

Sodium-based Battery Development

A Family of Batteries for Large Scale Energy Storage

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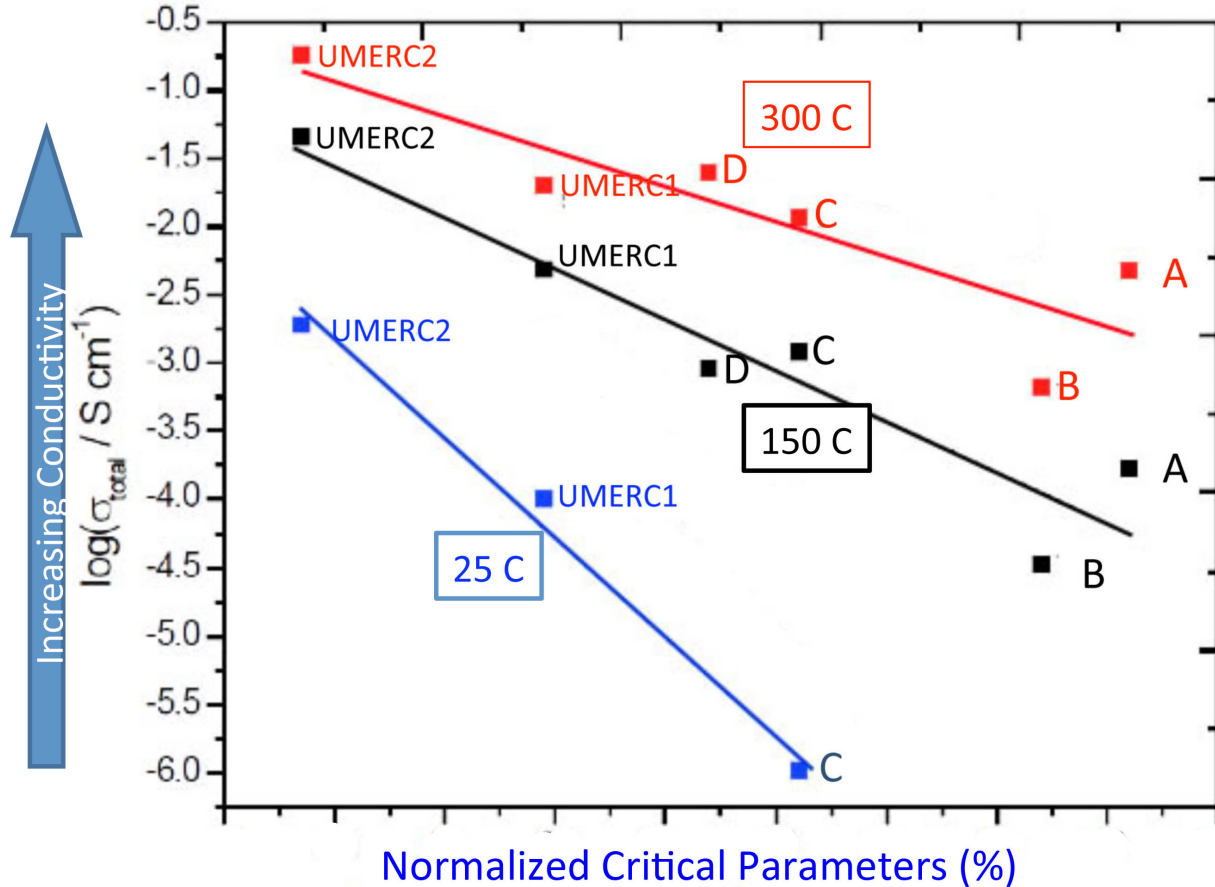
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Sodium-based batteries

- Purpose
 - Demonstrate a family of sodium-based battery chemistries
 - sodium-iodine, sodium-bromine, sodium-air, sodium insertion, sodium-metal, etc
- Goals
 - reduce the cost of power to values consistent with large-scale application needs, e.g. load leveling, frequency regulation, UPS, etc.
 - reduce the cost of energy to < 100 \$/kWh
- Approach – multi-organizational, multidisciplinary team encompassing both science and engineering
 - employ NaSICON as a solid ceramic separator/electrolyte
 - stable against molten sodium anode
 - high conductivity
 - variety of structures can/have been made, plates, tubes, supported membranes, etc
 - manufacturing demonstrated
 - demonstrate laboratory prototypes of various cell chemistries
 - utilize advanced *materials* diagnostics & and development to understand behavior and improve performance using laboratory prototypes

Toward improved materials

- Increasing the performance of NaSICON
 - developed hypothesis about what is necessary for Na⁺ mobility, and what can be done to improve it
 - validated hypothesis - synthesized & measured several materials
 - made predictions to improve performance
 - demonstrated improved performance with new materials
- Other Predictions made about how to further improve performance, and new materials being prepared



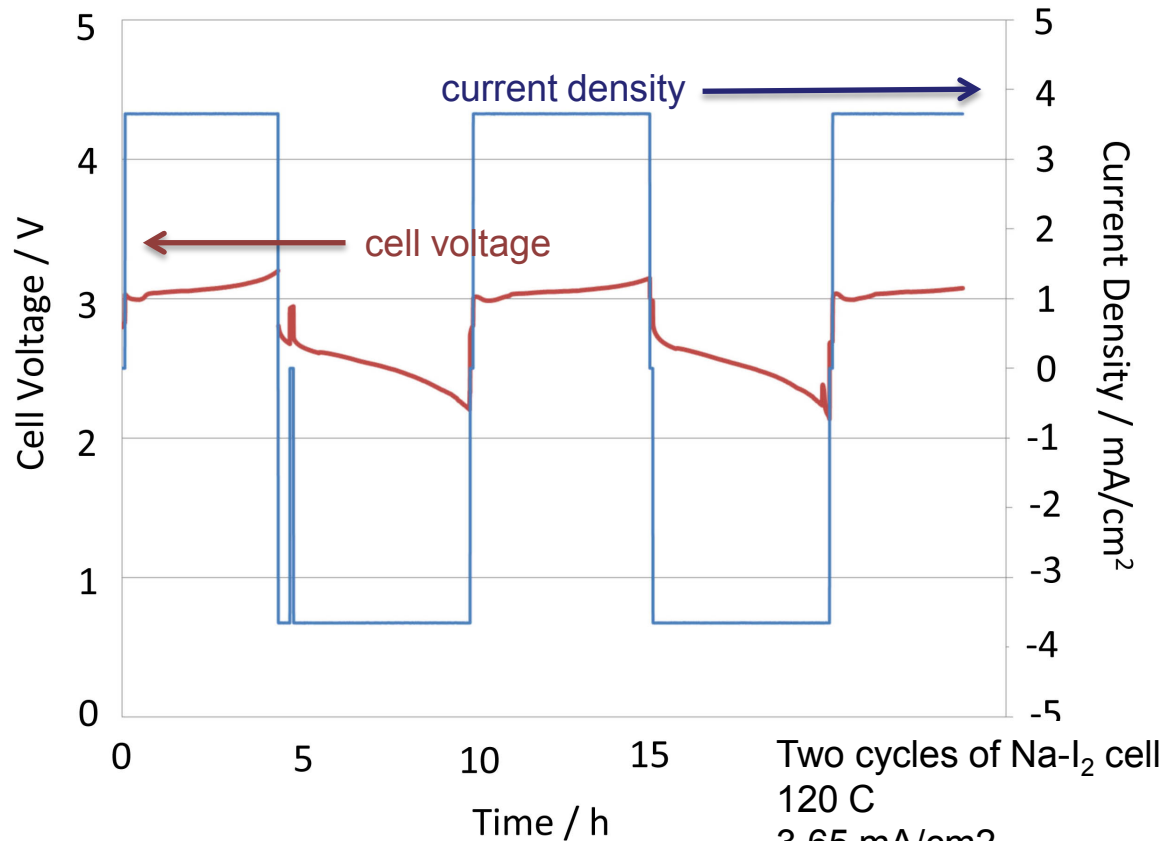
E. Wachsman, UMERC

Laboratory Prototypes

- Sodium-iodine - furthest along
 - sealed cell
 - thousands of cycles at high DOD
 - three catholytes developed and are being evaluated
 - I₂ vapor pressure not an issue
- Sodium-bromine – catholytes under development
- Sodium-metal (Zebra analogs) - have demonstrated cells
 - dendrites are an issue at the cathode
- Sodium-insertion – have developed cathodes and demonstrated cells
- Sodium-air – bifunctional catalyzed electrode at early stages of development

Redox Reactions

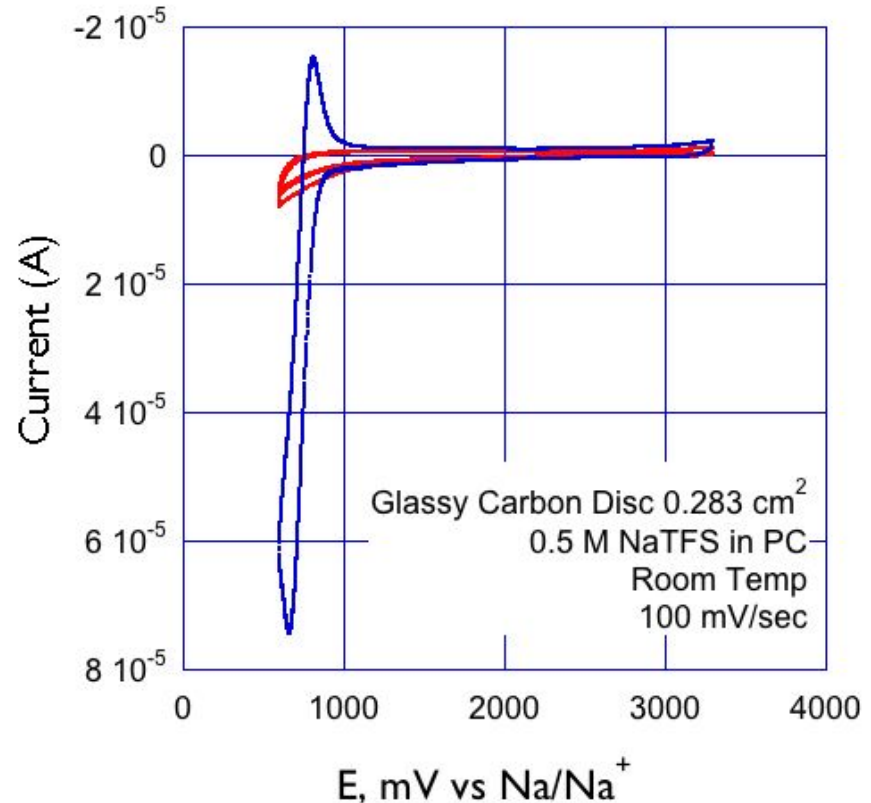
Anodic	Na	↔	Na ⁺ + e ⁻	-2.71V
Cathodic	2I ⁻ + 2e ⁻	↔	I ₂	0.54V
Overall	2Na ⁺ + 2I ⁻	↔	2Na + I ₂	3.25V



S. Bhavaraju, Ceramtec

Alternative Anodes

- Baseline anode – sodium metal
 - high energy density
 - low cost
 - molten above 100 C
 - no dendrites
 - below 100 C, solid
 - employing secondary electrolyte
 - dendrites
- Other anodes being developed
- that allow:
 1. flow configuration
 2. eliminate/mitigate dendrite issues at temperatures below 100 C
- lower energy density, but:
 - can be more easily pumped than sodium metal
 - simplifies means for eliminating shunt current associated with molten sodium (metallic conductor)
 - engenders lower cost plumbing than sodium metal

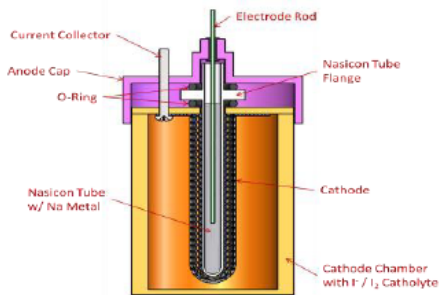


Cyclic Voltammogram showing redox behavior of possible alternative anode.

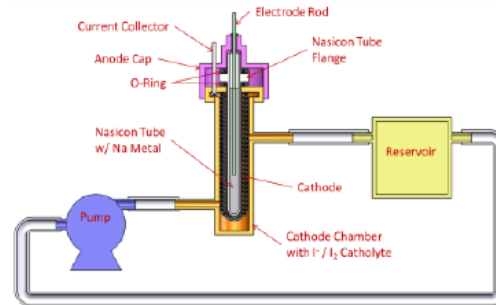
D. Ingersoll, SNL

Modeling as an Aid to Cell Design

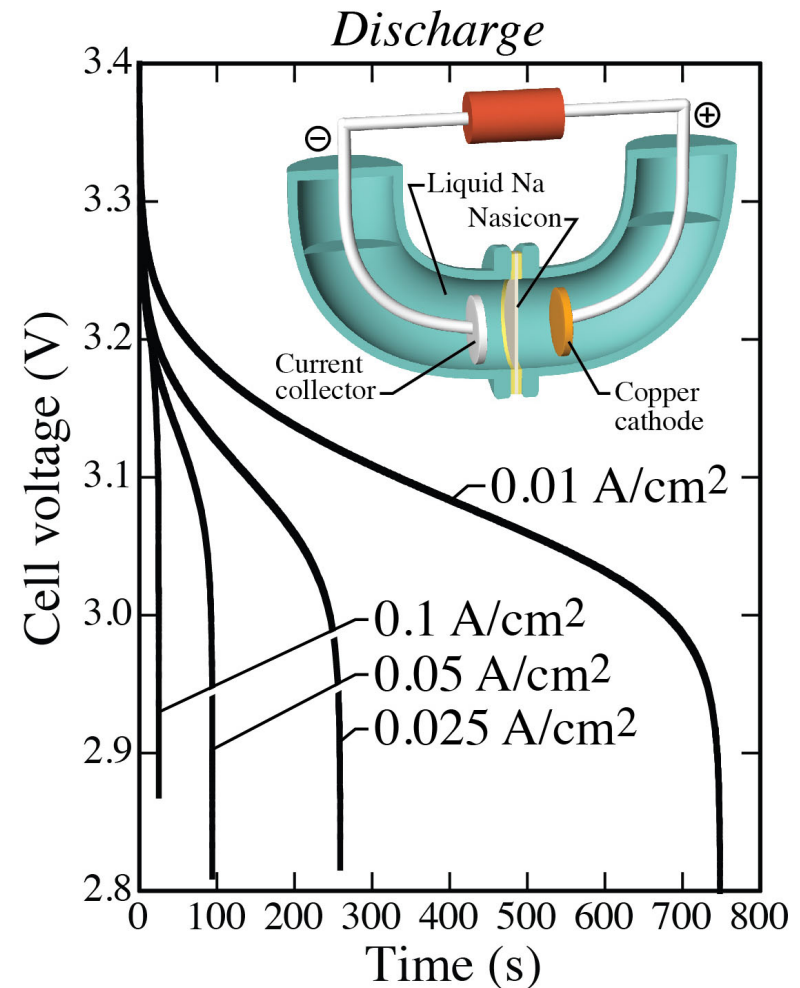
- Derive and implement physically based *predictive* models
- Apply models to aid in cell design and system development
 - Models to predict charge & discharge behavior as functions of:
 - geometry – cell design
 - operating conditions – temperature, cell operation, cell chemistry, etc
- Model for Sodium-metal (Zebra-analog) system developed
 - Ion transport limitations limit charge and discharge capacity at high rate
- Have begun to use the model for cell design for the sodium-iodine system



Non-flow design



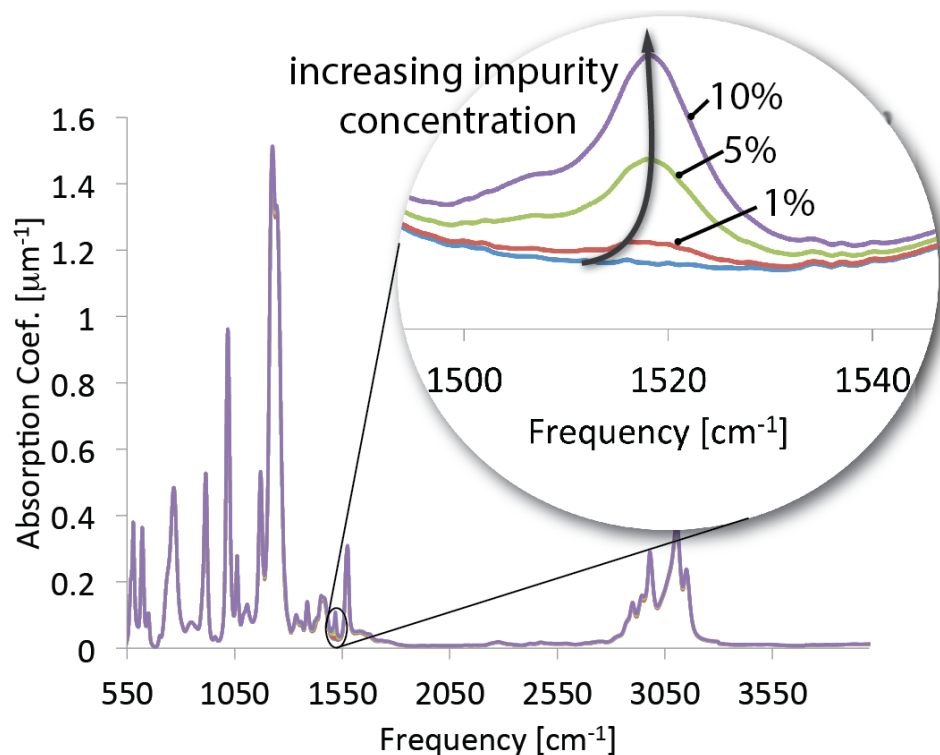
Hybrid design



R. Kee & Z. Hu, CSM

Advanced Diagnostics for Materials Development

- Develop and employ advanced diagnostics for materials characterization
 - NMR, TOF-SIMS, scanning probes, etc
 - includes for use in-situ to detect materials degradation and lifetime stability issues – e.g. long term stability of the catholytes or impurity detection in feedstocks
- We are currently using Room Temperature Ionic Liquids (RTILs) as a part of select catholyte formulations
 - low vapor pressure
 - thermally stable
 - electrochemically stable
 - but cost still high
 - cost reduction strategy - partnered (unpaid) with **Boulderionics**
- Techniques being developed, and baseline data being obtained using optical spectroscopies:
 - FTIR
 - UV-vis
 - fluorescence



FTIR of select RTIL used to quantitate impurities

J.M. Porter & C.B. Dreyer, CSM

FY13 Future Work

- Demonstrate sodium-air laboratory prototype
- Demonstrate sodium-bromine laboratory prototype
- Demonstrate improved solid ceramic membrane
- Continue materials development
 - improved ceramic
 - cathodes and electrolytes
 - We also have a poster that describes some of the other materials development activities

Acknowledgements

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