High Power, High Energy, High Safety Cell Technologies

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AMPRIUS AT A GLANCE – SILICON TECHNOLOGY INNOVATOR

Key Milestones

Founded in 2008

Fully Operational in 2009

KWh Scale Manufacturing in 2016

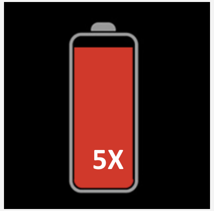
Customer Orders & Commercial Sales in 2018

MWh Scale Project in 2021

Technology Highlights

10X Higher Capacity than Graphite Anode

80% Higher Energy Density than Graphite Cells



5X Higher Power Density than Graphite Cells

15 Minutes to Charge to 85% Capacity

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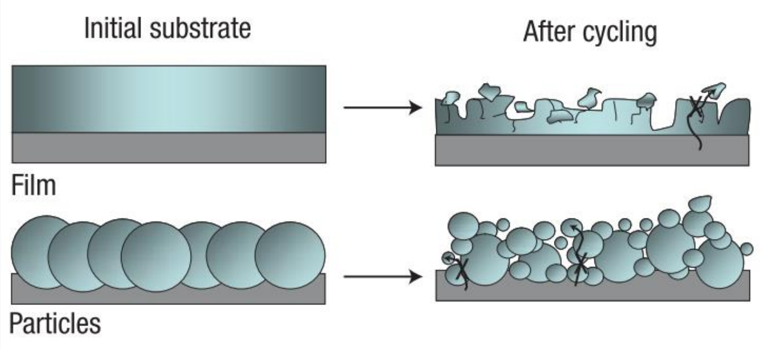
SILICON MATERIALS – THE SWELLING PROBLEM

Anode	Capacity	Swelling
LiC_6	372 mAh/g	10%
$Li_{15}Si_4$	3569 mAh/g	270%

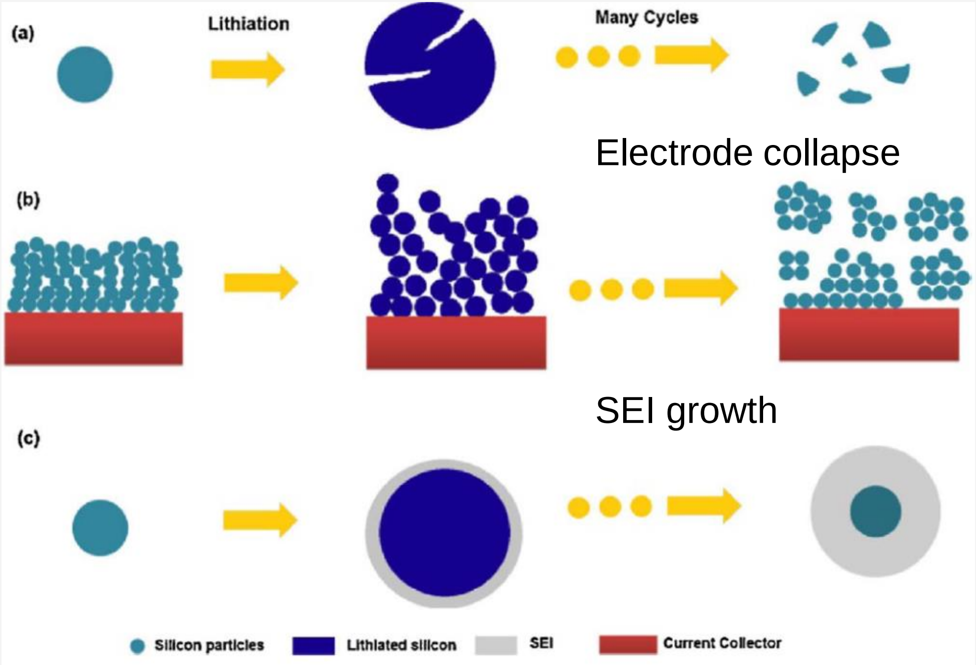


C.K. Chan, H. Peng, G. Liu, K. McIlwrath, X.F. Zhang, R.A. Huggins, Y. Cui, Nat. Nanotechnol. 3 (2008) 31–35.

Material pulverization

Electrode collapse

SEI growth

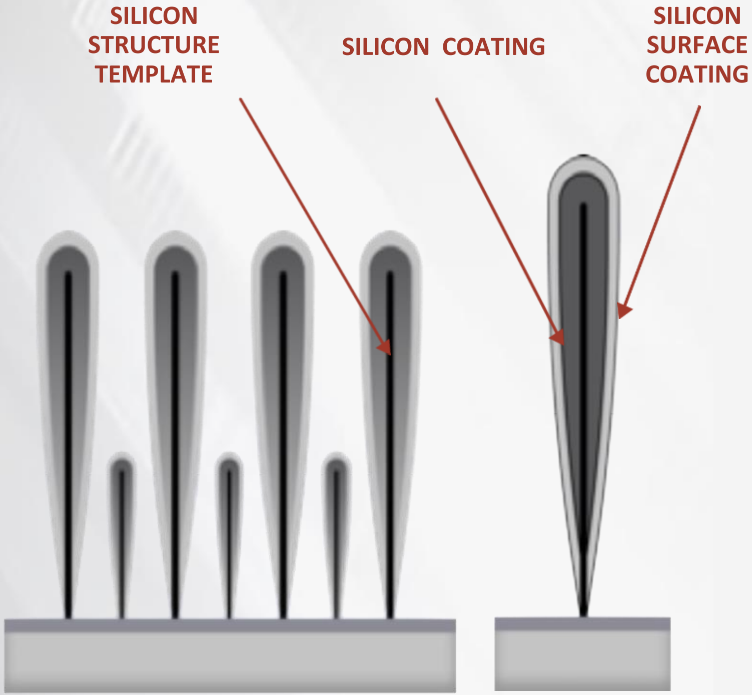


K.M. Abraham, J. Phys. Chem. Lett. (2015) 830–844.

Film or particle silicon materials have failed as practical battery anodes

THE AMPRIUS SILICON NANOWIRE ANODE SOLUTION

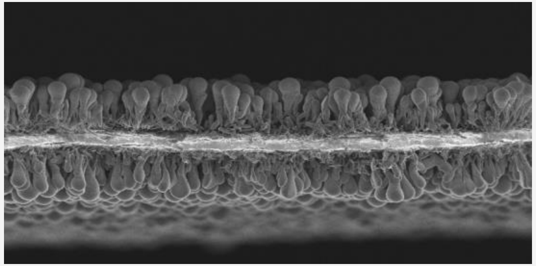
A New Structure for 100% Silicon Based on Nanowires



Nanowire rooted – mechanically and electrically connected to substrate.

Spacing between nanowires **avoids impact of silicon volume expansion**.

Micro & macro porosity – prevents cracking and interference between nanowires.



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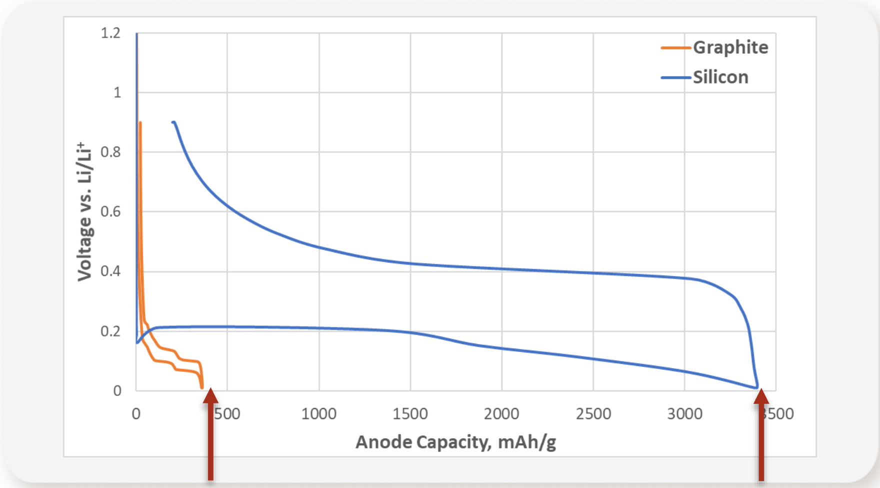
SILICON NANOWIRE ANODE PERFORMANCE

Charge-Discharge curve for 100% Silicon Nanowire/Lithium Half-Cell

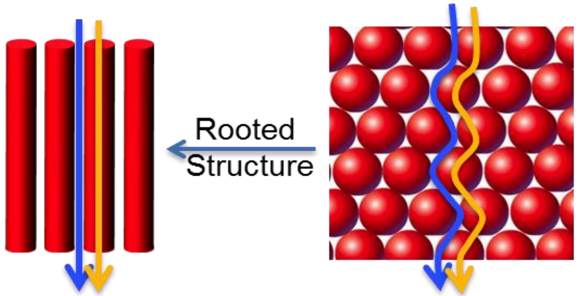


372
(theoretical Graphite)

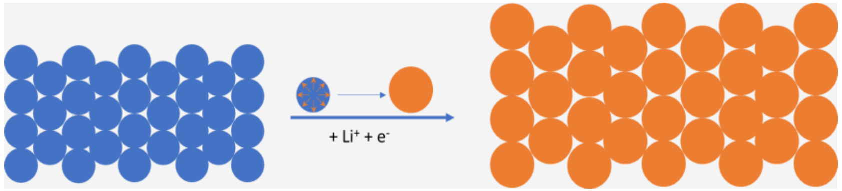
3400 (Si Nanowire)
3569 (theoretical Si)

Near-theoretical capacity for a silicon anode

High first cycle efficiency



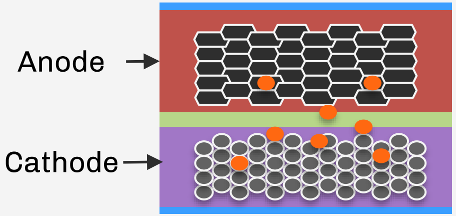
- Good electrical and ionic conductivity, low tortuosity
- Mechanically stable electrode structure – no particle-particle interactions



SILICON ADVANTAGE VS. GRAPHITE

80%+ advantage in energy density (Wh/L)
50%+ advantage in specific energy (Wh/kg)

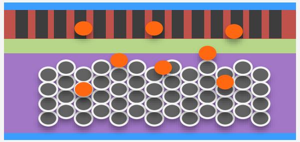
State of the art graphite anode cell



302 Wh/kg
730 Wh/L

<u>silicon anode</u>
much thinner than graphite

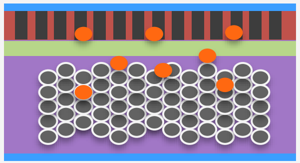
Silicon anode cell



406 Wh/kg
1080 Wh/L

<u>high loading cathode</u>
enabled by silicon anode

High loading silicon anode cell



450 Wh/kg
1320 Wh/L

- The silicon nanowire anode is a direct replacement for the graphite anode
- High loading advanced cathode designs only possible with silicon anode

MANUFACTURING: ROLL-TO-ROLL FOR SILICON NANOWIRE ANODE PRODUCTION

Leverages Existing Manufacturing Infrastructure

SILICON NANOWIRE ANODE

BATTERY CATHODE

Mixing

Coating

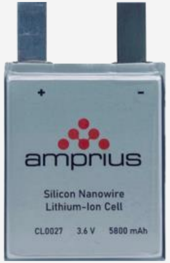
Calendaring

SILCON NANOWIRE ANODE BATTERY ASSEMBLY

Slitting

Stacking

Formation



SILICON NANOWIRE ANODE MANUFACTURING LINE

TRADITIONAL BATTERY MANUFACTURING LINE

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Products and Applications

ELECTRIC MOBILITY

Specific Energy – Key Enabler

Battery Pack Specific Energy	Potential Missions	Potential Market Introduction
> 700 Wh/kg		Single aisle, 150-passenger single-aisle aircraft, long range
500 Wh/kg		Expansion to various classes of hybrid-electric regional aircraft, short-range 150-passenger, single aisle hybrid-electric aircraft
400 Wh/kg Sweet spot for eVTOL		Desired capability for all-electric eVTOL urban air mobility, long-range all-electric commuter, Initial version of small hybrid-electric regional
300 Wh/kg		All-electric eVTOL urban air mobility with 4 passenger and 50+ mile range: 20-passenter all-electric commuter
SOA (150-170 Wh/kg)		Initial commercial introduction possible for all-electric with limited range and payload, extended capability with hybrid-electric

Sep. 2021, Argonne National Laboratory, White Paper

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EXAMPLE PRODUCTS

High Power capability with highest energy density and specific energy

Applications	HAPS, portable power, CE	Long Endurance Drones, eVTOL, UAM	High power drones	EV, Electric Flight
Dimensions (T x W x H) mm	Si/LCO Platforms			Si/NMC
	High Energy 0.5C max rate	Power-Energy 3C max rate	High Power 6C max rate	Power-Energy 2C max rate
4.5 x 50 x 55	420 Wh/kg 1125 Wh/L	415 Wh/kg 1040 Wh/L	365 Wh/kg 875 Wh/L	410 Wh/kg 950 Wh/L
5.4 x 54 x 65	450 Wh/kg 1150 Wh/L	420 Wh/kg 1050 Wh/L		420 Wh/kg 970 Wh/L
4.5 x 50 x 105	430 Wh/kg 1240 Wh/L			

Operating temperature range: -20°C to 55°C. Cycle life 150-600 cycles, depending on operating conditions

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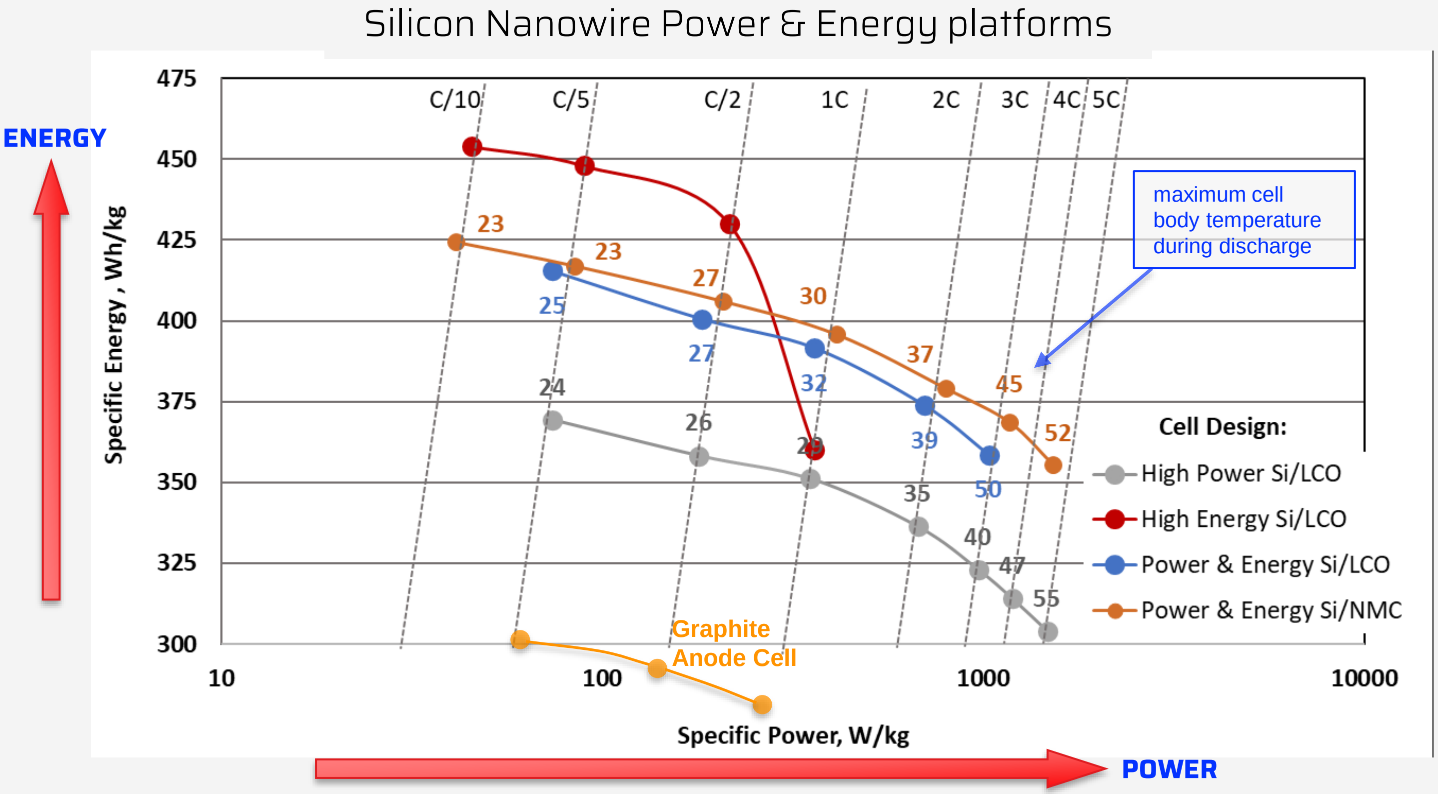
HIGH ENERGY AND POWER CAPABILITY

Amprius' cells enable the highest energy and power



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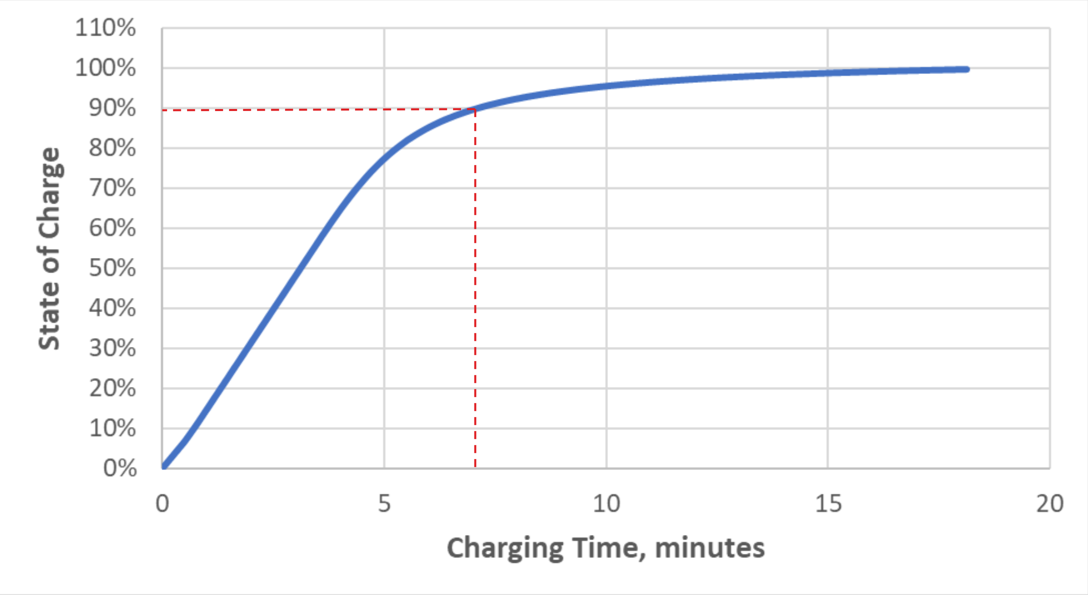
EXTREME FAST CHARGE (XFC) CAPABILITY

5-minute charging to 80%

2.8Ah cell, 370Wh/kg, 920Wh/L



Time	SOC
5 min	78%
6 min	85%
7 min	90%
18 min	100%

Allows fast turn-around flights in eVTOL applications

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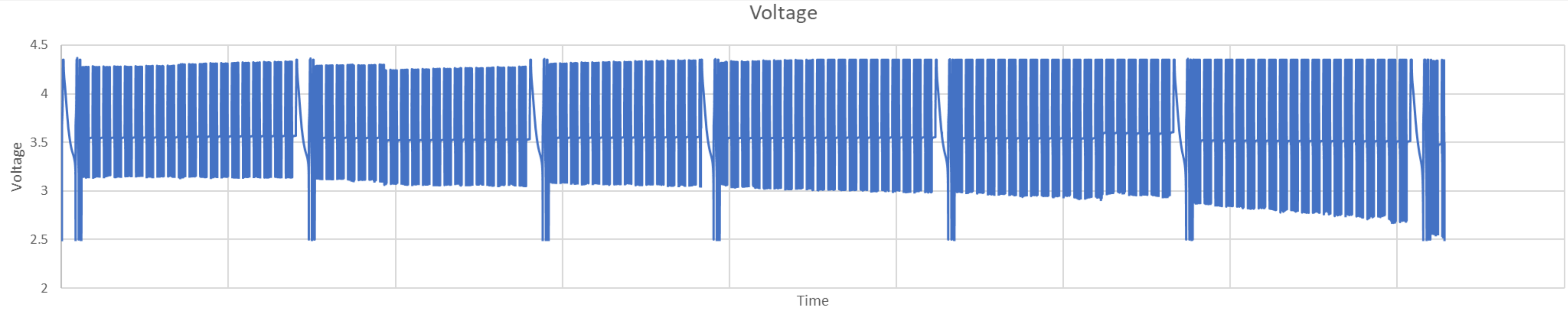
USE CASES

eVTOL Batteries

30-45 minutes trips, 15 minutes charge, 8-12 trips per day



Constant power (eVTOL/Uber protocol): 2E charge, 1E discharge, 4E pulses (E=full energy), ~60% energy cycled; RPT every 200 cycles

More than 1100 cycles performed

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USE CASES

Energy Cells for High Altitude Pseudo Satellites set New World Record for Longest Endurance

"The aircraft has achieved an altitude of 74,000 ft in Arizona and, critically, has remained above 50,000ft at dawn, after a night's flying with no sun to charge its batteries."

PORTABLE POWER APPLICATION

Conformal-Wearable Battery – 2X Energy Content

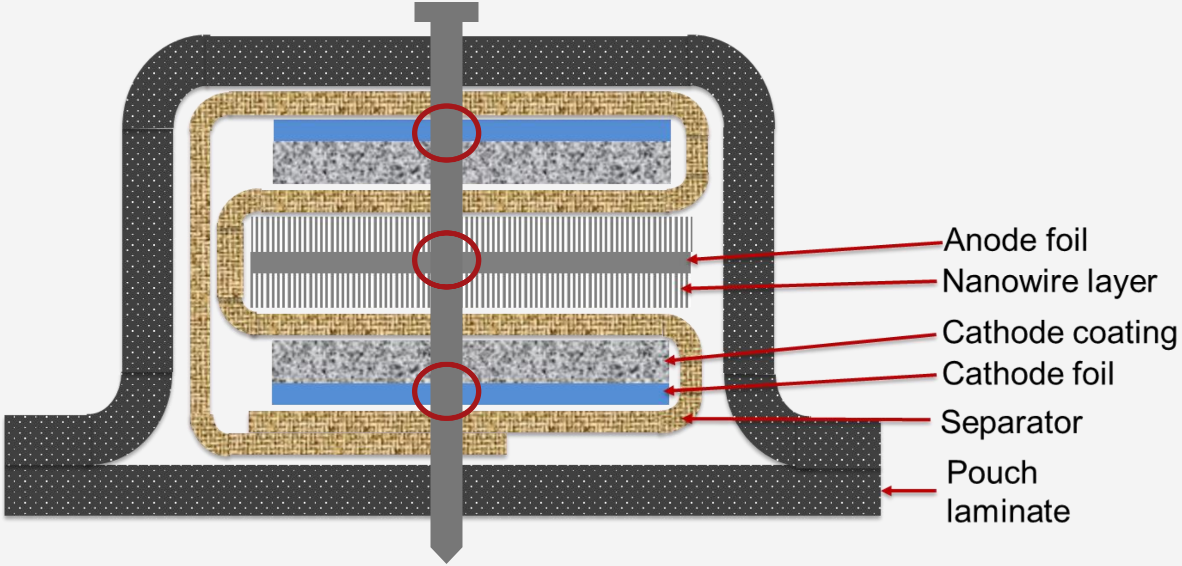
CONFORMAL-WEARABLE BATTERY

2X Energy Content

Specification	CWB-150 (Fielded Model)	Amprius
“Flexible” battery		
Energy (Pack)	148 Wh	320 Wh
Weight	2.6 lb	2.6 lb
Dimensions	8.7” x 7.65” x 0.7”	8.7” x 7.65” x 0.7”
Cells specific energy	201 Wh/kg	395 Wh/ kg

UN38.3 certified in 2020, confirmed performance in field test

NAIL PENETRATION MITIGATION STRATEGIES



- Break/stop short circuit immediately after penetration
- Delay or increase the onset thermal run-away temperature
- Mitigate thermal runaway effects by reducing temperature and flame generation of the process

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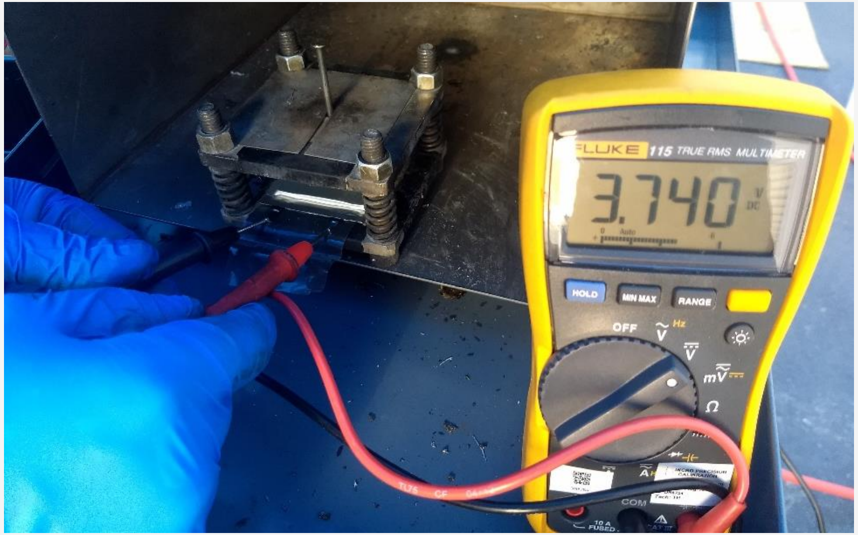
METALIZED PLASTIC CURRENT COLLECTOR (SOTERIA)

Welding solved for multilayer stacked cells



- Cells functional after penetration at up to 70% SOC in 5.4Ah cells
- Thermal runaway at >70% SOC

The thermal runaway is triggered by electric heating → needs an electric solution

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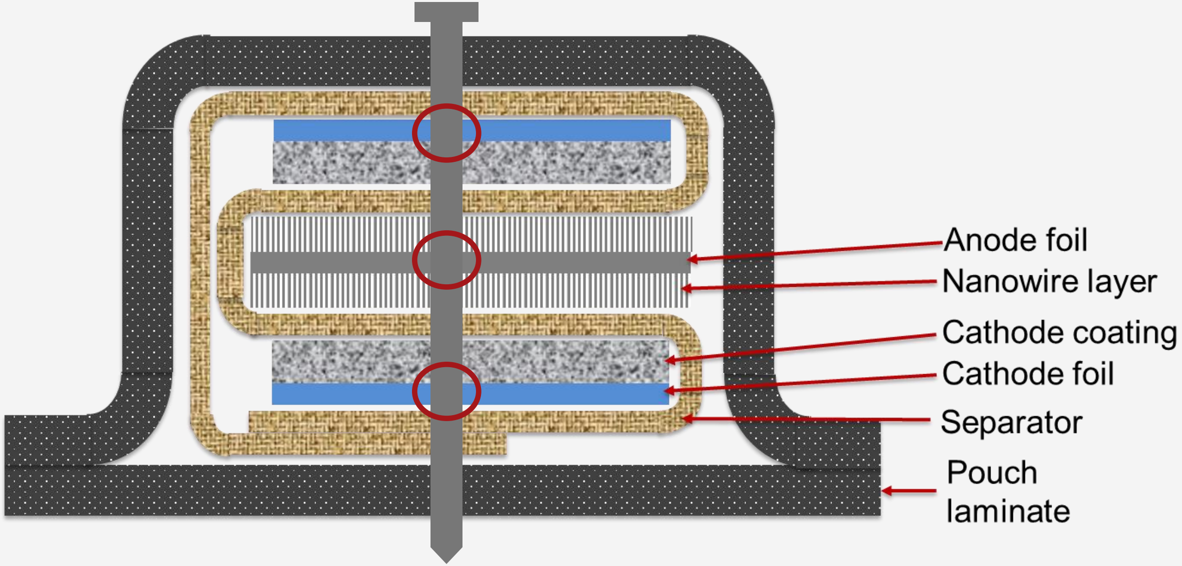
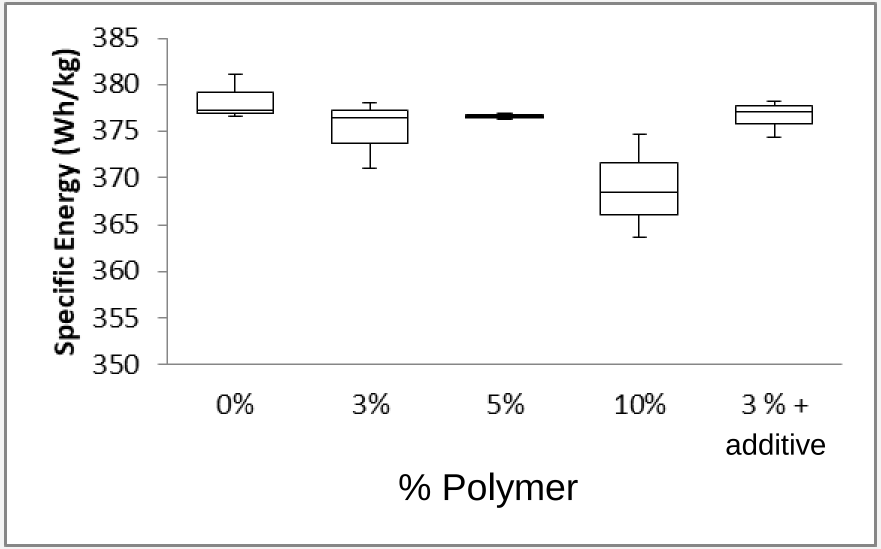
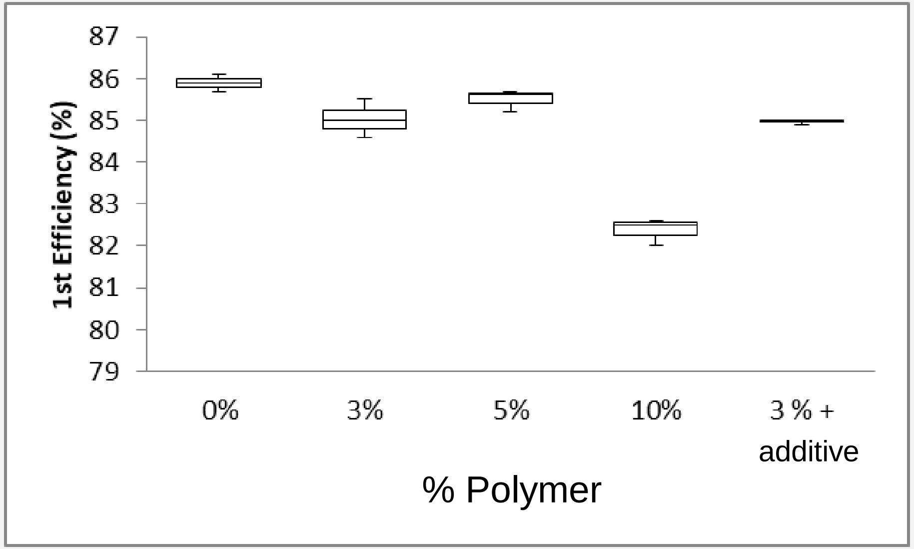


Don't allow short circuit to start – insulate the nail from electrodes

Si/NMC811 chemistry, 2.0 Ah, 7 Wh, 380 Wh/kg, 2.75-4.25V, C/5





No significant effect on capacity and power under 5%

IN-SITU GEL ELECTROLYTES

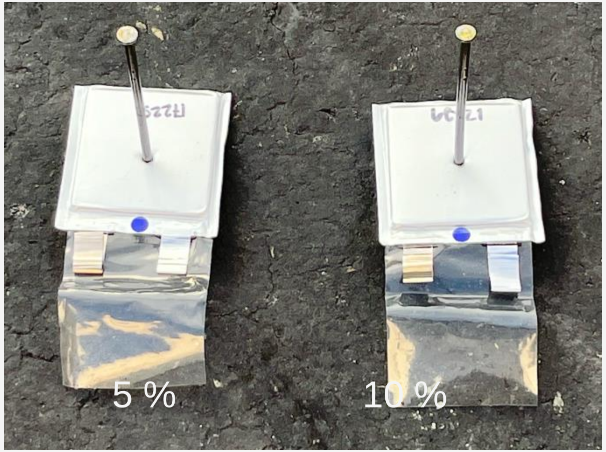
Si/NMC811 chemistry, 2.0 Ah, 7 Wh, 380 Wh/kg, 2.75-4.25V, C/5

Electrolyte	Device ID #	Cell Capacity (Ah)	Specific Energy (Wh/kg)	OCV (V) at Test	Result	OCV (V) after Test
Ref. (Liquid)	17223	2.01	377	4.21	**Fire**	-
3 % polymer	17233	1.97	371	4.21	**Fire**	-
5 % polymer	17225	2.02	377	4.20	**Pass**	4.11
10 % polymer	17229	1.97	364	4.21	**Pass**	4.19

Positive effect at full charge observed at 5% polymer content and above

IN-SITU GEL ELECTROLYTES

Si/NMC811 chemistry, 2.0 Ah, 7 Wh, 380 Wh/kg, 2.75-4.25V, C/5



- The cells suffer minimal voltage drop during test – nail effectively insulated from electrodes
- Nail to electrode connections indicate disconnection at end of test
- Likely the electrolyte (soft plastic like at 5% and above) smears onto the nail as it enters the cell
- Larger cell capacities under development

SUMMARY/CONCLUSIONS

Silicon solutions to energy problems

- Silicon anodes enable high power capability for charge and discharge
- Energy density levels compatible with electric flight are available today
- New materials and solutions can solve safety concerns for sensitive applications

Thank You

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