Internal

Temperature Sensing and Thermal Management of Large-format Li-ion Cells

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(08/2017 -)
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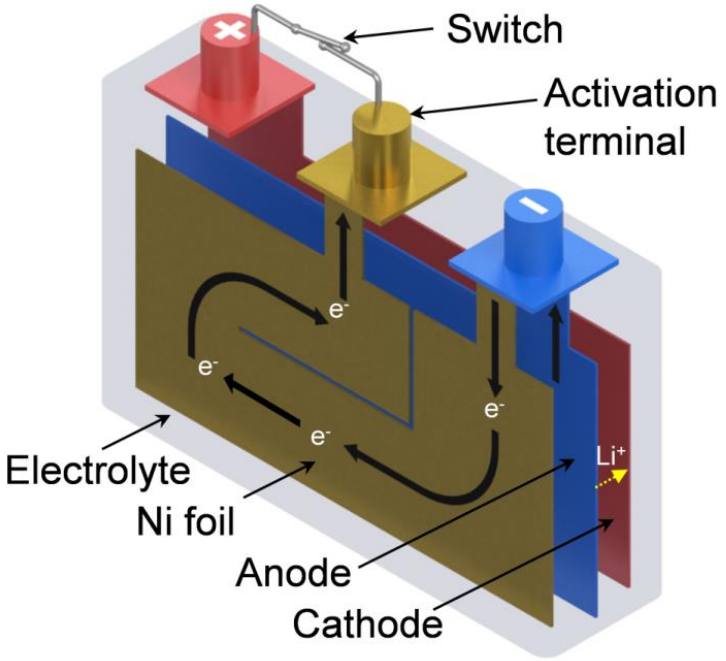

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EEDD

Acknowledgement
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PennState · ECEC Electrochemical Engine Center · battery & energy storage technology BEST center · EC POWER · Ford · Johnson Controls · U.S. Department of Energy Energy Efficiency & Renewable Energy Vehicle Technologies Office · pennsylvania Department of Environmental Protection · BMW

Lithium-ion (Li-ion) cells are increasingly used in automotive and aerospace applications


electrek.co


bmwblog.com

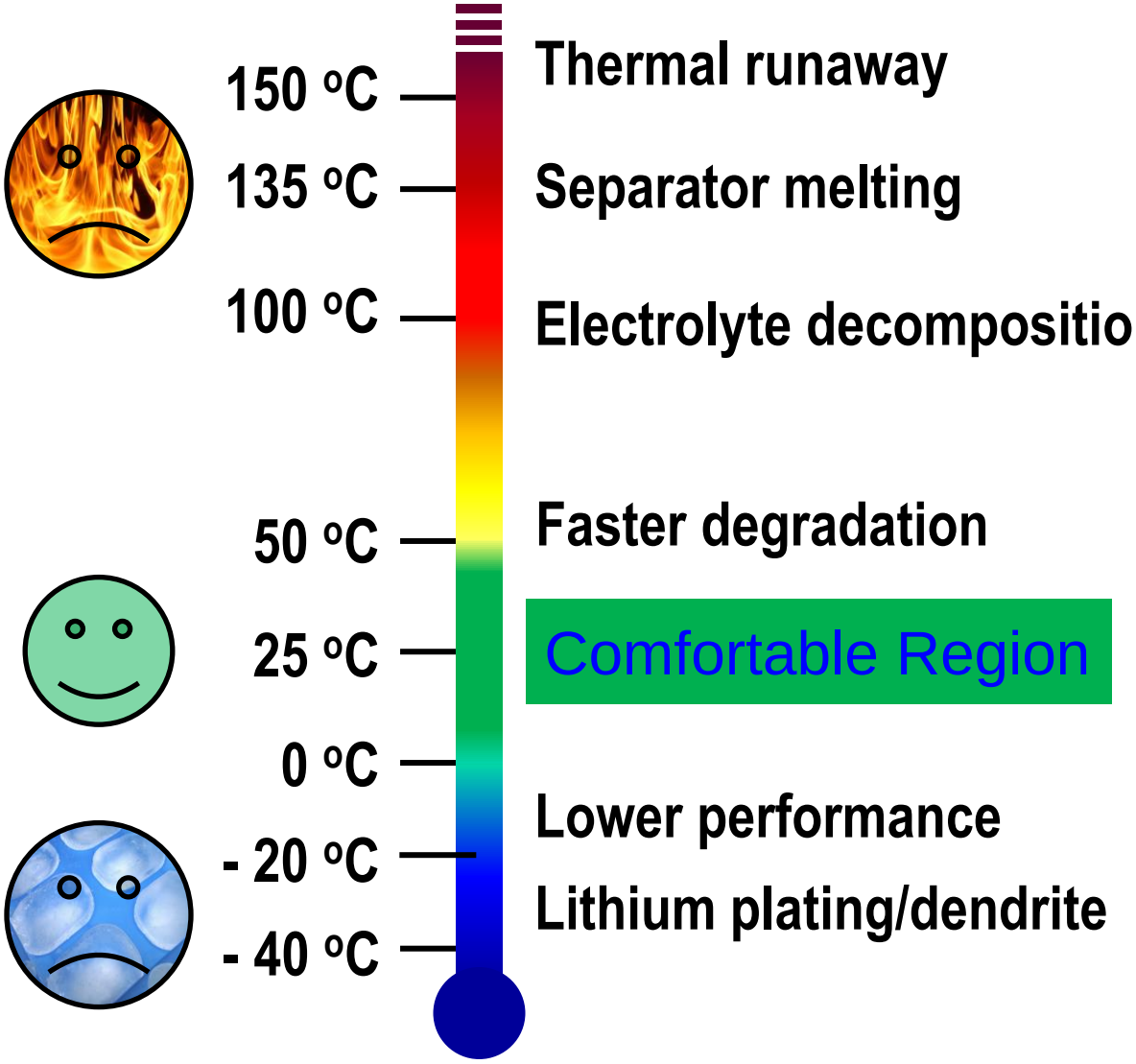
tesla.com

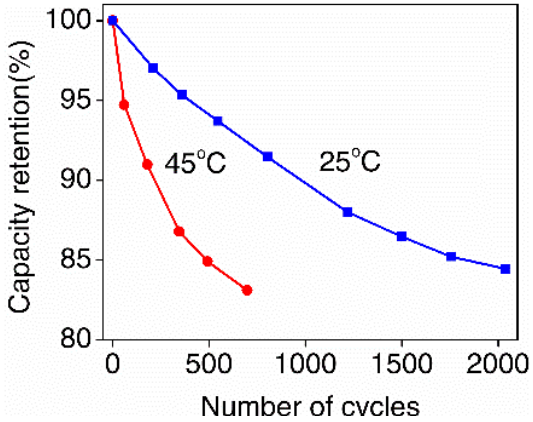
newairplane.com

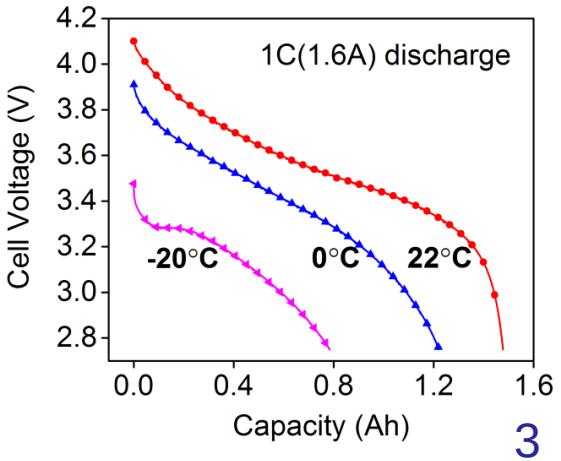
telegraph.co.uk


nasaspaceflight.com

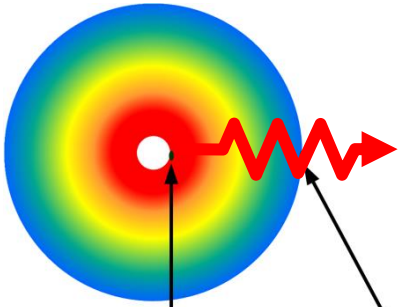
Li-ion cells are very sensitive to temperature, making their thermal management important





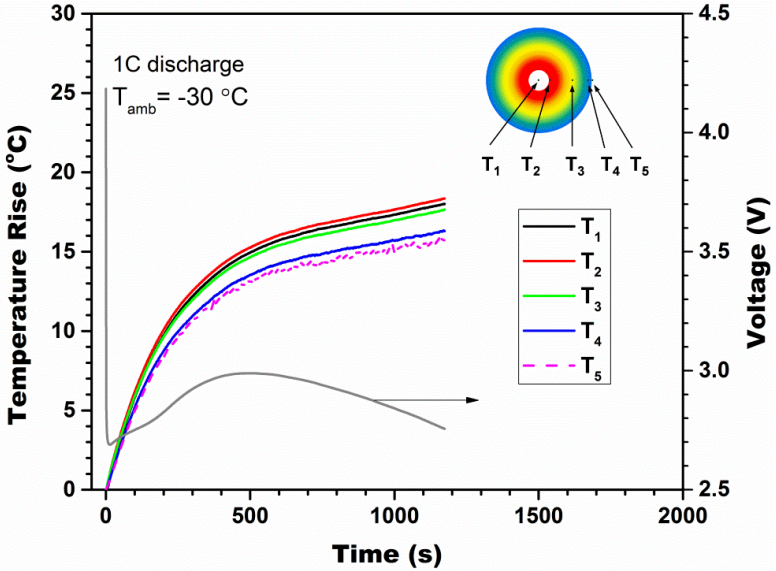


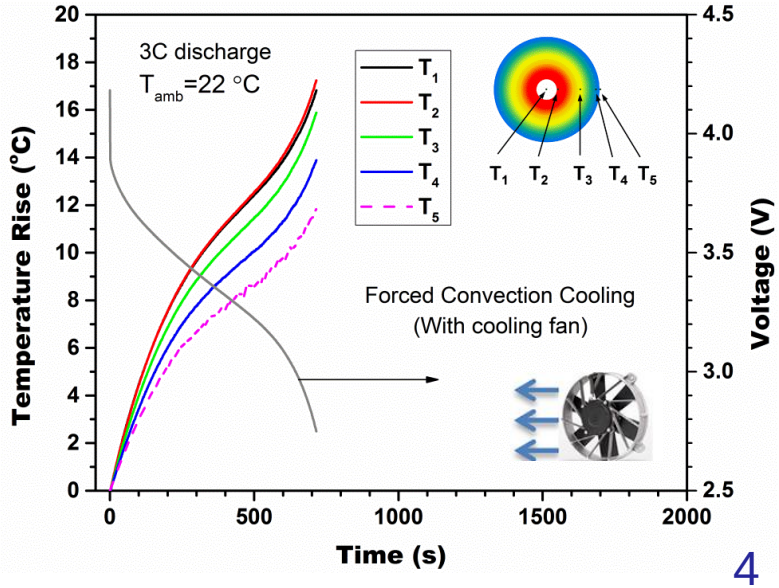
Temperature gradient can exist in Li-ion cells due to very low thermal conductivity in thru-plane direction



$k_{\text{through-plane}} \approx 1\ \text{W m}^{-1}\ \text{K}^{-1}$

~ 5 °C / 7 mm





Zhang, Cao, Ge, Wang, Shaffer, Rahn. ***J Electrochem Soc***, 2014

Automotive and aerospace Li-ion cells are typically large, making thermal management challenging

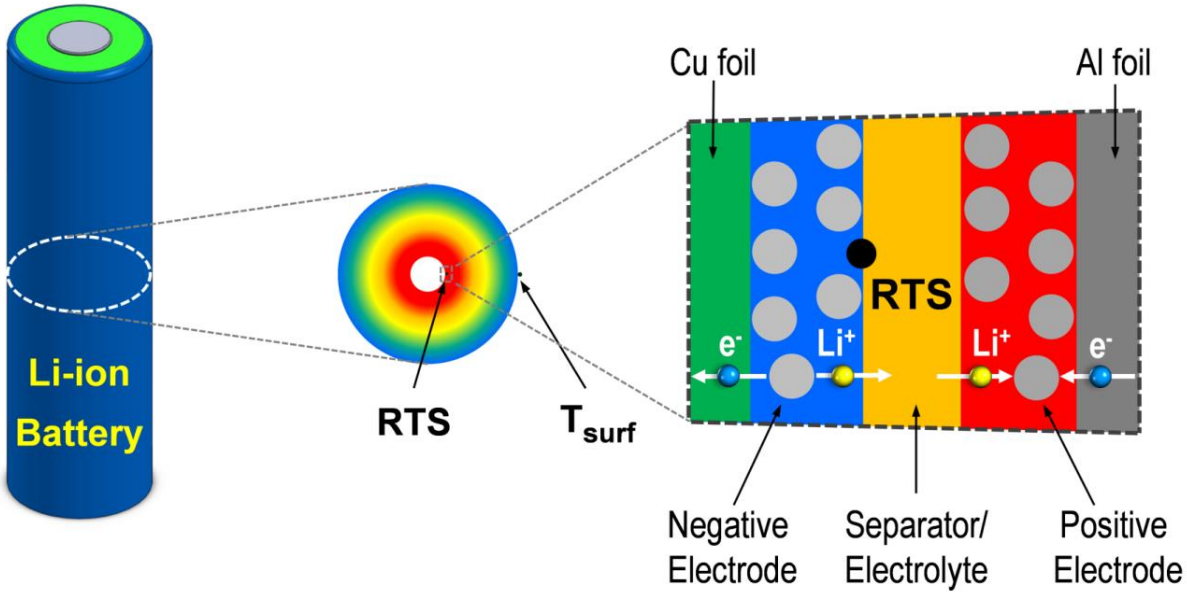
18 (D) x 65 mm
~50 g

173 x 45 x 125 mm
~2,000 g

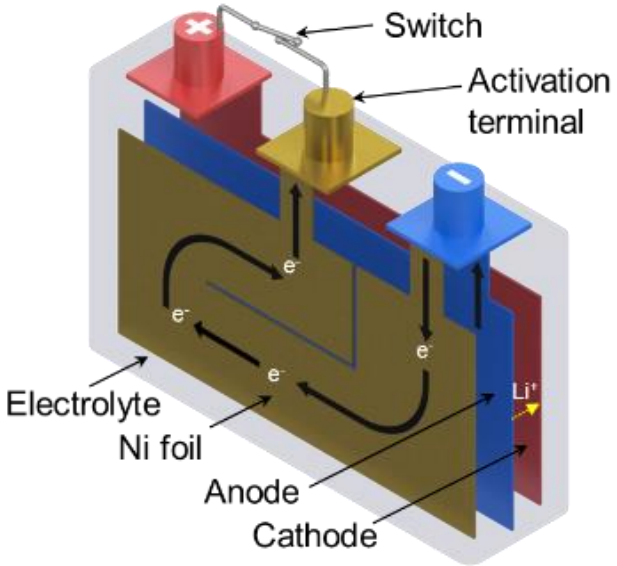
130 x 50 x 263 mm
~3,530 g

Internal temperature sensing and internal thermal management can be very useful

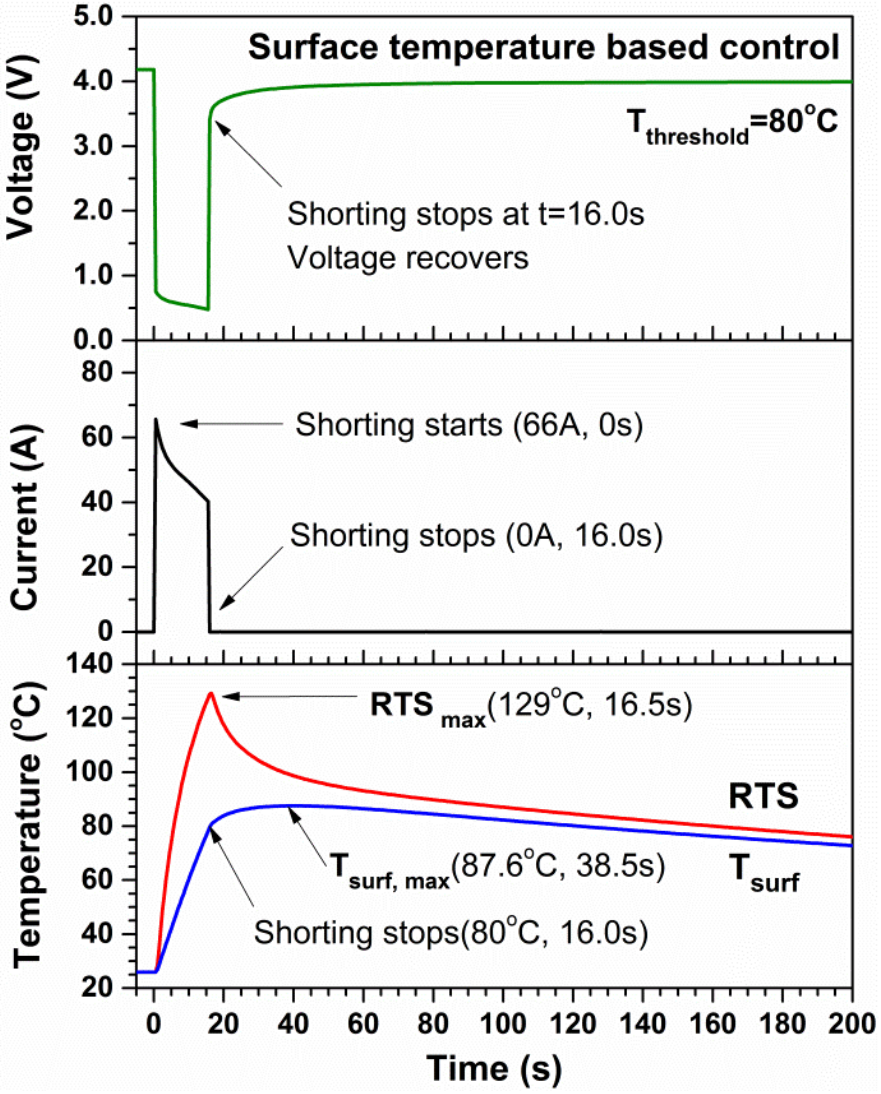
Case 1

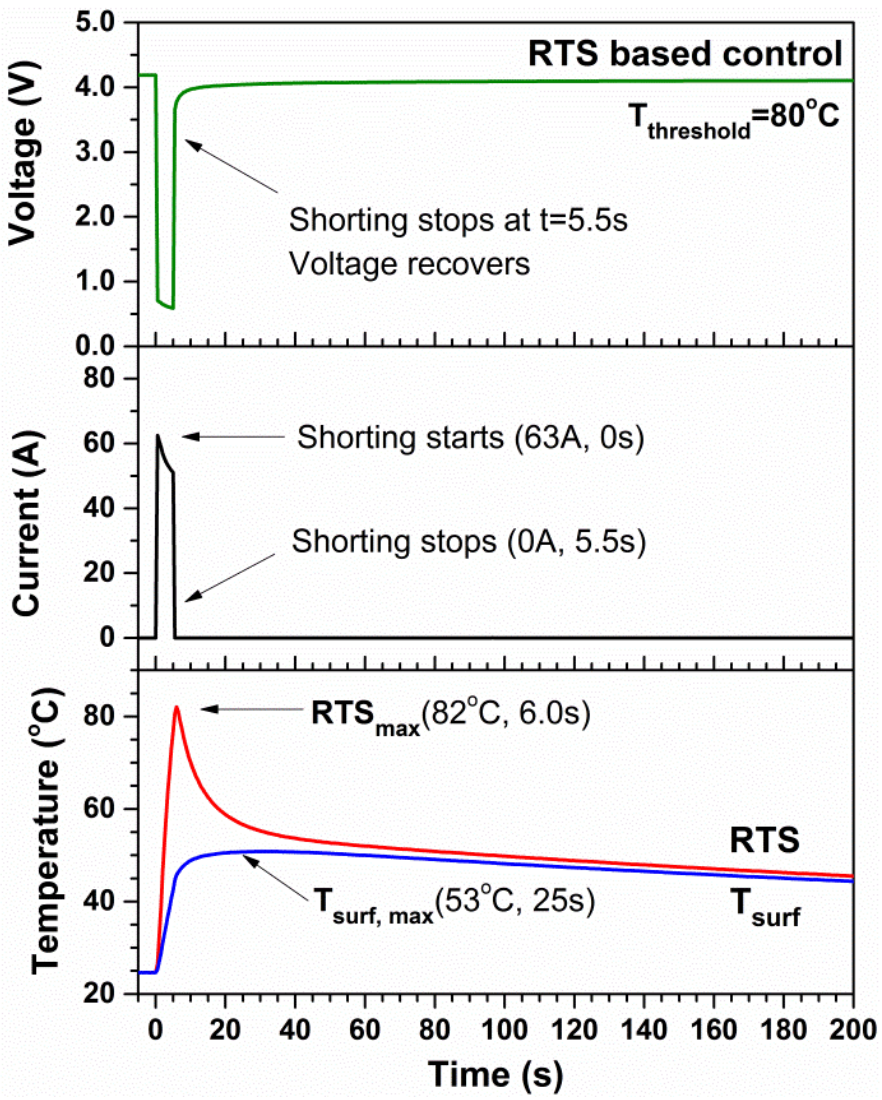


Case 2



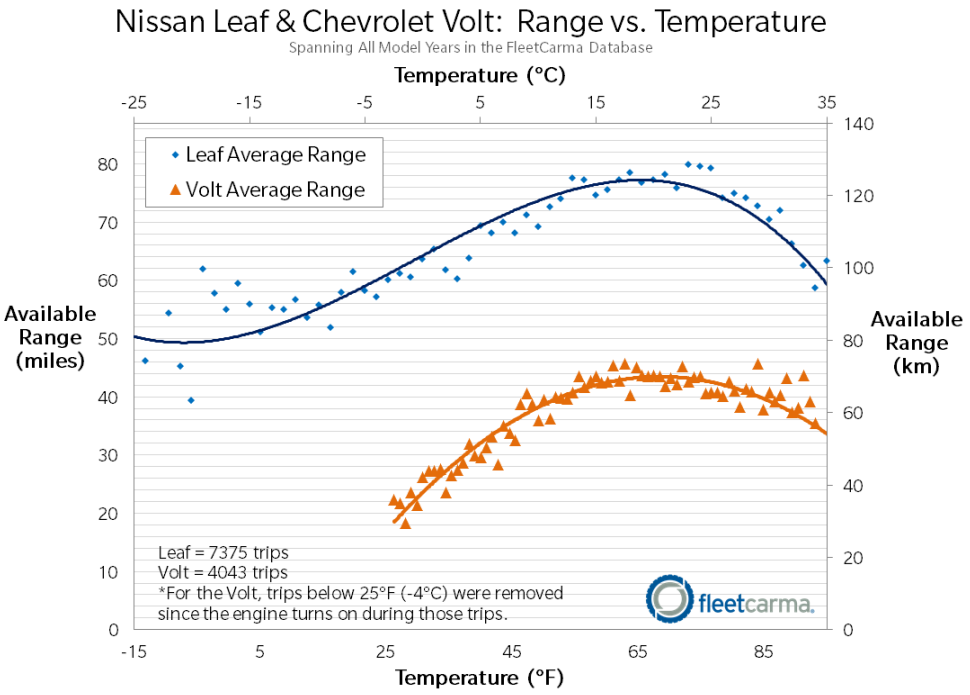
Case 1: Internal temperature sensing in early detection of abnormal behaviors for enhanced safety



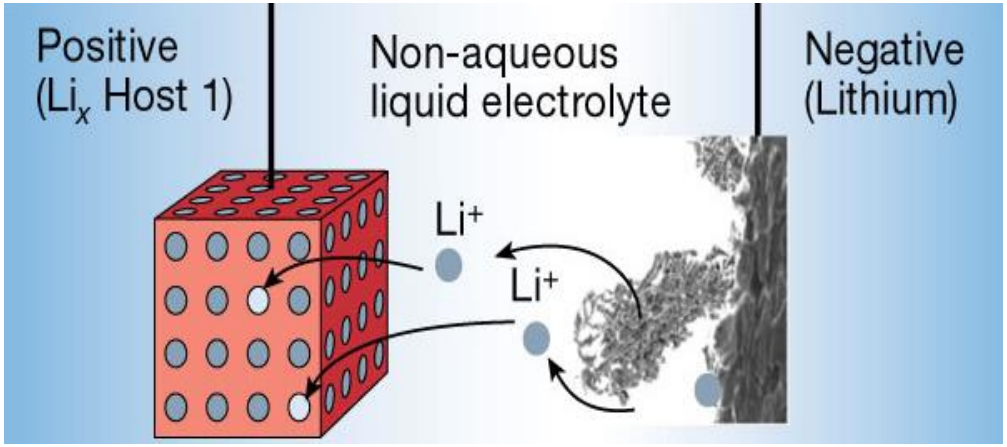


Case 2: Self-Heating Li-ion Battery (SHLB) with internal thermal management for low temperature challenges

Shorter Range

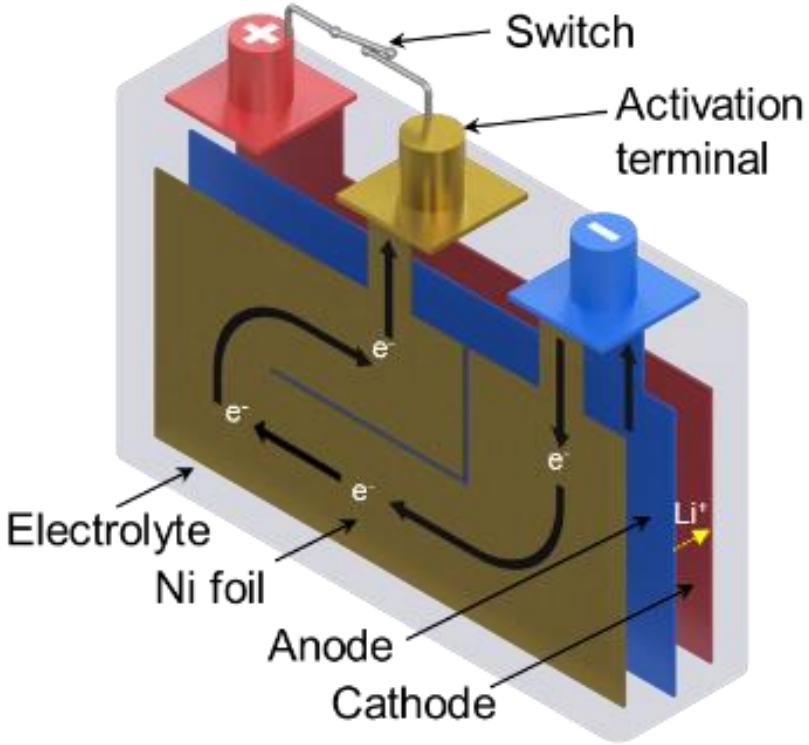


Slow Charging



Tarascon and Armand, *Nature*, 2001

Self-Heating Li-ion Battery (SHLB) cell has a novel structure for internal thermal management



Structure Innovation
(Making best use of materials)

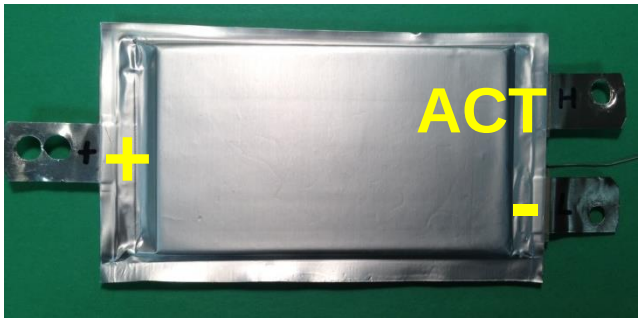
$T < T_{set}$: Switch ON

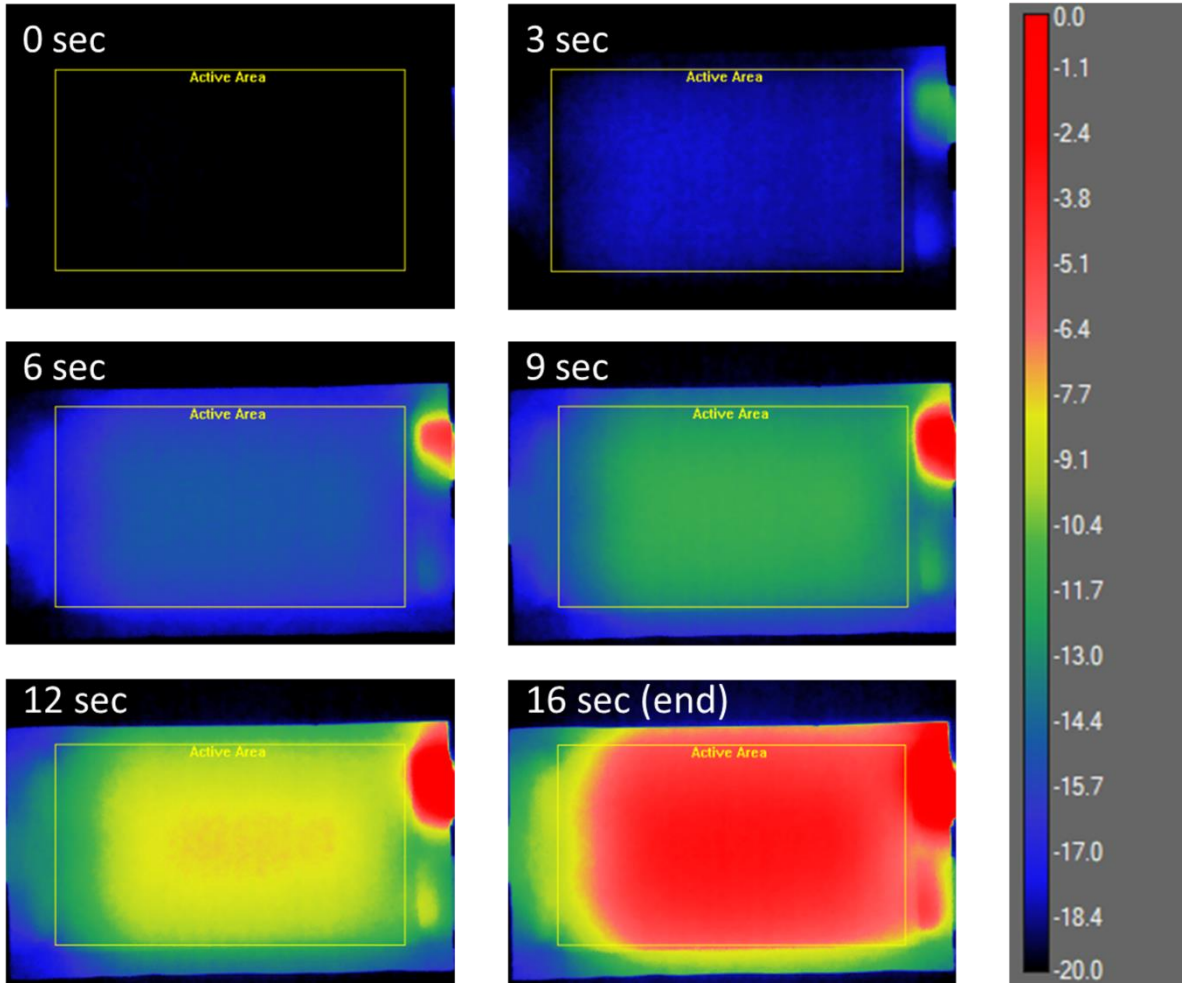
$T \geq T_{set}$: Switch OFF

Wang, **Zhang**, Ge, Xu, Ji, Yang, Leng. ***Nature***, 2016
Zhang, Ge, Xu, Yang, Tian, Wang. ***Electrochim Acta***, 2016

SHLB warms up quickly and uniformly

Infrared imaging of self-heating process

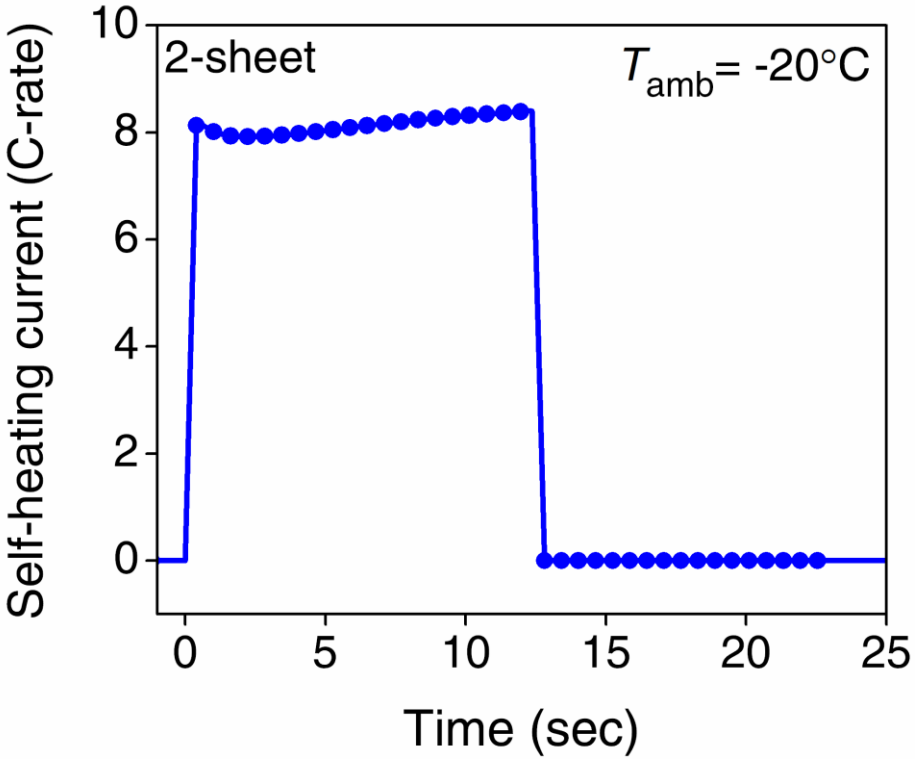


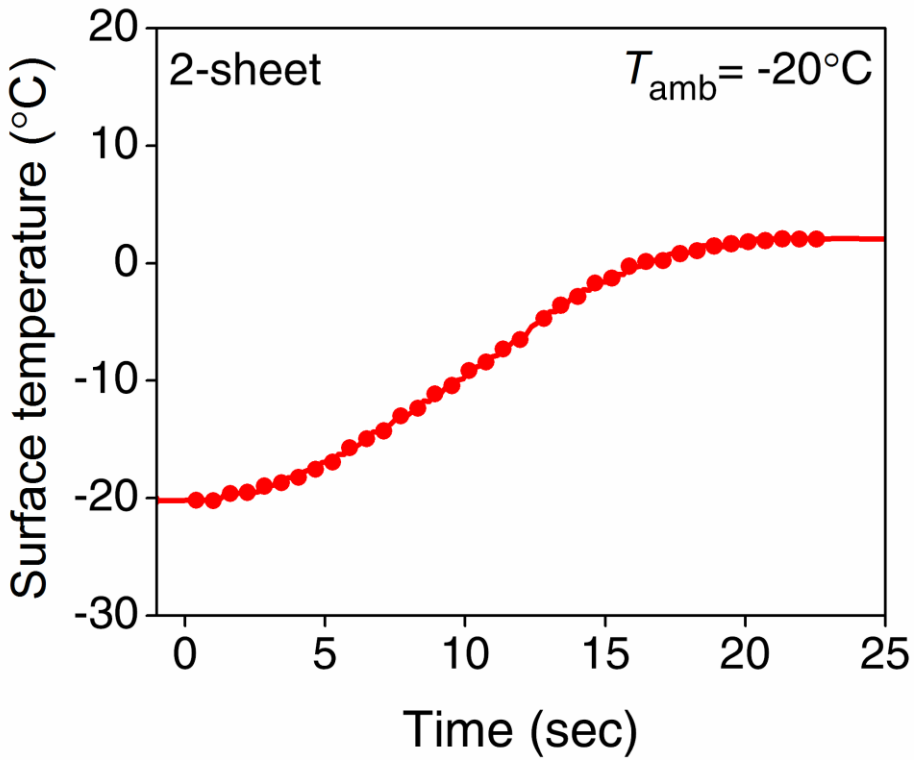


Videos available: http://www.sciencedirect.com/science/article/pii/S0378775317315197

Zhang, Tian, Ge, Marple, Sun, Wang. ***J Power Sources,*** 2017

SHLB warms up even more quickly with thermal insulation (practical applications)



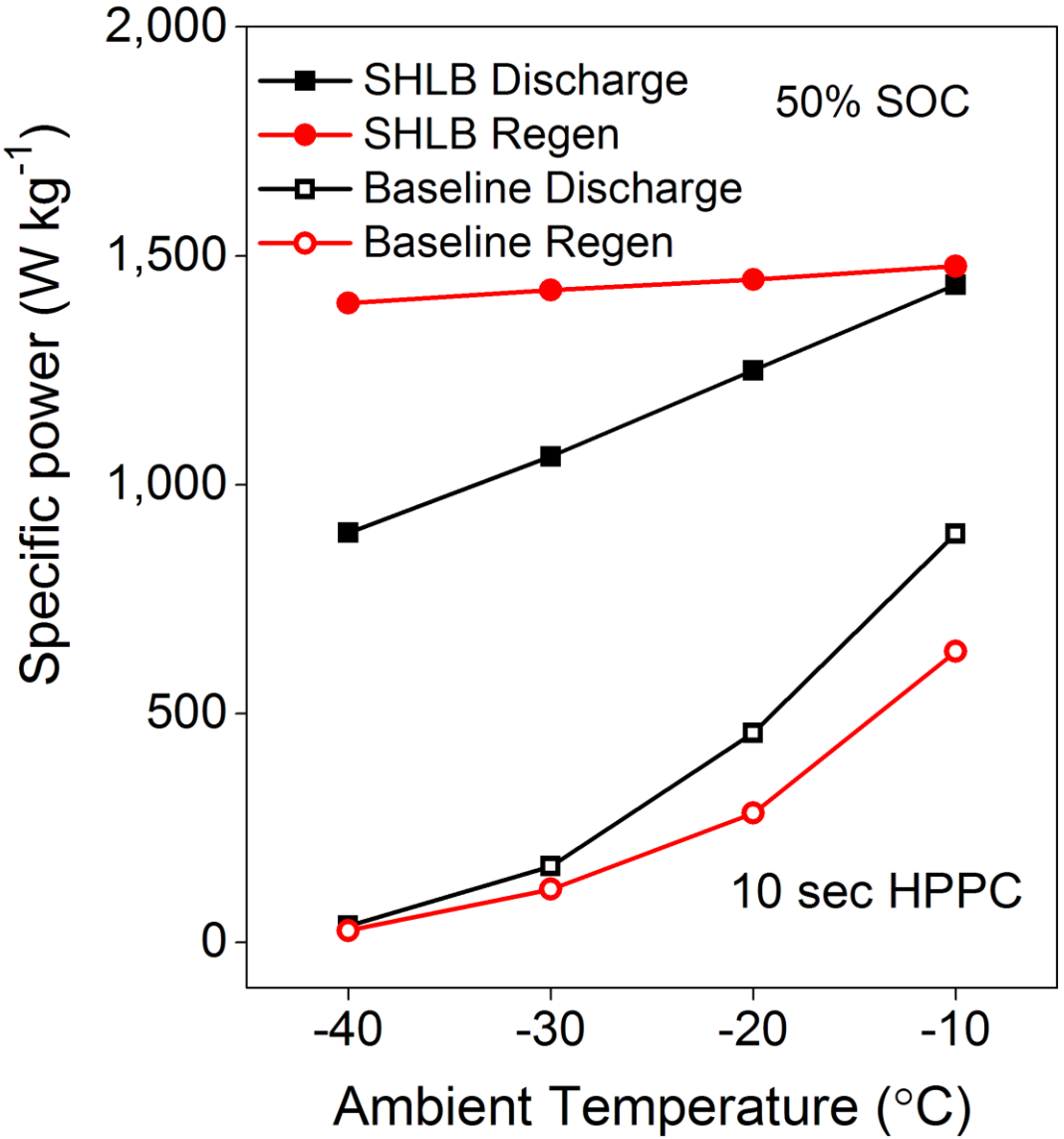


~12 seconds

from -20°C to 0°C

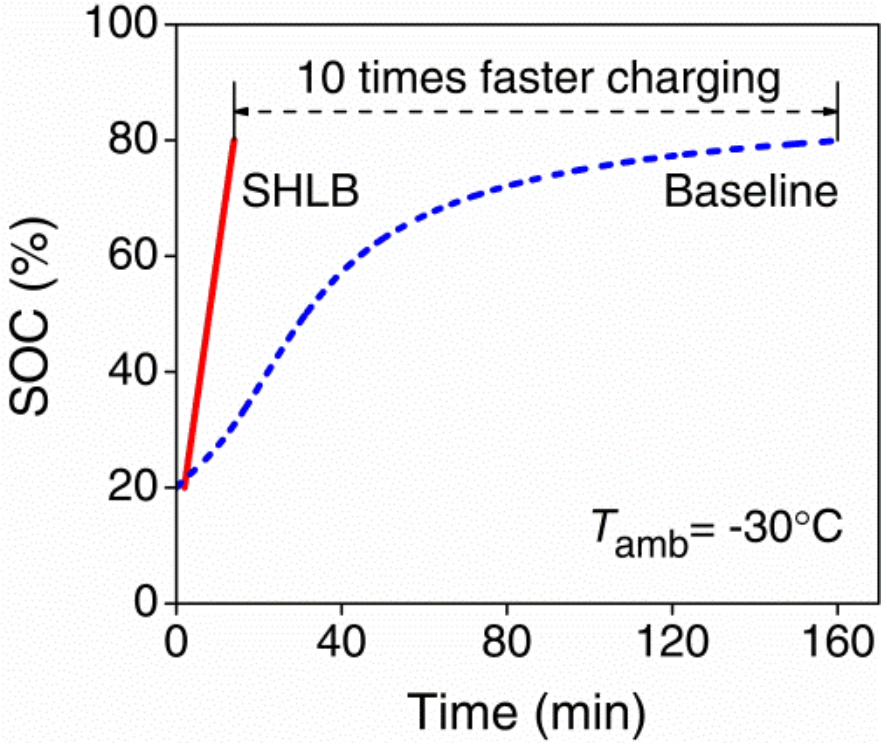
Zhang, Ge, Xu, Yang, Tian, Wang. ***Electrochim Acta***, 2016

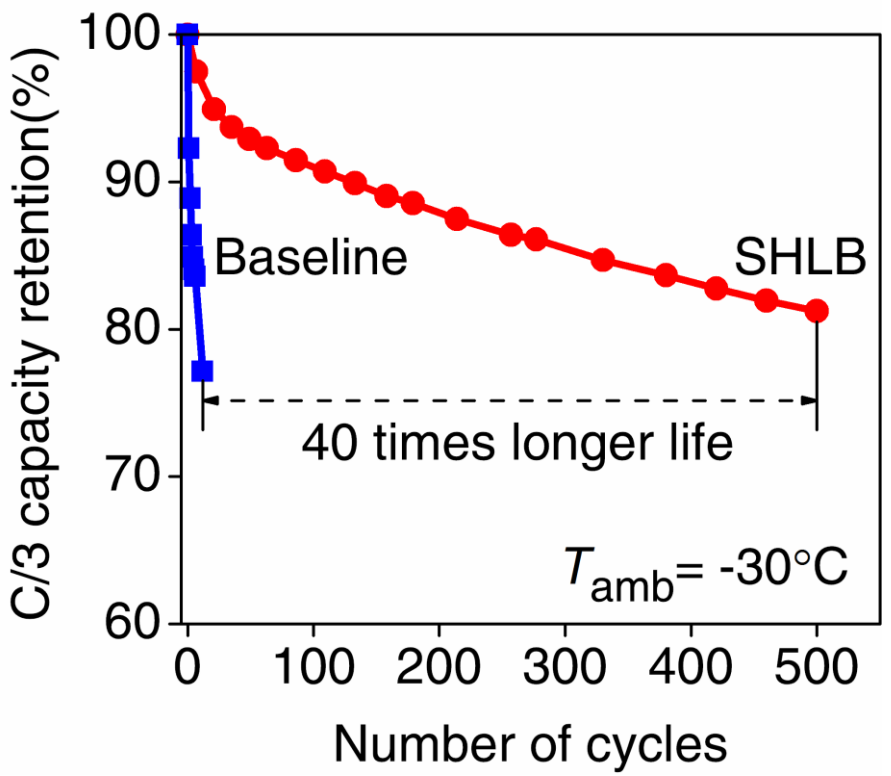
SHLB greatly boosts power at low temperatures



Wang, **Zhang**, Ge, Xu, Ji, Yang, Leng. ***Nature***, 2016

SHLB enables fast charging in extreme cold

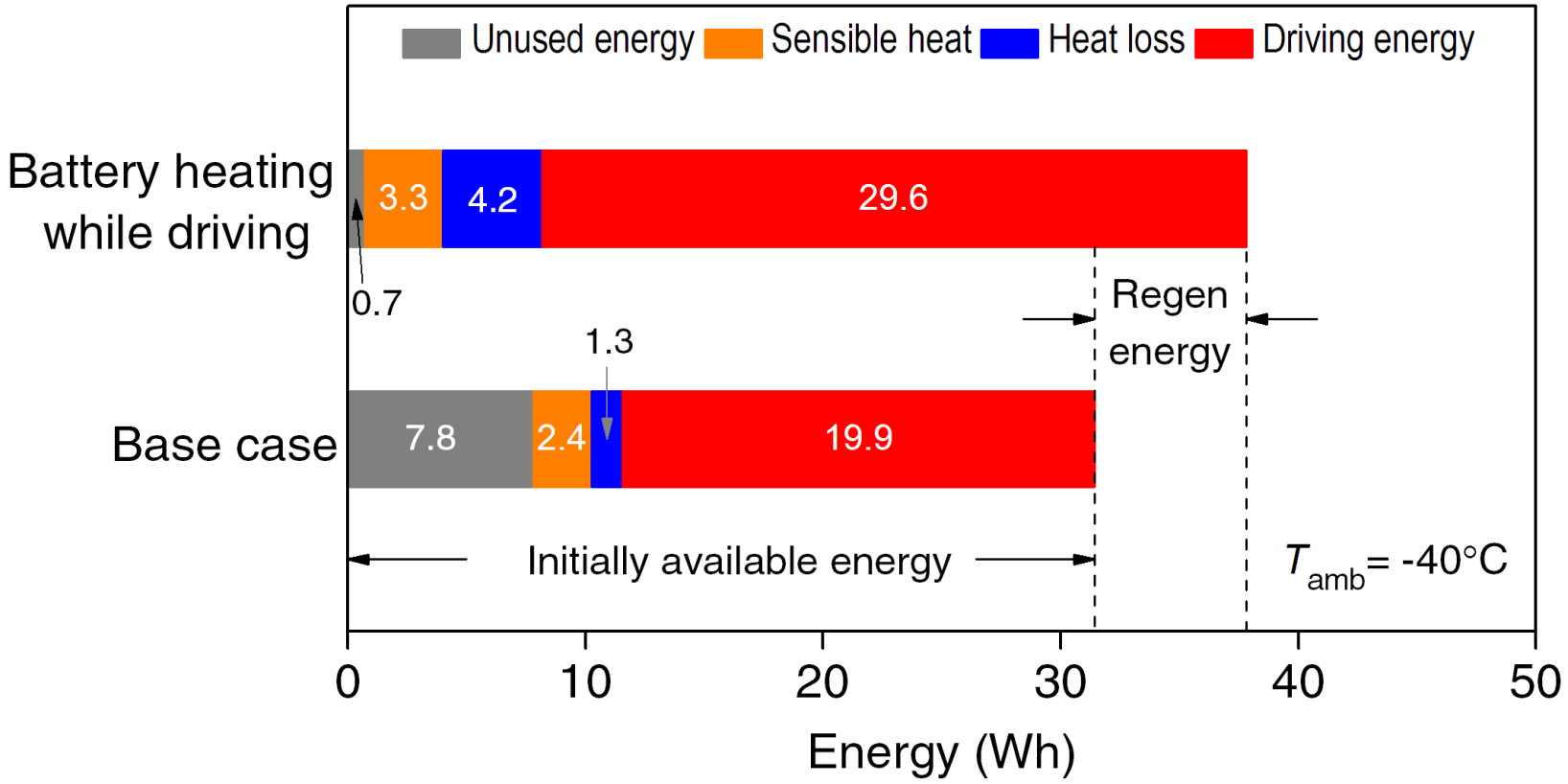




Wang, Xu, Ge, **Zhang**, Yang, Ji. ***J Electrochem Soc***, 2016

Self-Heating While Driving could increase EV driving range at -40ºC by ~50%

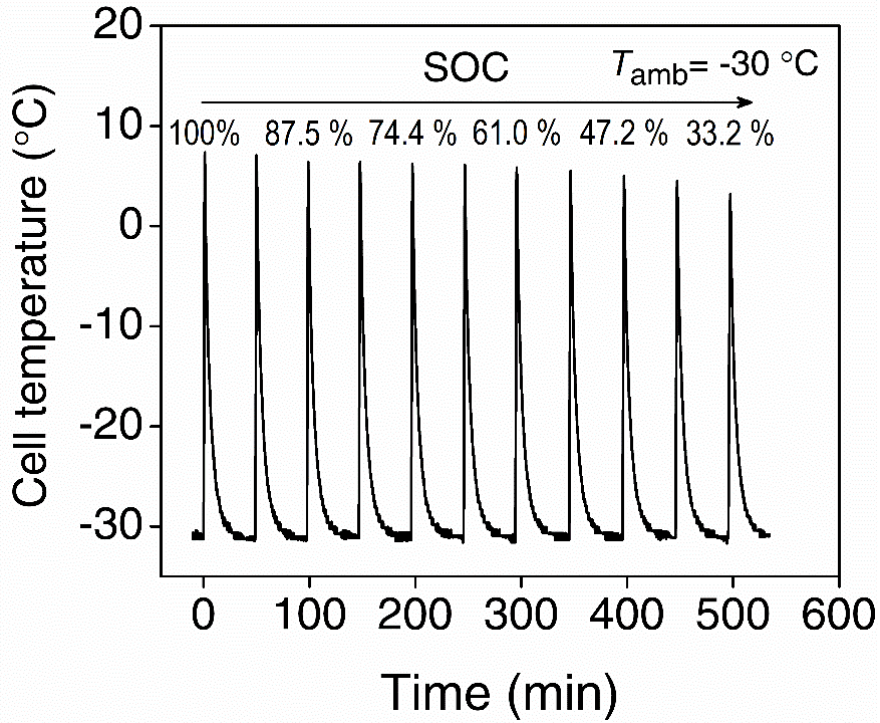
$$E_{\text{available}} + E_{\text{regen}} = E_{\text{driving}} + E_{\text{sensible heat}} + E_{\text{heat loss}} + E_{\text{unused}}$$



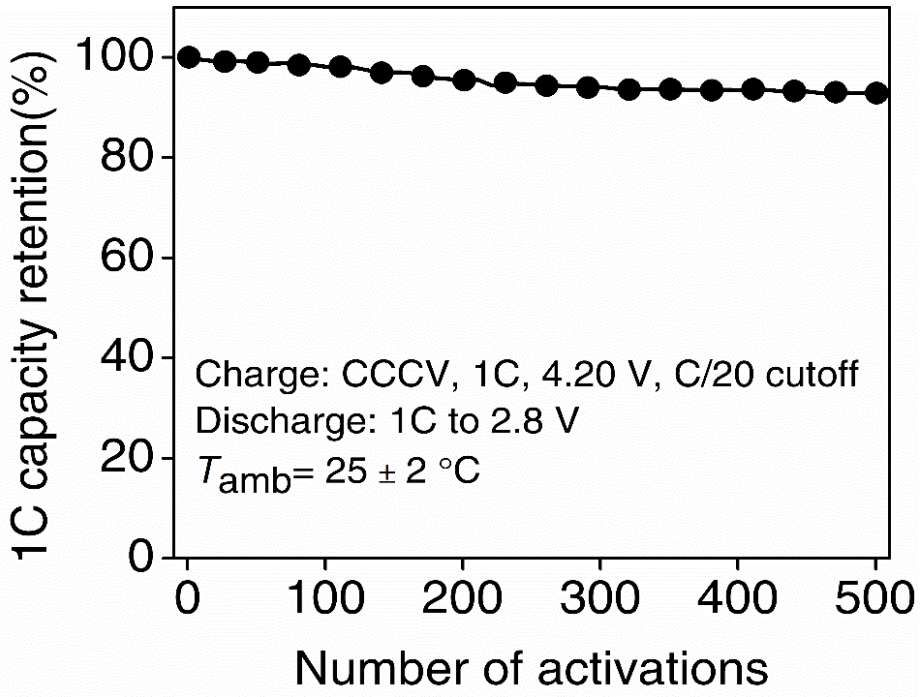
Increased range due to (1) Higher utilization, (2) Full recovery of regen energy

Zhang, Ge, Yang, Leng, Marple, Wang. ***J Power Sources***, 2017

SHLB is very durable



Repetitive activations at -30°C

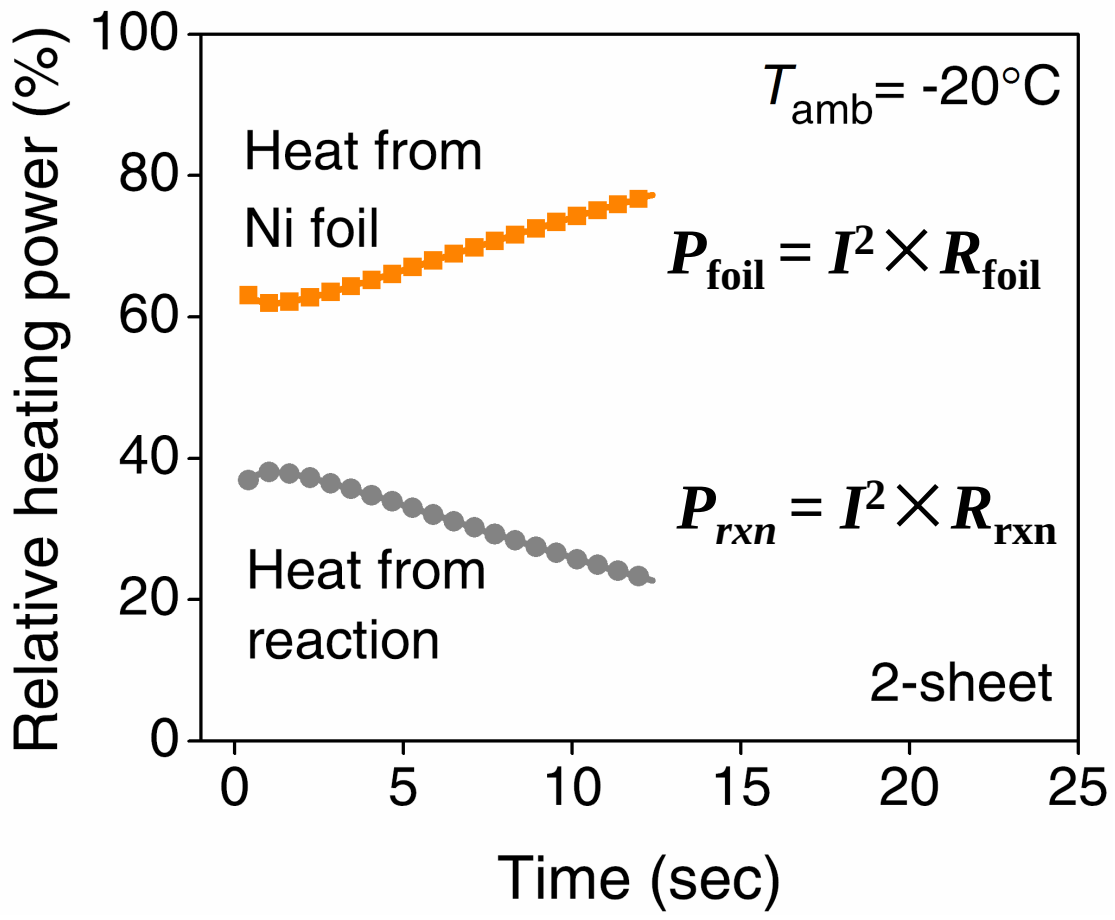


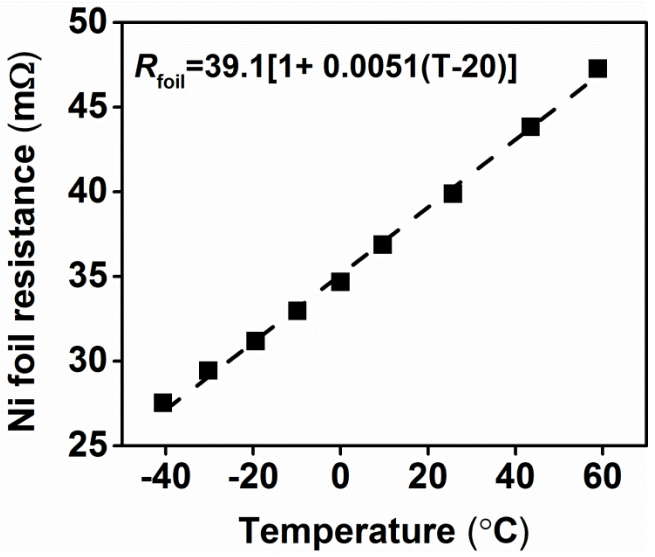
Only 7.4% degradation after 500 activations (indicating no obvious damage)

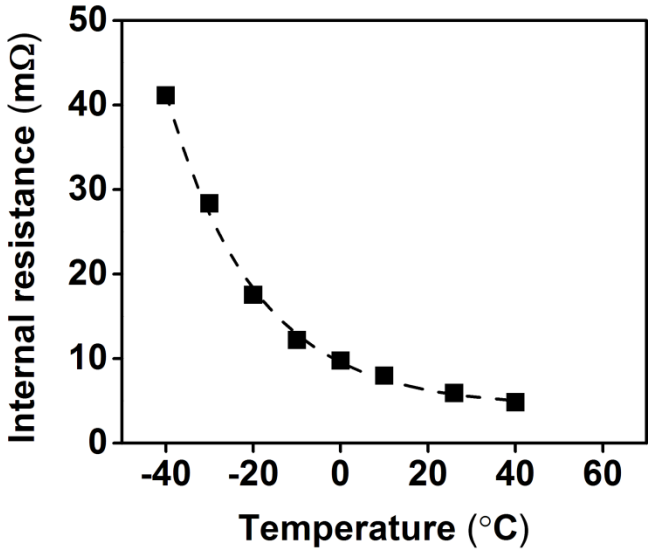
Over 2,600 cycles at room temperature

Wang, **Zhang**, Ge, Xu, Ji, Yang, Leng. ***Nature***, 2016

SHLB warms up quickly because heat generation is significantly enhanced by the embedded Ni foil

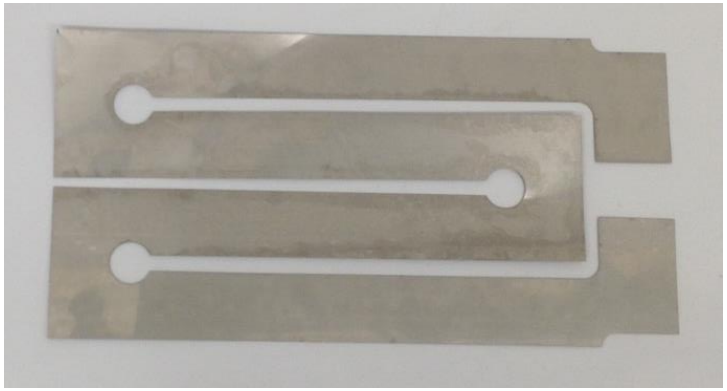


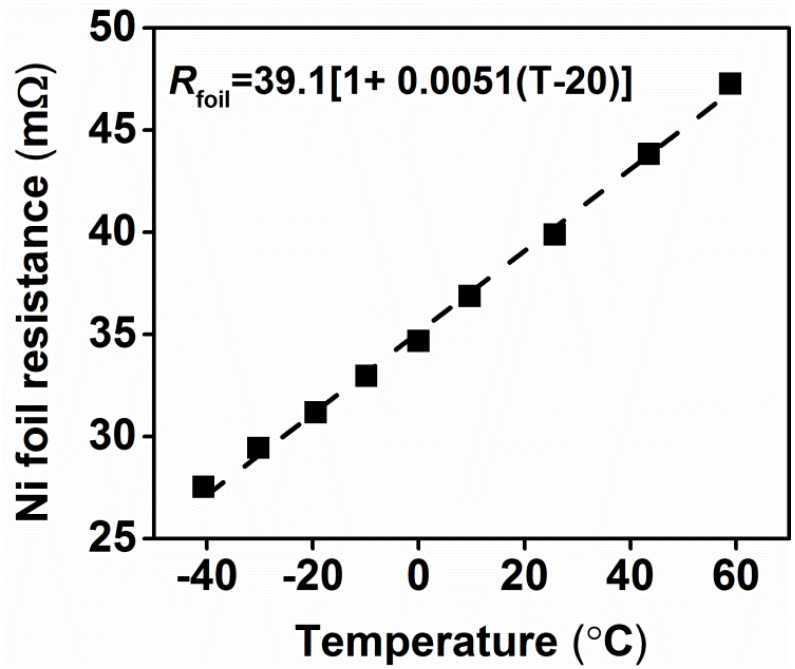


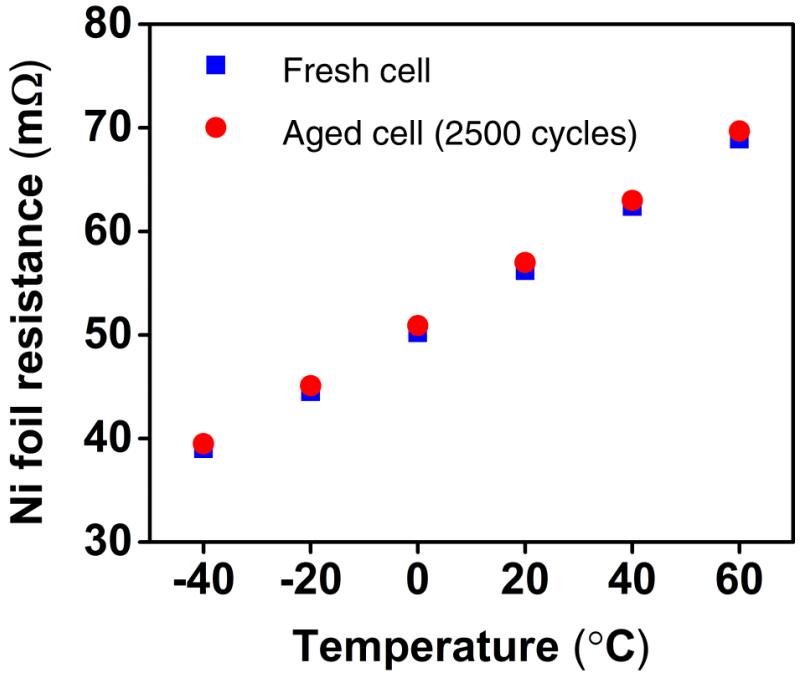


Zhang, Ge, Xu, Yang, Tian, Wang. ***Electrochim Acta***, 2016

The Ni foil in SHLB can simultaneously perform as a heater & an internal temperature sensor (RTD)

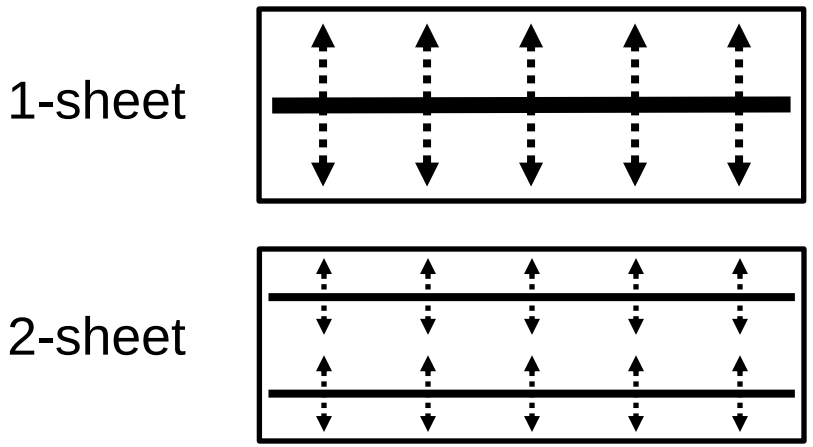


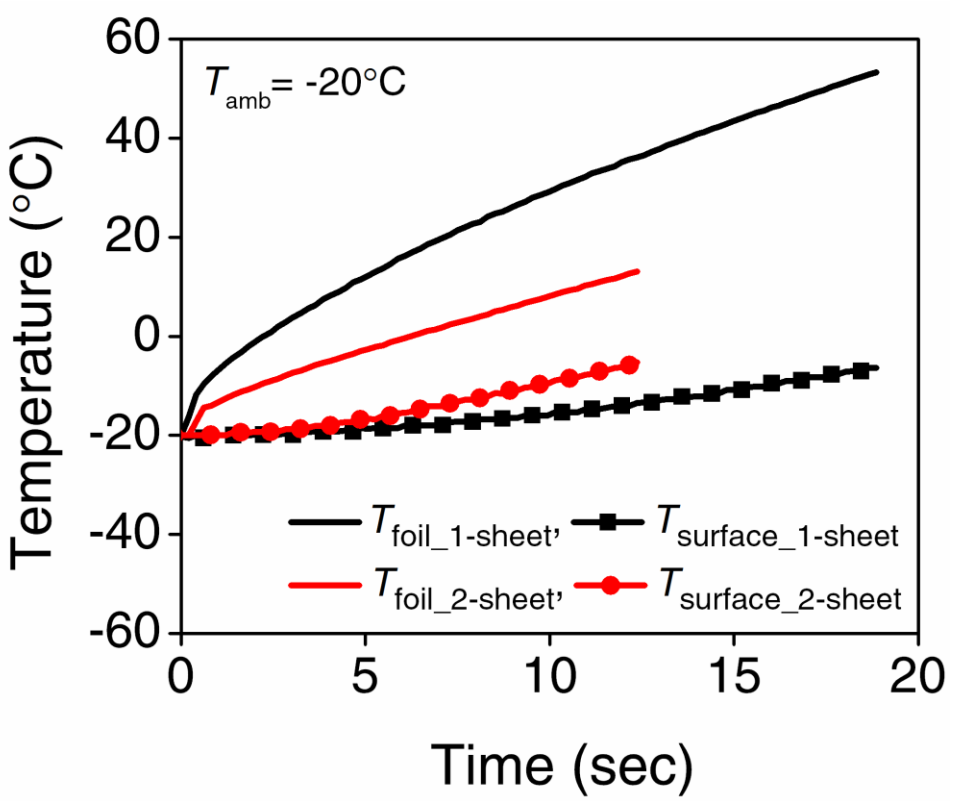




Zhang, Ge, Xu, Yang, Tian, Wang. ***Electrochim Acta***, 2016
Zhang, Ge, Leng, Yang, Marple, Wang. ***231st ECS Meeting***, *2017*

The RTD was used to measure internal temperature during rapid self-heating and improve SHLB design

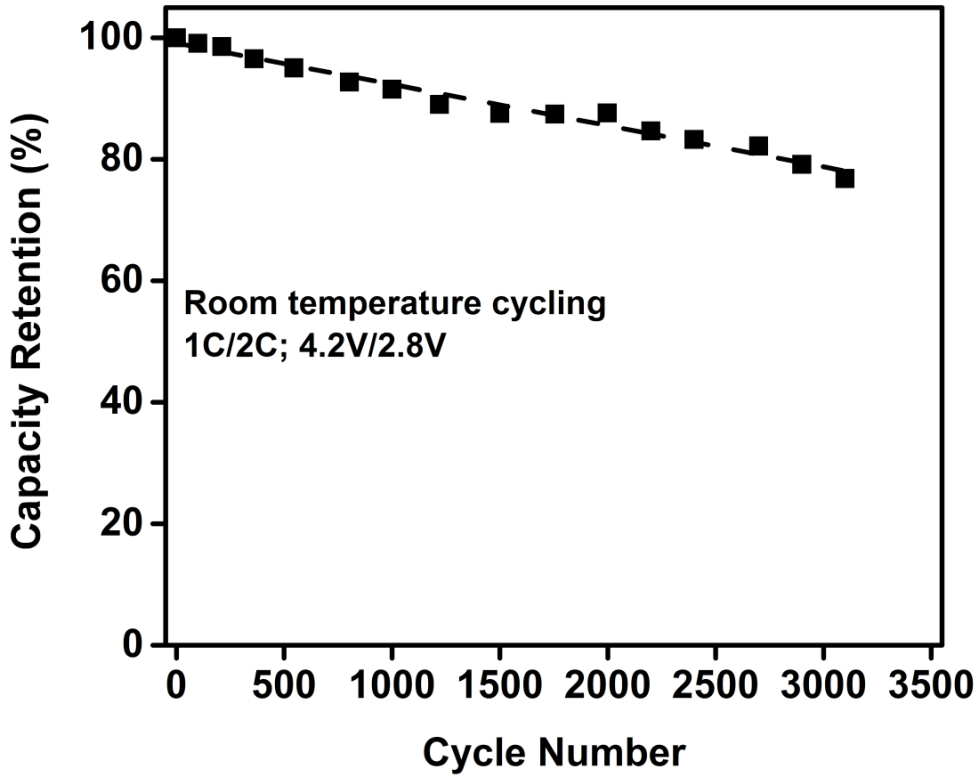


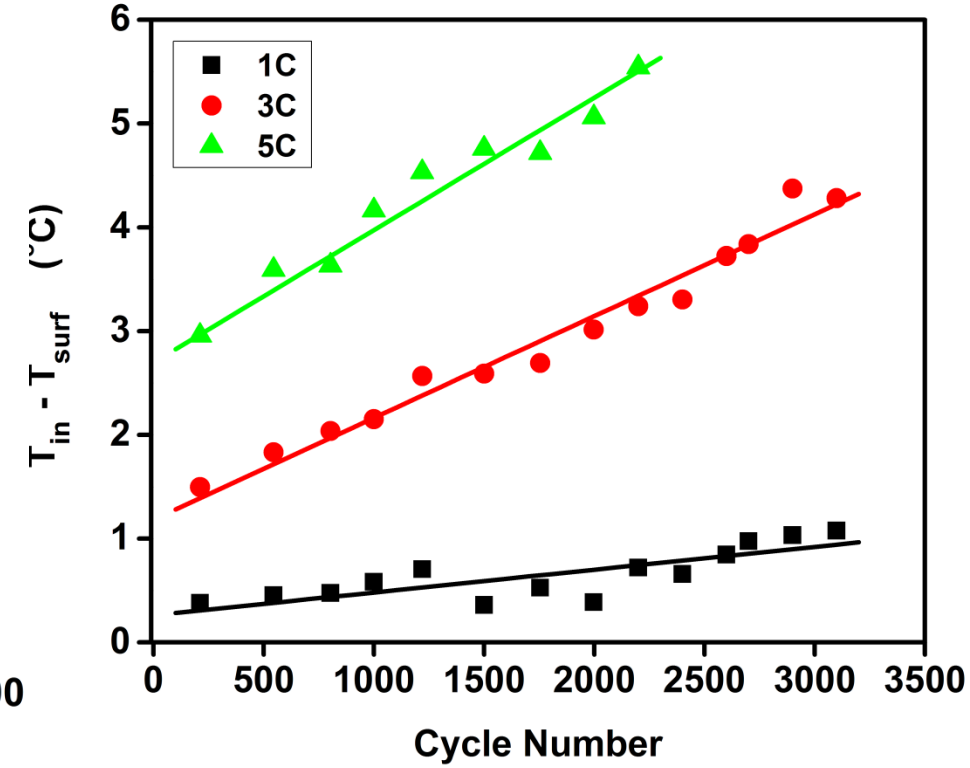


Temperature gradient was reduced by 3 times

Zhang, Ge, Xu, Yang, Tian, Wang. ***Electrochim Acta***, 2016

The RTD sensor is very durable and can be also used for investigation of Li-ion cell cycling

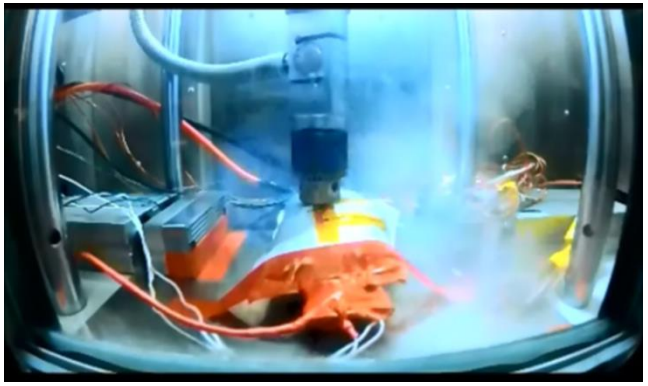




Zhang, Ge, Leng, Yang, Marple, Wang. ***231st ECS Meeting***, *2017*

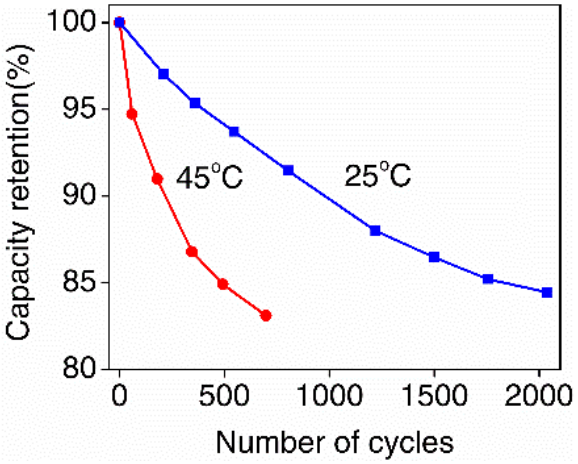
Future: there are many challenges & opportunities for in situ diagnosis & internal thermal management

Battery Safety



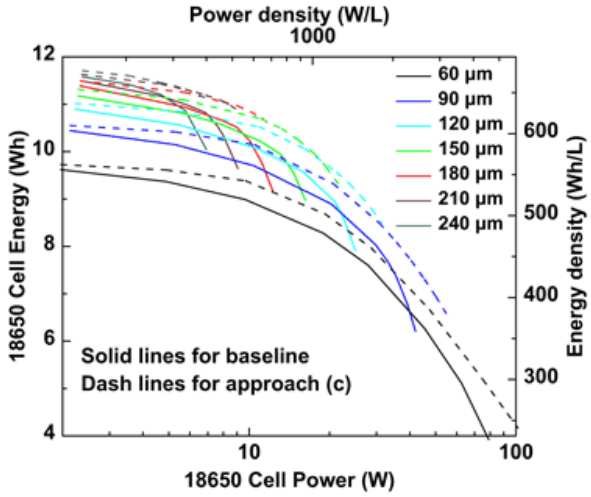
Zhang, Ge, Xu, Wang, Cao, Shaffer, Rahn. ***228th ECS Meeting***, 2015

Battery Durability at High Temperatures



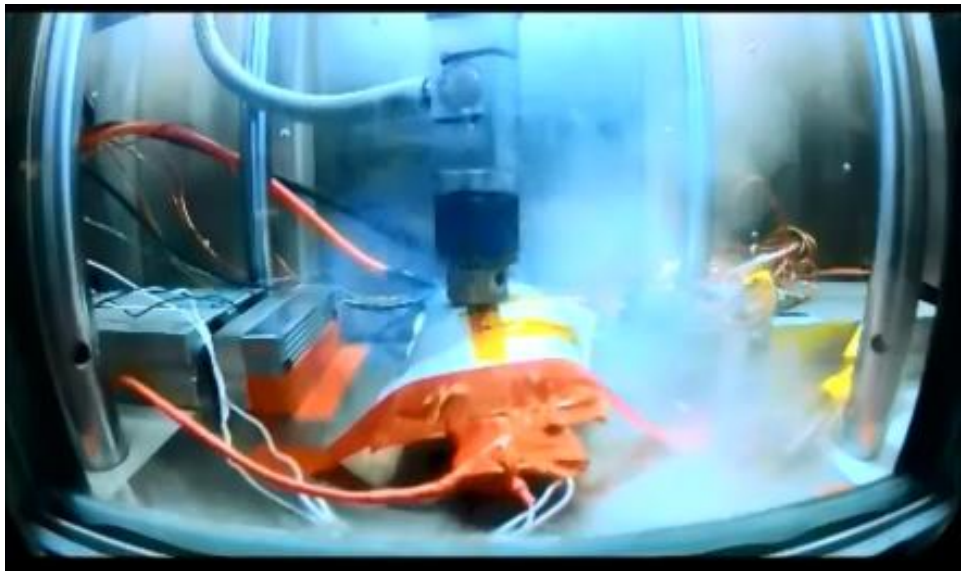
Wang, **Zhang**, Ge, Xu, Ji, Yang, Leng. ***Nature***, 2016

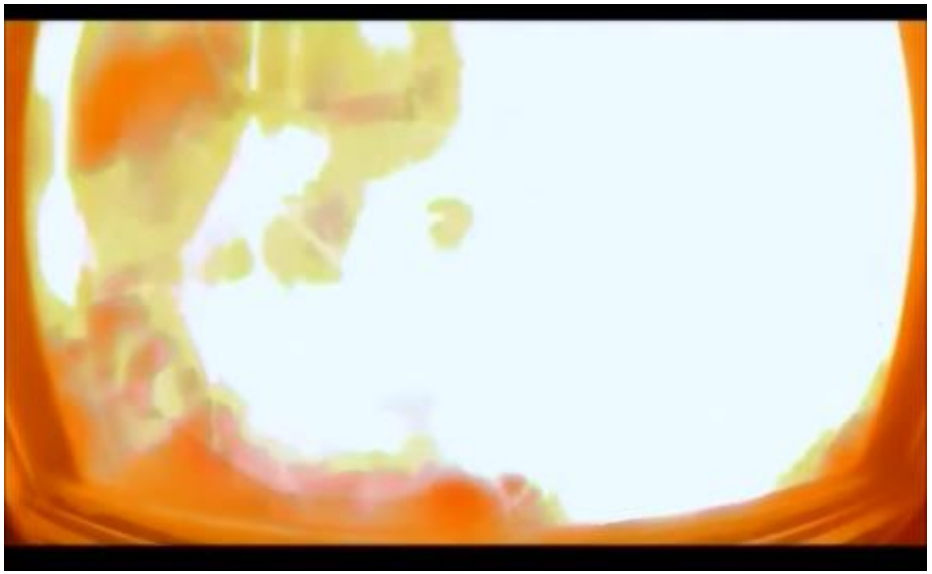
Power Density of High Energy Battery



Du, Wood, Kalnaus, Li. *JAE*, 2017

Future #1: Battery Safety





Challenges:

(1) Significant loss due to thermal runaway;

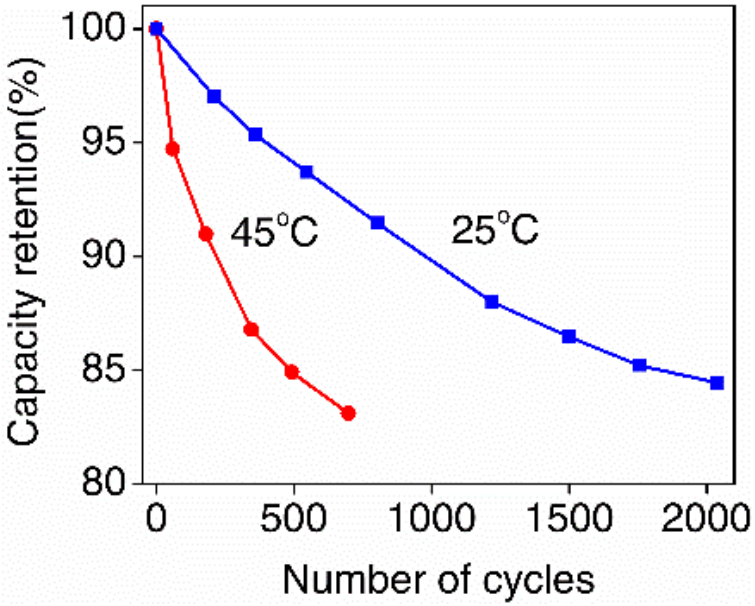
(2) No fundamental solutions yet.

Opportunities:

(1) Understanding trigger and thermal runaway mechanisms through in situ diagnosis;

(2) “Fail-Safe” design with internal thermal management.

Future #2: Battery Durability at High Temperatures



Challenges:

(1) Li-ion cells degrade much faster at higher temperatures;

(2) Non-uniform temperature distribution in large Li-ion cells;

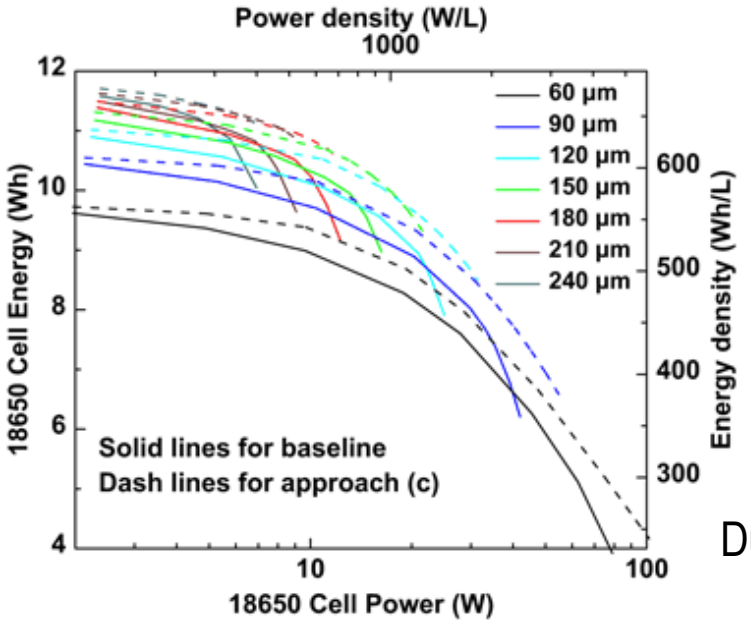
(3) Temperature range and fluctuation (aerospace applications).

Opportunities:

(1) Understanding degradation due to non-uniform temperature distribution through in situ diagnosis;

(2) Internal cooling of large-format Li-ion cells.

Future #3: Power Density of High Energy Battery



Du, Wood, Kalnaus, Li, *JAE* 2017

Challenges:

(1) Underutilization of high energy cell capacity;

(2) Slow charging of high energy cells.

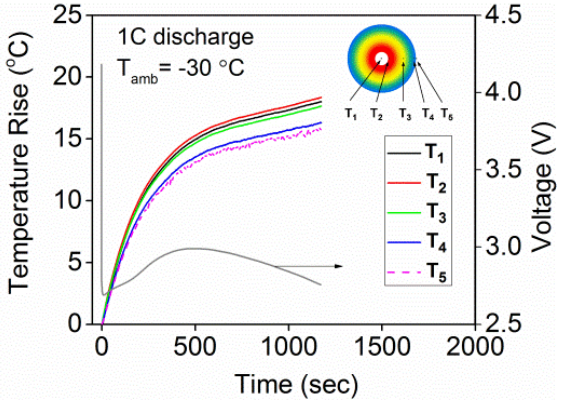
Opportunities:

(1) Understanding power limiting factors from in situ diagnosis, e.g. current density and SOC distribution;

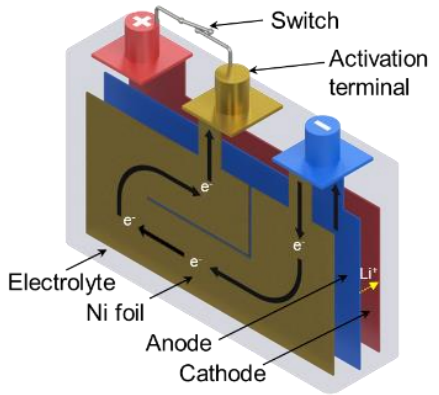
(2) Novel electrode/cell structures for high power density.

Summary

1. Internal temperature sensing is useful in understanding thermal behaviors of large-format Li-ion cells.



2. Internal thermal management, e.g. Self-Heating Li-ion Battery (SHLB) cell, can significantly boost performance.



3. There are many challenges & opportunities for in situ diagnosis and internal thermal management of large-format Li-ion cells.