Characterizing Lithium-ion Battery Internal Short Circuit with Slow-penetrating Micro Sensing Nails

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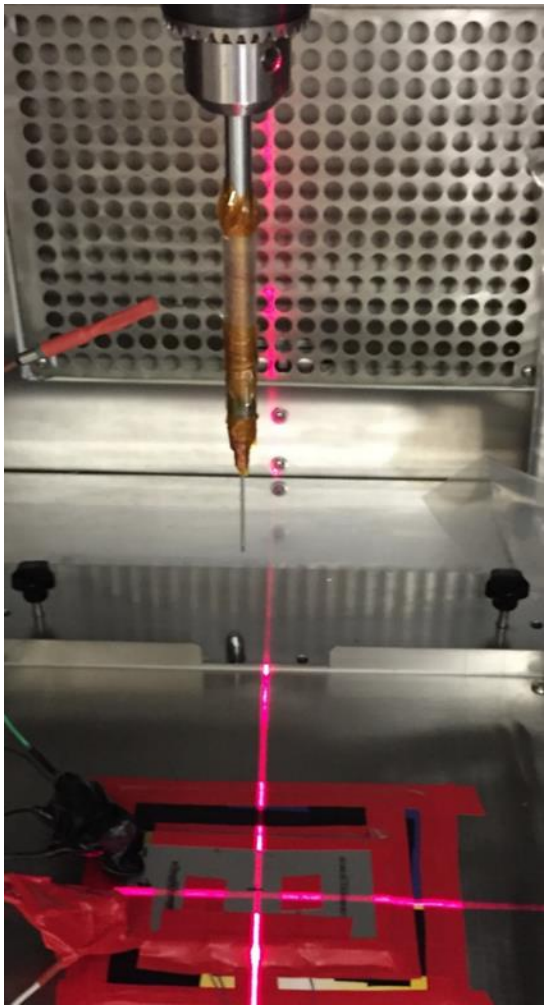


THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

Start-up Funding
New Faculty Research Program
COE Undergraduate Research Program
Honors Capstone Research Program

NASA Aerospace Battery Workshop, Nov. 27 - 29, 2018, Huntsville, AL, USA

Lithium-ion (Li-ion) batteries have been widely used

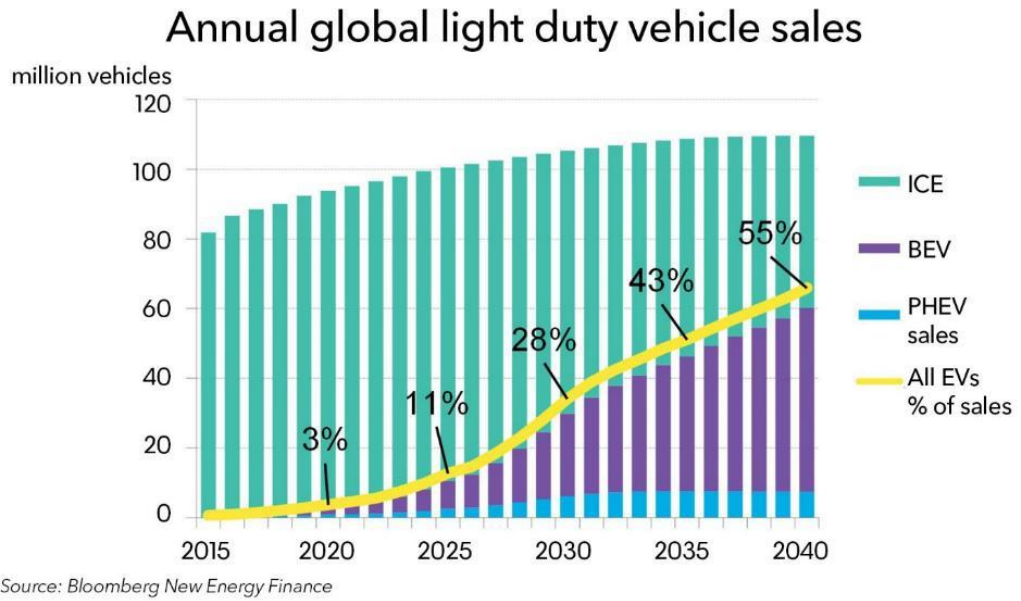
apple.com

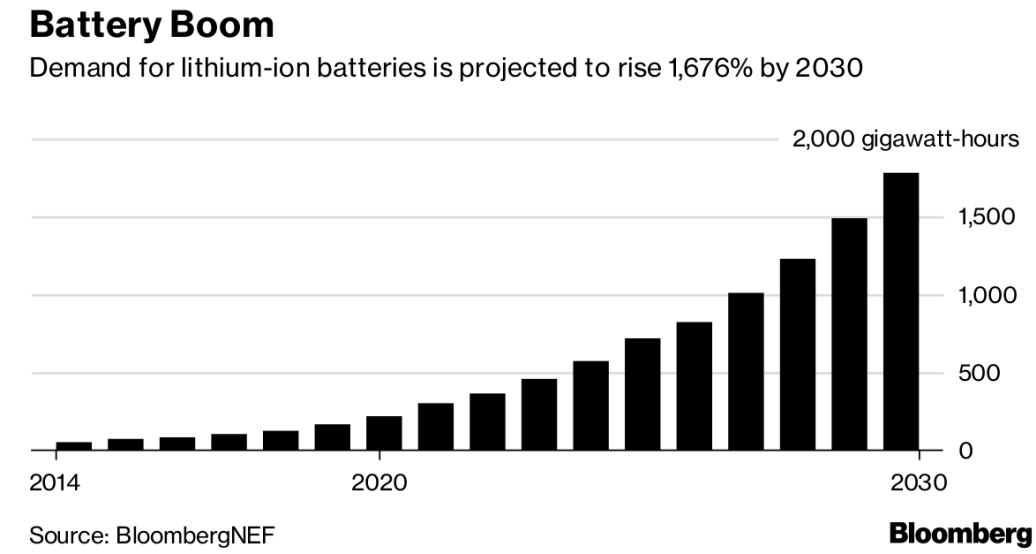
newairplane.com

telegraph.co.uk

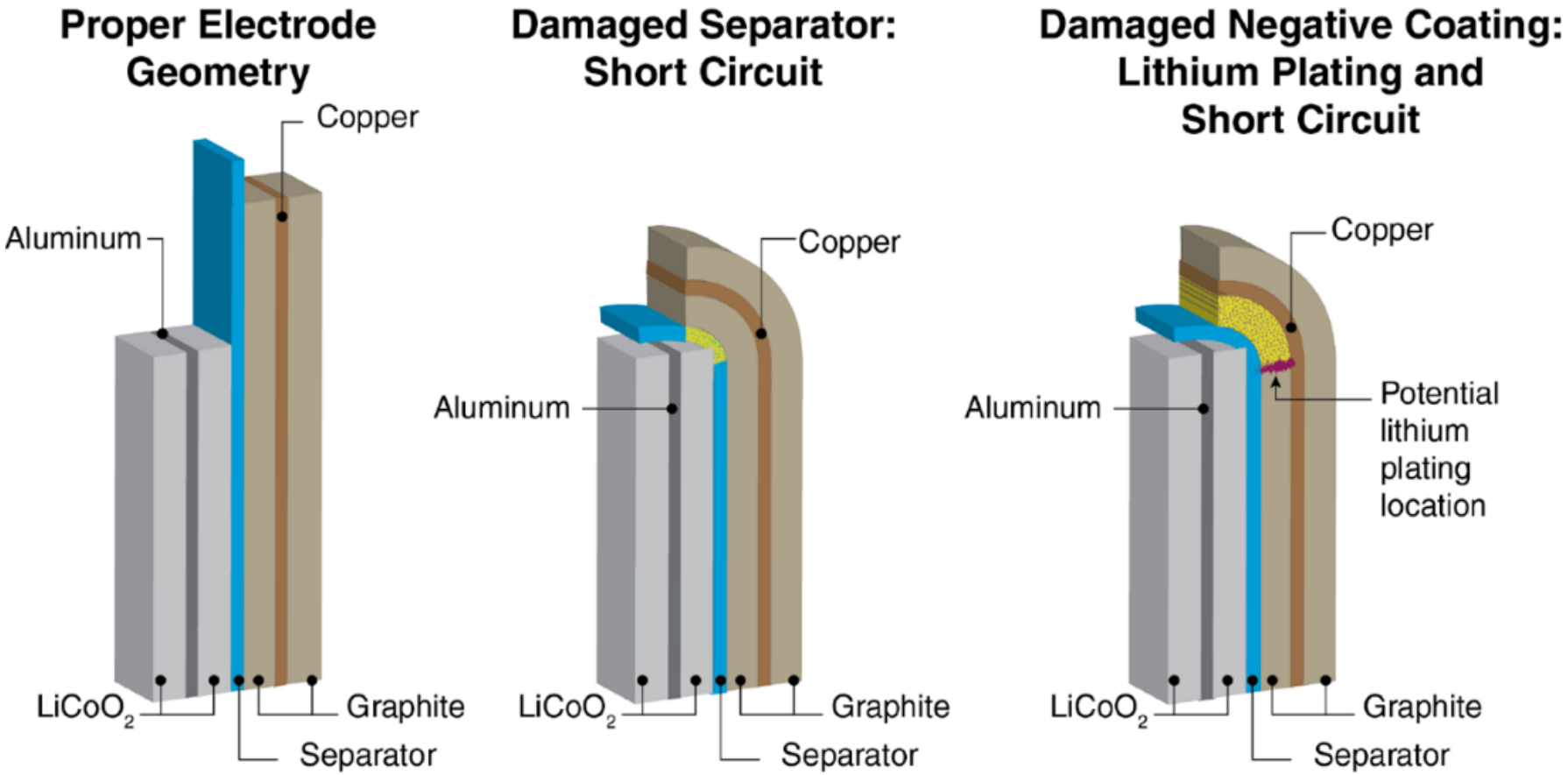
nasaspaceflight.com

Example of EV industry: Li-ion batteries enable the revolutionary development





Safety is still a concern, especially internal short circuit (ISC) that has caused many field failures



https://news.samsung.com/global/infographic-galaxy-note7-what-we-discovered

Various methods have been developed to simulate field failure internal short circuit

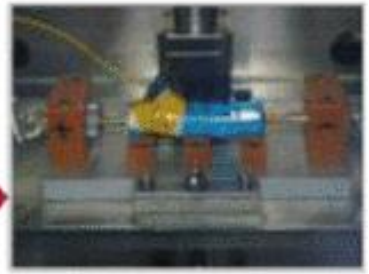
Slow Speed Nail Penetration Test
ITRI

Low-Melting Point Metal/Alloy Triggered ISC Test
SNL

Forced ISC Test
BAJ

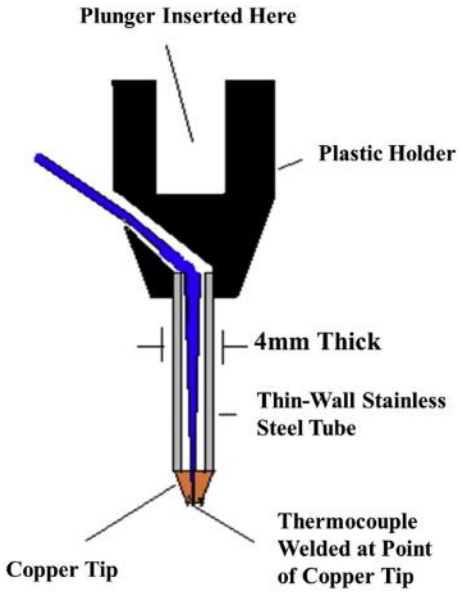
Pinch Test
ORNL

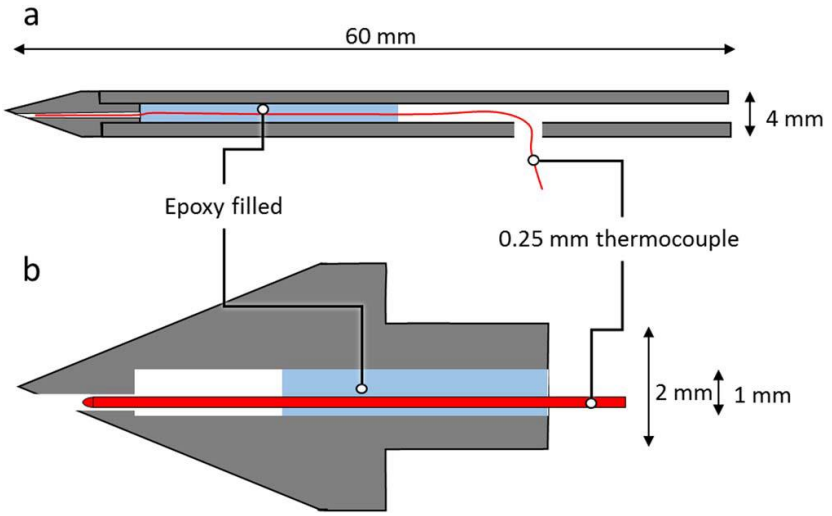
Indentation Induced ISC Test
UL/NASA

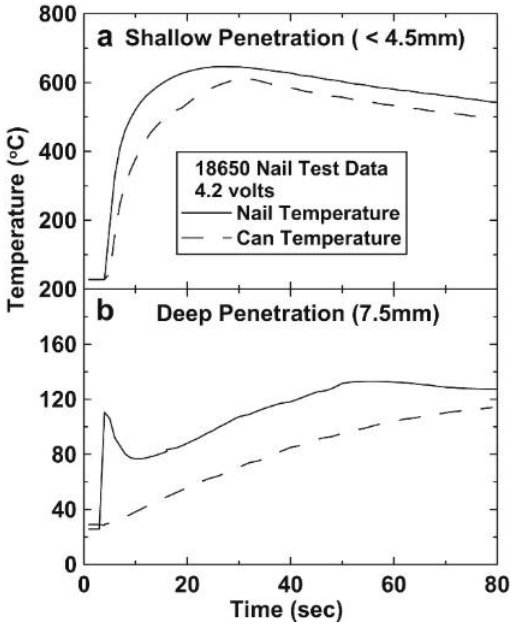


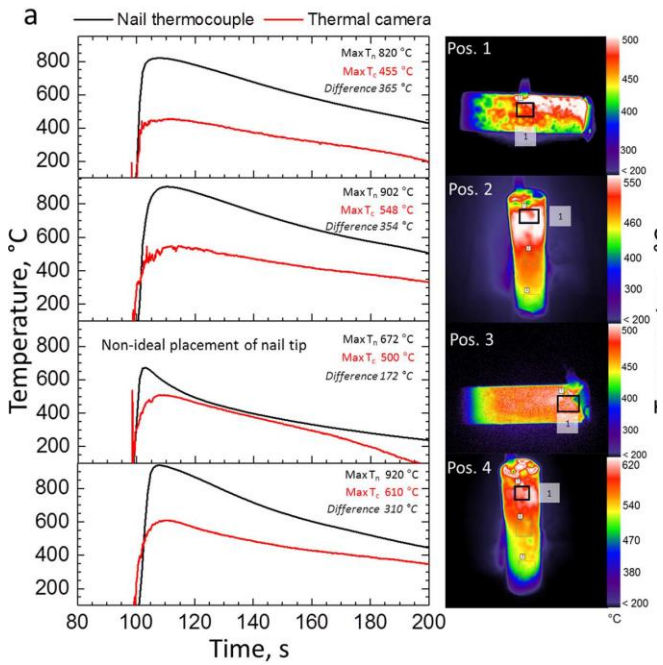
Wu, Tabaddor, Wang, Jeevarajan
2013 IEEE Transportation Electrification Conference and Expo (ITEC)

Smart nails with embedded sensors for insights





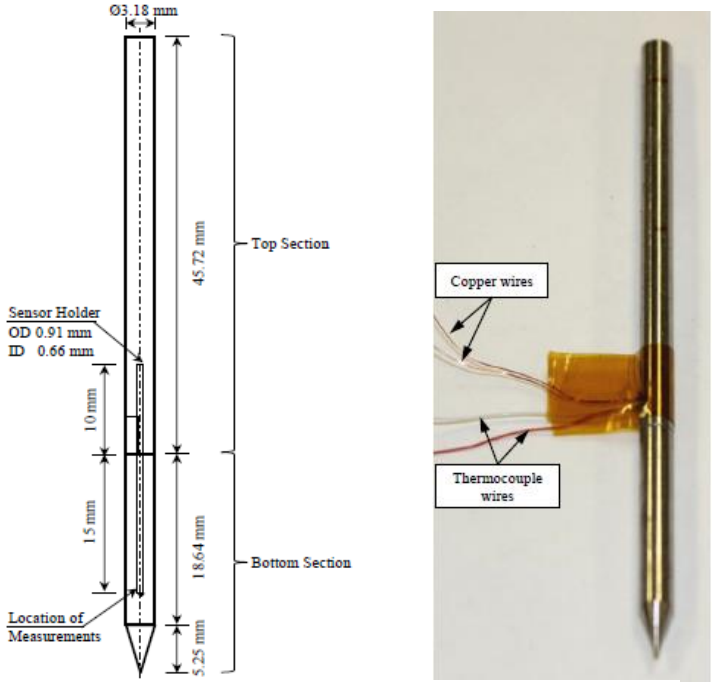


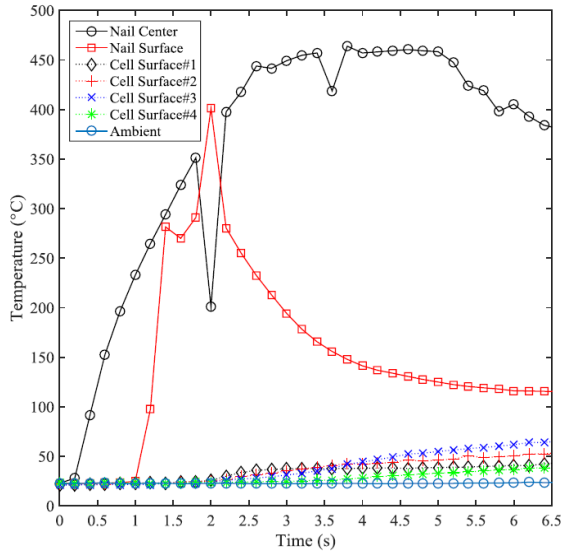


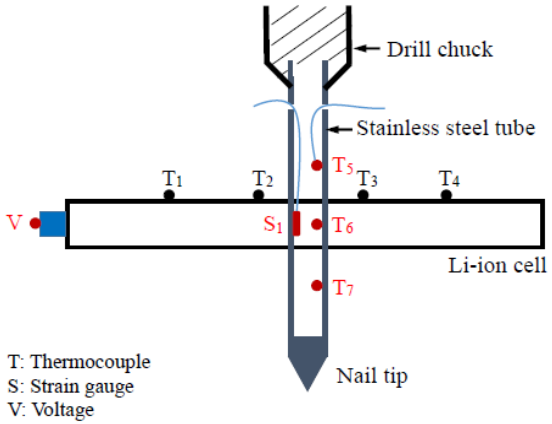
Hatcharda, Trusslera, Dahn, JPS 2014

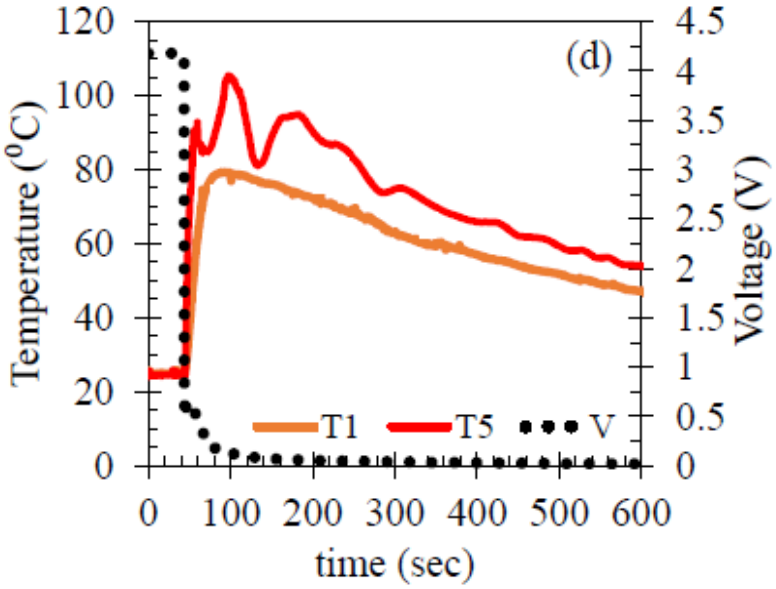
Finegan et al. JES 2017

Smart nails with embedded sensors for insights









Poramapojana, PhD thesis, Penn State University 2015

Tanim, Garg, Rhan.
ASME Power Energy 2016

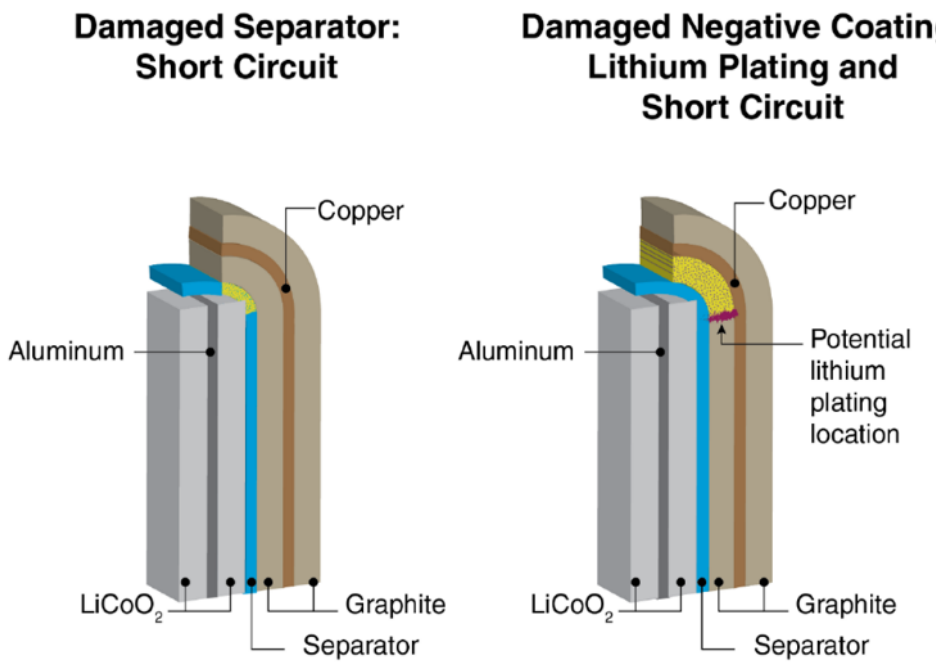
How well does nail penetration simulate field failure internal short circuit?

Field failure ISC:

1. Small shorting area
2. Single layer

Nail penetration:

1. Large nail (3-10 mm dia.)
2. Poor control of ISC layers (speed up to 80 mm/s)



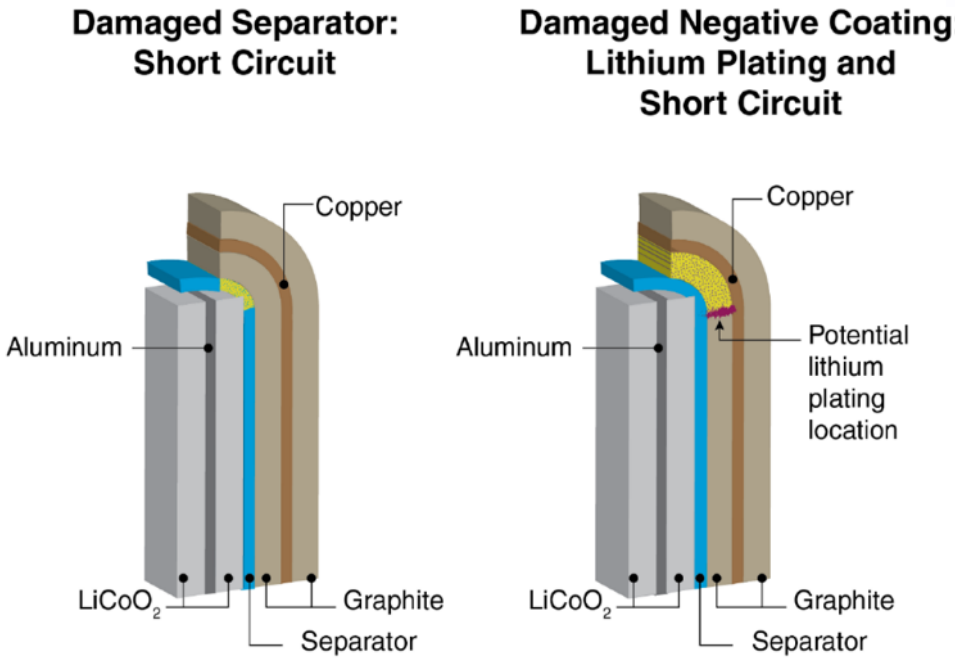
samsung.com

Internal short circuit testing method:

(1) Representative of field failure?

(2) Convenient to implement?

(3) Insights for safety improvement?



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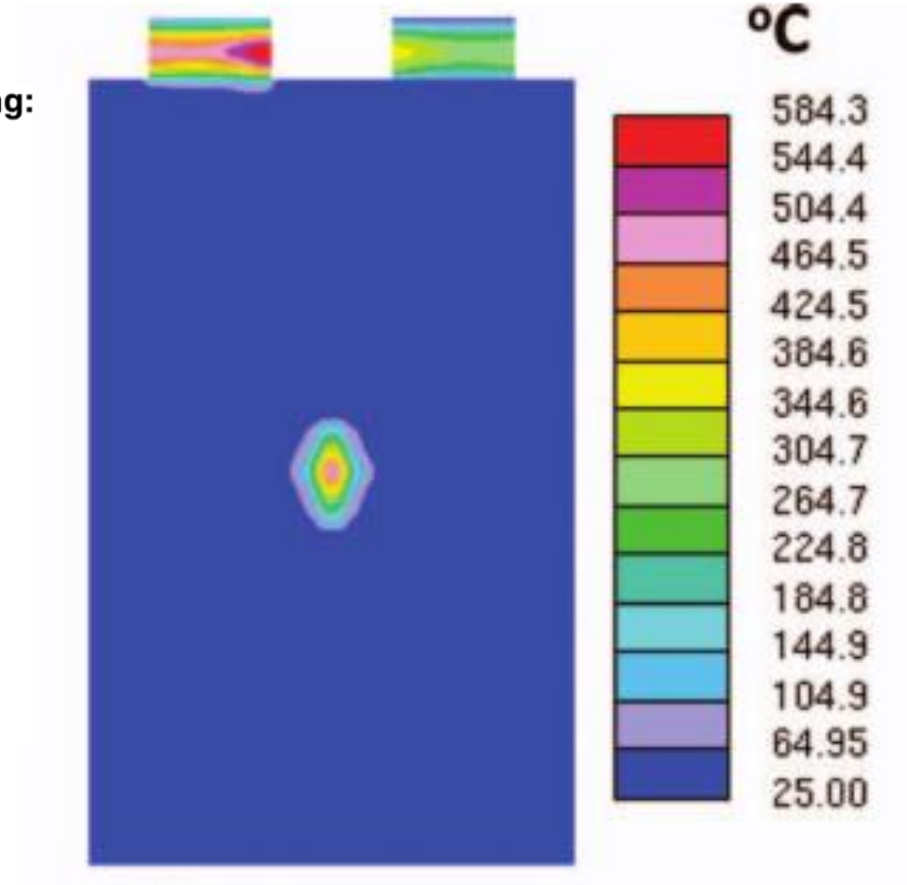
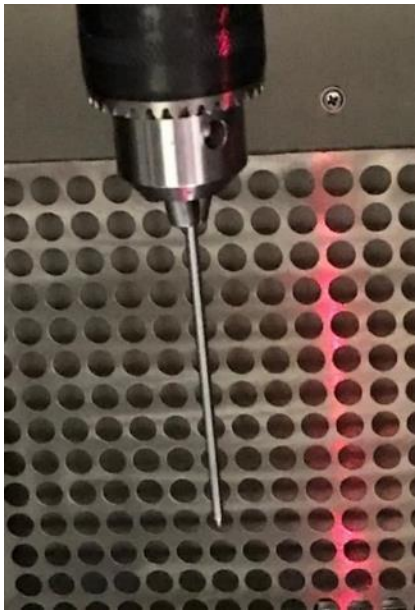


Zhao, Luo, Wang, JES 2015

Integrate nail penetration, indentation test, and in-situ sensing to characterize internal short circuit



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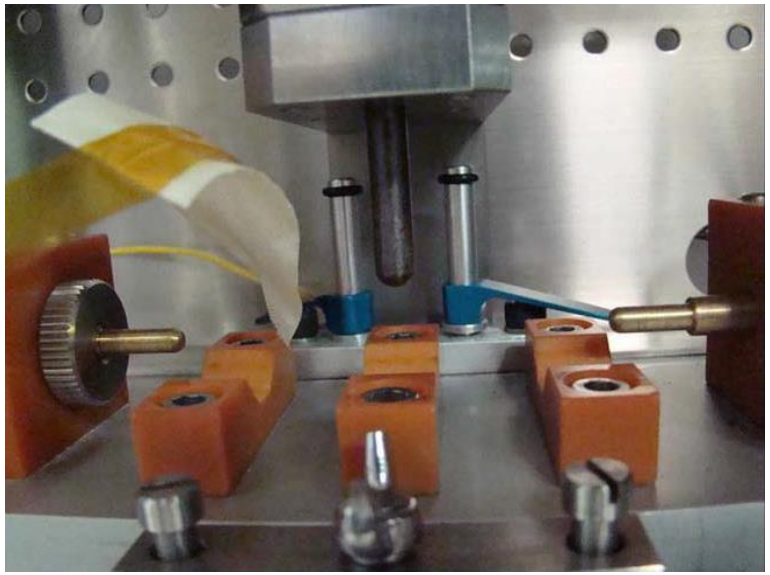

Jeevarajan, Lithium Power 2012

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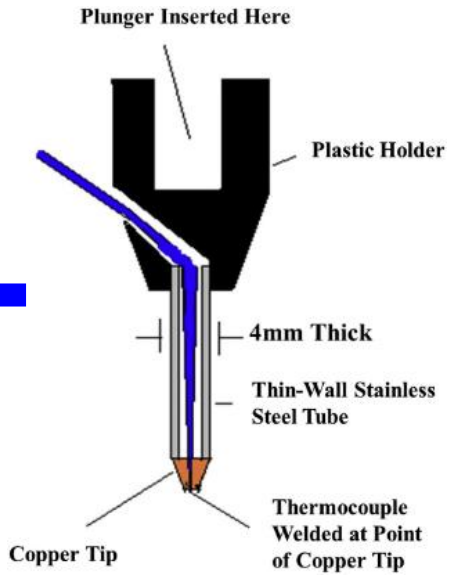


Hatcharda, Trusslera, Dahn, JPS 2014

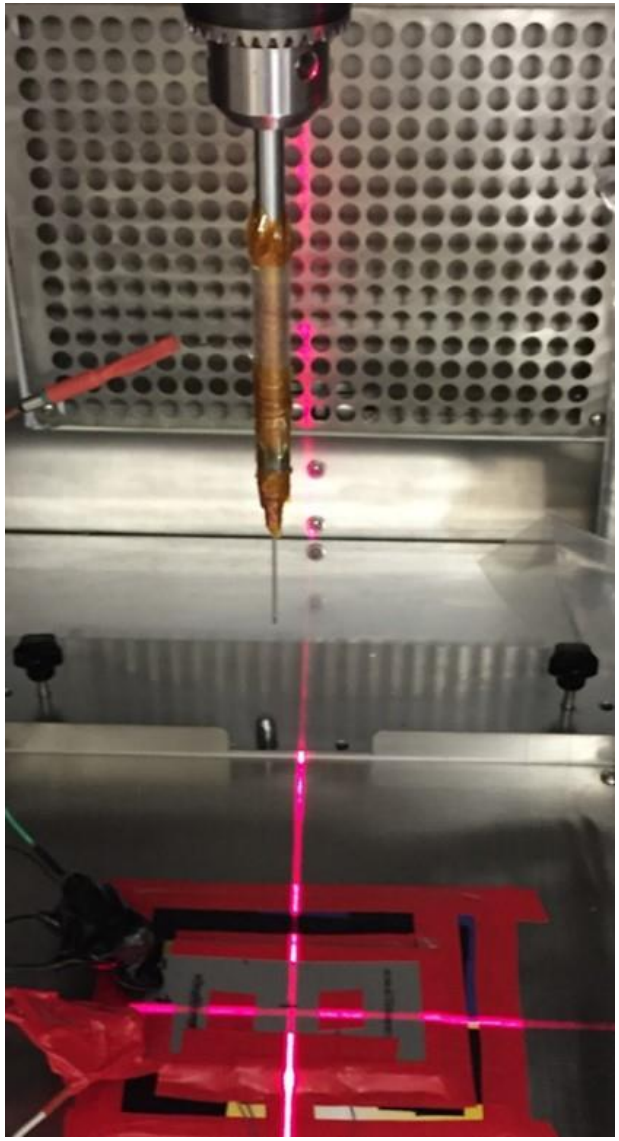
Convenient Implementation

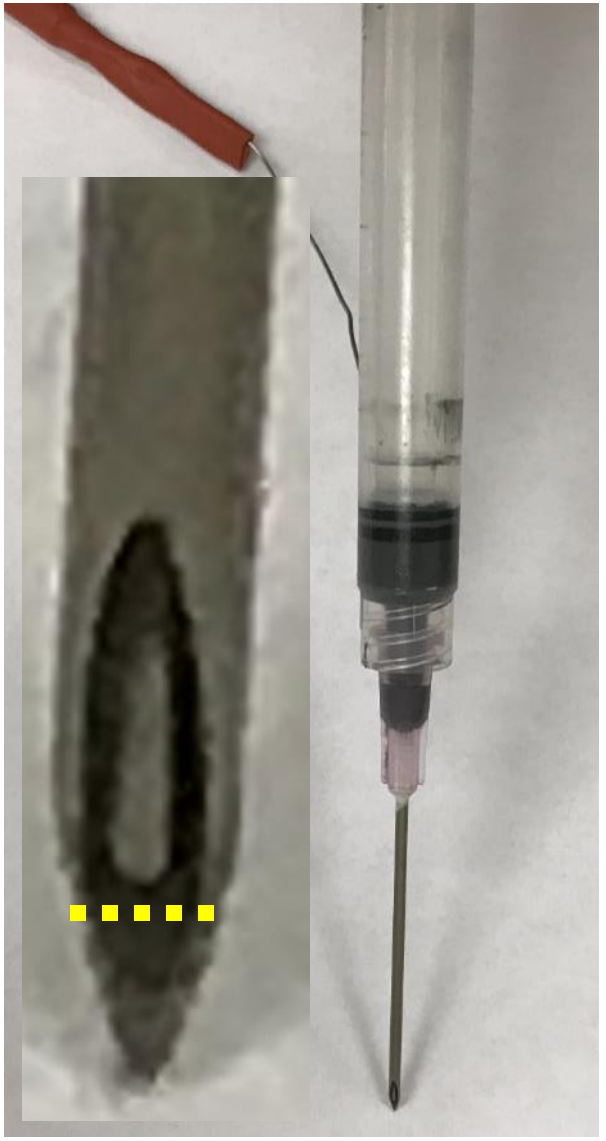
Slow

In-situ Sensing (Insights)

➡ **Slow-penetrating Micro Sensing Nails**

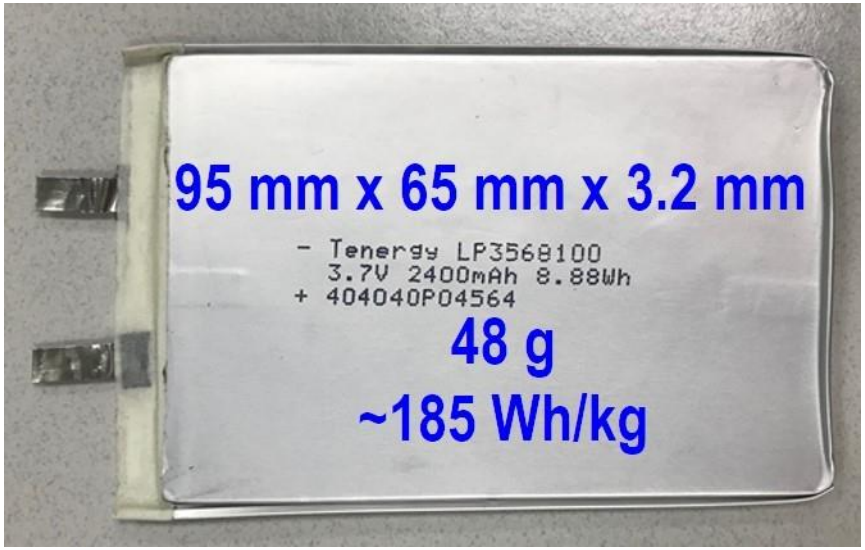
Prototypes made out of syringe needles and micro thermocouples (wire dia. 90 um; sheath dia. 500 um)

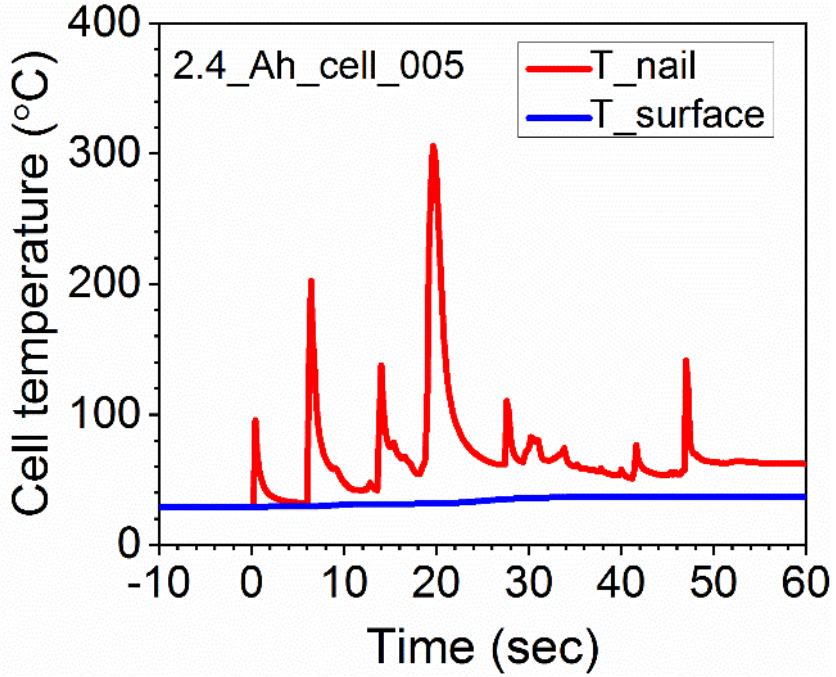




Nail penetration is done at low speed (0.1 mm/s or lower)

2.4 Ah Li-ion cell

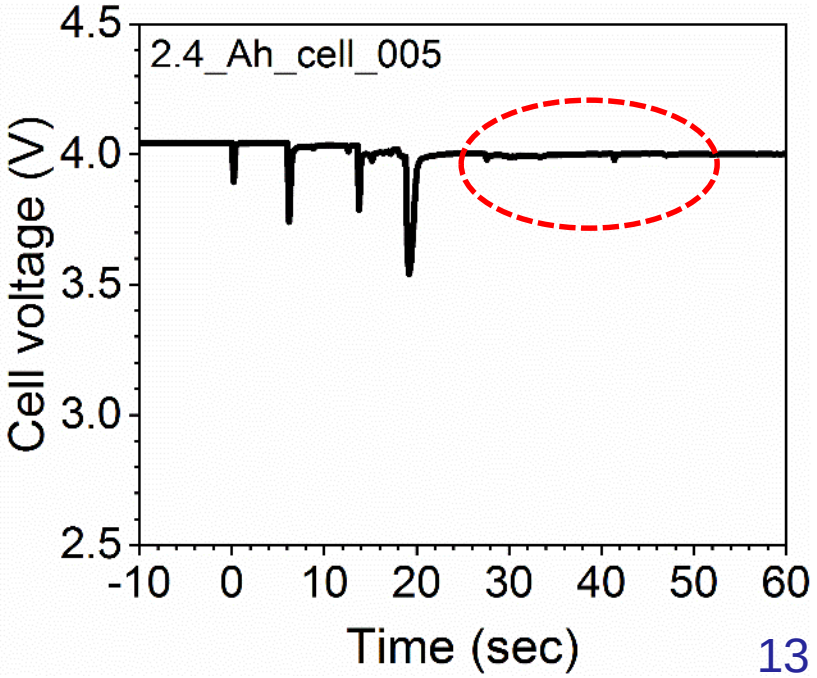




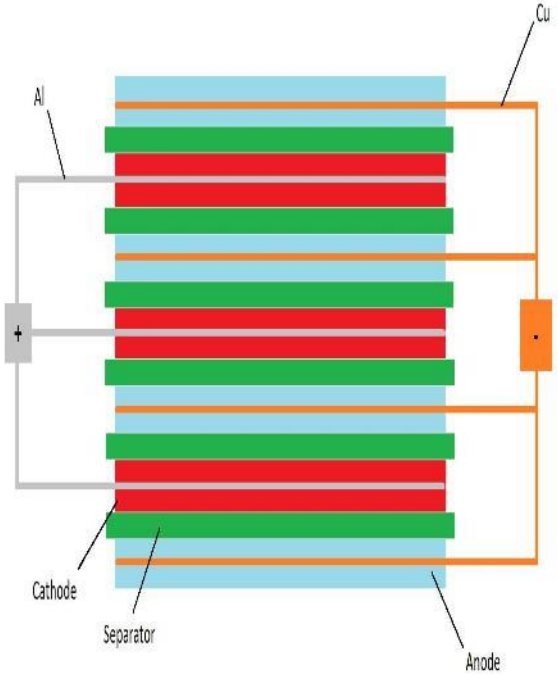
No fire, no smoke, but

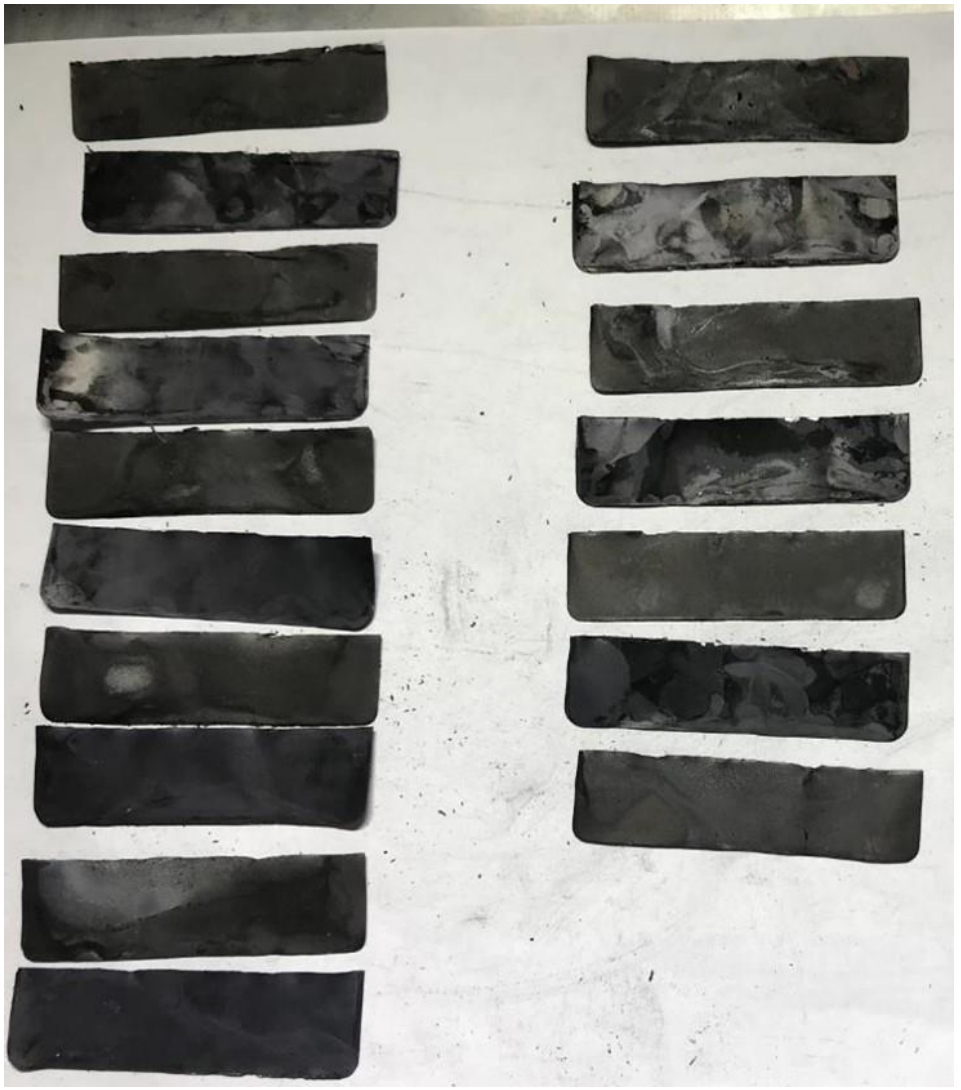
1. In-situ temperature is much more sensitive than surface temperature;

2. In-situ temperature is even more sensitive than cell voltage.



Why 8 in-situ temperature peaks with similar time intervals?



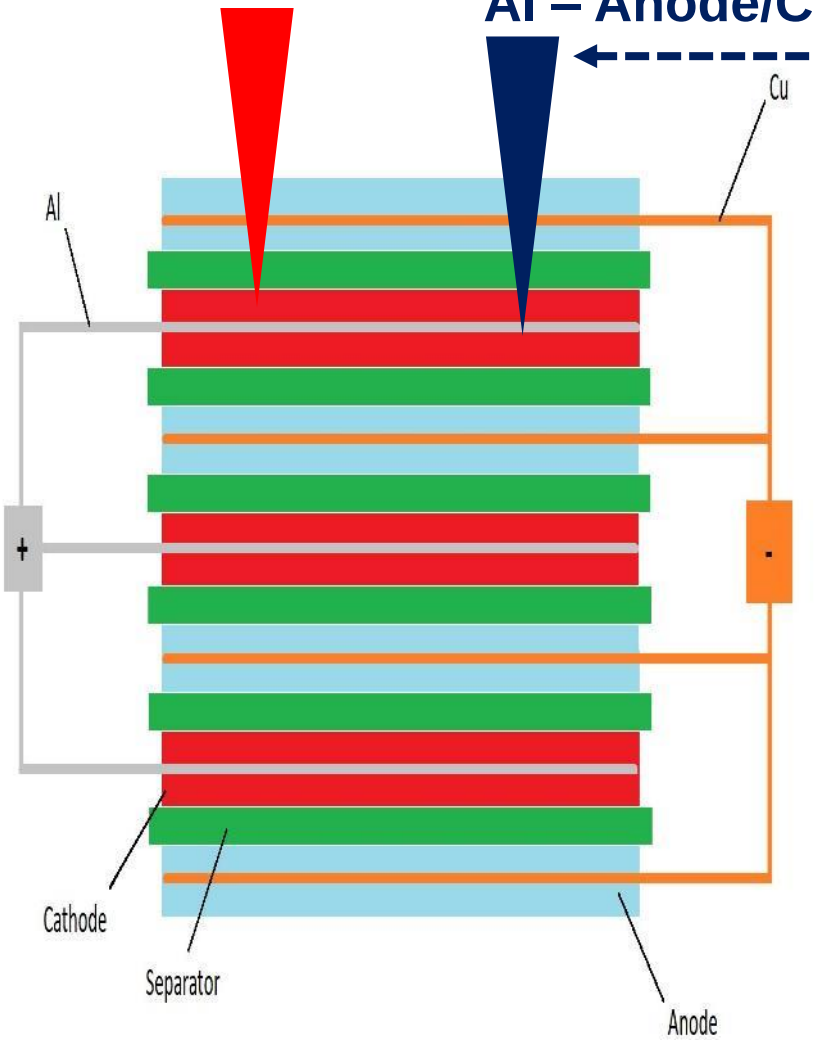


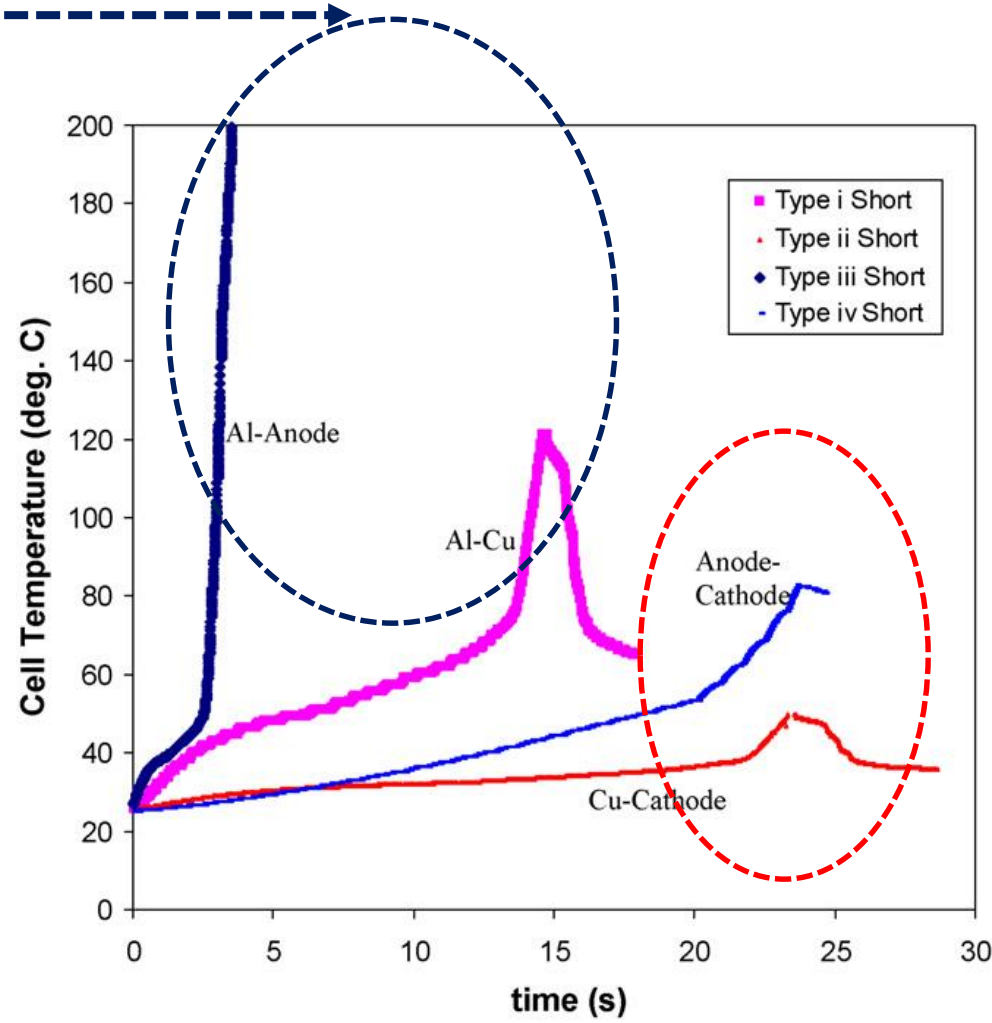
9 anodes & 8 cathodes stacked

Why 8 in-situ temperature peaks with similar time intervals?

Cathode - Anode/Cu ISC (Slow heat generation)

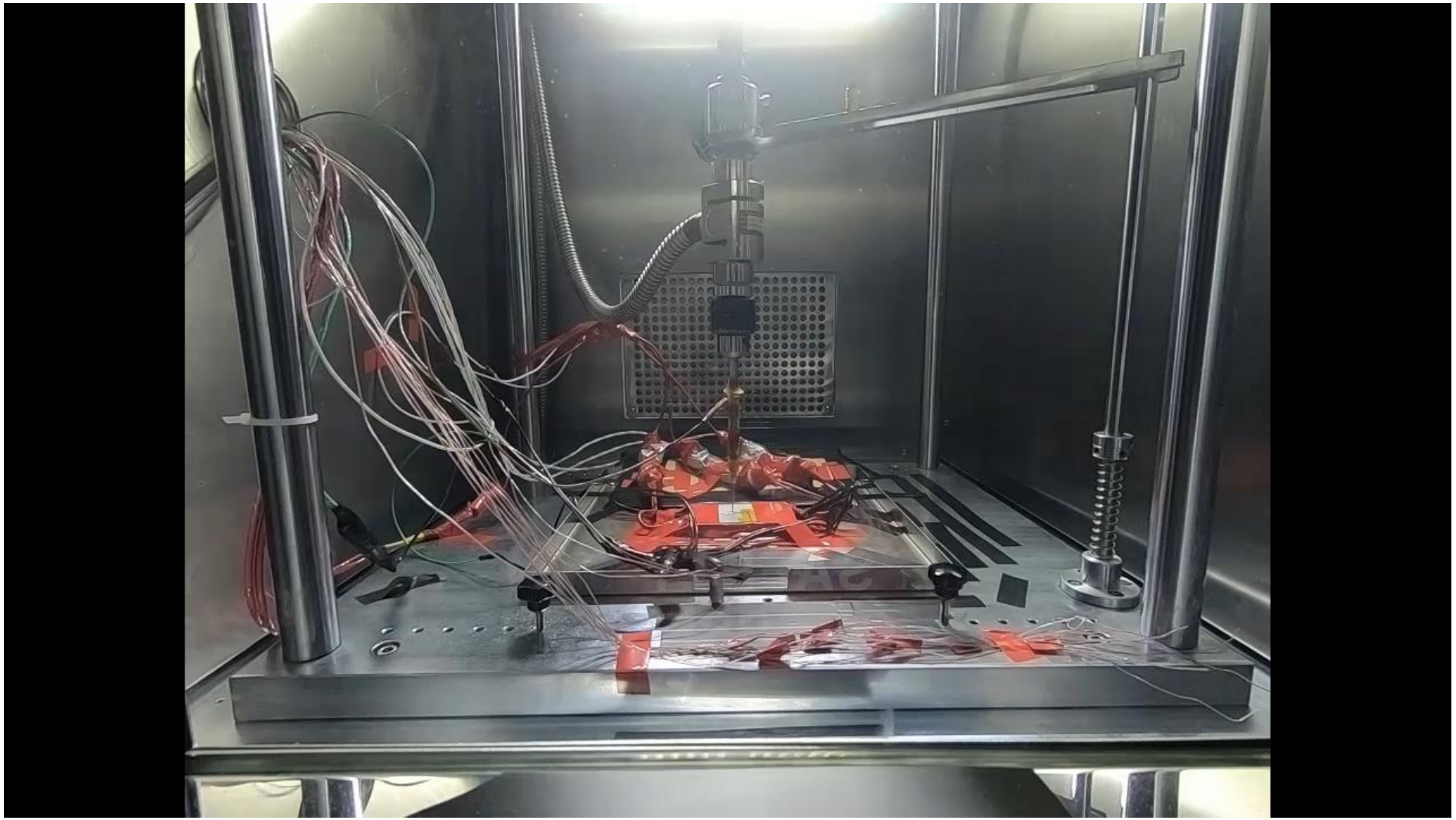
Al – Anode/Cu ISC (Rapid heat generation)





Santhanagopalan, Ramadass, Zhang, JPS 2009

Three 2.4 Ah Li-ion cells connected in parallel (simulating thick Li-ion cell) _ Video

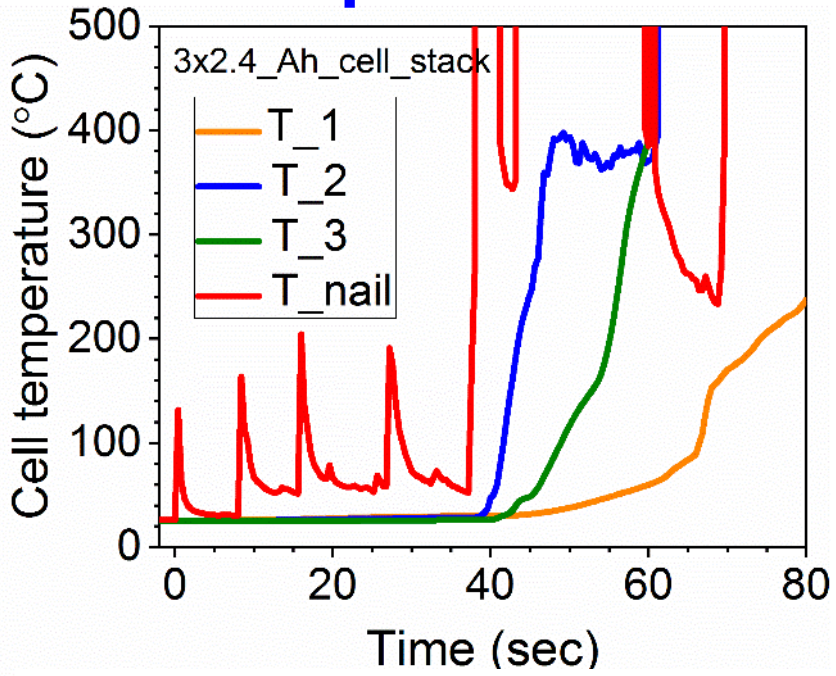


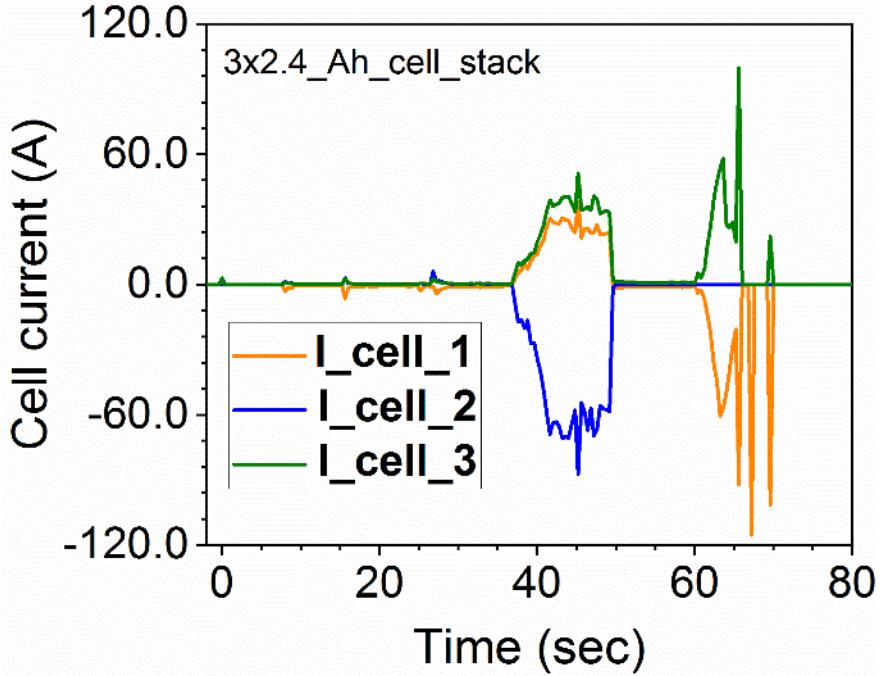
Three 2.4 Ah Li-ion cells connected in parallel (simulating thick Li-ion cell)

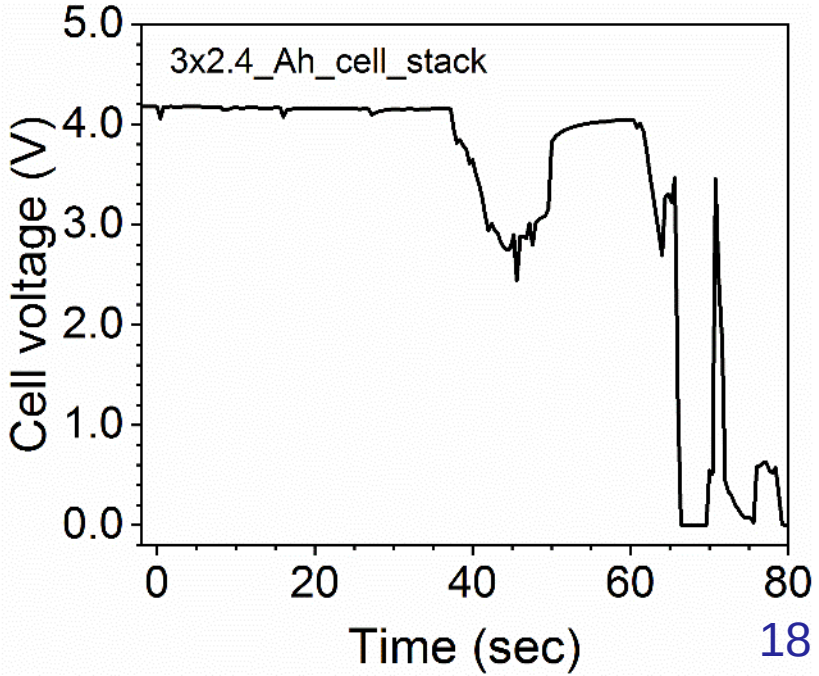
Top surface

Bottom surface

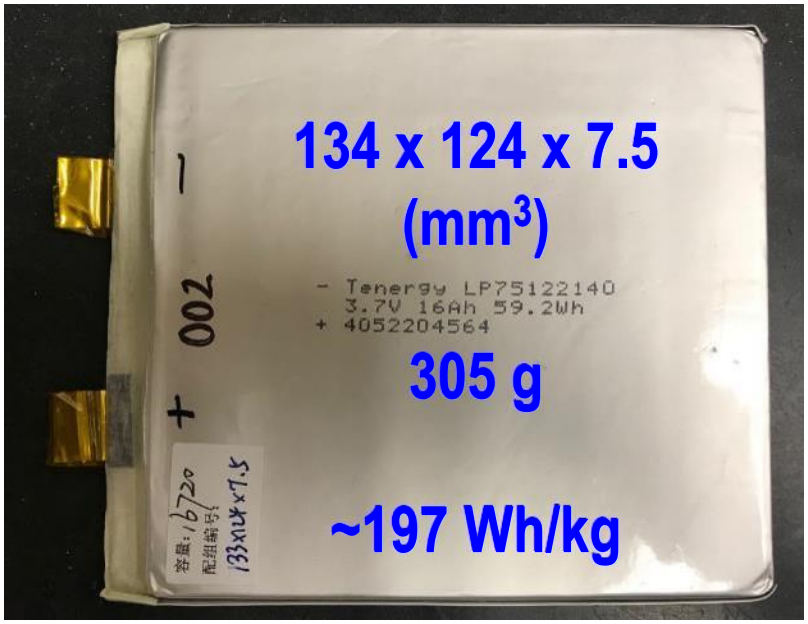
Three 2.4 Ah Li-ion cells connected in parallel (simulating thick Li-ion cell)

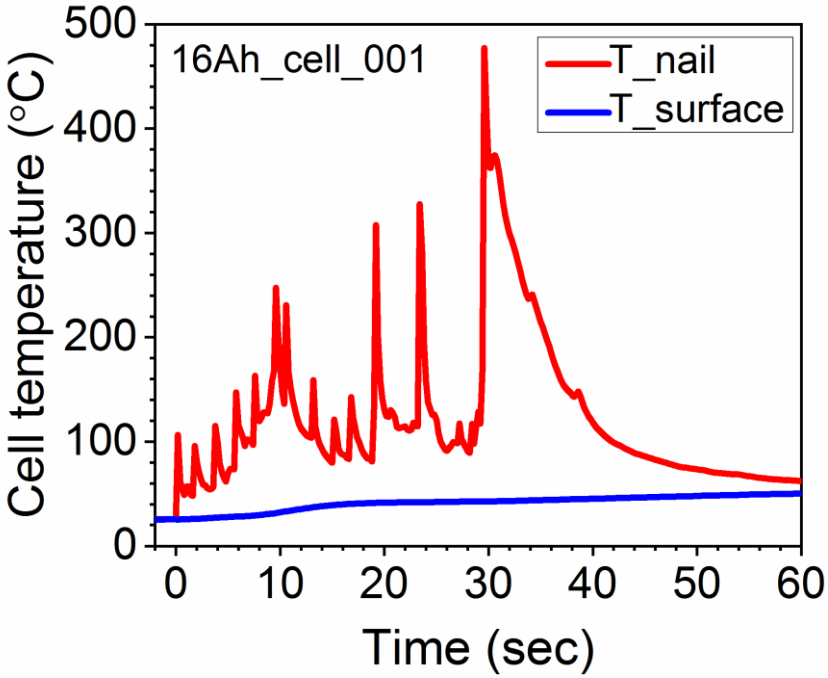






Large Li-ion cell (16 Ah)

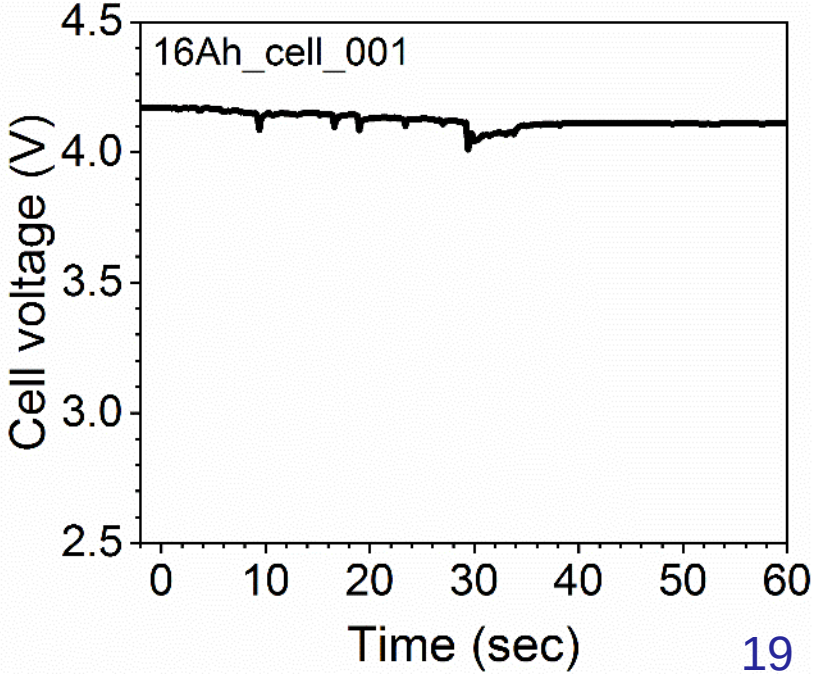




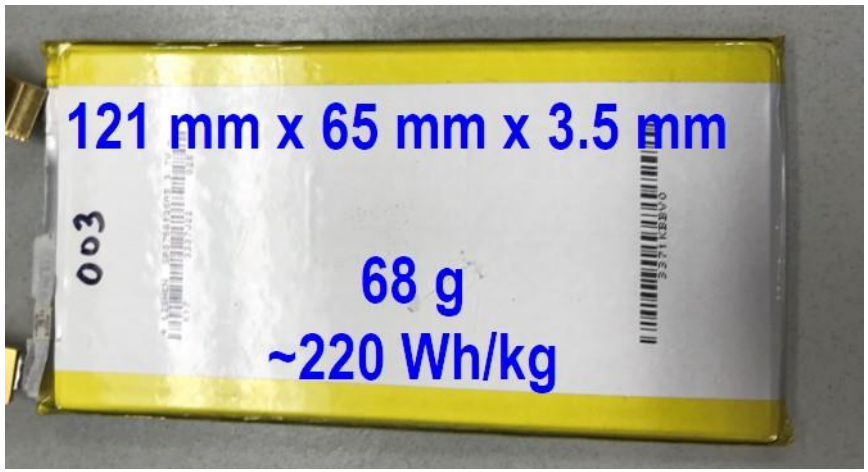
1. Voltage drop is more difficult to detect than small cell (2.4 Ah);

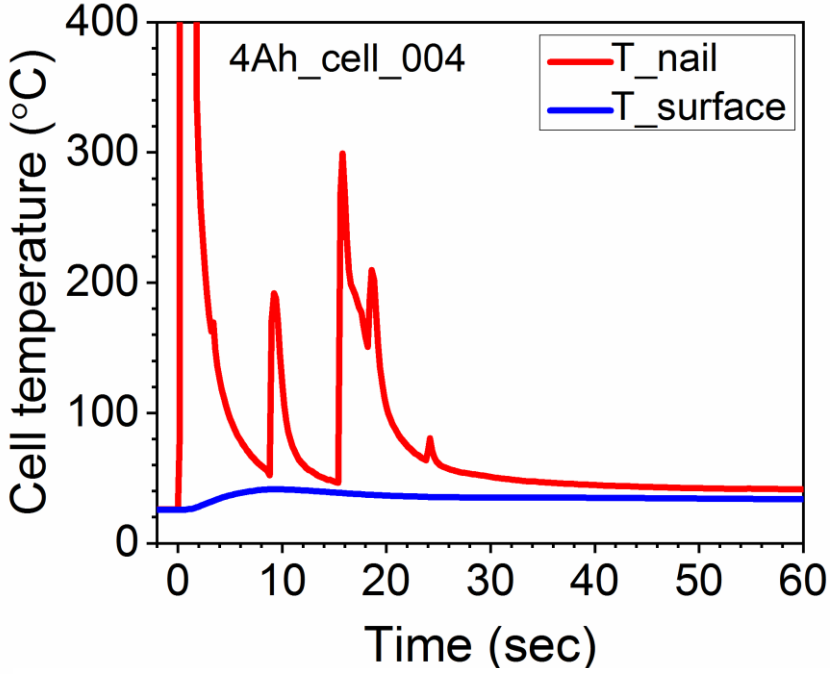
2. In situ temperature has many peaks and is overall increasingly higher;

3. ISC in larger cell has higher risk.



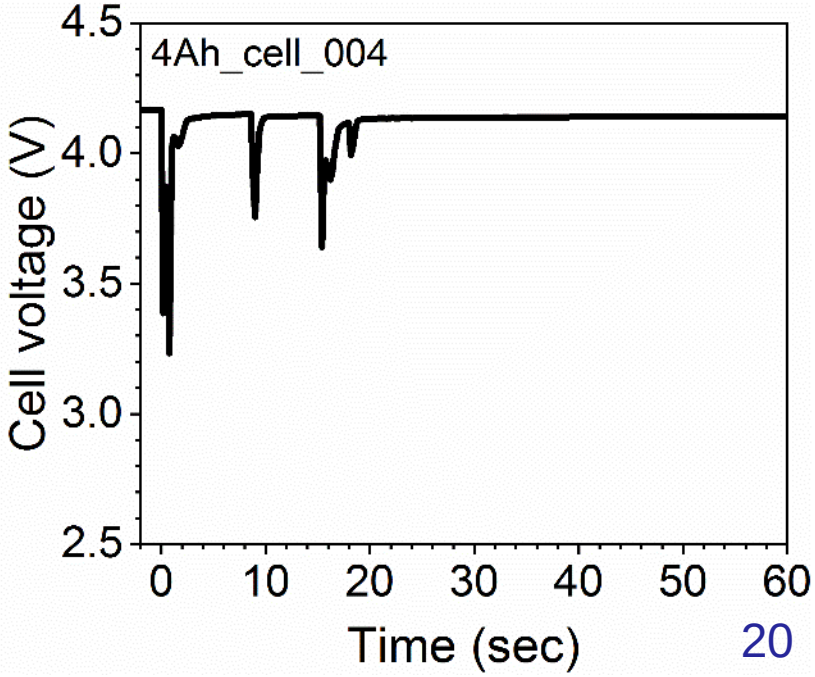
Li-ion cell with different internal structure



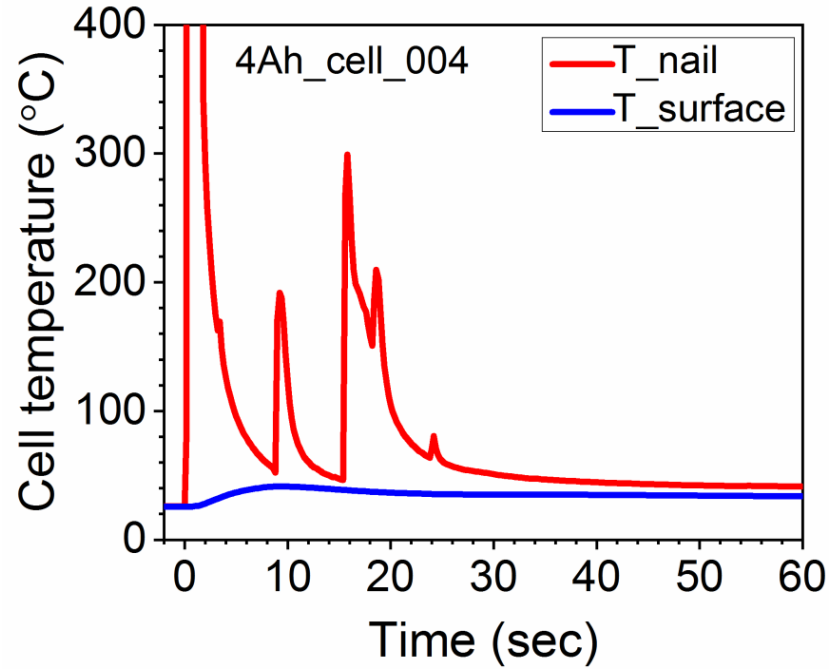


1. In situ temperature peaks are also observed.

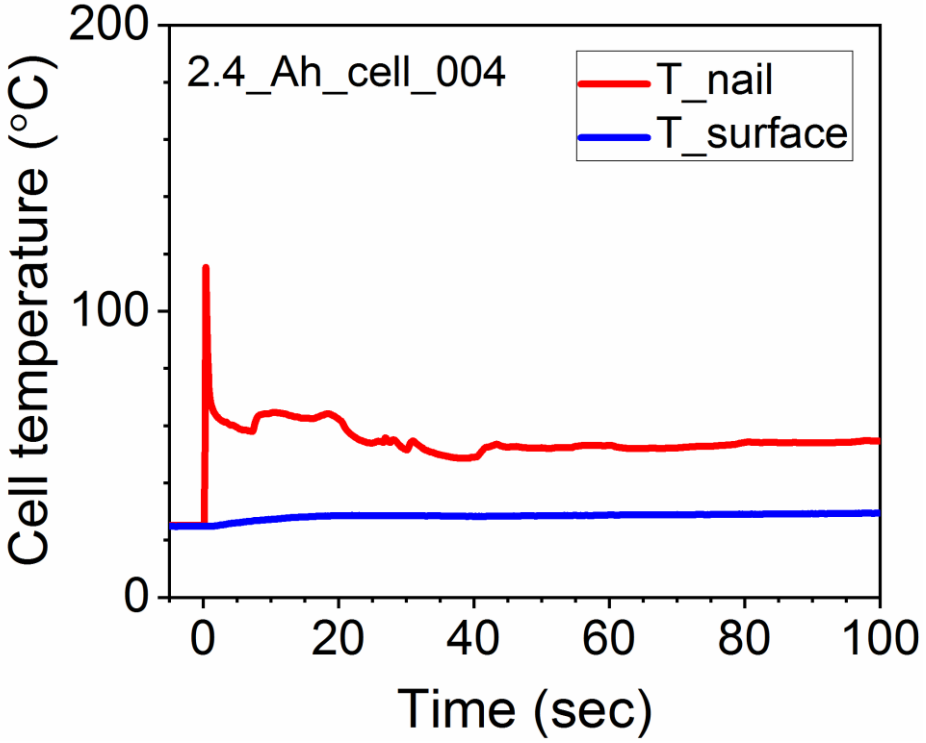
2. But the trend is different from 2.4 Ah cell (stacked electrodes): the first peak is highest.

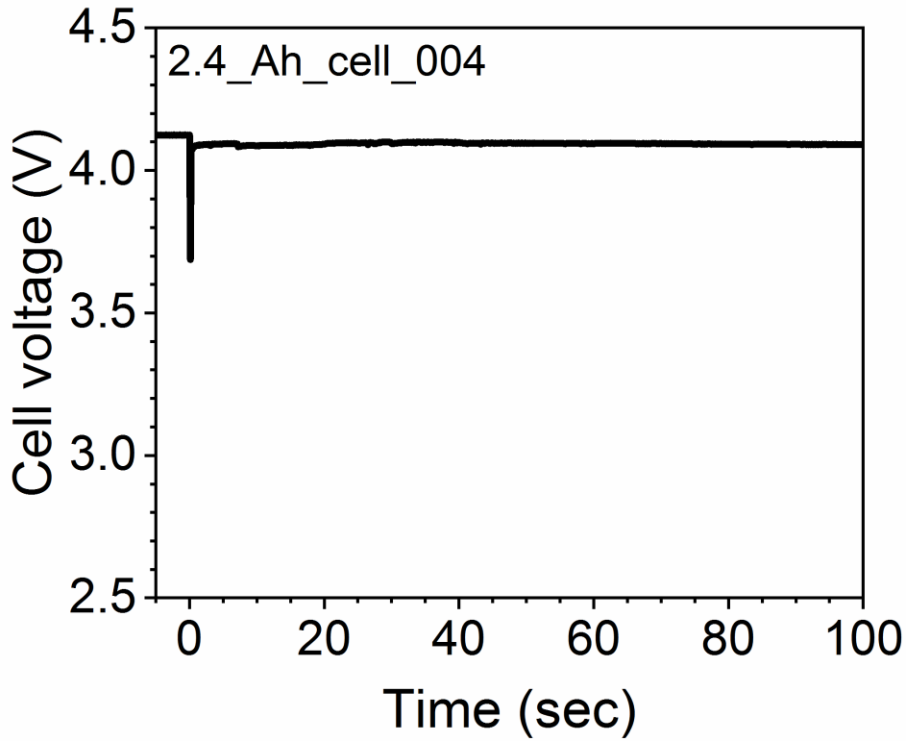


Li-ion cell with different internal structure



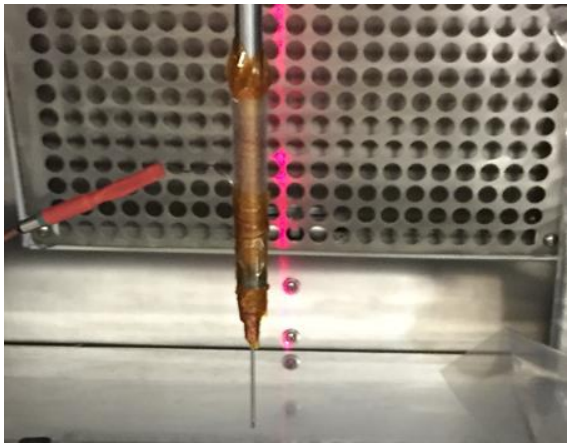
Single-layer nail penetration: only one layer of aluminum current collector penetrated



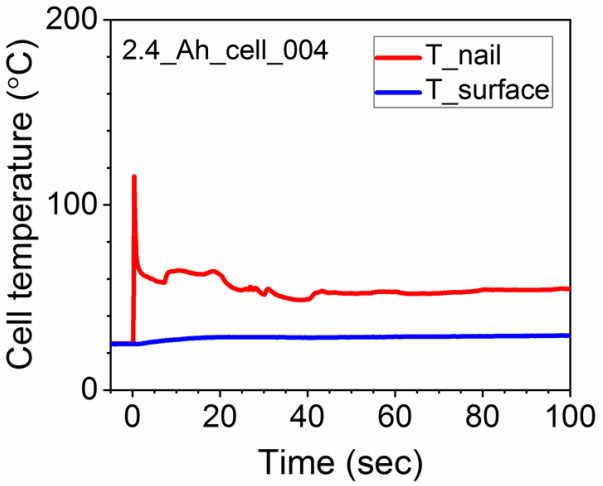


Summary

1. We proposed a method of using Slow-penetrating Micro Sensing Nails to characterize internal short circuit.



2. It enables single-layer penetration and detection of more details. In situ temperature is more revealing than surface temperature, even more than cell voltage.



3. It was used to investigate effects of cell thickness, size and internal structure on safety behaviors.