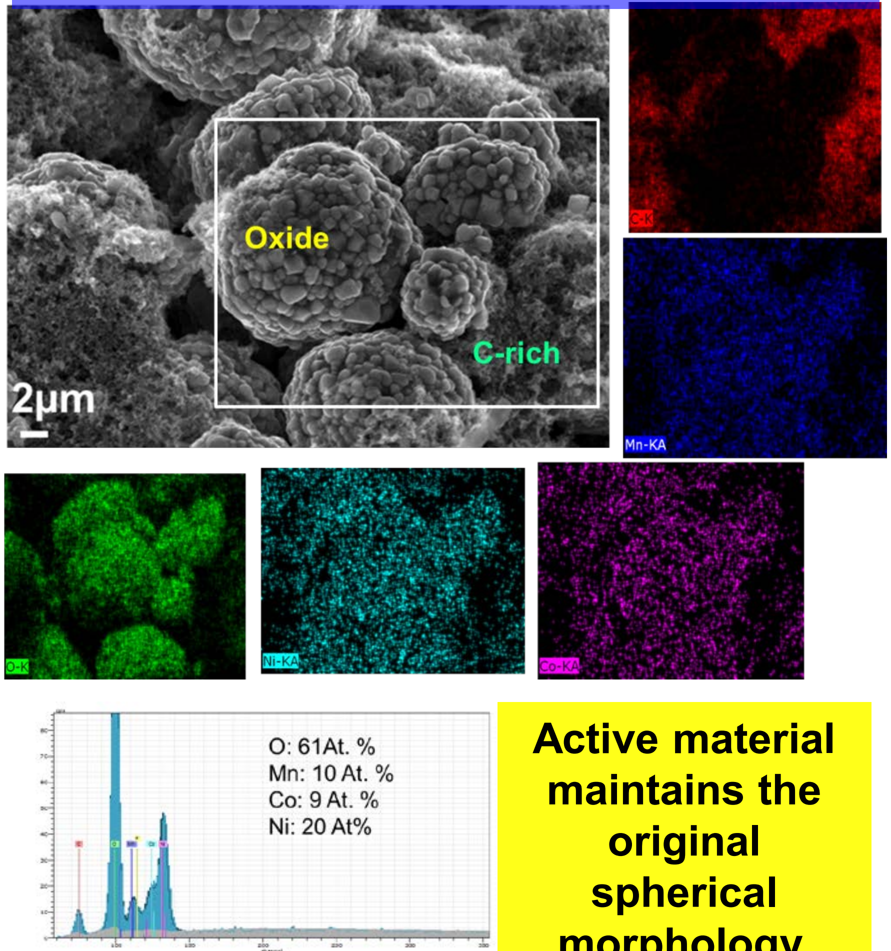




The gravimetric discharge capacity values were <u>lower</u> for the case of defective electrodes having pinholes, metal particle contaminants, and missing coating than the baseline NMC 532 electrodes. For the case of electrodes with large agglomerates, gravimetric capacity was similar to the baseline NMC 532 electrodes.

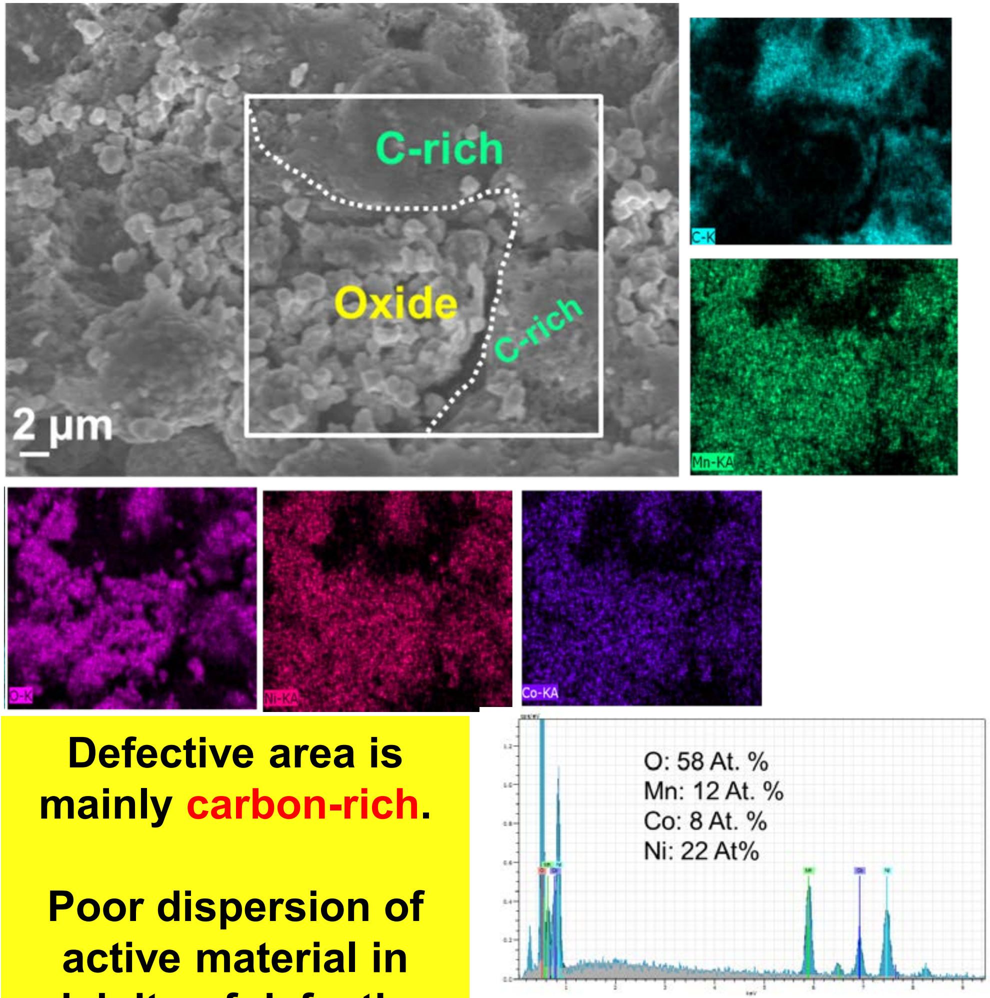
Technical Accomplishments –Materials Characterization on Defective Electrodes

Electrodes without defects



Active material maintains the original spherical morphology.

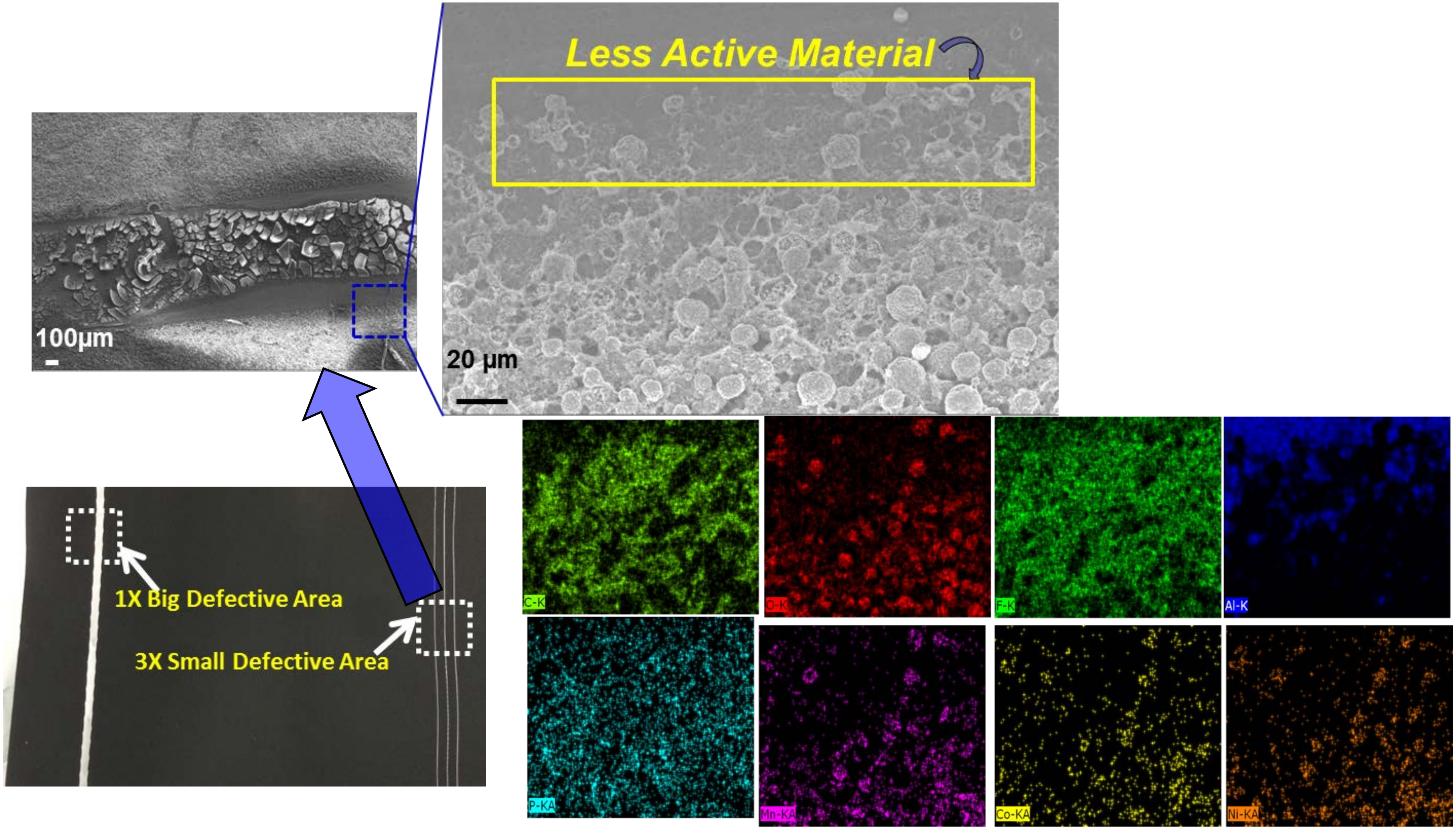
Electrodes with defects (agglomerates)



Defective area is mainly carbon-rich.

Poor dispersion of active material in vicinity of defective area.

Technical Accomplishments – Materials Characterization of Defective Electrode



Non-uniform electrode material distribution along uncoated length.

Technical Accomplishments – Relative Effect of Defects on Cell Performance

Electrodes		Discharge rate: 2C		Discharge rate: 5C	
		*Gravimetric Capacity retention (%)	*Full Capacity retention (%)	*Gravimetric Capacity retention (%)	*Full Capacity retention (%)
Baseline		70%	68%	75%	58%
Non-Uniform Coating (1X Big defective area)		60%	40%	45%	60%
Non-Uniform Coating (3X Big defective area)		27%	30%	7%	4%
Agglomerates		12%	6%	14%	12%
Metal contaminants	Co	Zero capacity	Zero Capacity		
	Al			22%	25%
Pinholes		47%	18%	40%	28%

*** After 200 Cycles**

Collaborations

- Partners
  - Equipment Suppliers: Frontier Industrial Technology, Keyence, FLIR Systems
  - Battery Manufacturers: XALT Energy, Navitas Systems
  - Raw Materials Suppliers: TODA America, Superior Graphite, GrafTech International, Zenyatta Ventures
  - National Labs: ANL, NREL

- Collaborative Activities
  - Ongoing discussion with industry partners XALT Energy, Navitas Systems, and A123 Systems on implementation of IR thermography, laser thickness measurement, optical reflectance, and thermal diffusivity techniques on industrial electrode production lines.

Future Work

- Remainder of FY15
  - Statistically investigate and propose cell failure mechanism(s) from defective electrodes by employing materials characterization tools.
  - Identify/monitor new defects during electrode coating.
  - Quantify long-term capacity fade (1000 1C/-2C cycles) for at least three different types of anode and cathode coating defects in full 1-Ah pouch cells.
  - Publish findings (i.e. transfer technology to domestic LIB manufacturers).
- FY16
  - Identify industrial partner to scale selected in-line QC methods.
  - Analysis of cost saving by implementing NDE.

Summary

- **Objective:** This project facilitates lowering unit energy cost of EVs and PHEVs by addressing the electrode scrap rate, QC enhancement, and calendar life.
- **Approach:** implements QC measures utilized effectively in other industries.
  - Processing costs tied to QC are addressed.
  - Ease of implementation of measurement technology with low equipment cost.
  - Quantify effect of electrode coating defects such as divots, blisters, pinholes, agglomerates, and metal-particle contaminants on cell rate performance and cycle life.
- **Technical:** Successful implementation of IR thermography equipment on ORNL slot-die coater; identified defects critical to cell performance; characterized the defective electrodes to understand the cell failure mechanism.
- All FY15 Milestones Are on Schedule.
- **Collaborators:** Active discussions with industry partners XALT Energy and Navitas Systems on scaling measurement techniques; developing new in-line NDE and QC techniques based on thermal diffusivity and optical reflectance with NREL.
- **Commercialization:** High likelihood of technology transfer because of strong industrial collaboration, significant electrode production cost reduction, and lower-cost QC measurement equipment.

Acknowledgements

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- ORNL Contributors:
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  - Ralph Dinwiddie
  - Curt Maxey

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- Fabio Albano
- Mike Wixom
- Mike Ulsh
- Peter Rupnowski
- Guido Bender
- Bhushan Sopori
- Andy Jansen

Information Dissemination and Commercialization

Refereed Journal Papers and Presentations

- D. Mohanty, J. Li, R. Born, L.C. Maxey, R.B. Dinwiddie, C. Daniel, and D.L. Wood, "Non-Destructive Evaluation of Slot-Die-Coated Lithium Secondary Battery Electrodes by In-Line Laser Caliper and IR Thermography Methods," *Analytical Methods*, **6**, 674–683 (2014).
- Highlighted in back cover of the journal: http://pubs.rsc.org/en/content/articlelanding/2014/ay/c4ay90003k/unauth#!divAbstract
- D. Mohanty, J. Li, R. Born, C.L. Maxey, R.B. Dinwiddie, C. Daniel and D.L. Wood, "Reducing the Scrap Rate in Lithium-Ion Battery Manufacturing by Implementing In-Line Non-Destructive Electrode Evaluation Techniques," 3rd International Conference and Exhibition on Materials Science & Engineering, San Antonio, Texas, October 6-8, 2014.
- D. Mohanty, J. Li, S. Nagpure, D.L. Wood, III, and C. Daniel, "Correlating Electrode Defects with Electrochemical Performance of Lithium-Ion Batteries," 2015 MRS Spring Meeting & Exhibit, San Francisco.
- D.Mohanty, J. Li, C. Daniel, D. L. Wood, "Effect of Electrode Defects on Electrochemical Performance of a Lithium Ion Battery; From Non-Destructive Evaluation to Microstructural Investigation"; *ACS Applied Materials and Interfaces*, In Preparation, 2015.

Thank you for your attention!