AMPED *SENSOR*:

*S*mart *E*mbedded *N*etwork of *S*ensors with *O*ptical *R*eadout

AMPED Meeting 2015, Chicago, IL

Project Team/Key Personnel

parc
A Xerox Company

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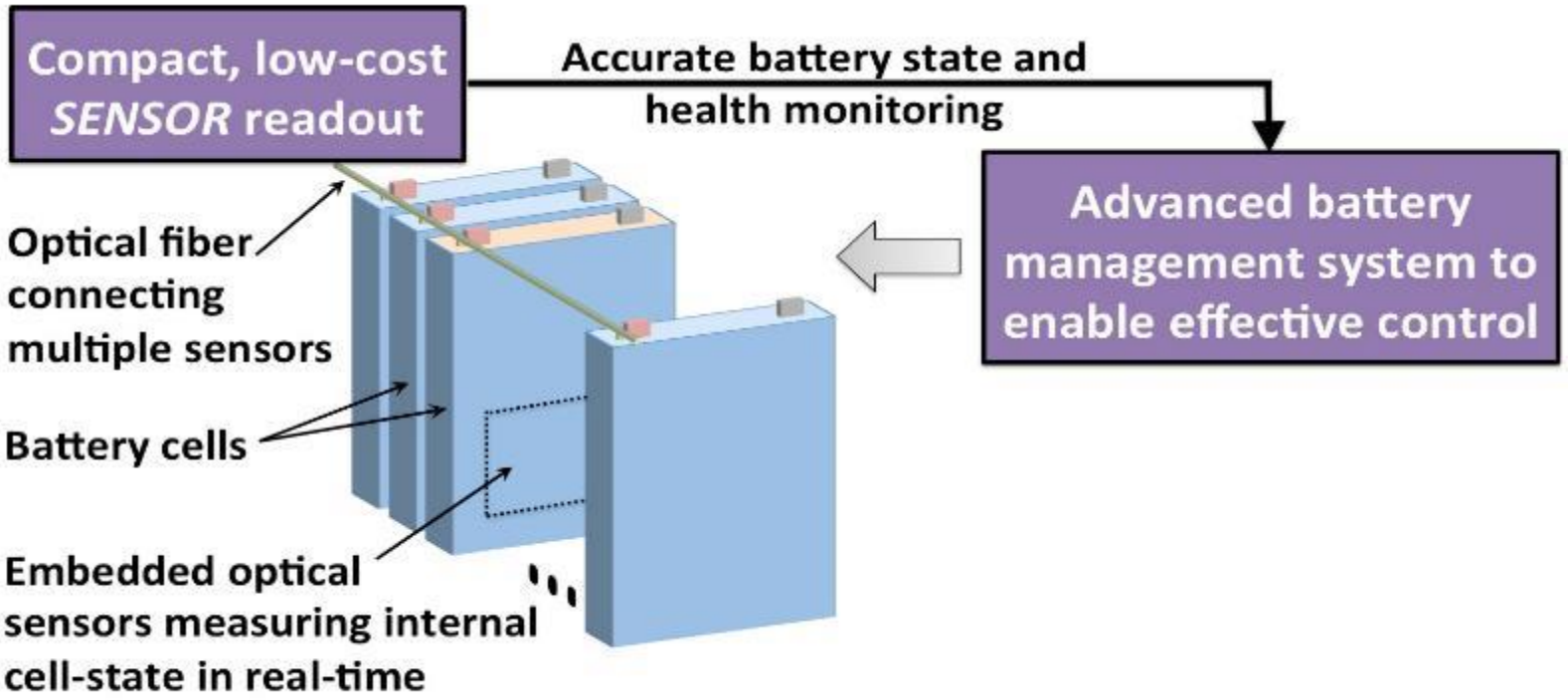
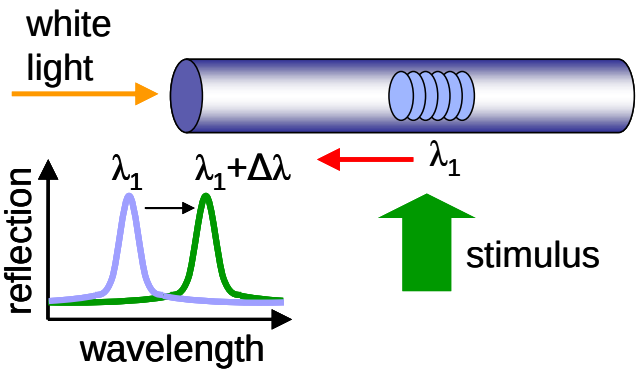
SENSOR Overview

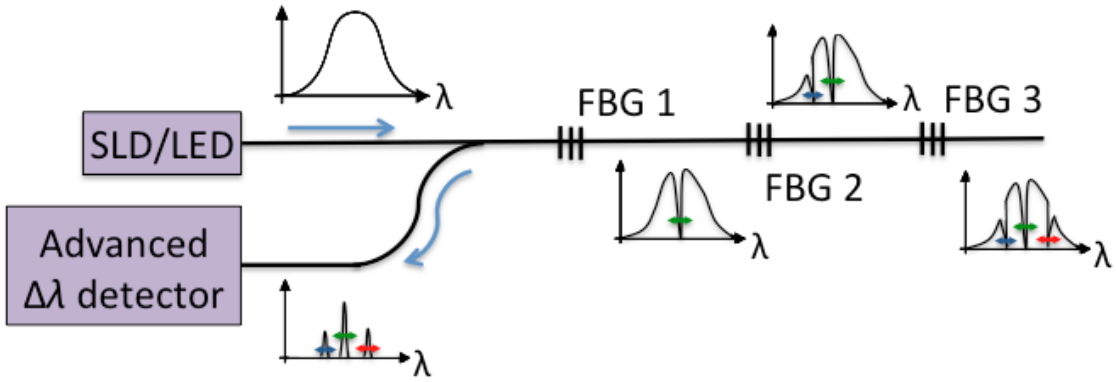


- Fiber-optic (FO) cell sensing, smart algorithms for BMS
- Low-cost, high-accuracy, field-able PARC readout
- LG Chem Power expertise for EV-grade technology

Cell State Sensing with FO Sensors

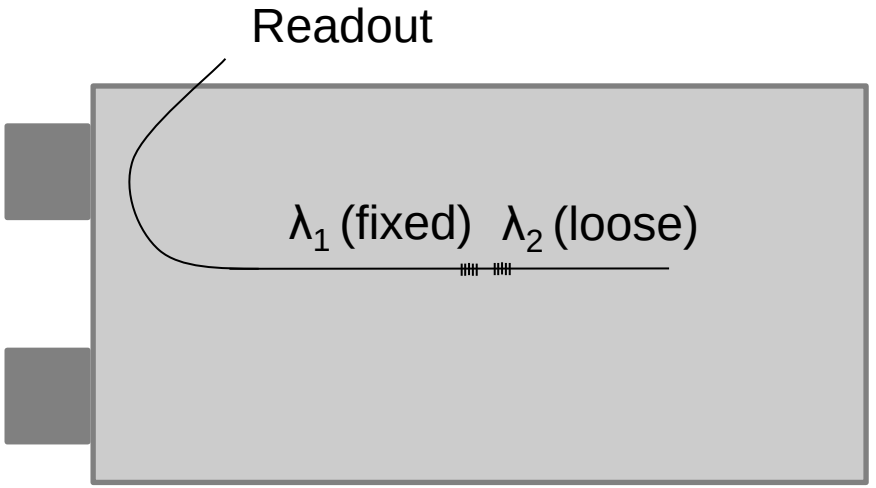
FO Sensor Example: Fiber Bragg Gratings (FBGs)

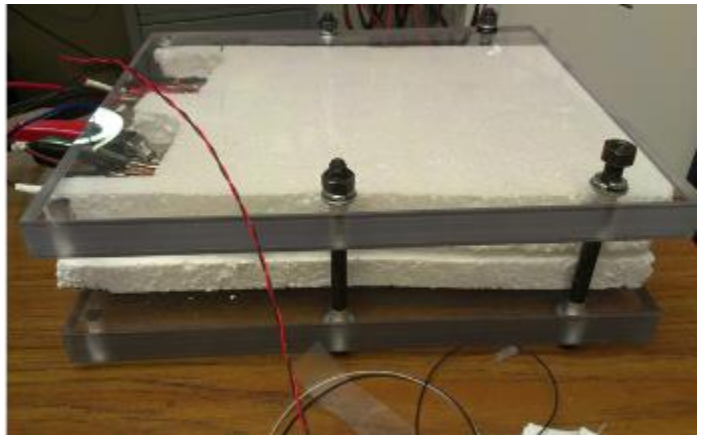




- Can be selectively sensitive to various stimuli:
  Strain, temperature, chemical conc., current, voltage
- Multiplex-able for multiple sensors on single FO
- Hair-thin, light-weight, EMI-free, robust

Early Study for External Strain, Temperature

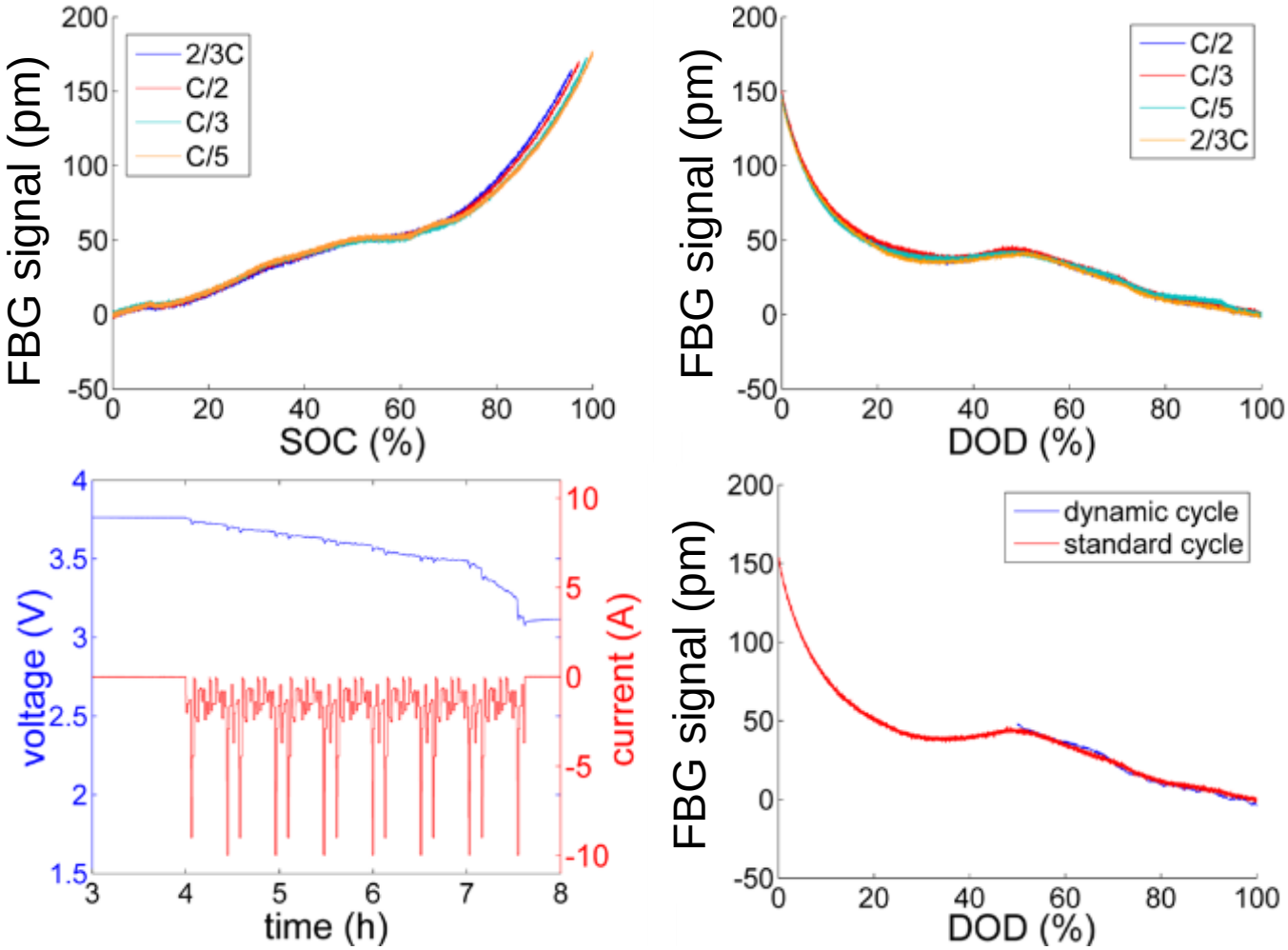




"Loose" external FBG picks temperature only

Cell-fin-cell setup mimics module pressure, cooling

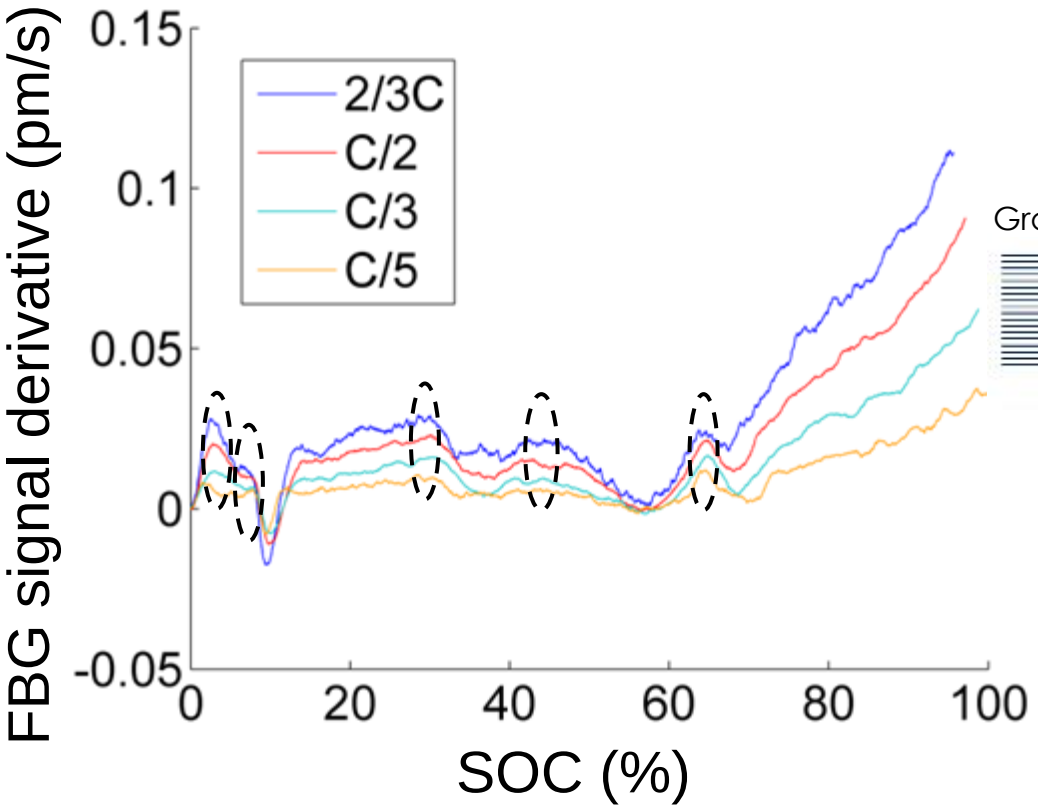
Mechanical Strain Across C Rates



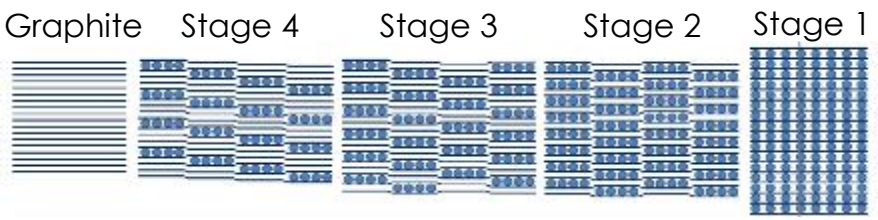
Curves very similar across C rates, incl. dynamic cycles

Accurate SOC algorithms trained on few static cycles

Intercalation Stages from FBG Strain Signal



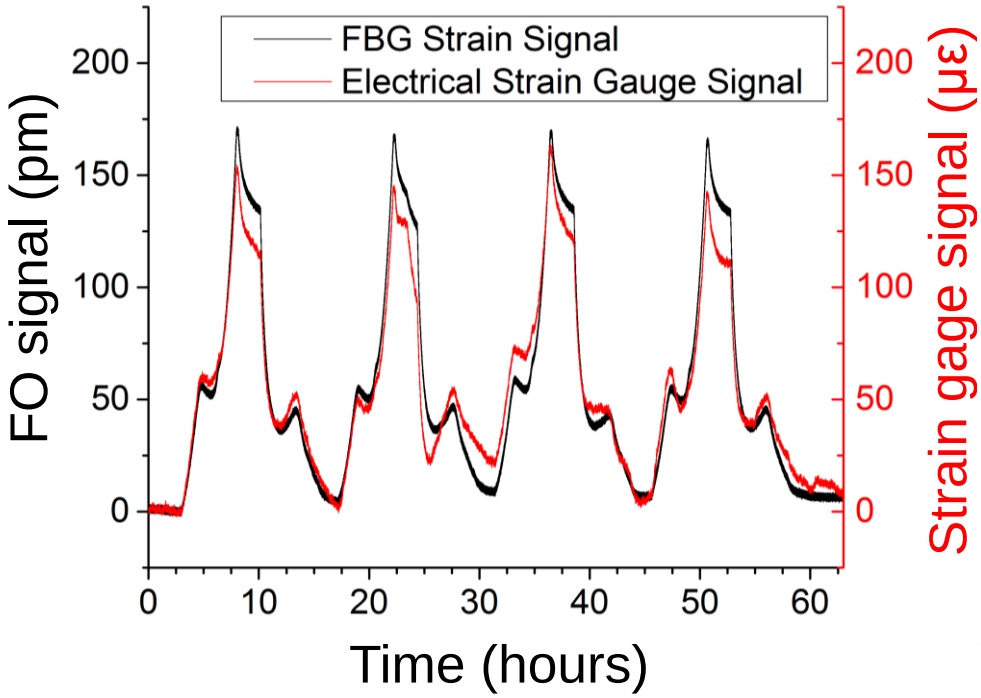
FBG derivative peaks ≡ intercalation stage transitions



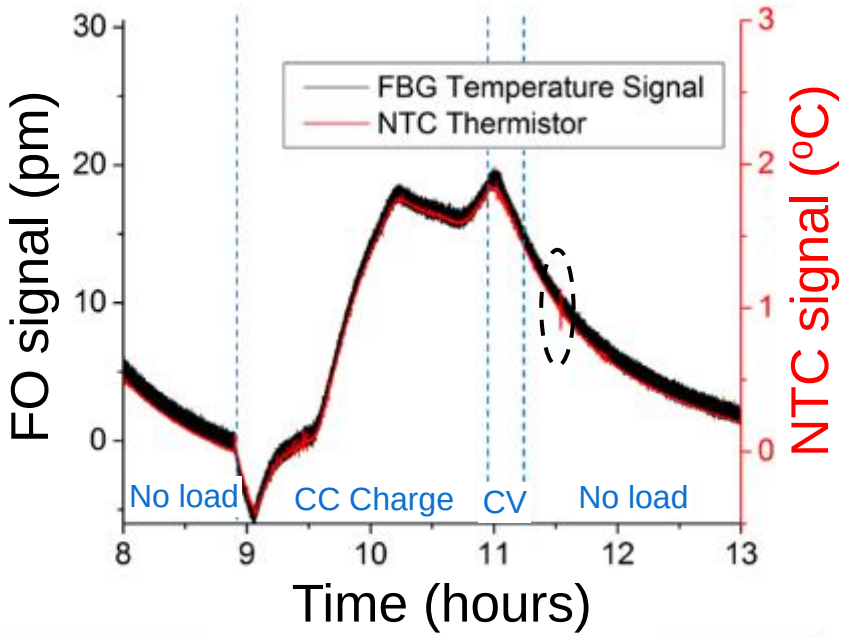
From Sethuraman 2010

- FBG derivative peaks match across C rates
- Useful for SOX estimation; stage shifts indicate aging
- Peaks of cell V signal derivative weaker, vary w/ C-rate

External FBG: Preliminary Comparison w/ Electrical Strain Gage, NTC Signals



FBG strain v/s electrical strain gage

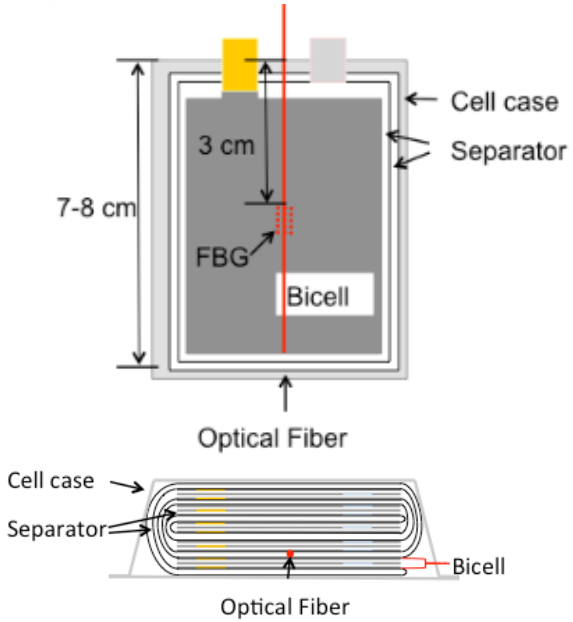


"Loose" FBG v/s NTC thermistor

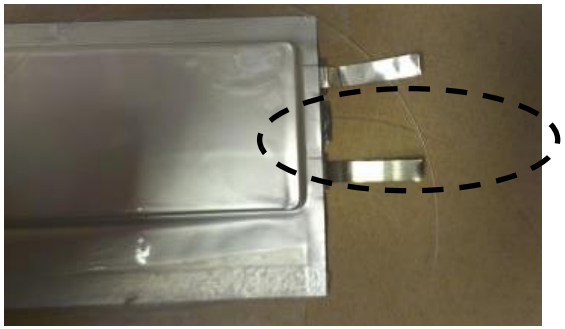
Electrical strain gage signals seem not as repeatable

NTC signal shows tendency to pick up EMI

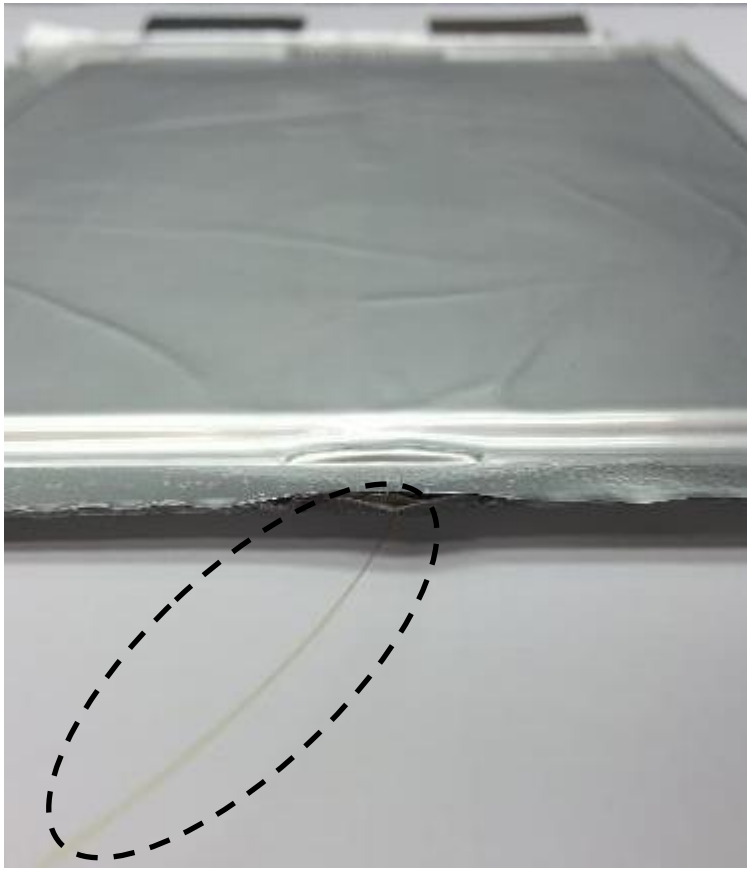
Pouch Cells w/ Internally Embedded FO



1.5 Ah small-format



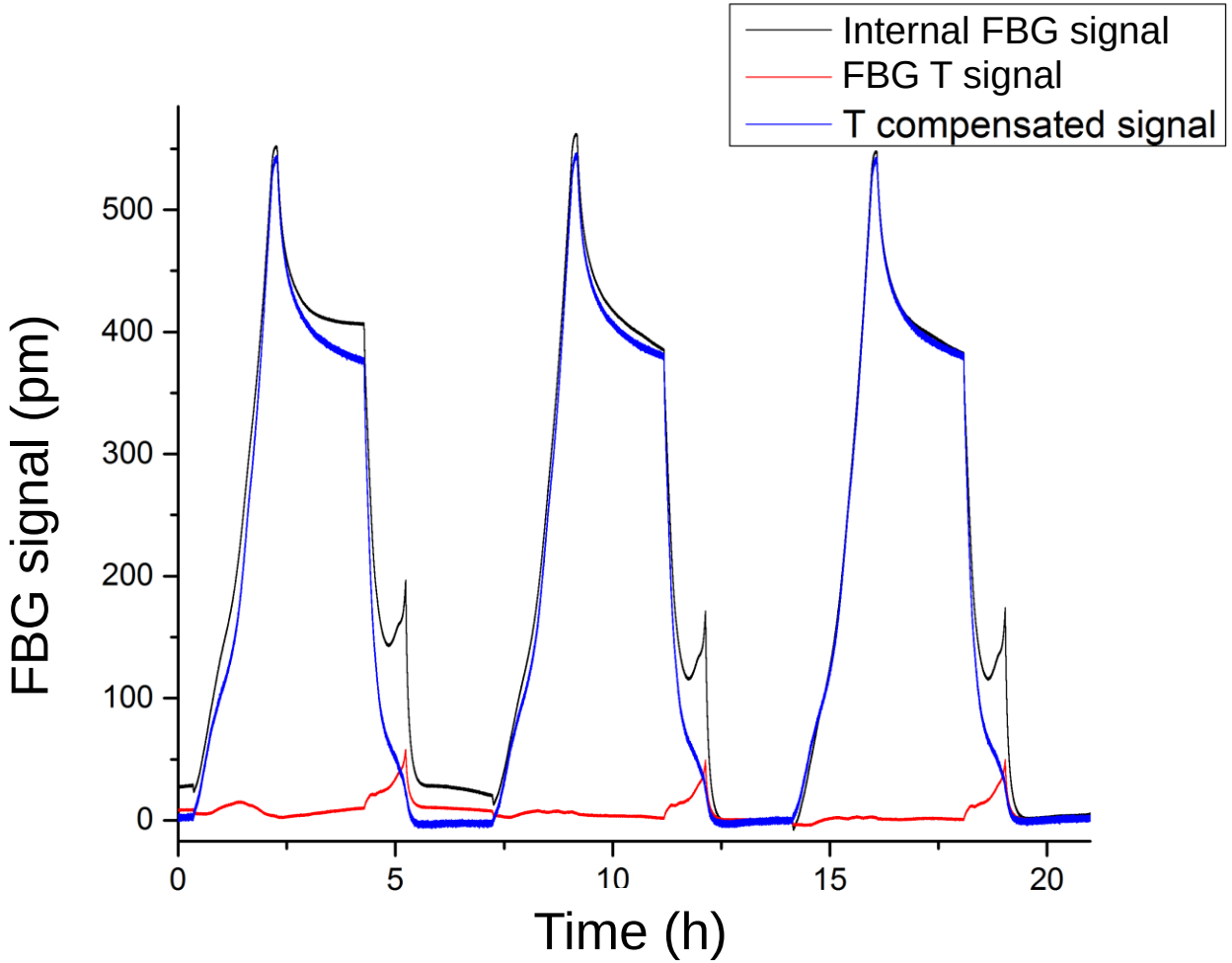
15 Ah large-format



Stable embedded config w/ FBGs bonded to electrode

Approach extended to large-format cells

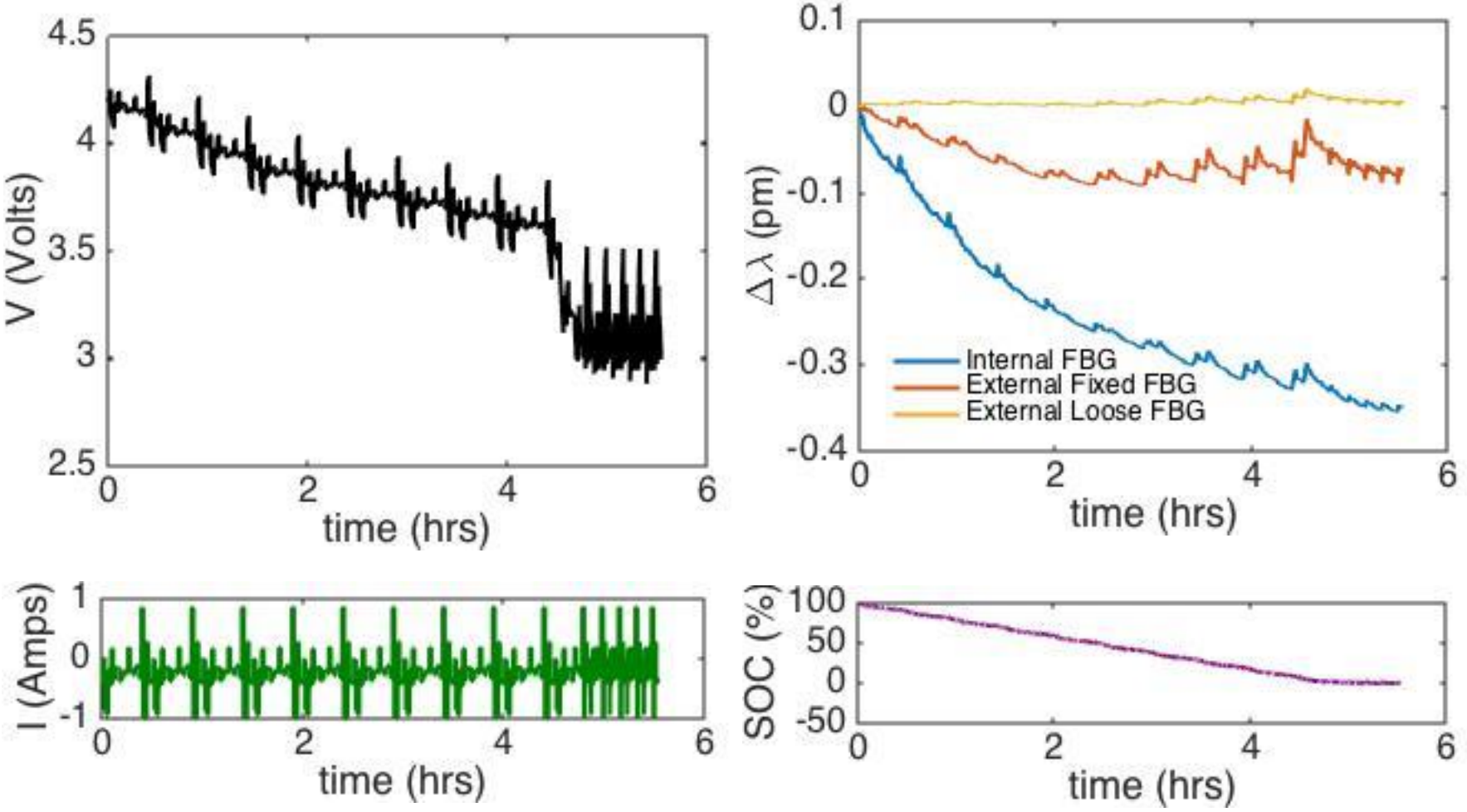
Internal Small-Format Cell FBG Signals



Internal signals 2-5x stronger than external, repeatable

Cell internal temp., other useful SOX features detectable

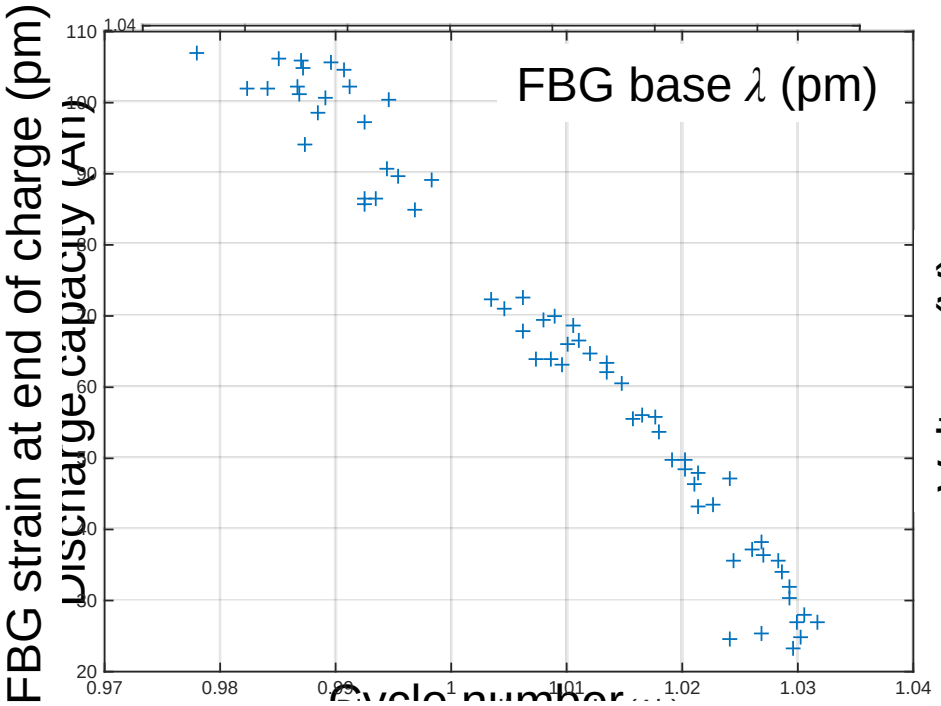
Internal FBG Robustness: Dynamic Cycles

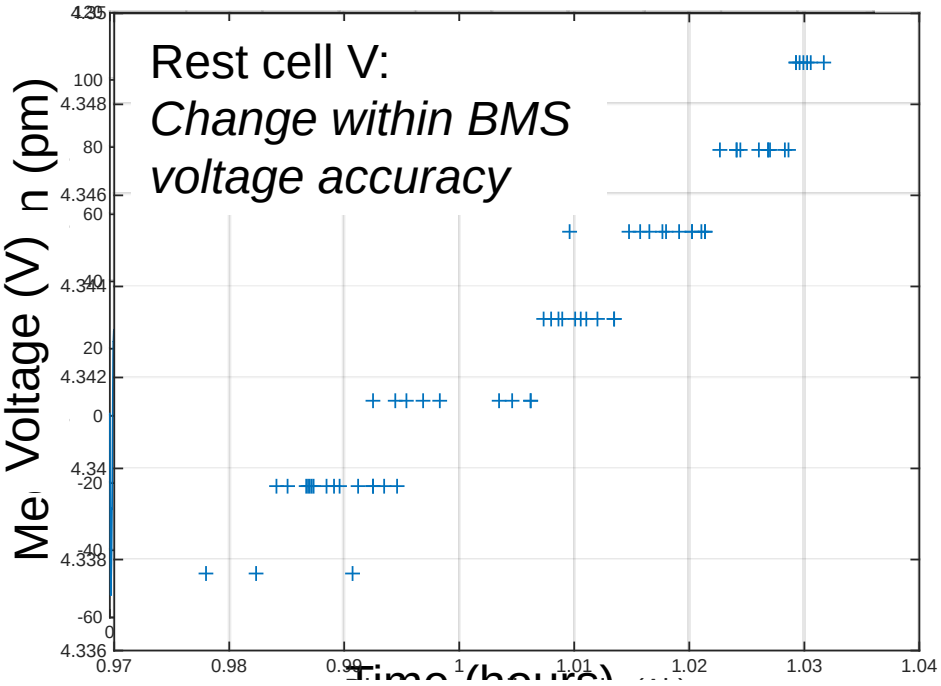


Internal more robust than external; both better than cell V

2.5% SOC or better achieved in dynamic cycles

SOH with Internal FBG Signals: Early Results





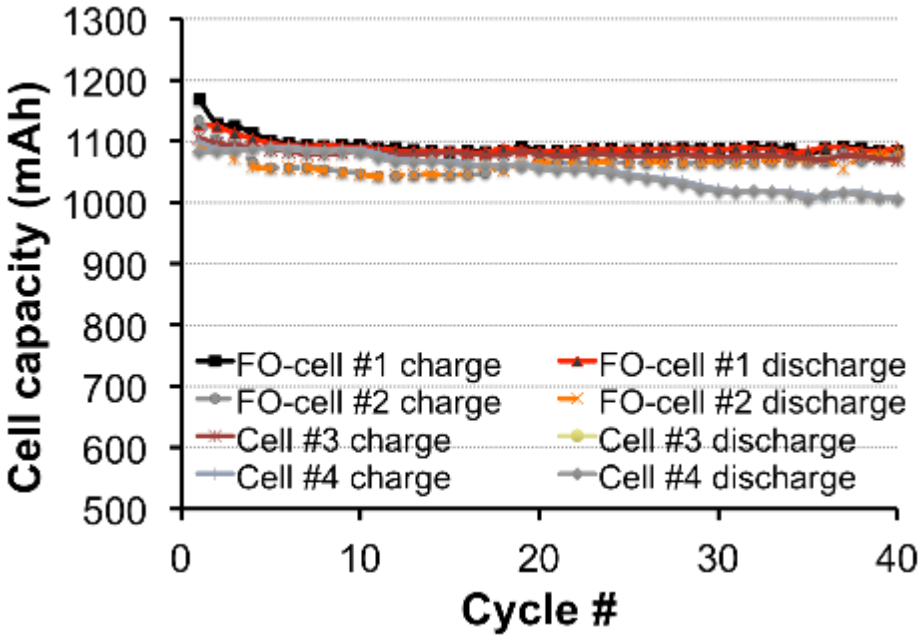
- Experimental chemistry: cell life ~100 cycles
- Steady increase in base FBG wavelength over life

10-cycle look-ahead capacity prediction error of <1.8%!

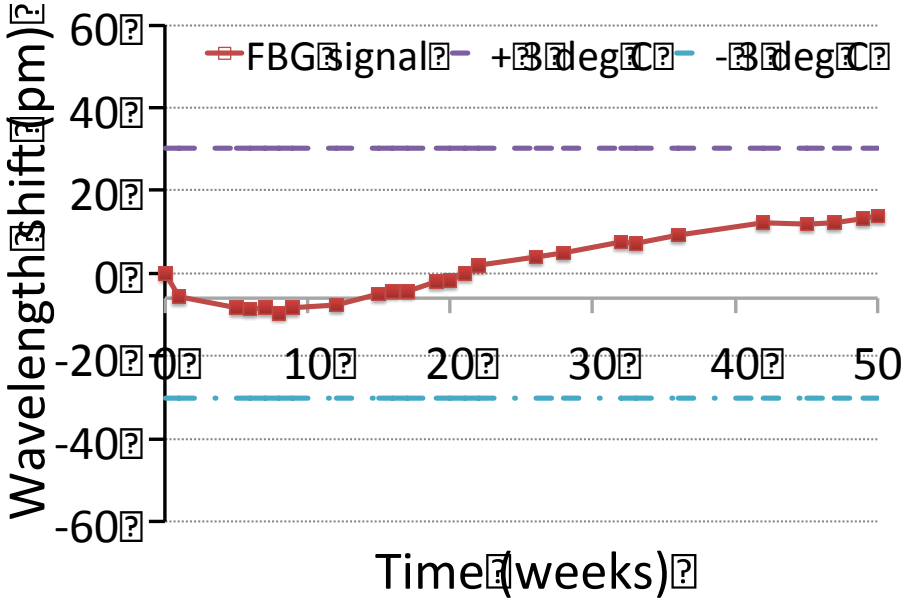
Also possible to detect subtle overcharge, failures

Results towards xEV Pack Field Deployment

Functional Cells w/ Embedded FO



Experimental cell capacity w/ cycling



Signal drift in long-term stability test

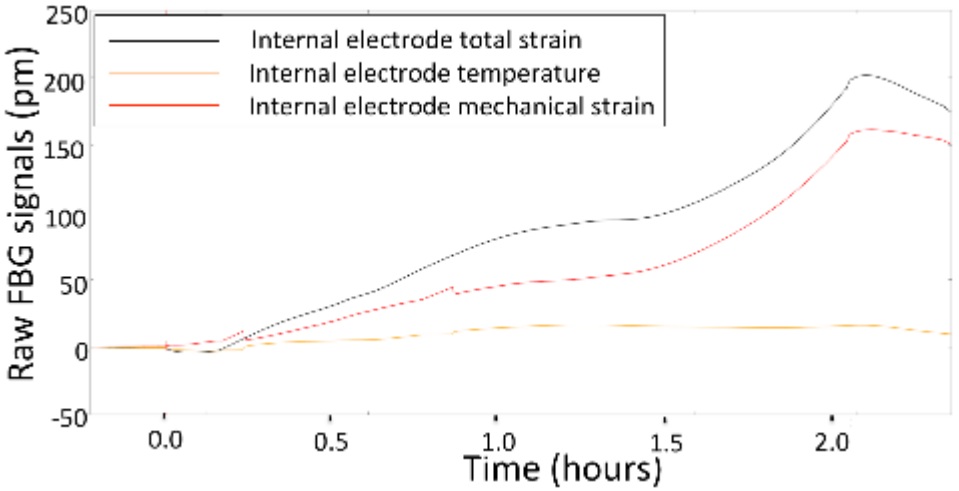
Cell performance unaffected by FO sensors (30+ cells)

FO sensors with certain coatings unaffected in electrolyte

PARC's Low-Cost Multiplexed FO Readout

Prototype size:
8" x 4.5" x 4"

Prod. size:
3.5" x 3" x 0.7"

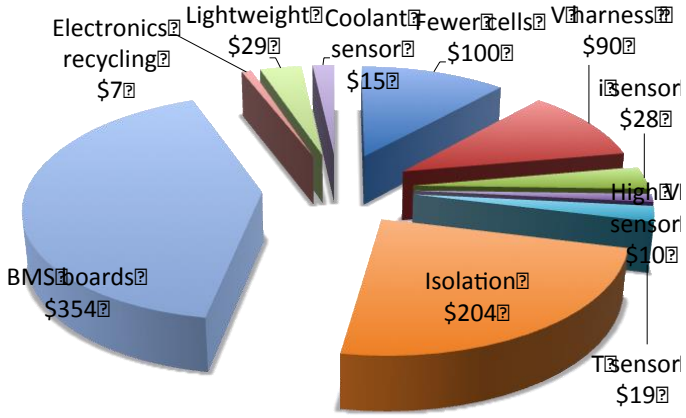


C/2 charge cell FBG signal w/ new readout

- *10 fm accuracy (*~0.01 με), up to 1000 channels
- 3-7% pack cost feasible for SENSOR system
- xEV vibration robustness demo'ed (200 fm or better)

SENSOR can replace BMS electrical sensing

Ext. v/s Int. FO Sensing Value: 2011 Volt



External FO 2011 Volt

1 of | | strings monitored

Savings: $856+ 8.3 lbs.

Cost: $294+ 0.2 lbs.

***Net*: $562 + 8.1 lbs.**

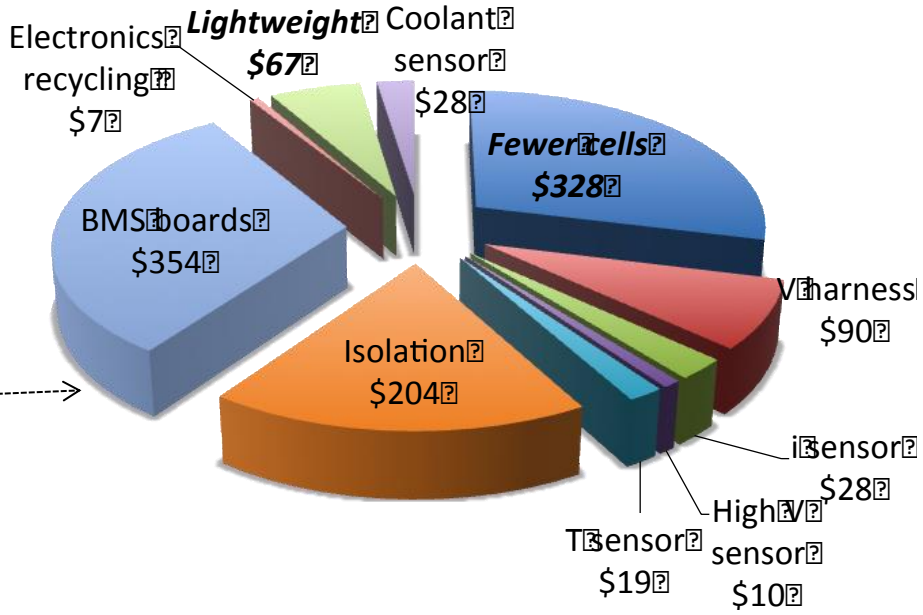
Internal FO 2011 Volt

All cells w/ embedded FO

Savings: $1134+ 19.2 lbs.

Cost: $333 + 0.2 lbs.

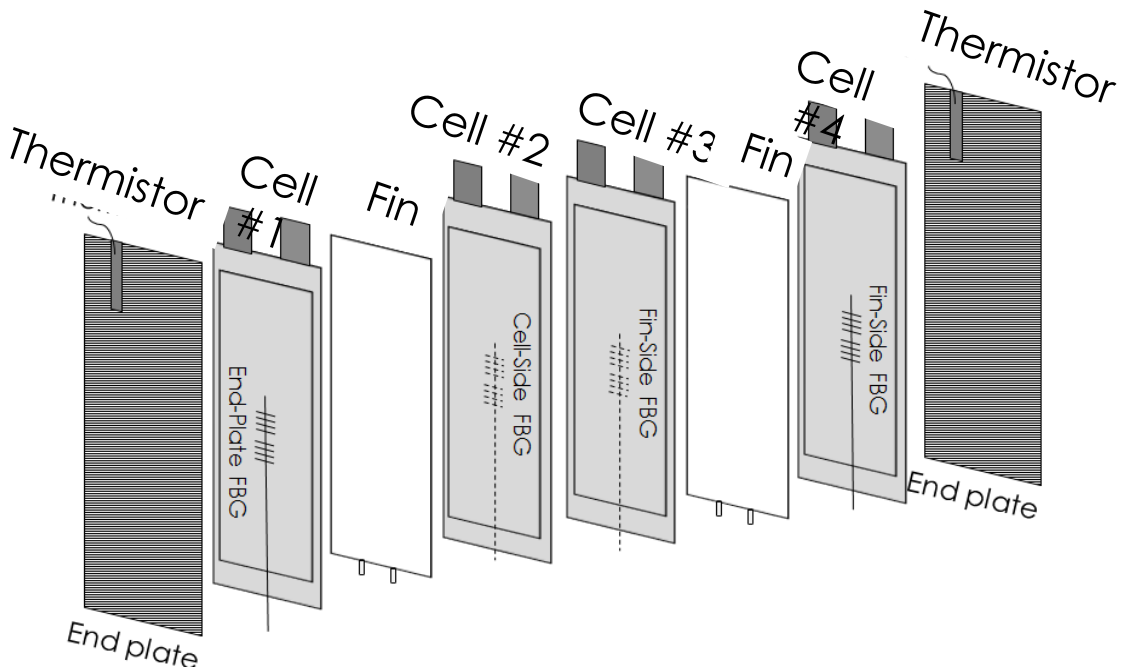
***Net*: $801 + 18.9 lbs.**

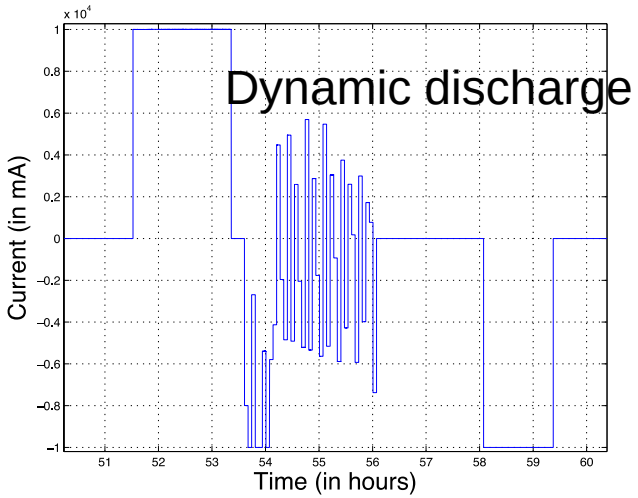


Costs comparable; internal can offer more oversizing trim

Low added $ for more sensors; more value w/ big packs

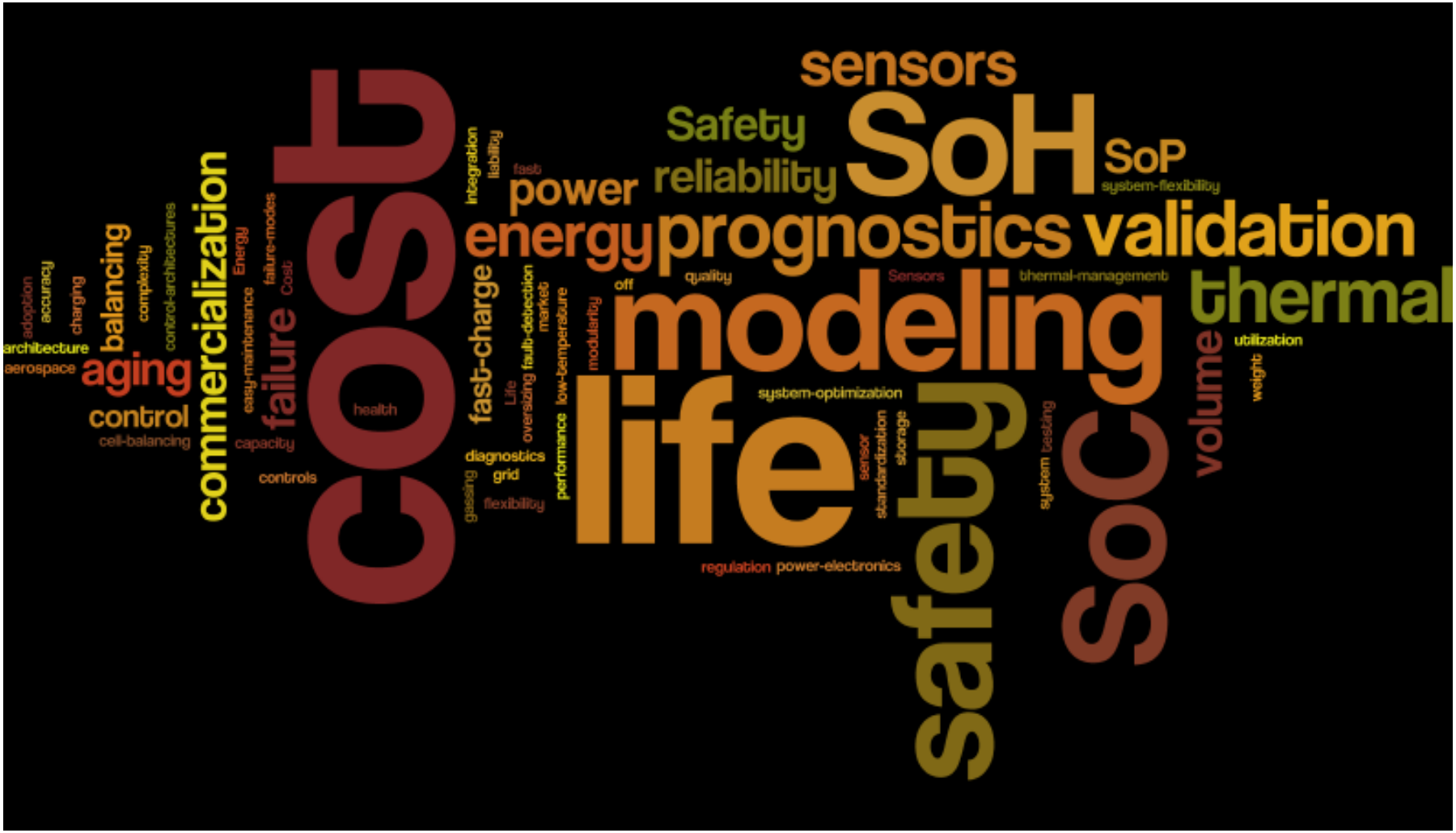
Ongoing Validation, Module-Level Tests





- Presently 4-cell module; larger module test w/ OEM
- Modest training, more testing: xEV dynamic, T-tests
- For internal FBGs: similar SOC tests, plus stress tests
- Also instrumenting in PARC e-Bike fleet Li-ion packs

AMPED Attendees' Pooled BMS Challenges

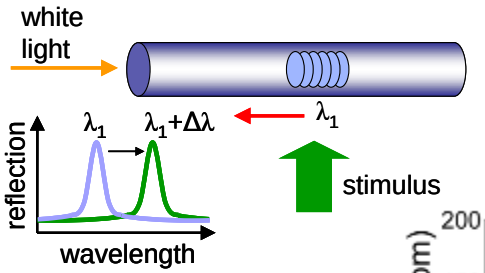


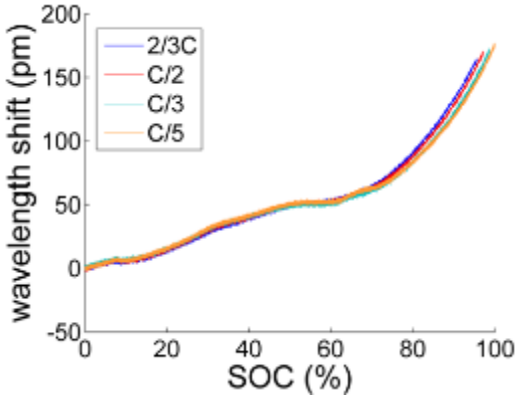
SENSOR project addresses 40% of attendee-BMS issues

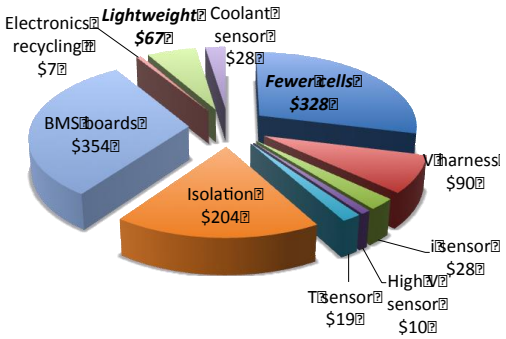
Summary and Concluding Remarks

Exciting results for BMS sensing, cell state challenges:

- FO new BMS sensing mode for cell state, aging
- Promising cell-level results: 2.5% accurate SOX
- Shown path to field deployment with PARC readout
- Cost-perf. model indicates pack trim w/ simpler BMS







In OEM discussions for further validation, tech transfer