2023 Space Power Workshop
April 25-27, 2023

Effect of Anode Prelithiation on LEO Cycling Life of Graphene Batteries

Elena Bekyarova, Ph. D.

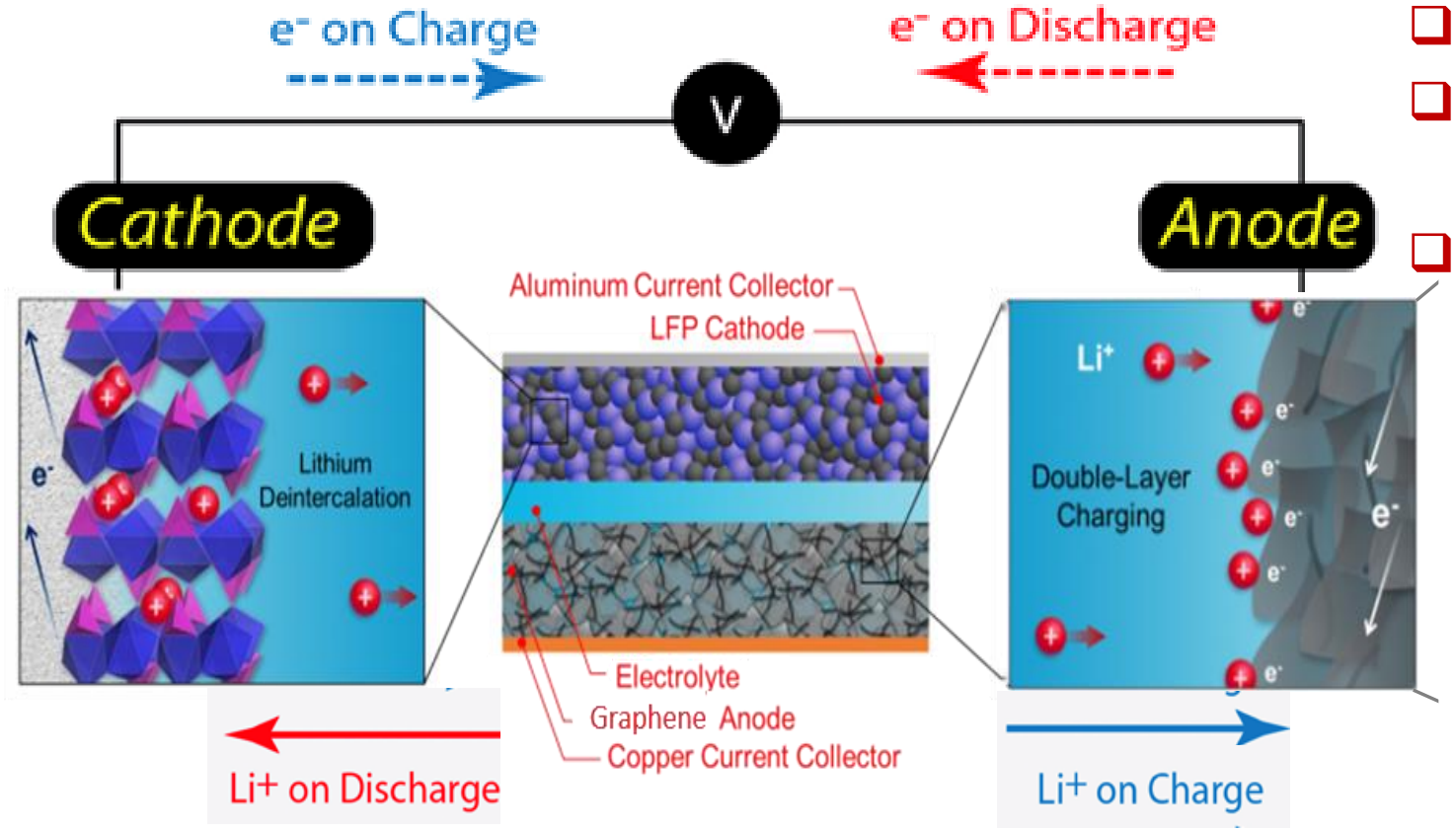
Carbon Solutions Inc.

bekyarova@carbonsolution.com

Batteries for Space Applications

- Critical role in satellite operation
- Low-earth orbit (LEO) satellites: batteries supply power during eclipse

Lithium-Ion Batteries (LIBs)



Space batteries requirements:

- *High energy density*
- *Charge and discharge rates:* LEO satellites circle the earth in 90 minutes; eclipsed for 35 minutes
- *Lifetime:* 5,000 cycles per year
- *Depth of Discharge (DOD):* limited to low levels to reduce stress
- *Weight*: typically 10 to 20% of the overall mass

Benefits of Graphene

- Graphite is the main anode material in LIBs
- Graphene has 2X the capacity of graphite

Anode	Capacity, mAh/g
Graphite (LiC_6)	372
Graphene (LiC_3)	744

Graphene Benefits

- Specific capacity ~ 1264 mAh g^{-1}
- Record in-plane chemical diffusion coefficients for Li at room temperature 7×10^{-5} cm^2 s^{-1} vs. 10^{-7}–10^{-6} cm^2 s^{-1} in graphite

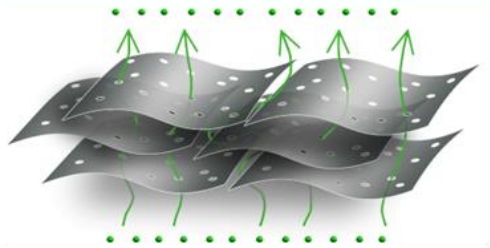
Graphene

Technical Challenges

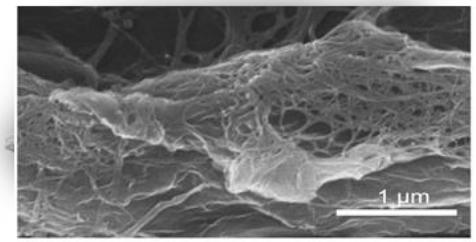
- Graphene re-stacks during electrode preparation
- Irreversible Li insertion, capacity loss with cycling
- Dendrite growth

Graphene Materials for Next Generation LIBs

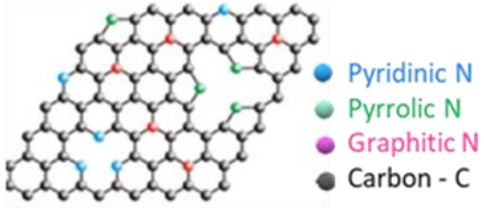
Graphene Materials



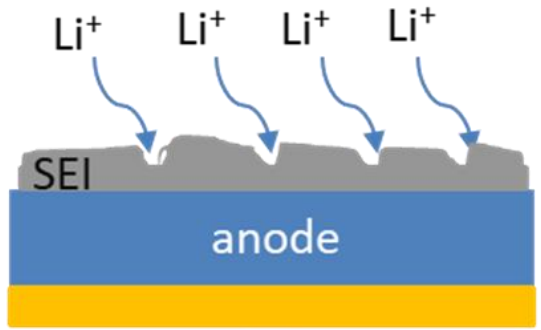
hybrid graphene - carbon nanotube



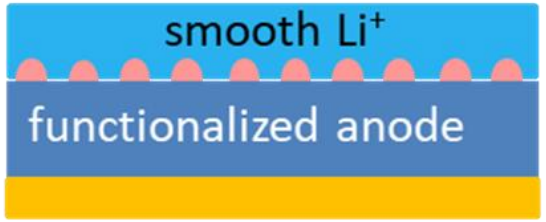
added lithiophilic sites



Prelithiation



dendrite free

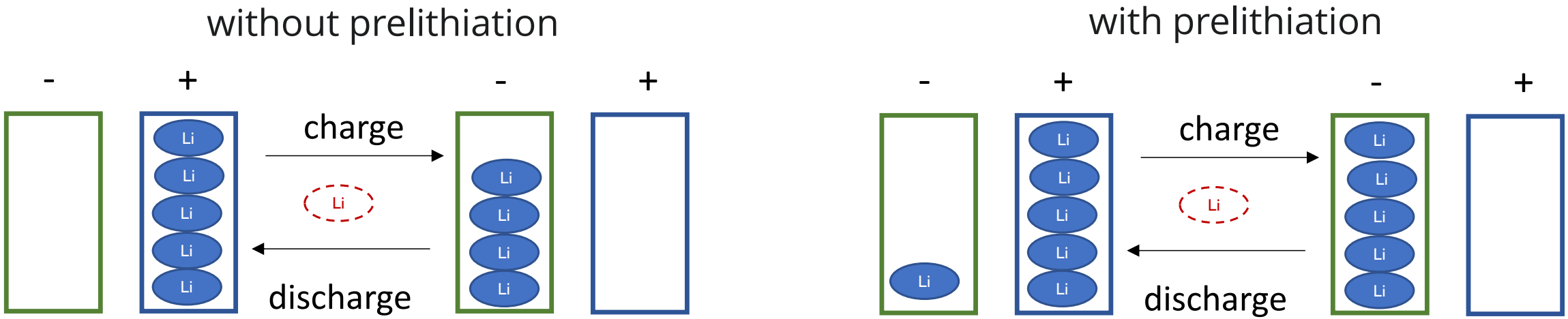


Next Generation Lithium Ion Battery

- high energy density
- light weight
- safe dendrite free
- high cycling stability
- long calendar life
- conformal design
- scalable manufacturing

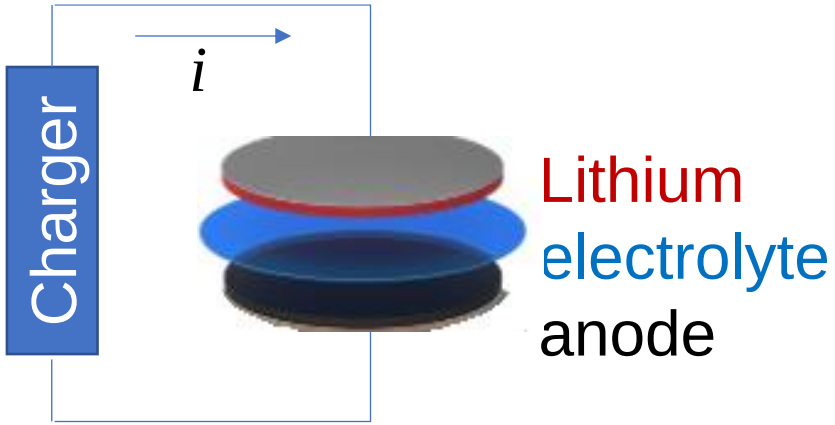
Prelithiation of Graphene Anodes

LIBs Operation



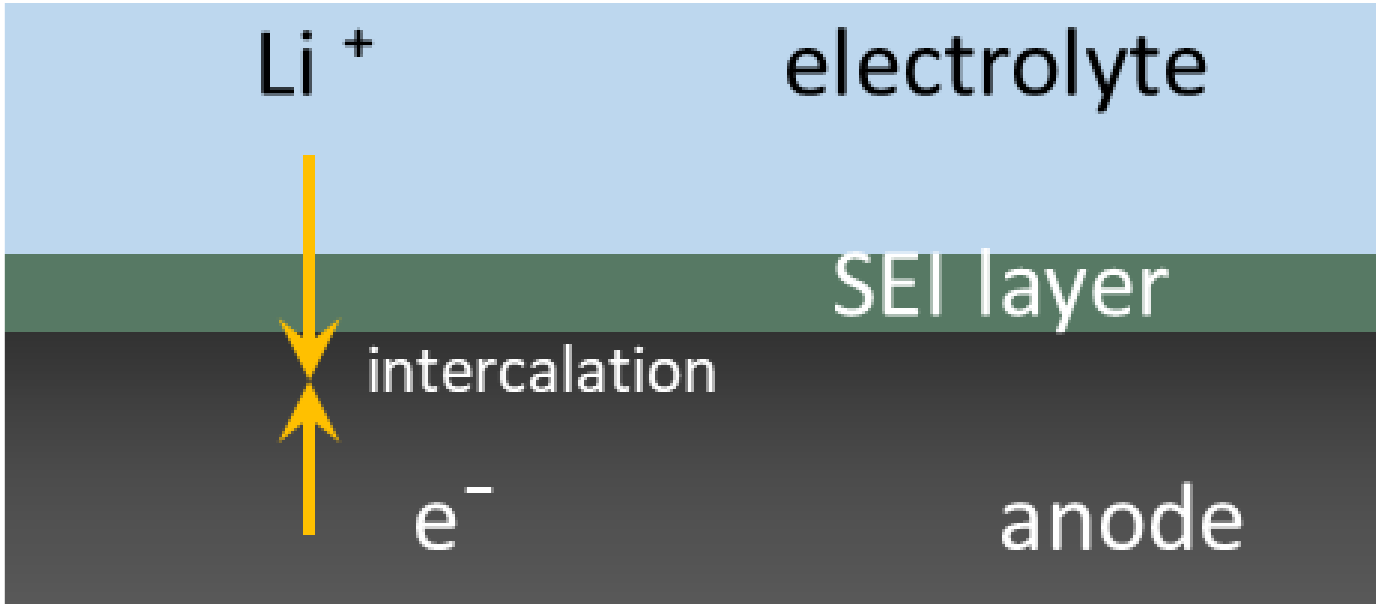
Electrochemical Prelithiation

- ❑ Compensates initial capacity loss
- ❑ Raises working voltage
- ❑ Decreases electrolyte consumption



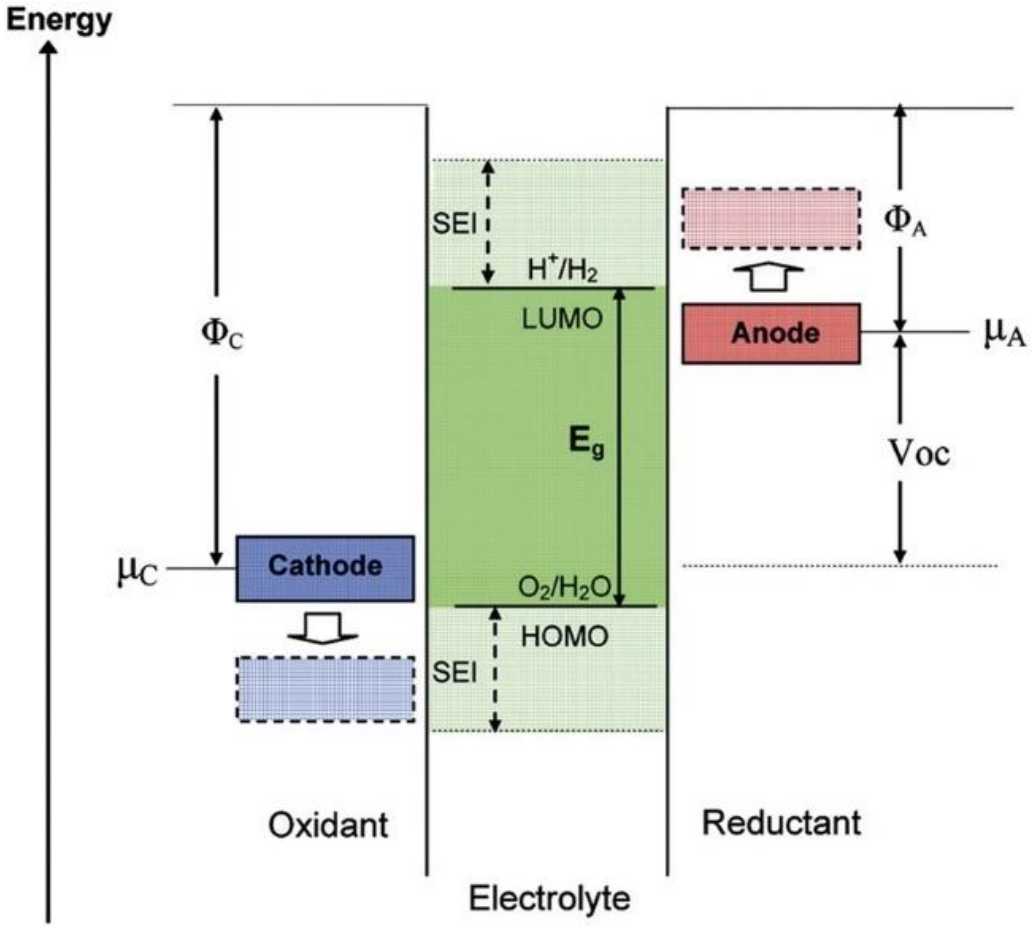
Role of Electrolyte in Prelithiation Process

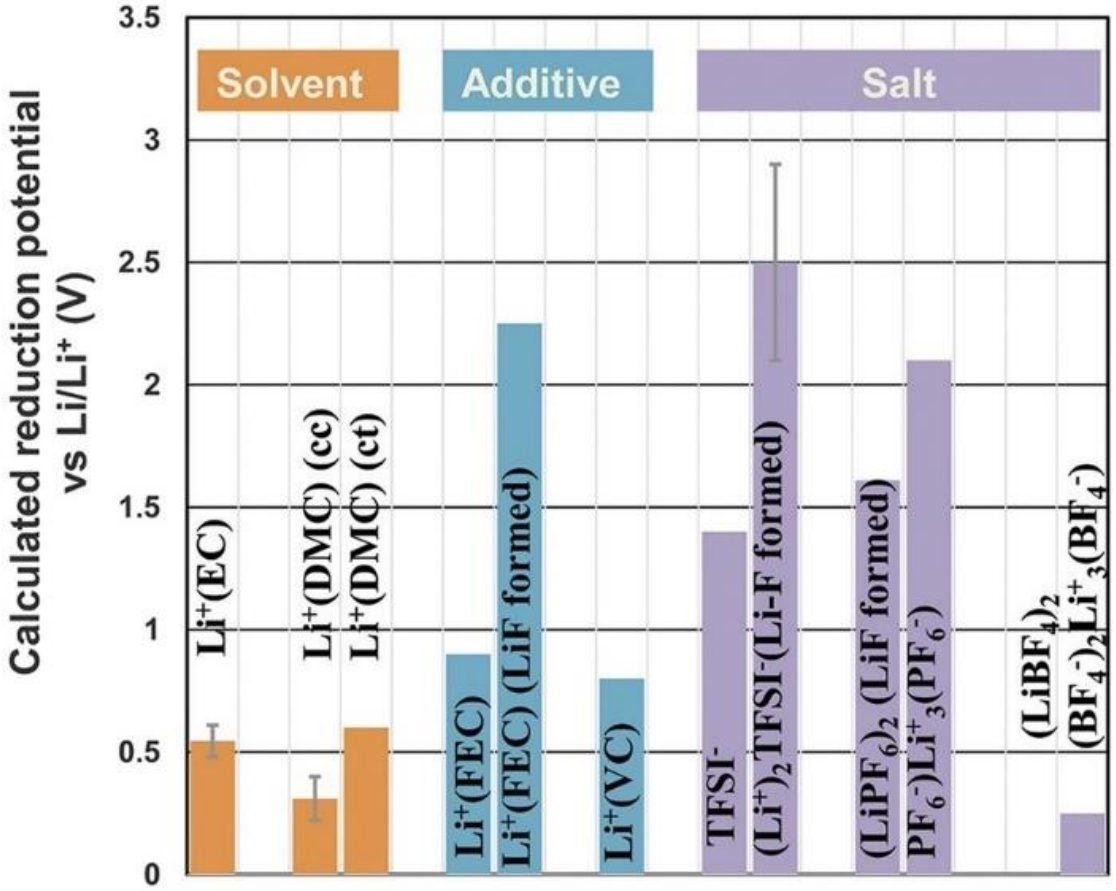
Solid Electrolyte Interface (SEI)



- Cyclability of the anodes is affected by the structure and composition of the formed SEI
- Electrolyte determines the formed SEI

Electrolyte Compositions for Graphene Batteries





Reduction order:
EC > DMC > VC > FEC > EMC > DEC

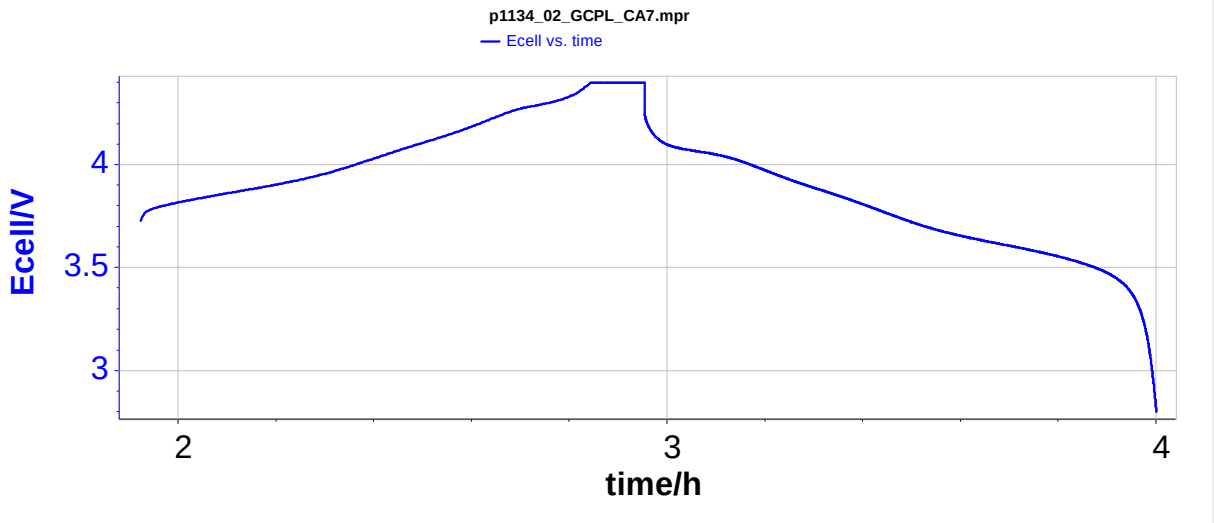
Goodenough and Kim, J. Power Sources 2011, 196, 6688.
Delp et al., Electrochimica Acta 2016, 209, 498.

Electrolyte Compositions for Graphene Batteries

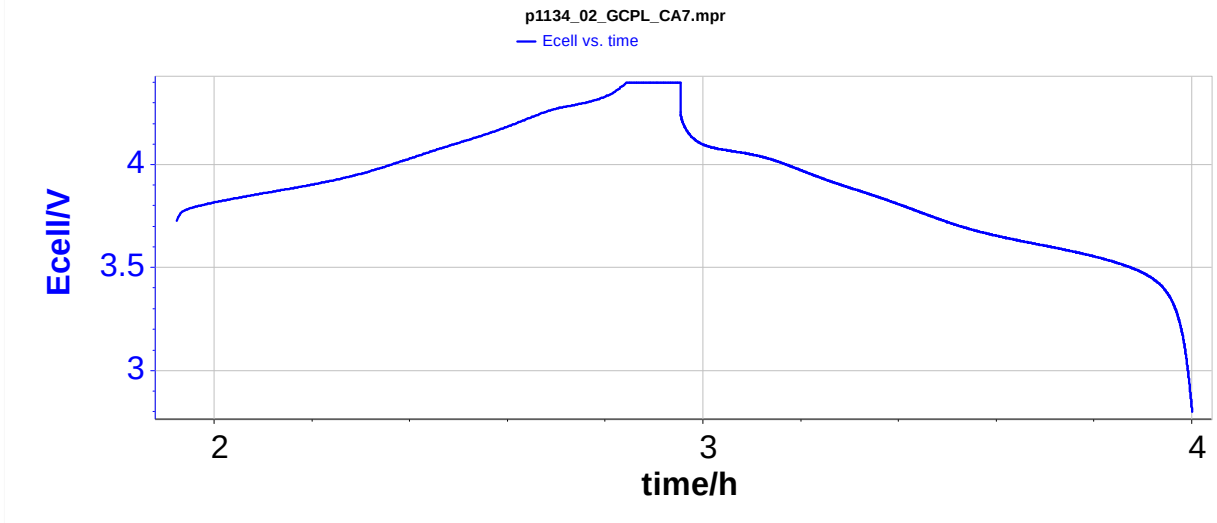
Electrolyte	LiTFSI	Vinylene (%)	Li salt (%)	FEC (%)
1				
2	1M			
3	1M	5%		
4	1M	5%	5%	
5	1M	5%	10%	
6	1M	5%	10%	5%

Pouch Cells with Prelithiated Graphene Anodes

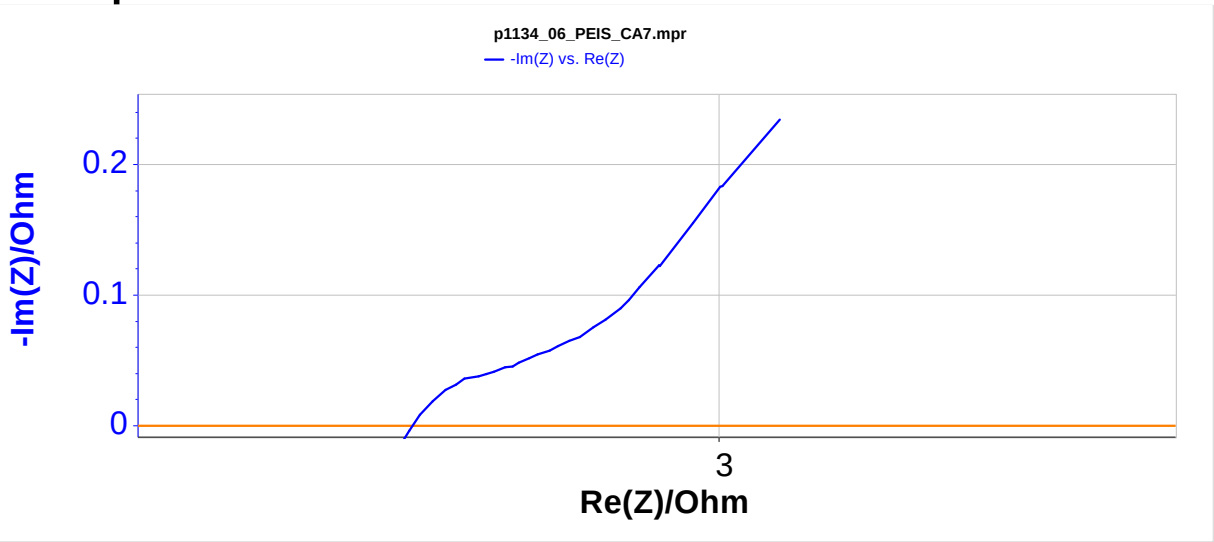
1C E = 300 Wh/kg



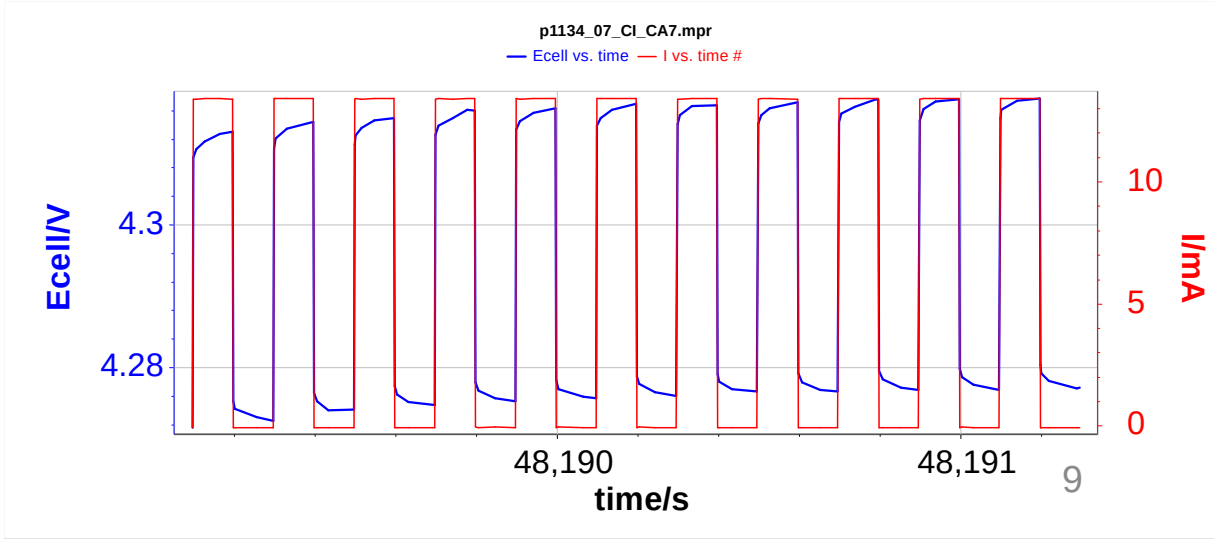
C/2.25 E = 318 Wh/kg C=33.4mAh



Impedance 2.25 Ohm

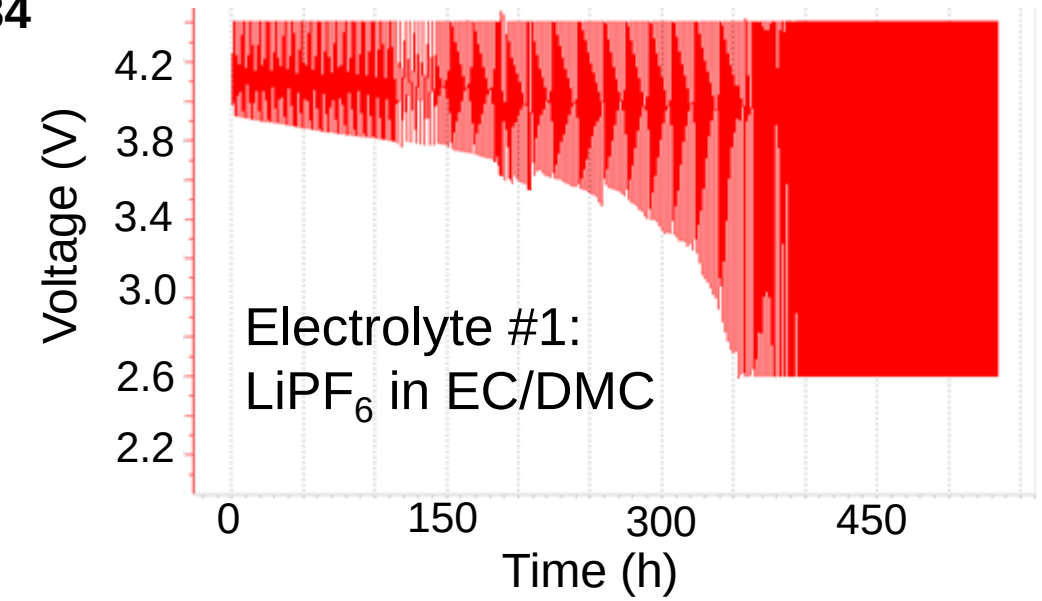


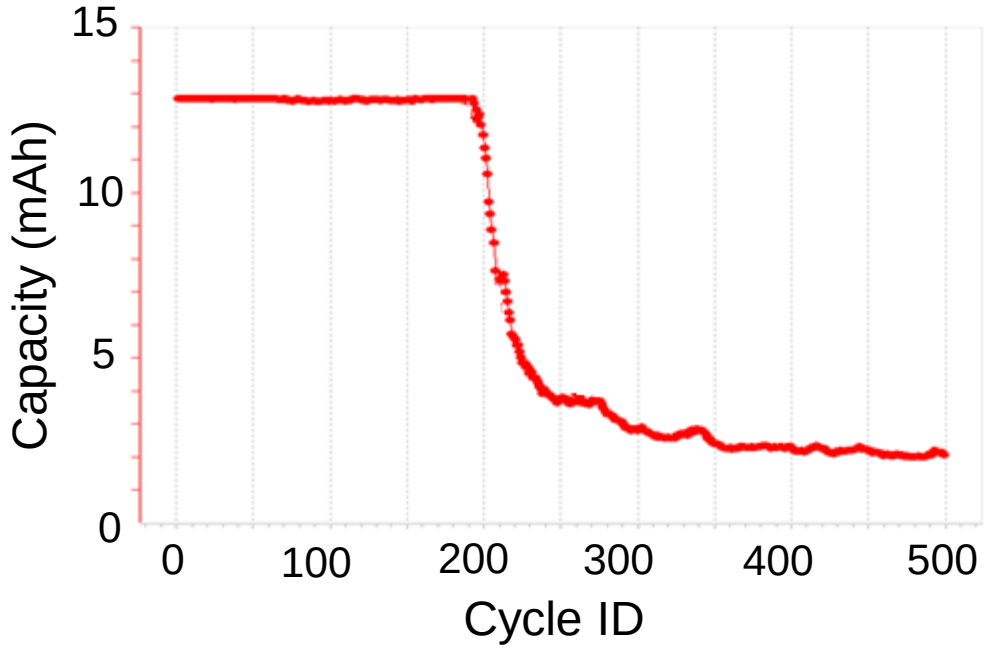
DCR Rc=2.77Ohm



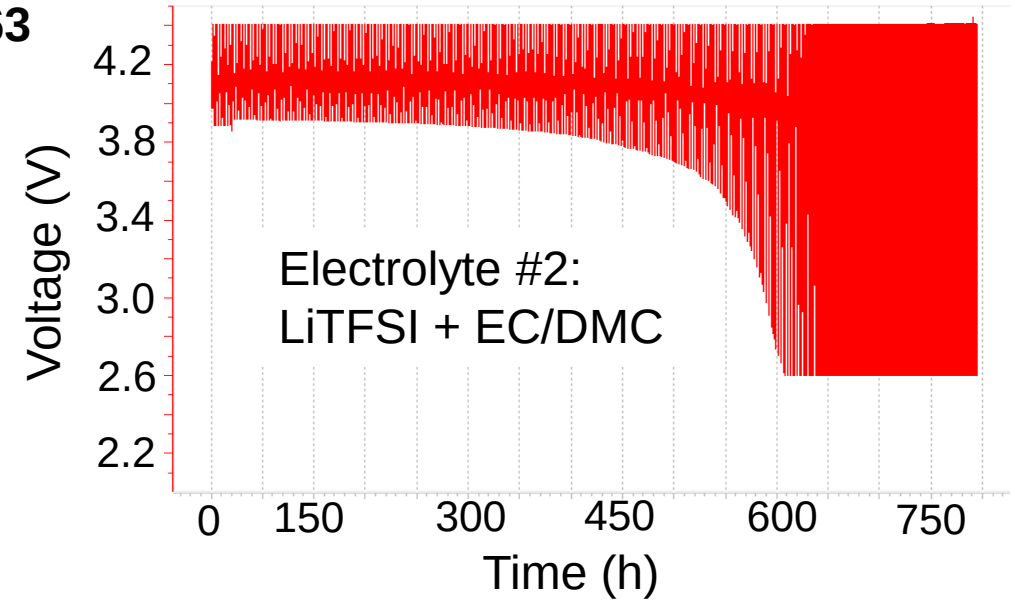
Effect of Electrolyte on LEO Cycling at 40% DoD

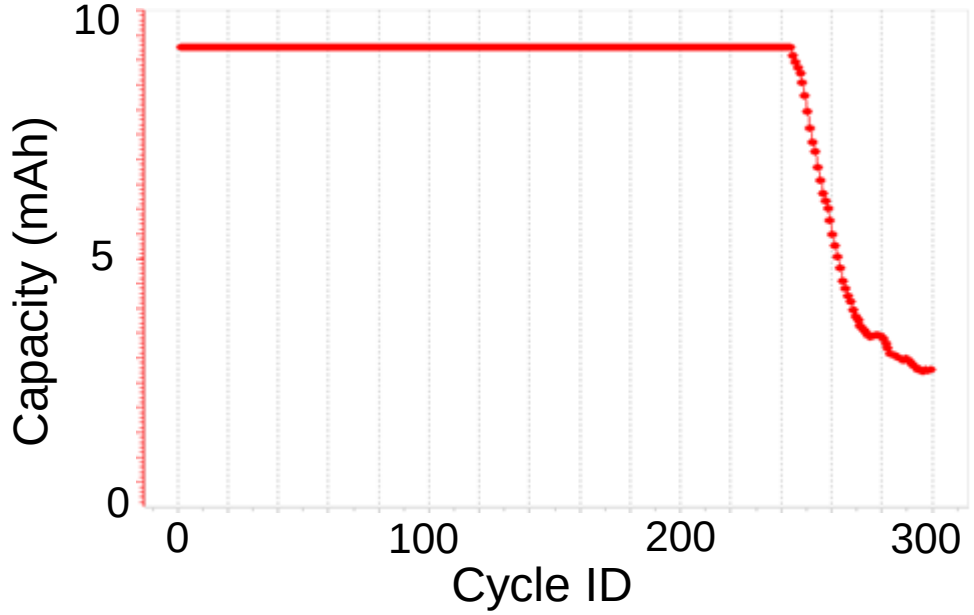
p1134





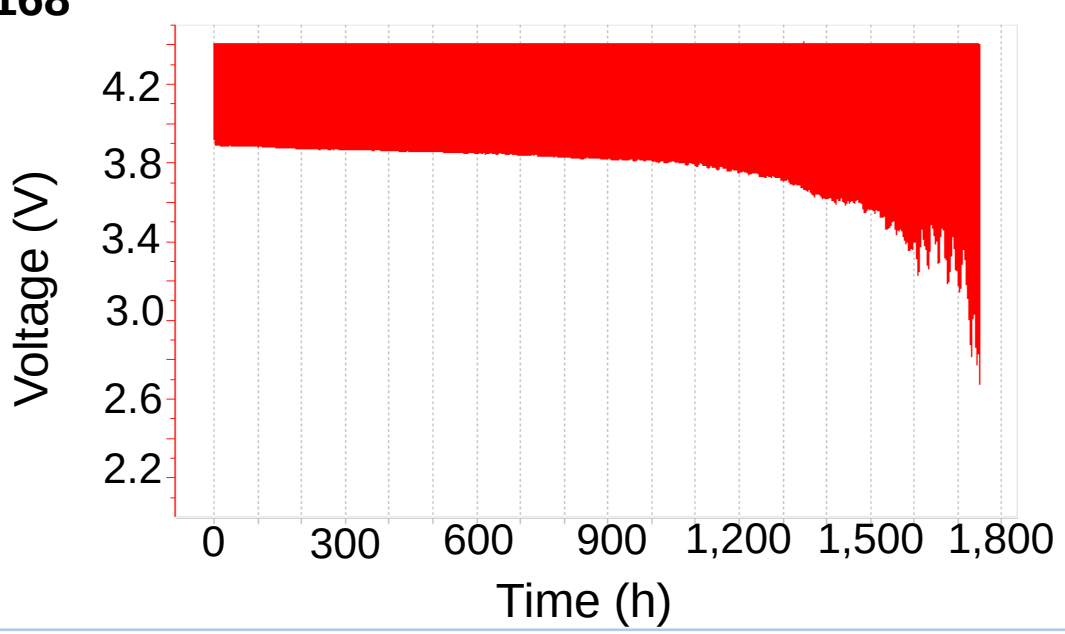
p1163

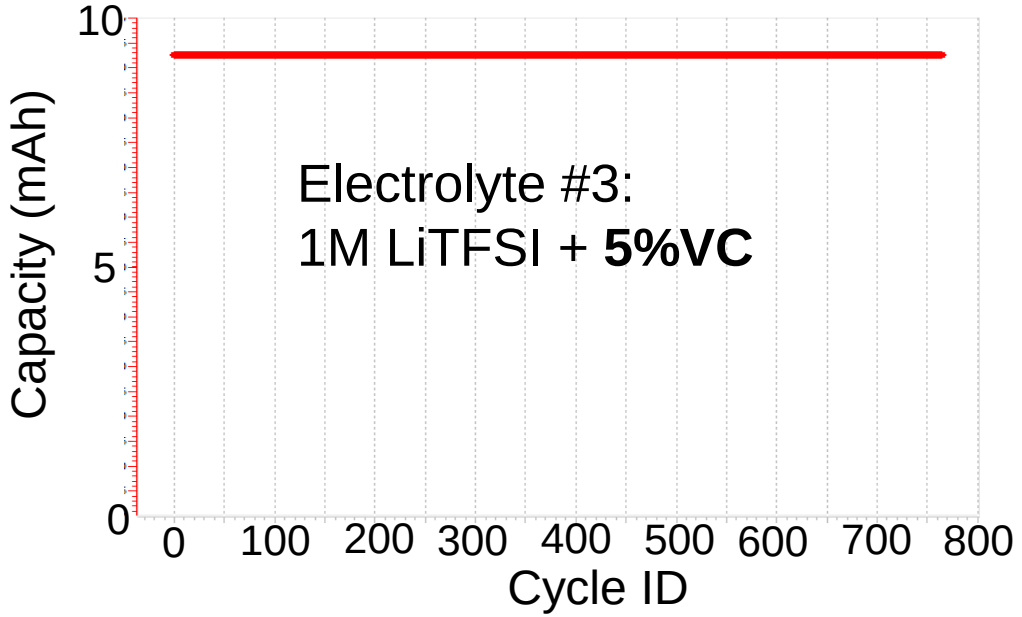




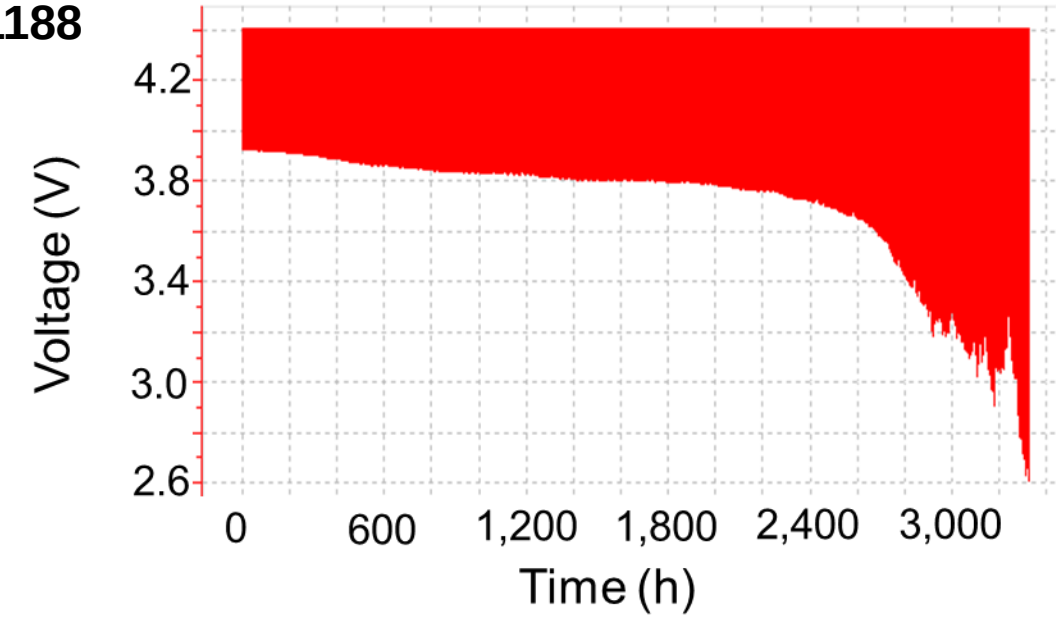
Effect of Electrolyte on LEO Cycling of Graphene Batteries

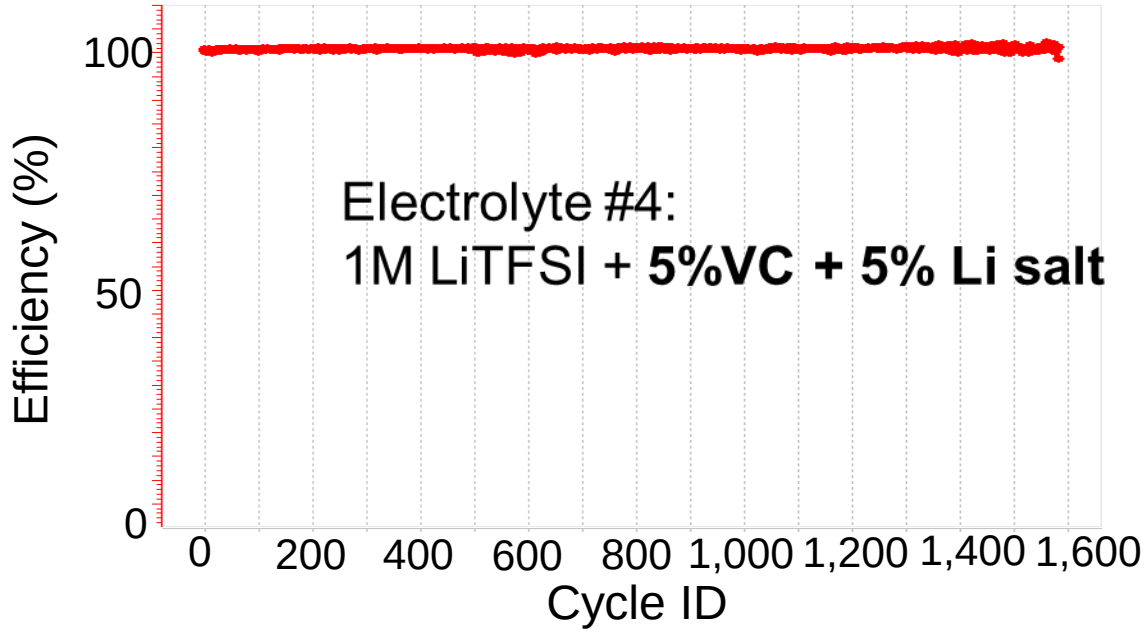
p1168





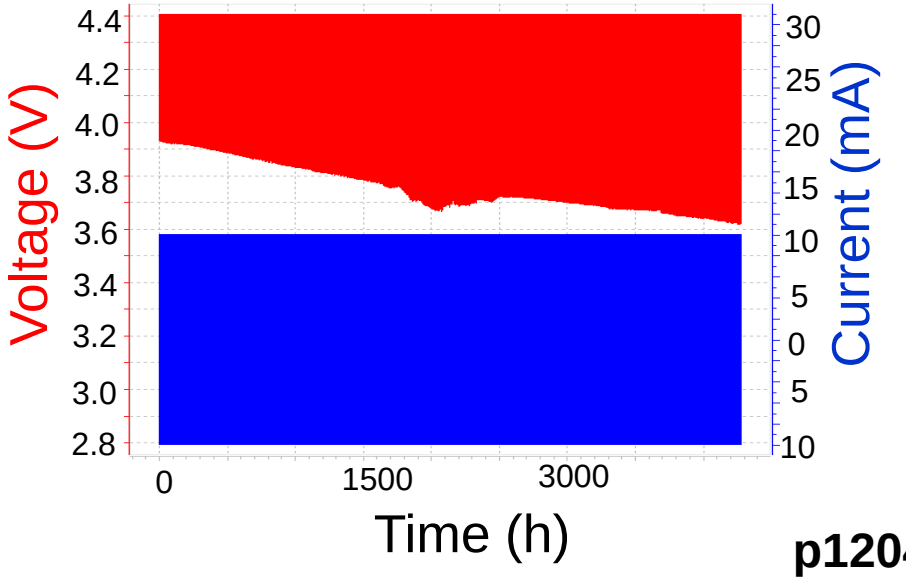
p1188

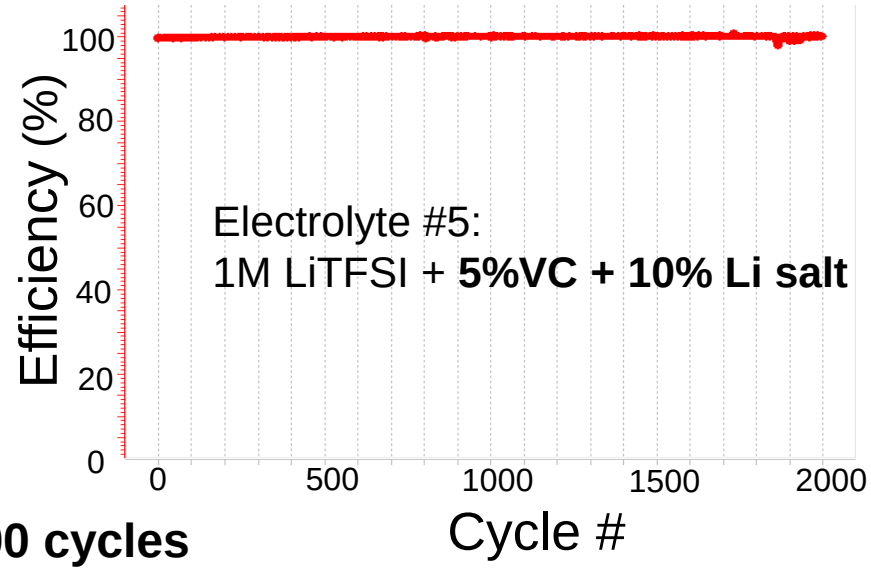




Effect of Electrolyte on LEO Cycling of Graphene Batteries

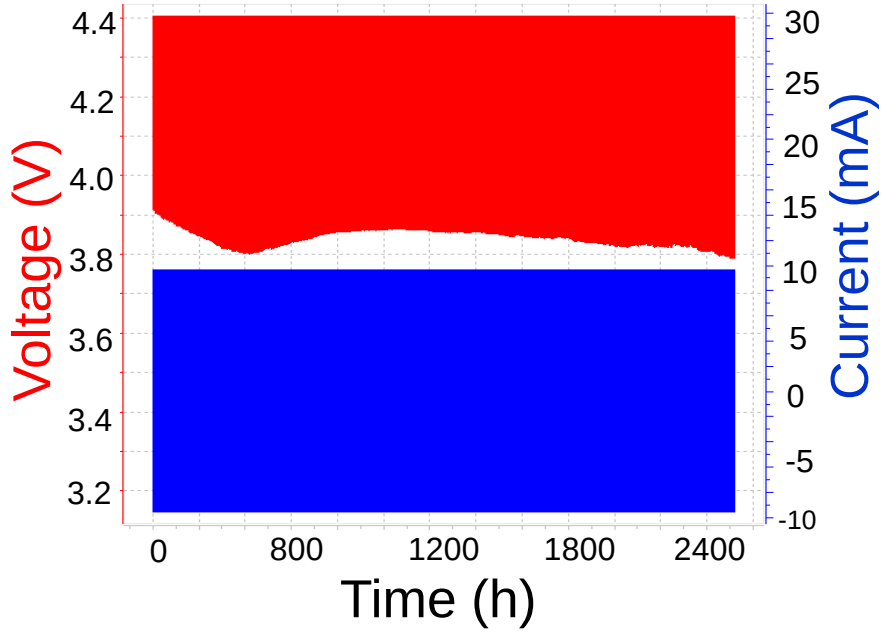
p1191 2,000 cycles

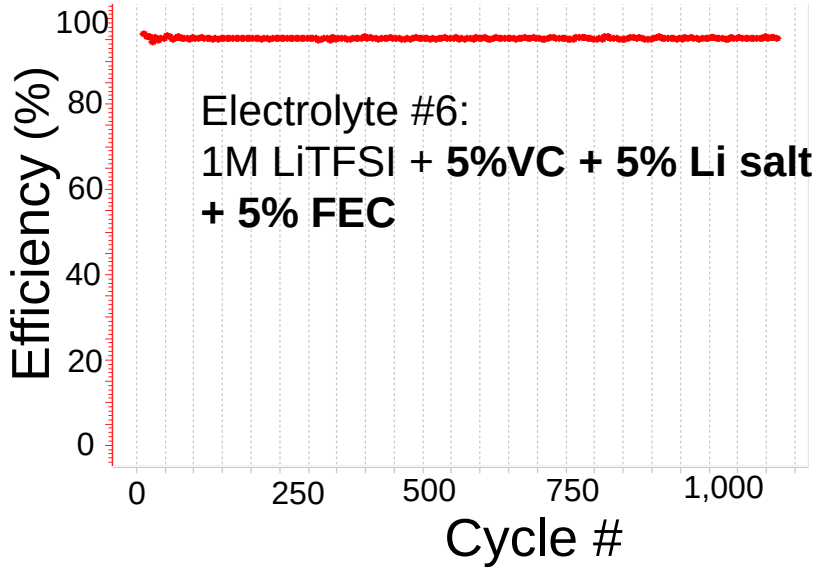




LEO cycling
40% DoD

p1204 1,500 cycles

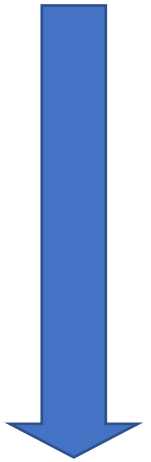




Effect of Electrolyte on LEO Cycling Stability

Electrolyte	LiTFSI	Vinylene (VC) %	Li salt %	FEC %	Cells	LEO Cycles
1					p1134	189
2	1M				p1163	245
3	1M	5%			p1168	765
4	1M	5%	5%		p1188	1585
5	1M	5%	10%		p1191	2000+
6	1M	5%	10%	5%	p1204	1500+

Cycling Stability



Li salt in combination of additives such as VC and FEC form stable SEI increasing the cycling stability of the graphene-based anodes.

Summary

- Graphene-based batteries with high energy density > 350 Wh/kg and Coulombic efficiency of > 95% using prelithiated graphene anodes
- The composition of the electrolyte plays critical role in the stability of the battery cycling performance
- A combination of Li salts and carbonate additives can be used to form a high-performance stable SEI and regenerate the prelithiated graphene surface during LEO cycling
- The graphene batteries have stable performance for more than 2000 cycles at 40% DOD with capacity retention of 100 % and stable resistance

Acknowledgement

This work was supported by the US Air Force (AFRL/RVS) Small Business Innovation Research (SBIR) program under contract FA9453-22-CA-117
TPOC Alec Jackson