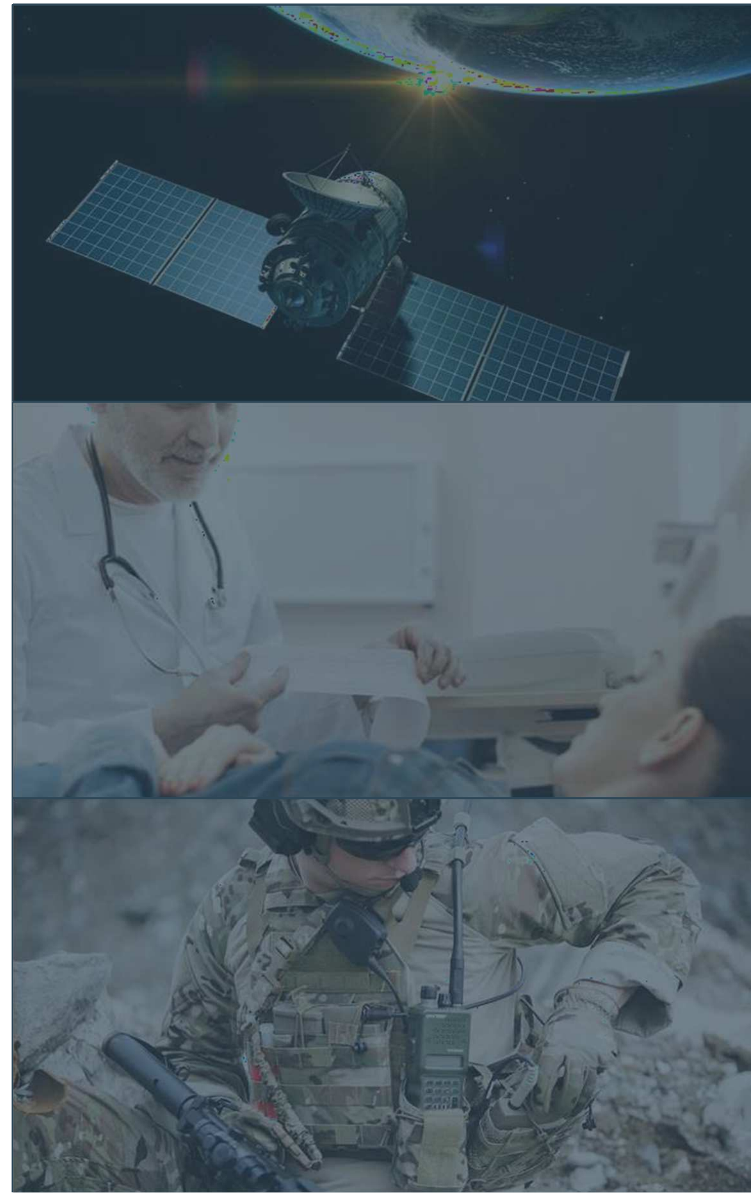
AMERICAN LITHIUM ENERGY

Studies on Zero-voltage Stability on ALE18650Si4000ZV Cylindrical Cells for NASA Applications

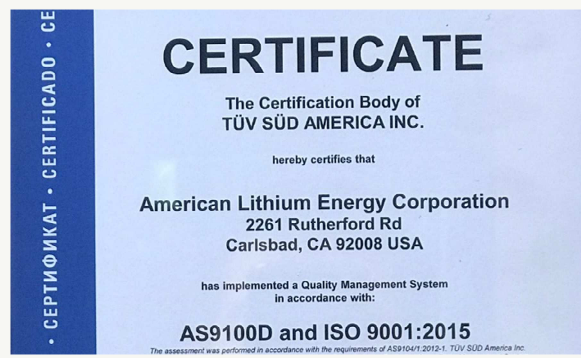


American Lithium Energy (ALE) Introduction

ALE's headquarters in Carlsbad, CA

Advanced Silicon Anode Lithium Batteries for Defense, Aerospace, Medical, and EV Markets

- Founded in 2006 to develop advanced lithium-ion ("Li-ion") batteries initially for Department of Defense ("DoD") applications
- Full-time operational facility (23000 sq ft) for battery R&D, testing and production in San Diego County.
- Certification of AS 9100D quality system
- Innovative products
- Over 65 awarded patents with several patents having world-wide coverage



• СЕРТИФИКАТ • CERTIFICADO • CE

CERTIFICATE

The Certification Body of
TÜV SÜD AMERICA INC.

hereby certifies that

American Lithium Energy Corporation
2261 Rutherford Rd
Carlsbad, CA 92008 USA

has implemented a Quality Management System
in accordance with:

AS9100D and ISO 9001:2015

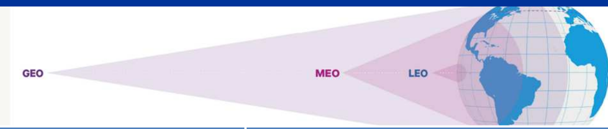
Market Validation by the Most Demanding Customers

Outside USA-made batteries identified as strategic risk - long-term effort initiated to source onshore suppliers

Unmanned Autonomous Systems	Space and Missiles	Advanced Energy Weapons & Vertical Lift Aircraft	Mini-Grid / Energy Storage	Wearables	Vehicles
EnergyCore Battery Technology	Missile/Missile Launch and Satellite Battery	Li-ion Battery/Supercap Hybrid Cell (LBSCHC)	Ultra-Lightweight Expeditionary Power System (U-LEPS)	Conformal Wearable Battery / SAPI Battery	6T Vehicle Battery Pack and BB-2590 Man-Portable Battery Pack using Non-Flammable High-Capacity Li-ion Cells

ALE is actively shipping product to Commercial, US military, the Dept. Energy, US defense primes, and Commercial Customers.

Challenge 1: Space Battery Requirements for Satellites



Satellite Orbit	GEO (Geostationary Earth Orbit)	MEO (Medium Earth Orbit)	LEO (Low Earth Orbit)
Altitude	36,000Km	5,000-20,000Km	500~1,200Km
latency	>500ms	<80ms	<30ms
Earth coverage	Very large	Large	Small
Satellites Required	Three	Six to Twenty	Hundreds to thousands
Time circle earth	24hr	2~12hrs	~90 minutes
Satellites Lifespan	~15 years	~10 years	5-7 years
Application	weather data, broadcast TV, and low-speed data communication	GPS, other navigation applications, and high-bandwidth data service	Real time data service, International Space Station, Star link for global coverage
Battery requirement	Long cycle life; long time storage; high energy density		

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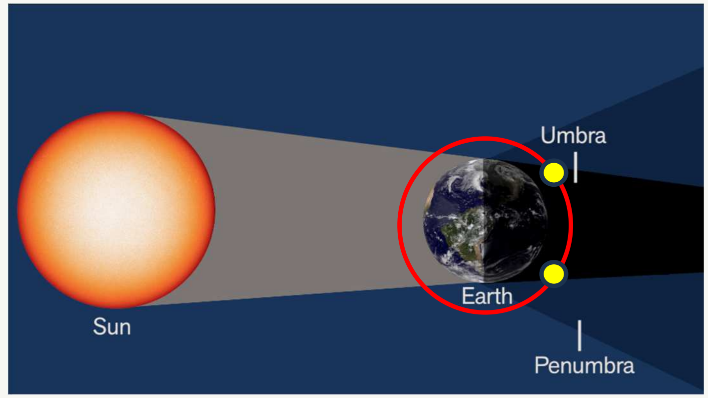
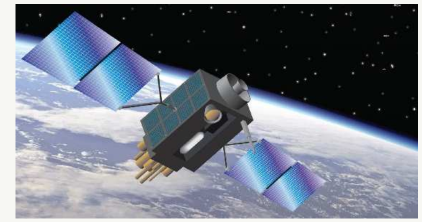
Challenge 1: Space Battery Requirements for Satellites

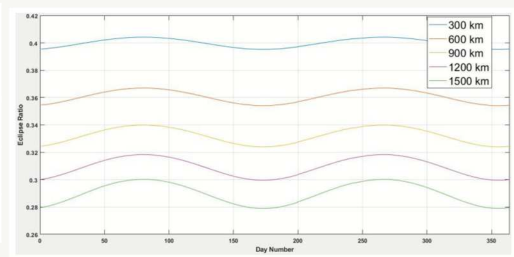


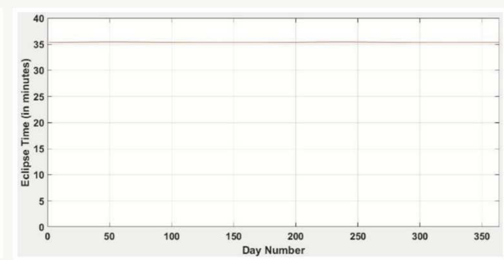


40,000 LEO satellites for Star link

Satellite Eclipse

Mission	Satellite	Cycles	DOD (%)	Time (years)
1	LEO	15,000	20	3
2	LEO	25,000	20	5
3	LEO	75,000	20	15





Space battery needs for
(1) matching lifespan of satellites
(2) matching numerous satellites for global coverage

~5000 times eclipse/year, 35 minutes/time

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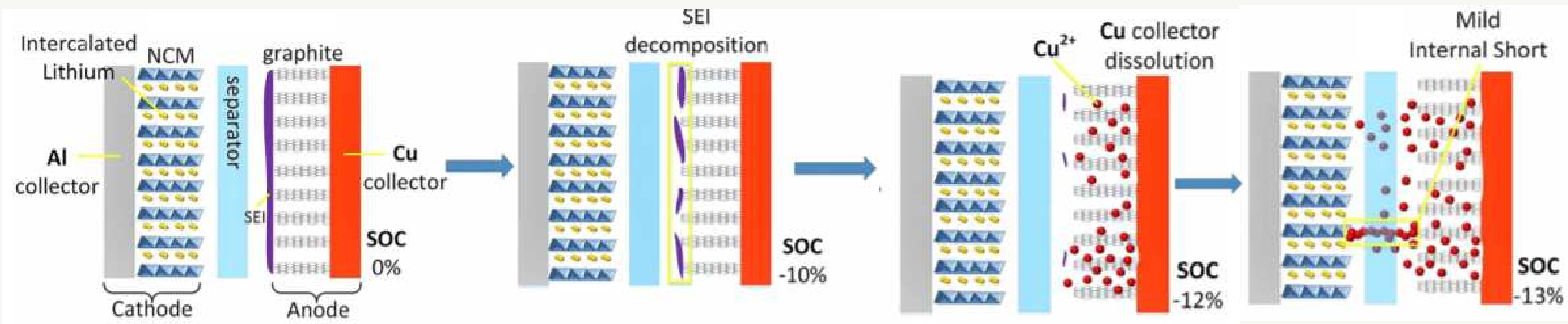
Challenge 2: Dead Bus Recovery – Zero Volt Stability

Battery Complete Discharge ⟶ Battery Failure ⟶ Spacecraft Power failure ⟶ Dead Bus

Battery failure mode



SOC<0

Overdischarge Process: Cu dissolution and dendrites, Internal short

Recovery Battery from Deep Discharge even Zero voltage Exposure

ALE Solutions: Prevent Cu dissolution at low Voltage

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Zero Voltage Technology

Challenge:

When U is close 0 voltage, the potential of negative electrode increase to 3.56 V vs Li+/Li, the corrosion of negative (Cu foil) happen (Cu oxidization to Cu+)

Negative Impact:

- Existing Li-ion batteries are dead or damaged if discharged to zero volt
- Billion dollars of satellite lost every year due to the dead bus caused by the failure of the batteries
- To avoid the dead bus issue, some low energy density batteries such as Ni-metal Hydride batteries (50 to 75 Wh/kg) were used for space application

Solution:

When a sacrificial electrode applied, whose corrosion happen first and protect Cu foil.

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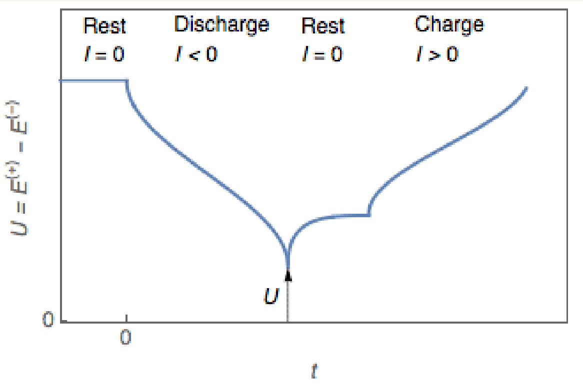
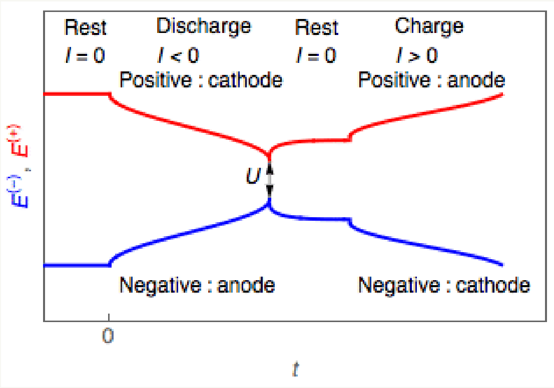
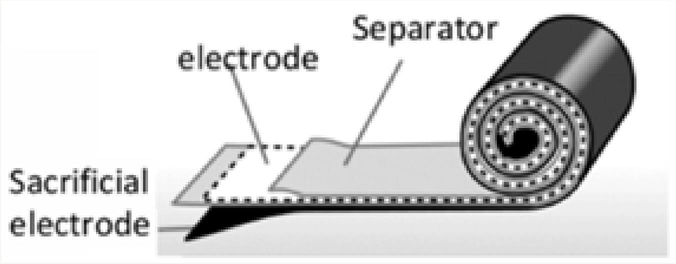
Zero Voltage Technology







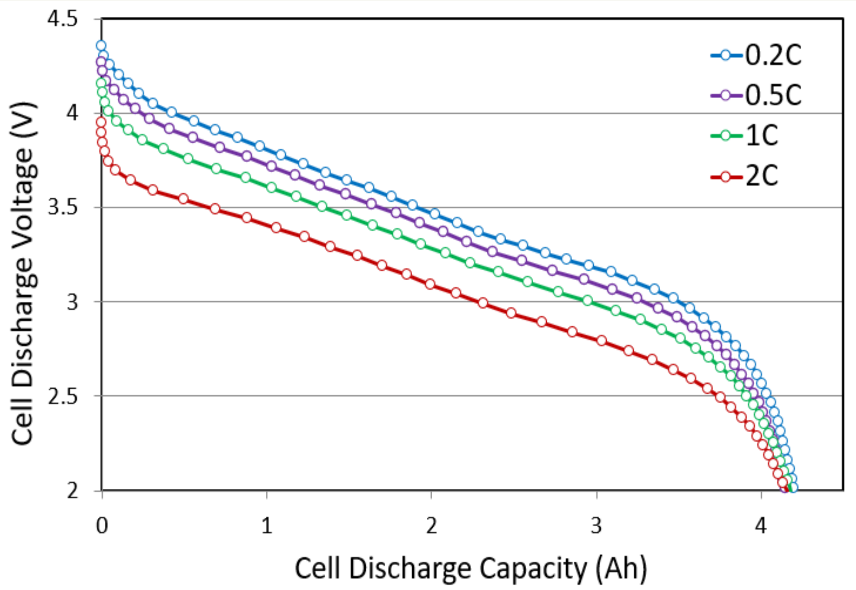
Battery voltage

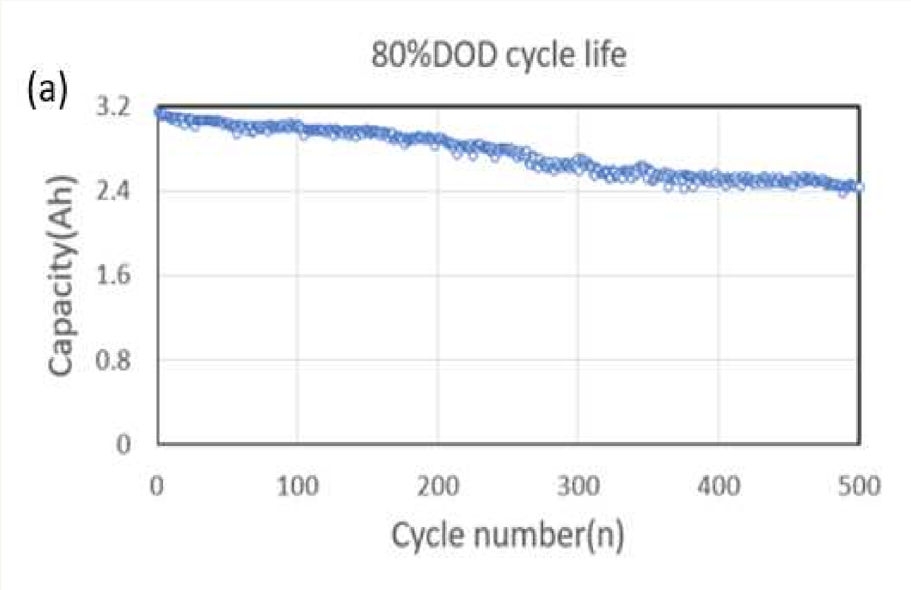
Potential of Negative and Positive electrodes

ALE Patented ZVT:

- Materials is low cost and not moisture sensitive or air sensitive
- Not participate in the normal electrochemical reaction
- The protection starts when the cell is assembled (close to zero voltage)
- Improved cycle life due to the protection in the wetting period before the formation
- Applicable to any lithium-ion battery cells when Cu foil is the current collector
- Very useful in the battery logistics, battery shelf life, and battery safety

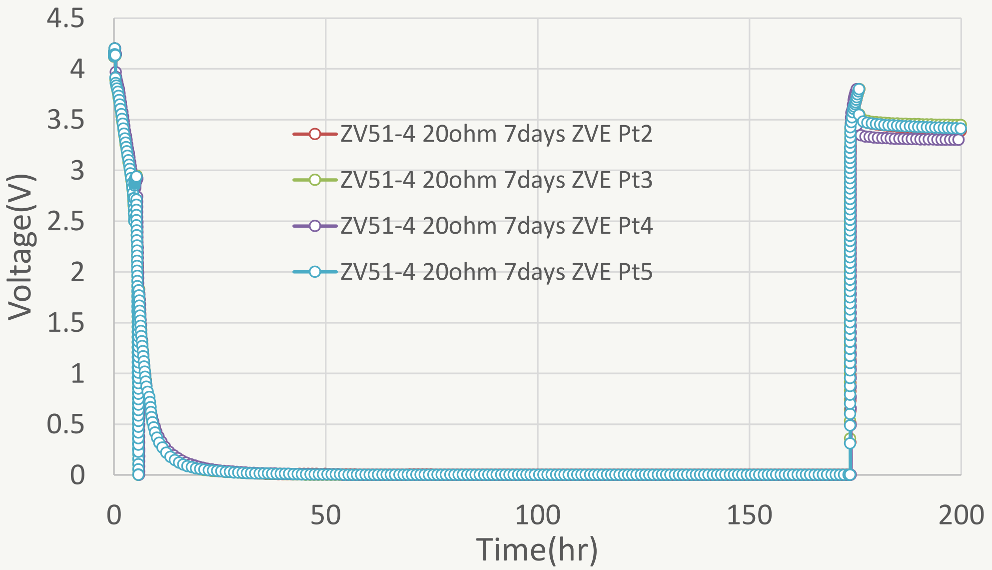
18650 Cell Performance at Room Temperature





- **Cell capacity:** 4.2Ah at different rates
- **Specific energy:** ~330Wh/kg
- **Specific power:** ~700W/kg
- **Cycle life:** ~500 cycles at 80%DOD(80% retention)

Zero voltage Exposure: Sacrificial Design with long life 1000 cycles



ZVE/20 ohm 7days	Capacity (4.2-2.5V)	Capacity (2.5-0V)	Capacity (0V 7days)
Pt1	3.199	0.366	0.310
Pt2	3.154	0.323	0.307
Pt3	3.120	0.330	0.299
Pt4	3.193	0.311	0.311
Pt5	3.136	0.321	0.300

- The cell capacity (4.2-2.5V) have little change after ZVE, the cell retention is 98% after ZVE 35 days (7days X5).

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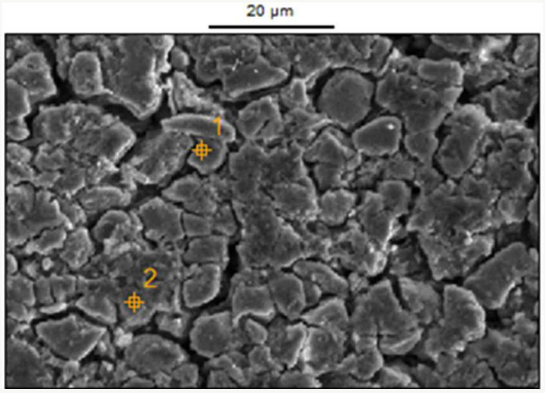
Microscopy: Non-Sacrificial Design

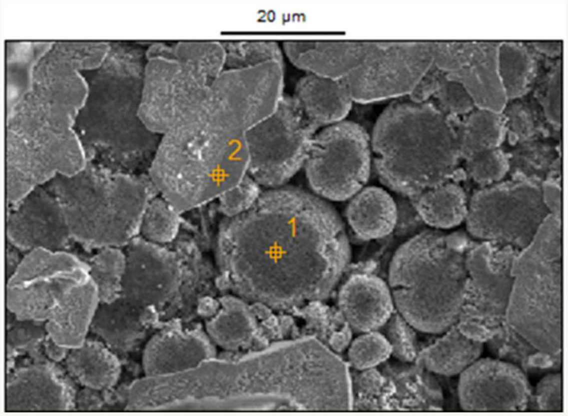
Negative Electrode



C-K	O-K	F-K	Na-K	Si-K	P-K	Cu-L
11.8	50.2	3.6	0.2	34.2		
35.1	35.4	8.3	0.5	19.2	0.9	0.6

Si/C anode confirmed
Cu foil severely corroded

Positive Electrode



C-K	O-K	Al-K	Mn-K	Co-L	Ni-L	Cu-L
16.7	52.9		2.1	2.3	25.9	
4.0	2.9	0.8		0.8	0.0	91.6

811 polycrystal sphere confirmed
Cu plate deposited on
the positive electrode

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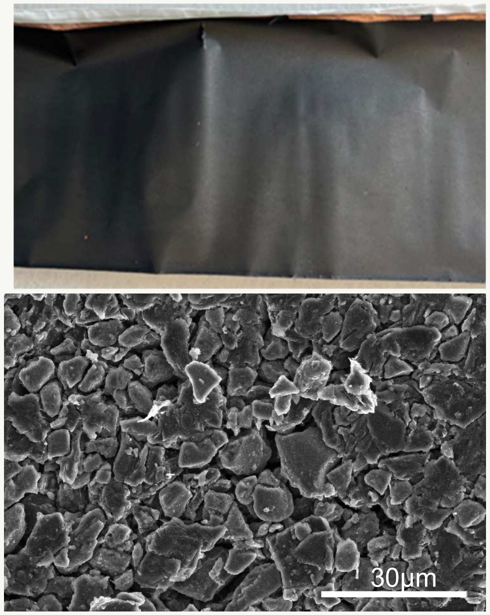
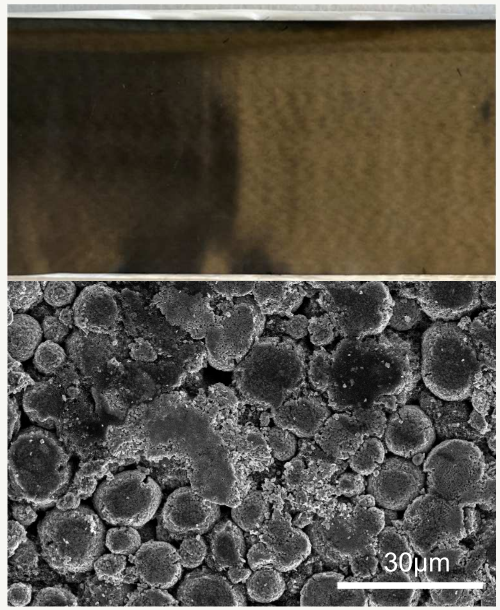
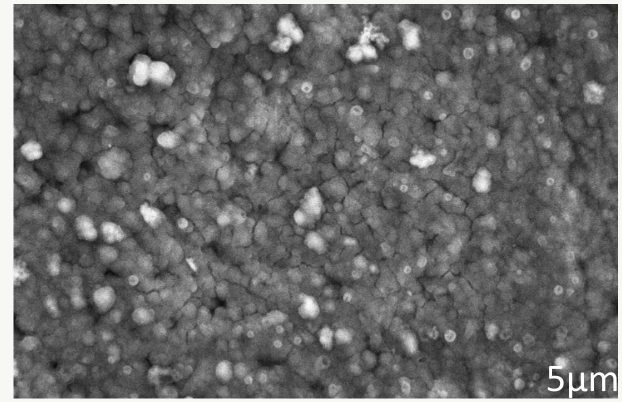
Microscopy: Sacrificial Design 2



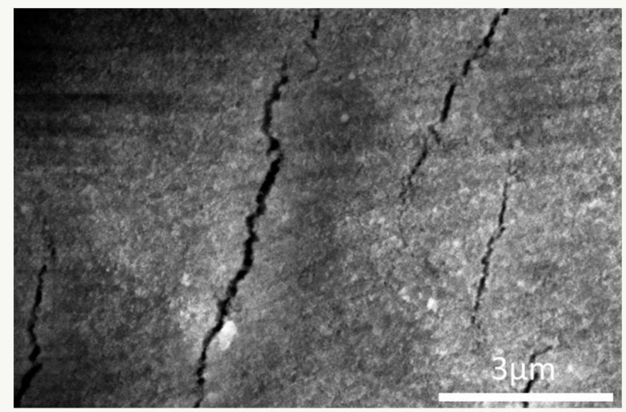
Negative Electrode
After ZVE 20ohm 7days X5



Positive Electrode
After ZVE 20ohm 7days X5



Sacrificial Electrode before ZVE



Sacrificial Electrode after ZVE

- No corrosion observed on negative and positive electrode
- Deep cracks observed from electrochemical sacrificial protection

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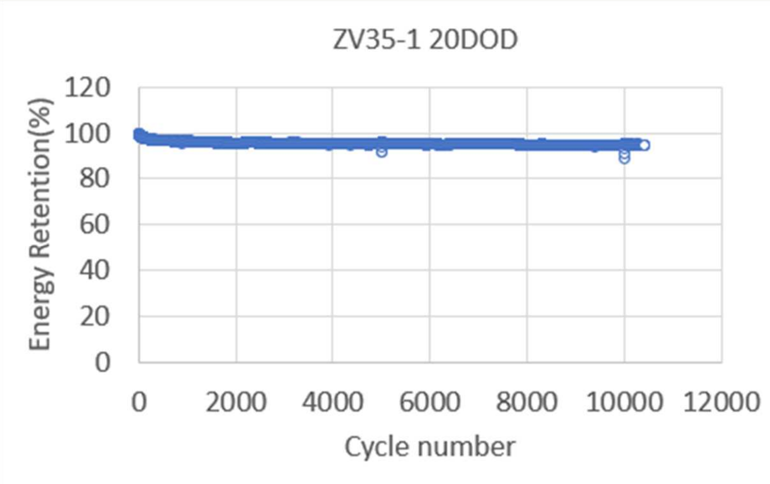
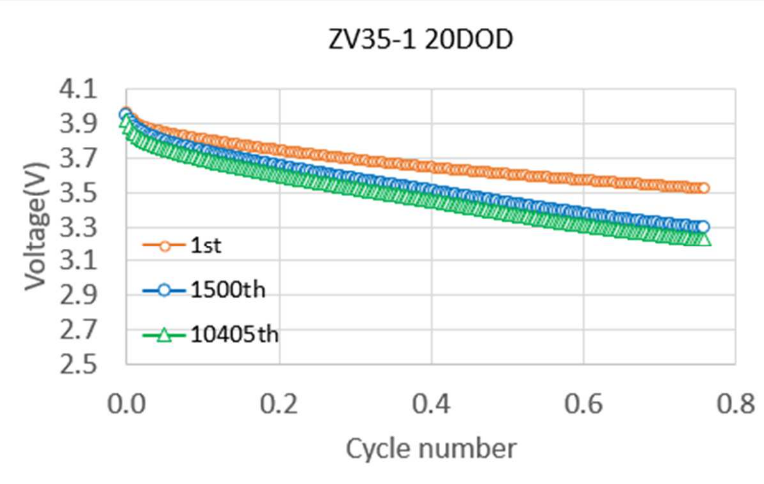
20%DOD





3.76% loss

- **Polarization cumulation**
- **Decrease in SoC**
- **Cell degradation**

1.56% loss

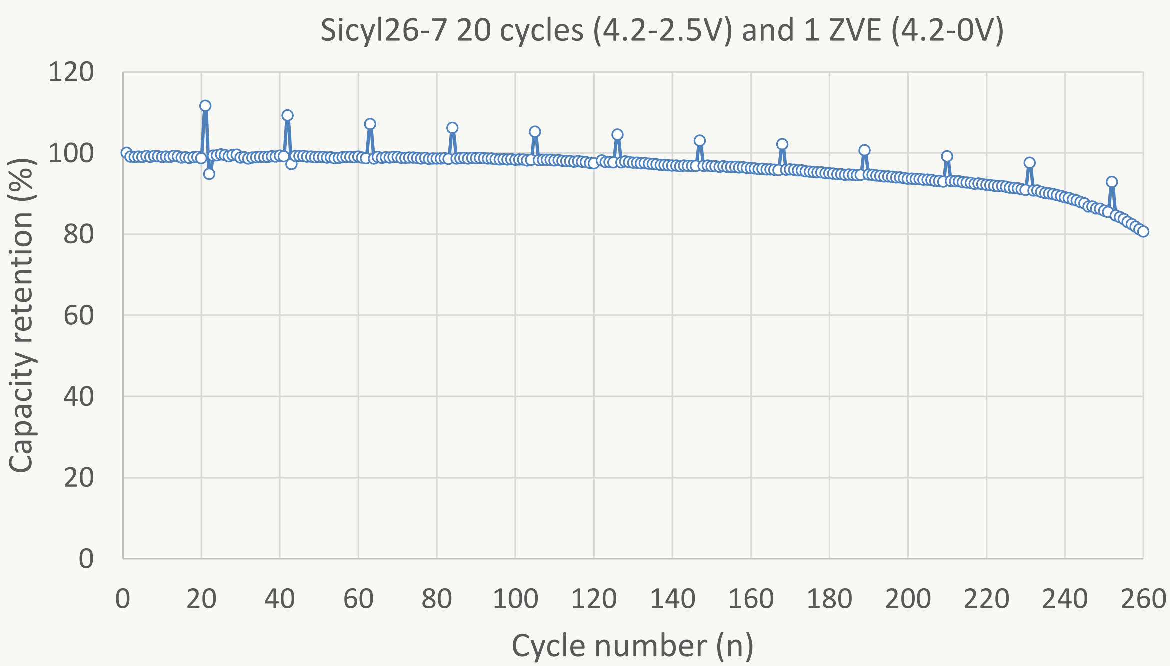
- **Cell degradation**

Cycle number	1	1500	10405
End voltage	3.5663	3.2912	3.2240
Energy retention	100%	96.24	94.68

Test Procedure:
Discharge C/3: 35 minutes
Charge C/4.5 to 4.1V cut off C/20: 60minutes

- ~3.76% reversible discharge polarization energy reduction from 1st to 1500th cycle (equilibrium state to steady state)
- ~1.56% discharge loss from 1500th to 10405th cycle (2.5 years data, the cycle life is still on going).
- **Projected cycle life:** >92,703 cycles (18 years); longer than the 75,000 cycles (15 years).

100%DOD: Sacrificial Design 3



Cycles	Capacity (4.2-2.5V)	Capacity (4.2-0V)
1st, 21st	3.755	4.193
22nd, 42nd	3.564	4.103
43rd, 63rd	3.654	4.025
64th, 84th,	3.702	3.987
85th, 105th	3.703	3.952
…	…	…
232nd, 252nd	3.407	3.488
260th	3.029	NA

- Cell are tested 20 cycle life (4.2-2.5V) and 1 cycle life (4.2-0V); and looped 12 times.
- 260 cycle life with 80% capacity retention. The major failure mode is due to the cell being over discharged repeatedly. The Cu dissolution should not be the cause of the capacity loss per cycle

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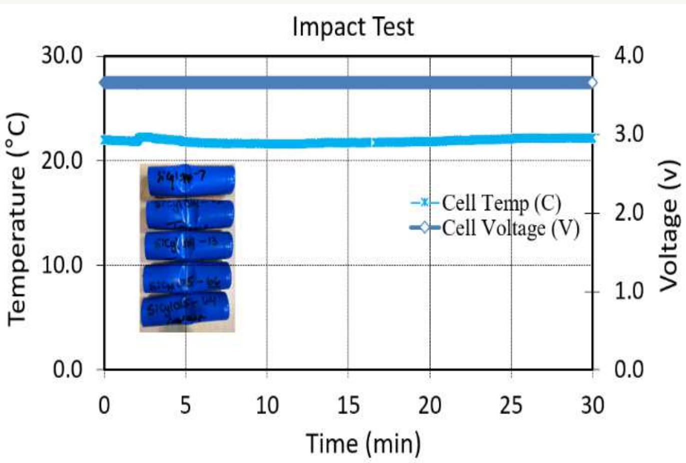
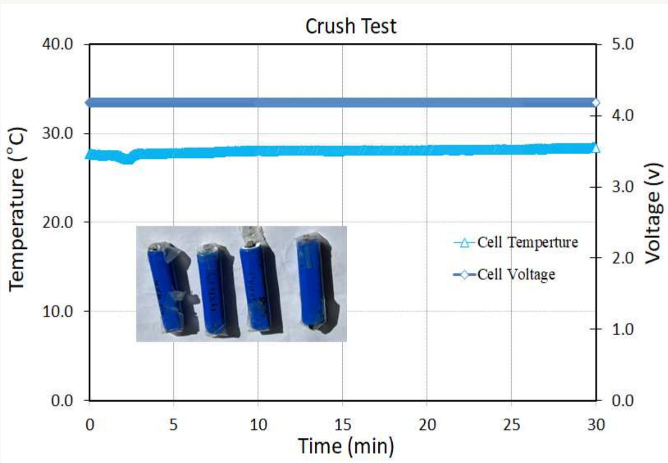
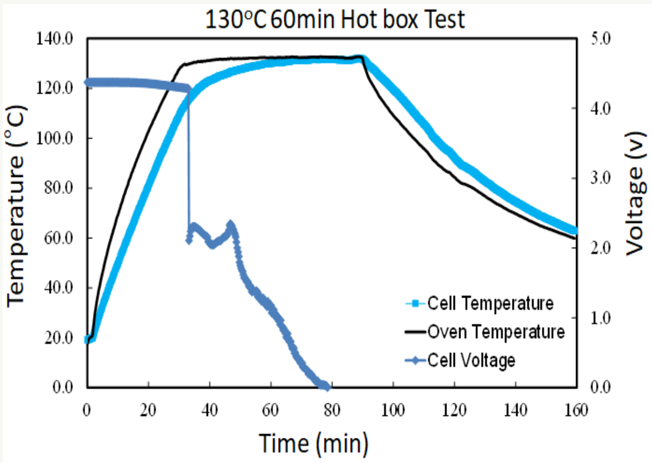
Safety: UN38.3 Certified







- 18650 4Ah passed overcharge, attitude, shock, vibration, thermal shock, impact, crush, and hotbox test

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Summary

- High specific energy and energy density: ~330Wh/kg and 700W/kg.
- Excellent zero voltage stability, ~98% capacity retention after 20ohm 7days for 5 times, which is very good for GEO and MEO satellites.
- The projected cycle life: >92700 cycles (18 years) per our three years cycle life data
- UN38.3 certified

Thank You!

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