Control Enabling Solutions with Ultrathin Strain and Temperature Sensor System for Reduced Battery Life Cycle Cost

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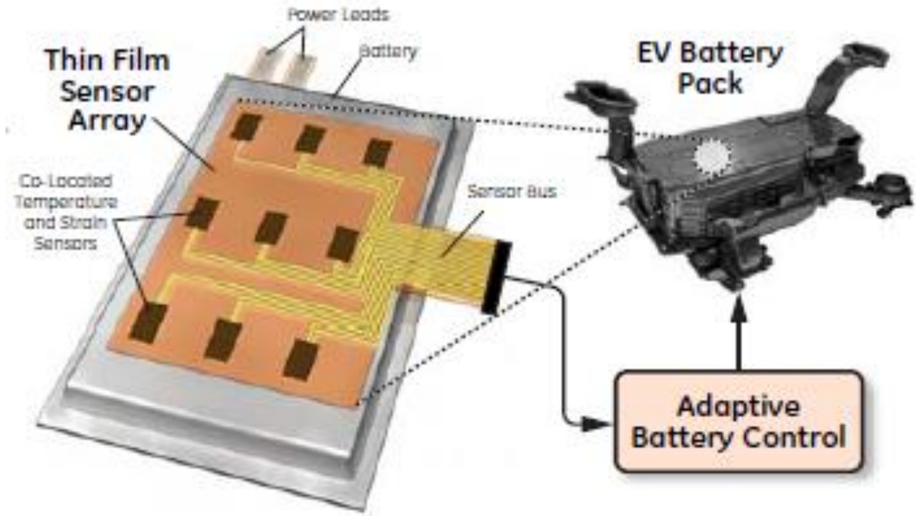
Ford

Technology & Value Proposition



Enhancement over SotA

- Current measurands limited (V, I, T)
- New observability – Expansion
- Smaller size (<100μm)

Unique Approach

- Leverage adv. Packaging & thin film processes to create expansion & temp sensors capable of being placed between cells & configured as arrays
- Combine new observability with multi-physics models & parameterization for new predictions of cell SoH

System Benefit

- Improved cell utilization utilizing minimalistic sensor configuration & Reduced Order Modeling

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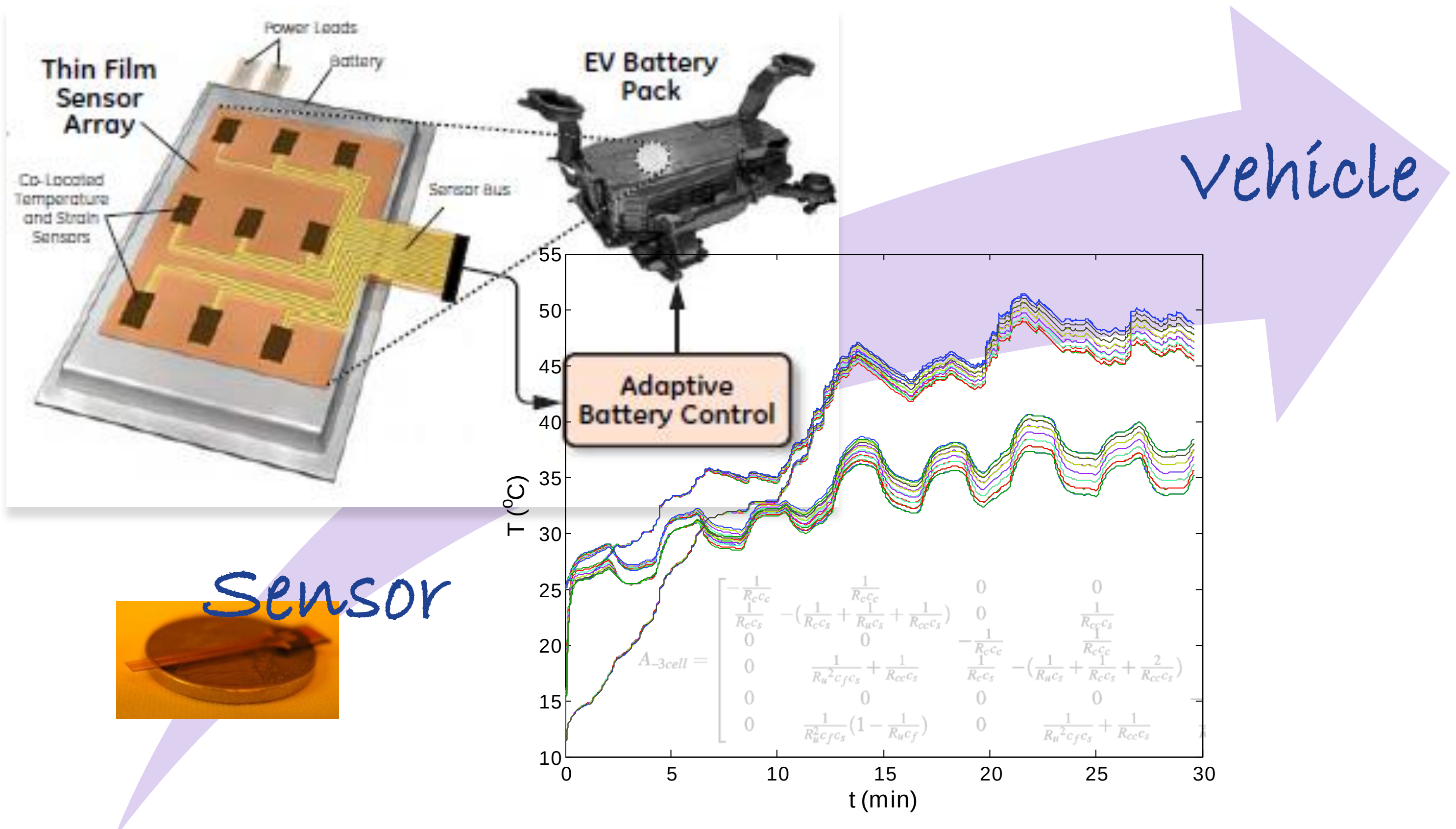
Technology & Value Proposition



U-M will use multiphysics models for selecting the critical sensor locations, extracting the thermal and stress features for new battery control algorithms. The sensors and control will be implemented in a battery pack and tested by Ford.

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Validation Plan & Performance Targets

Summary of Major Milestones

2013

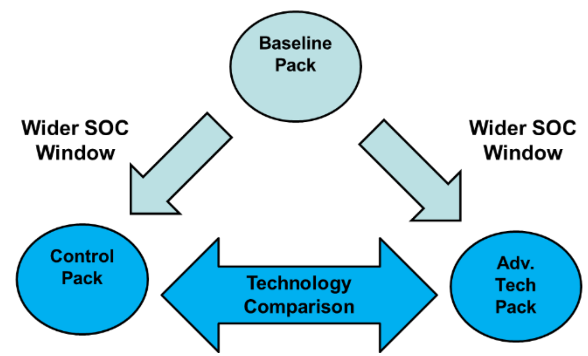
- ✓ *Prototype temperature sensor arrays (GE)*
- ✓ *Demonstrate combined temperature and strain measurement (GE)*
- ✓ *Cell level TEC model (UM)*
- ✓ *Performance and test objectives definition (Ford)*

2014

- *Prototype temperature & strain sensor arrays (GE)*
- *Multi-physics cell model with GE's strain & temperature sensor array (UM)*
- *Operating pack level model with distributed temperature observability analysis for optimum sensor placement*
- *Sensor integration within a pack (Ford)*

2015

- *Side by side demonstration with un-instrumented pack showing cell utilization benefit (Ford)*
- *Adaptive battery management that utilizes the strain and temperature model predictions on a sub-set of cells (UM)*
- *Achieve 10% strain prediction accuracy for a single defect-free cell (UM)*



Comparison of 2 Packs with & without Sensors over 30,000mi
Periodic capacity & power tests

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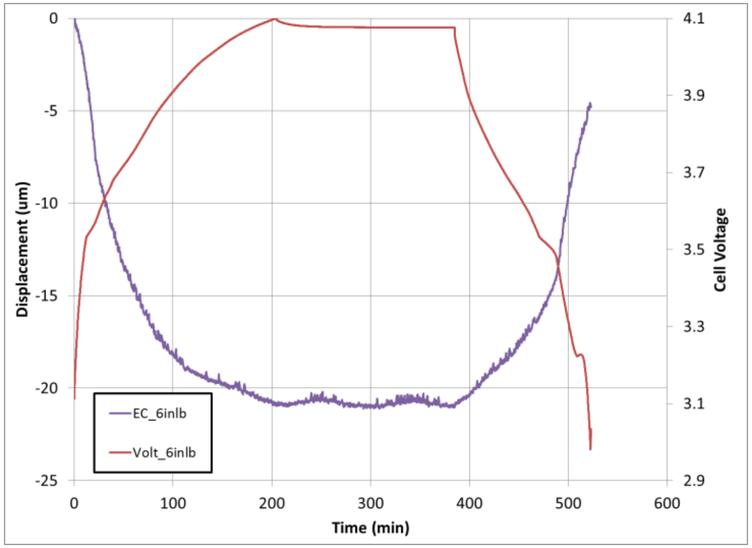
Temperature & Expansion Sensors Demonstrated

- Fabricated temperature arrays (6 points – 36 points on cell face)
- Arrays tested on U-M 3 cell rig to validate temperature models
- Developed expansion sensor with co-located temperature sensors with 1μm resolution

6 Point temperature sensor array fabricated by GE



Cell expansion quantified to >20μm, Simultaneous temp data taken

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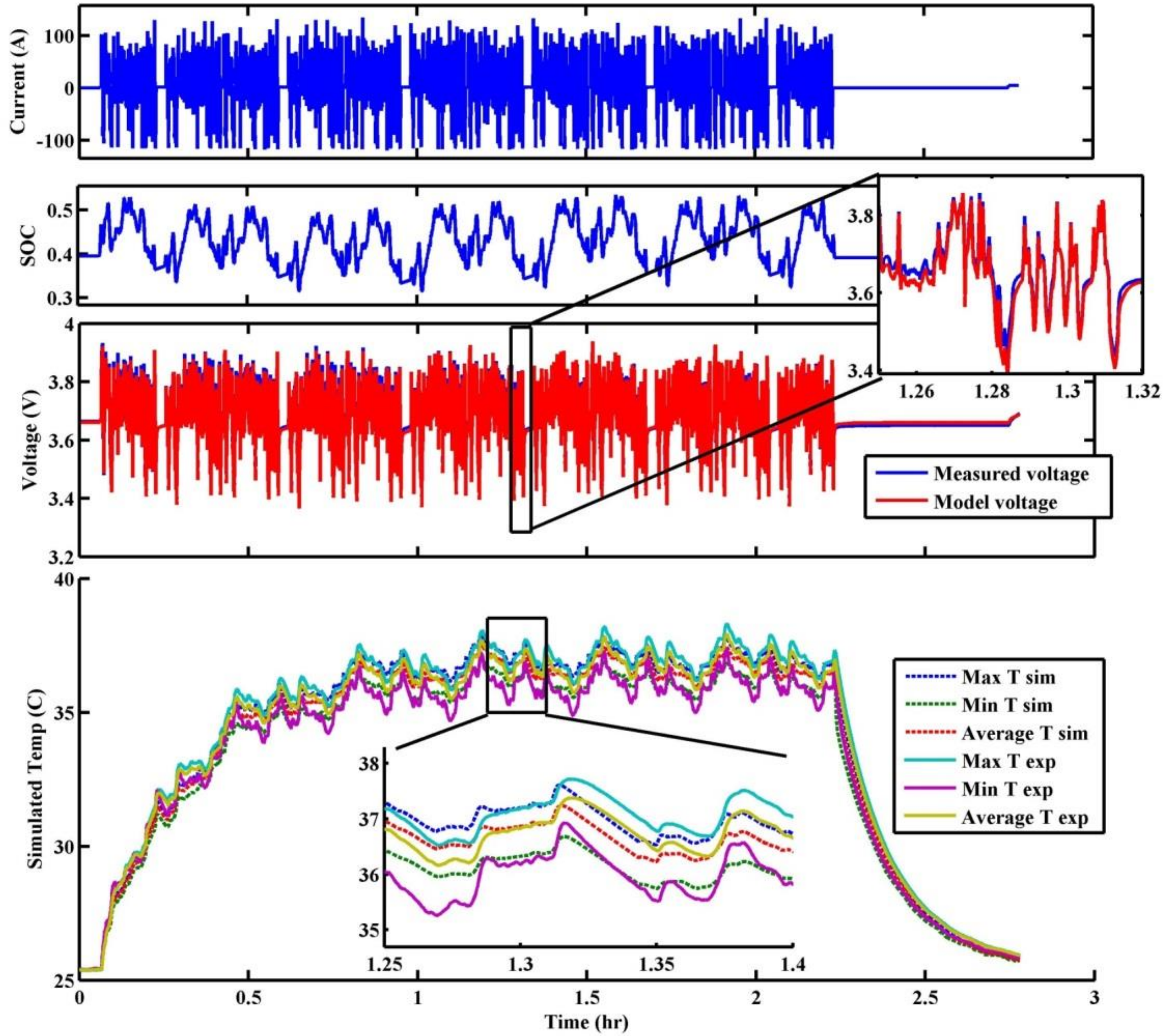
Surface Temperature Prediction within 0.5°C



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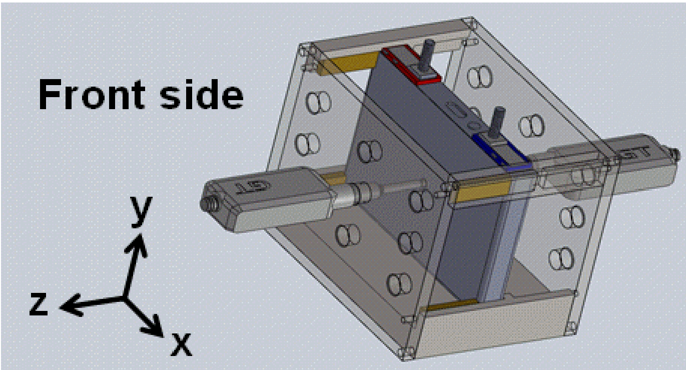
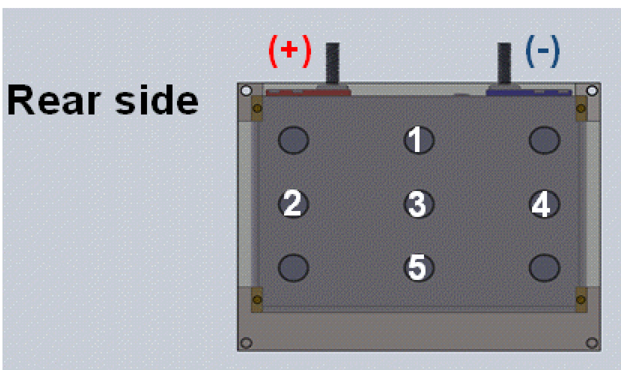
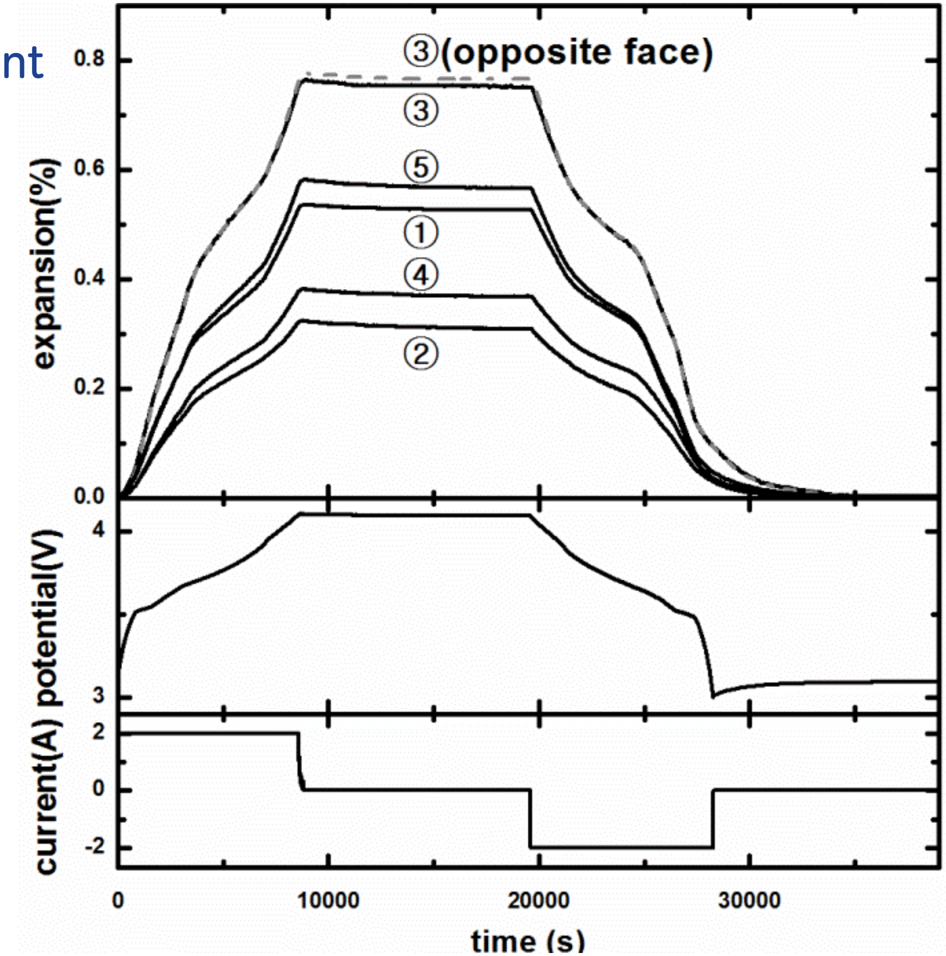
US06 Drive Cycle

Swelling Sources: SOC, Rate & Temperature

Low rate cycling expansion measurement







Low Rate (0.4C) Spatial Expansion Distribution

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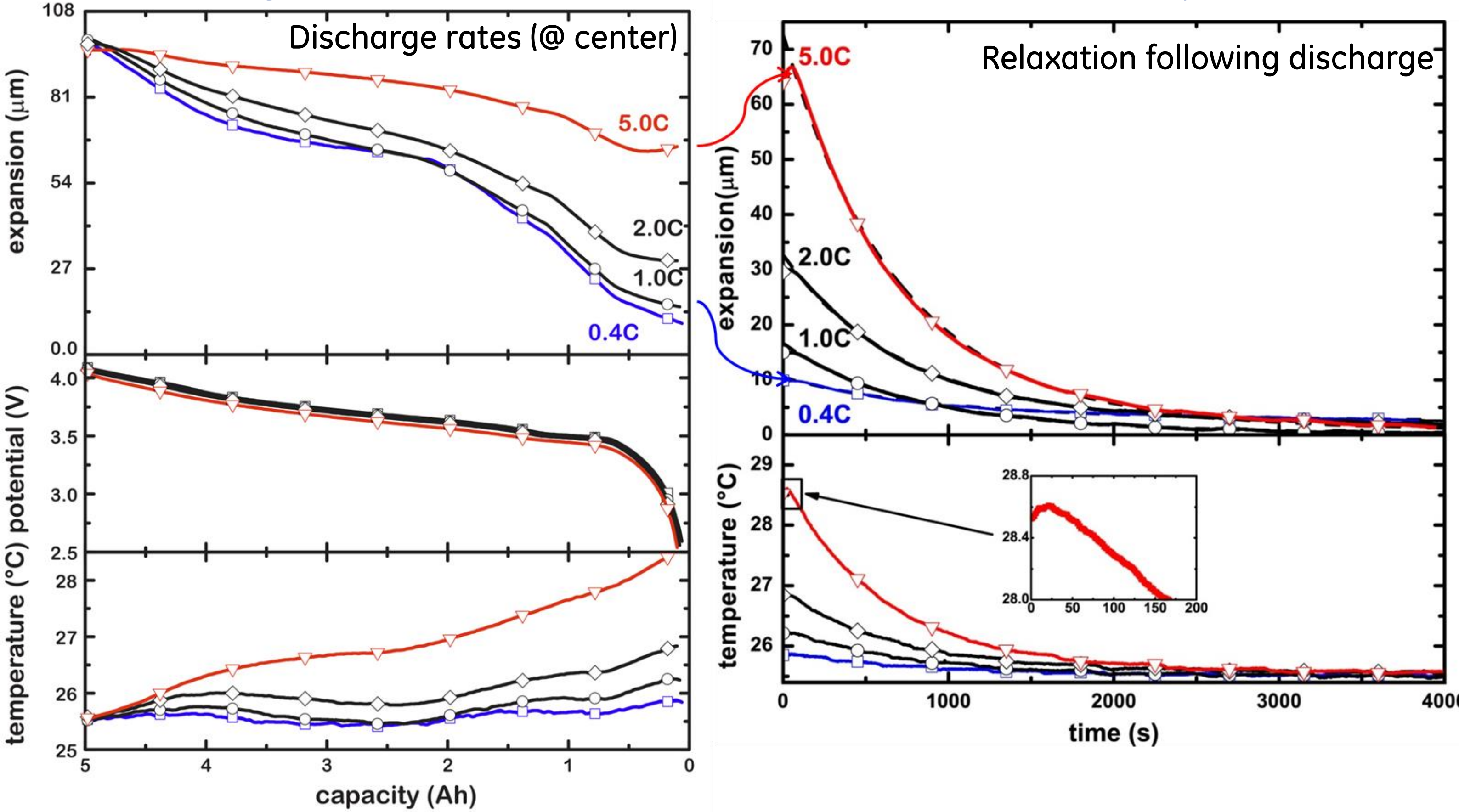
Swelling Sources: SOC, Rate & Temperature



- The residual swelling upon completion discharge has a strong dependence on the C-rate even though cell terminal voltage doesn't change significantly
- The residual displacement slowly relaxes to zero:

→ Dynamic model requires two time constants

- ➢ Fast response: thermal relaxation
- ➢ Slow response: diffusion or mechanical relaxation

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