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Insplorion

Investigating plasmonic based fibre optic sensing as an in-situ battery diagnostic method

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Coventry University- C.ALPS
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Industrial partner: Elin Langhammer- Insplorion

Project partners

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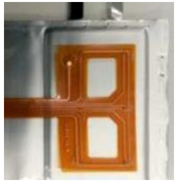
CENTRE FOR ADVANCED LOW-CARBON PROPULSION SYSTEMS

Insplorion

Li-ion Batteries

Cell testing

Diagnostic sensors



Supercaps

Power Electronics
E- Machines

Hydrogen

Air Quality

Hydrogen

Battery sensors

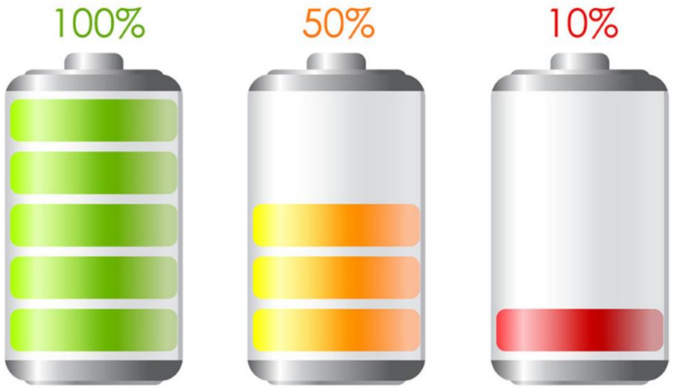
Research Instruments

Image credit: T. Amietszajew, J. Fleming, A.J. Roberts, W.D. Widanage, D. Greenwood, M.D.R. Kok, M. Pham, D.J.L. Brett, P.R. Shearing, R. Bhagat, Hybrid Thermo-Electrochemical In Situ Instrumentation for Lithium-Ion Energy Storage and Insplorion AB.

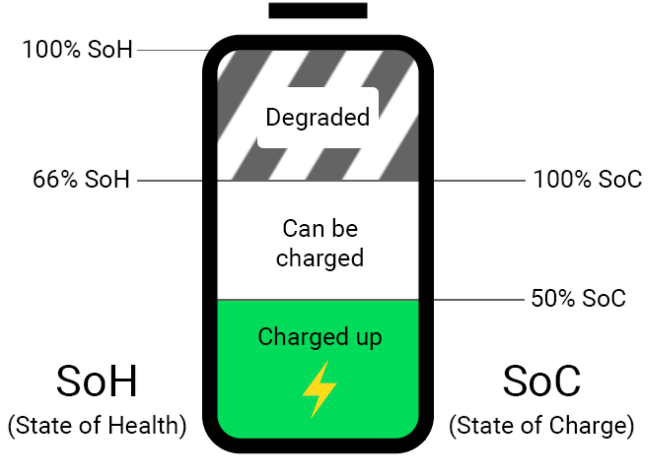
Battery cell diagnostics

Battery diagnostics is the measurement of the state of the battery.

State of Charge (SOC)



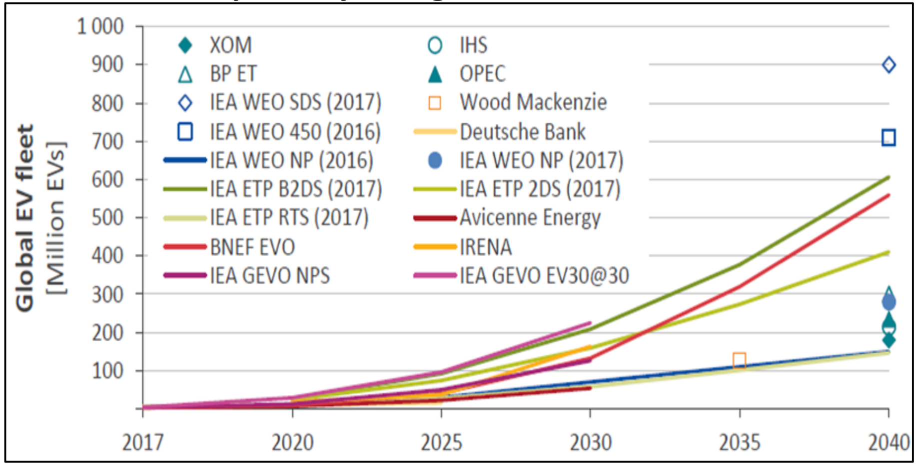
State of Health (SOH)



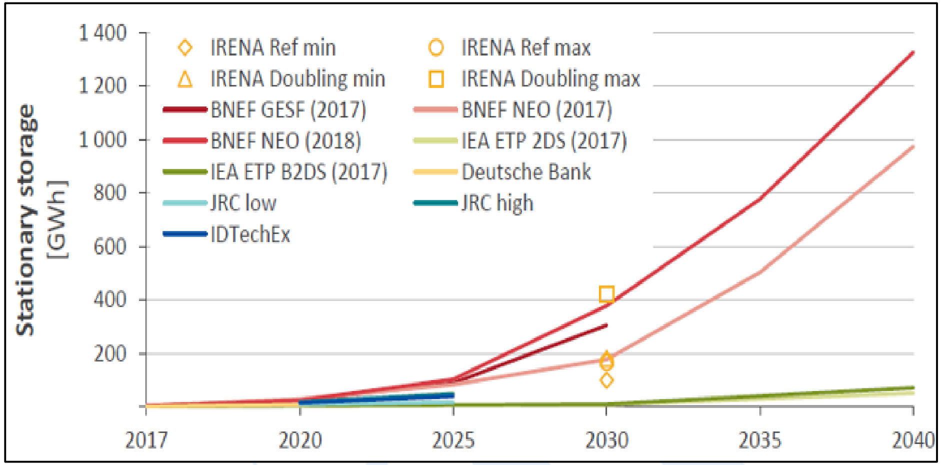
Other properties that can be measured include temperature and failure modes such as internal lithium plating.

Growing lithium-ion battery market

<u>Automotive</u>- 55% of li-ion power production in 2020, possibly as high as 90% in 2030



<u>Stationary energy storage-</u> grids/ micro-grids etc.



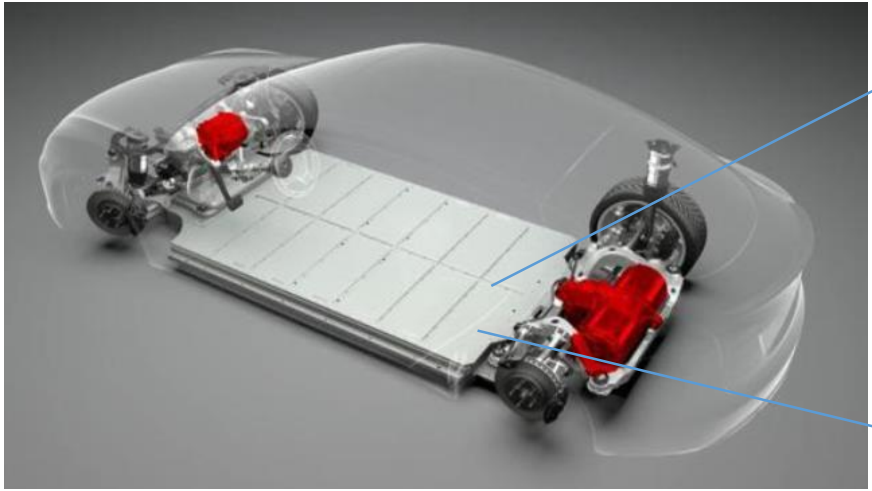
<u>PED's</u>- laptops, cameras, mobiles, dominated by li-ion cells, 100's of millions of devices annually

Other applications include Aerospace and Space

Li-ion battery power production was 22 GWh/y in 2010, 125 GWh/y in 2020 and could be 390 GWh/y in 2030

G. Zubi, R. Dufo-López, M. Carvalho, G. Pasaoglu, The lithium-ion battery: State of the art and future perspectives, Renew. Sustain. Energy Rev. 89 (2018).
I. Tsiropoulos, D. Tarvydas, N. Lebedeva, Li-ion batteries for mobility and stationary storage applications, 2018.

Potential benefits of improved diagnostics



Battery pack cost
Battery pack market average cost $137/kWh

Tesla model Y 75KWh dual motor starts at $42000

Battery pack cost estimate of $10275, approx. 25%

Battery size and weight

Reducing cost, weight and size without reducing performance is key for business case and adoption.

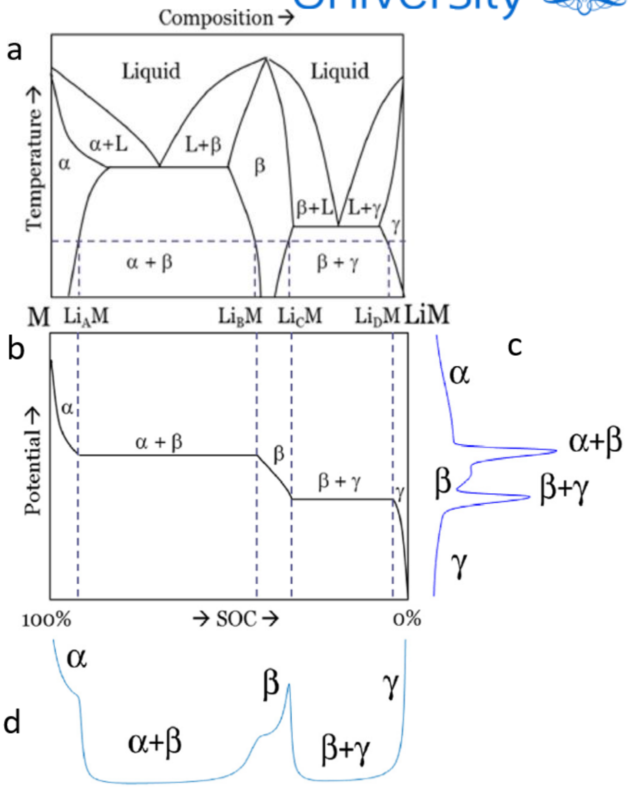
Superior diagnostic methods could facilitate more optimally sized and utilised batteries.

Enhanced safety and supporting second life and swapping applications also possible.

Image credits: Tesla

Existing measurement techniques

- Existing typical real time measurement techniques take external cell measurements
- Coulomb counting most common, OCV and EVS are other methods.
- Coulomb counting techniques develop SOC errors of at least a few percent.
- Inaccuracies such as measurement, processing efficiency etc., plus grow over time due to open loop nature.
- OCV and EVS measurements tend to be qualitative in the information they provide



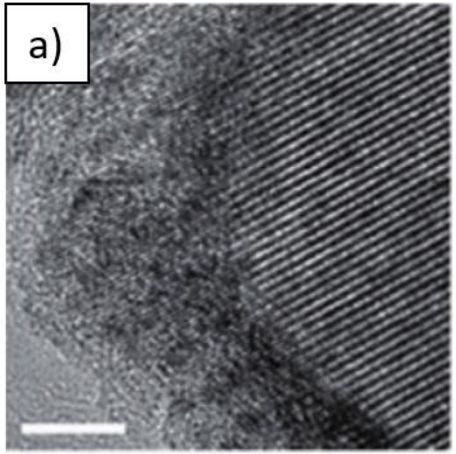
Relationship between a) phase diagram of material 'M' being lithiated, b) voltage curve, c) IC and d) DV

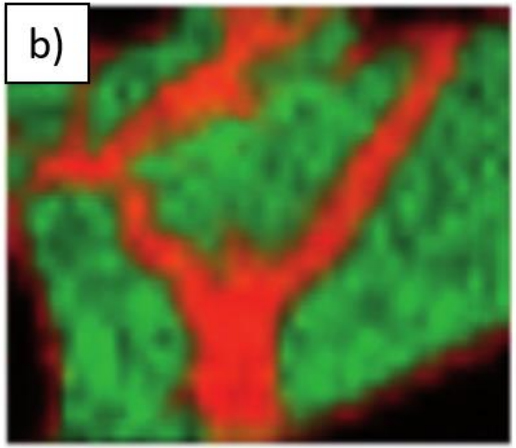
A. Barai, K. Uddin, M. Dubarry, L. Somerville, A. McGordon, P. Jennings, I. Bloom, A comparison of methodologies for the non-invasive characterisation of commercial Li-ion cells; K.S. Ng, C.-S. Moo, Y.-P. Chen, Y.-C. Hsieh, Enhanced coulomb counting method for estimating state-of-charge and state-of-health of lithium-ion batteries, Appl. Energy. 86 (2009); A. Vezzini, Lithium-Ion Battery Management, in: Lithium-Ion Batter. Adv. Appl., Elsevier B.V., 2014; K. Movassagh, A. Raihan, B. Balasingam, K. Pattipati, A Critical Look at Coulomb Counting Approach for State of Charge Estimation in Batteries, Energies. 14 (2021)

Laboratory based techniques

Generally require modified cells and/ or extensive equipment.

Examples include; Scanning electron microscopy, X-ray microanalysis, scanning ion conductance, transmission electron microscopy and a variety of destructive testing.



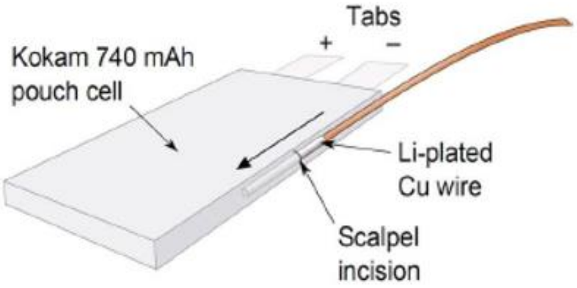


a) High resolution TEM images of an Fe_3O_4 single crystal showing the spinel and rock-salt phases during in situ Li intercalation, b) High resolution TEM electron energy loss spectra mapping of Ni^{2+}(green) and Li^{+} + Ni^{0}(red) in a lithiated NiO nanosheet at high-rate discharge

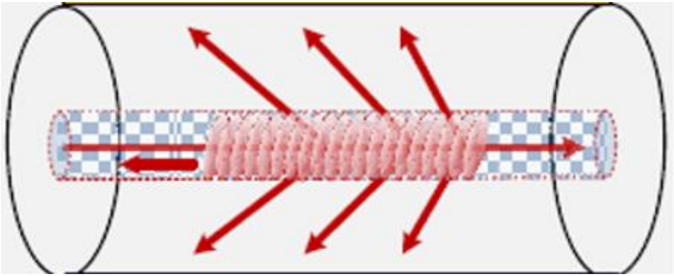
T. Shang, Y. Wen, D. Xiao, L. Gu, Y.-S. Hu, H. Li, Atomic-Scale Monitoring of Electrode Materials in Lithium-Ion Batteries using In Situ Transmission Electron Microscopy

Existing in-situ techniques- in development

Reference electrodes- difficult to place in production cell but has been done, separates anode/ cathode voltages.

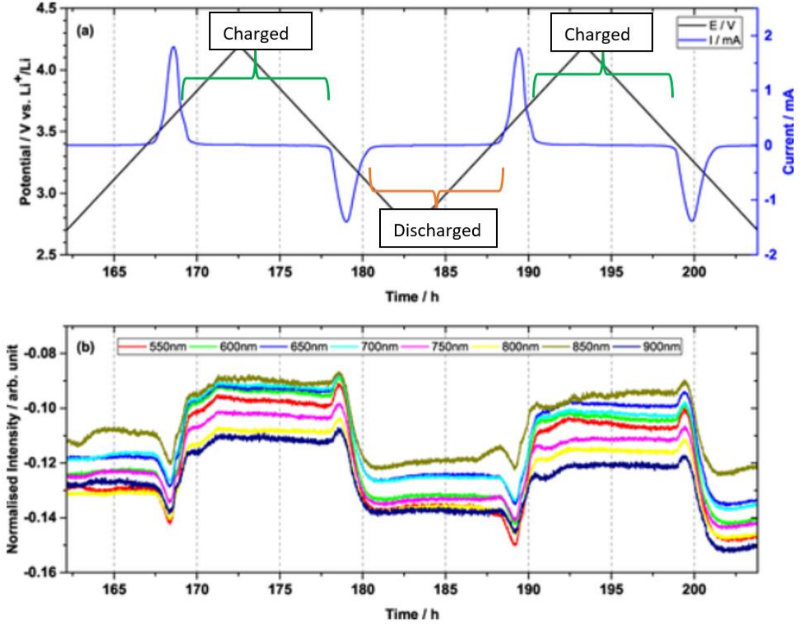


TFBG, thermistors- utilised to measure temperature and strain. Potential relationship between strain and SOC.



Colorimetry corresponding with SOC.

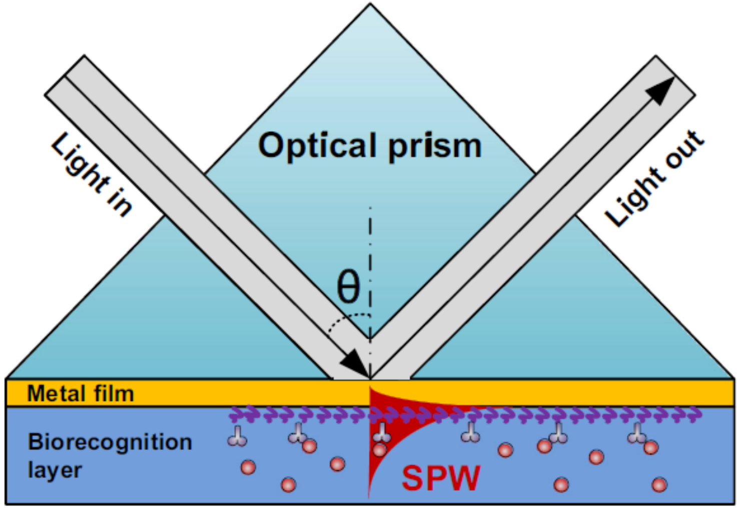
ATR with fibres has been utilised, with interesting results and correlation but limited accuracy so far.

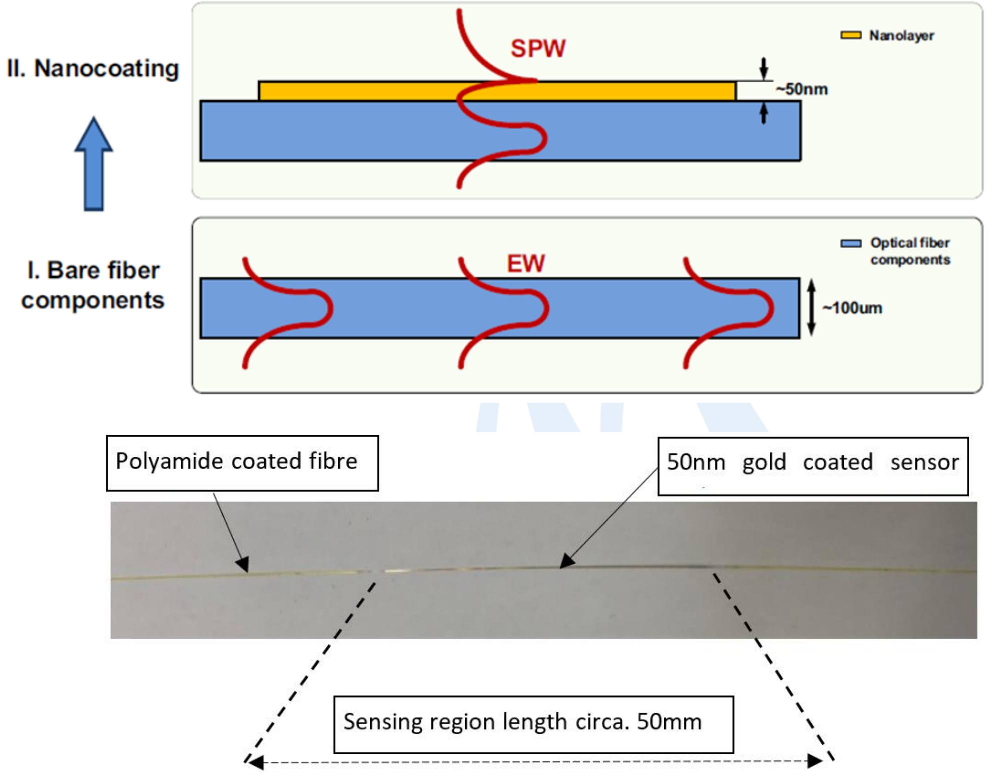


Cyclic voltammetry profile and corresponding ATR response

E. McTurk, C.R. Birkl, M.R. Roberts, D.A. Howey, P.G. Bruce, Minimally invasive insertion of reference electrodes into commercial lithium-ion pouch cells
J. Hedman, D. Nilebo, E. Larsson Langhammer, F. Björefors, Fibre Optic Sensor for Characterisation of Lithium-Ion Batteries

Sensing technology being utilised





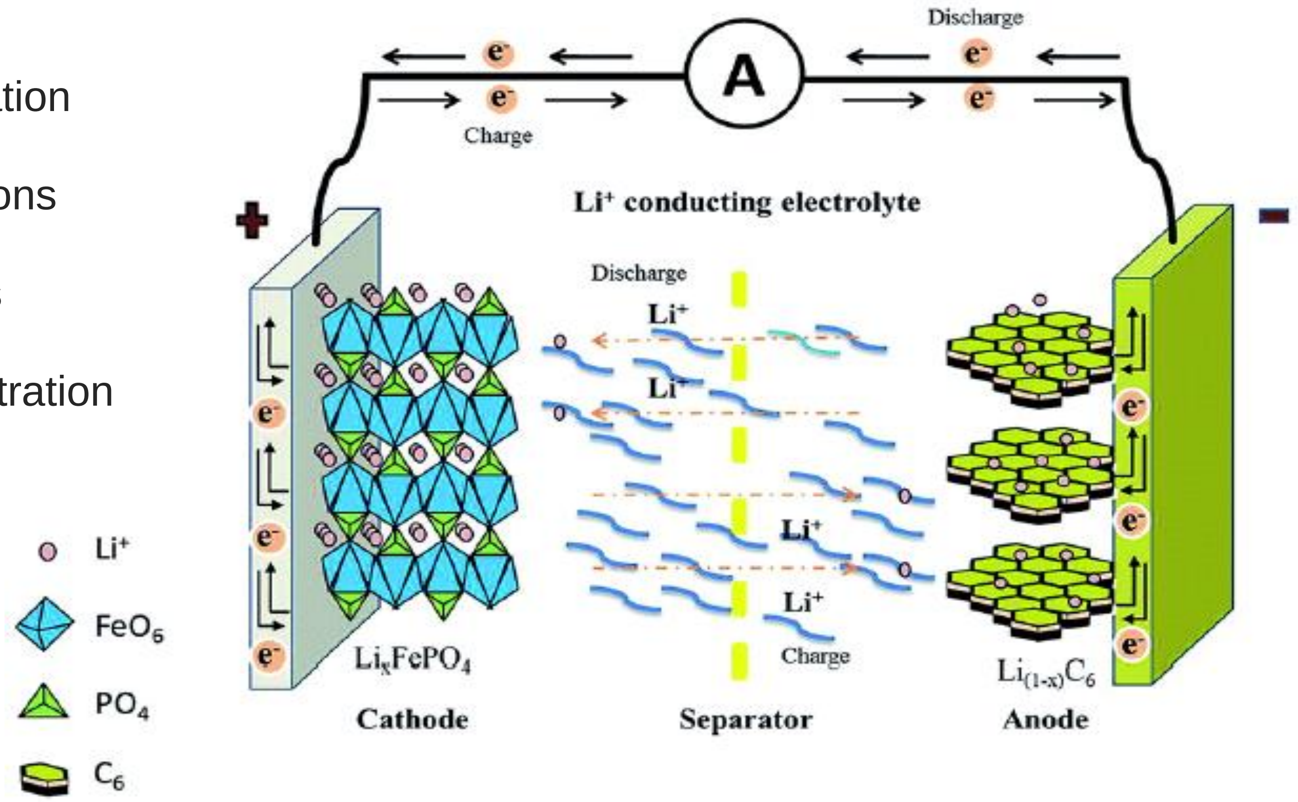
A typical configuration for inducing SPPs- called a Kretschmann-Raether configuration.

A thin metal film, such as gold, is deposited on an optical prism.

C. Caucheteur, T. Guo, J. Albert, Review of plasmonic fiber optic biochemical sensors: improving the limit of detection

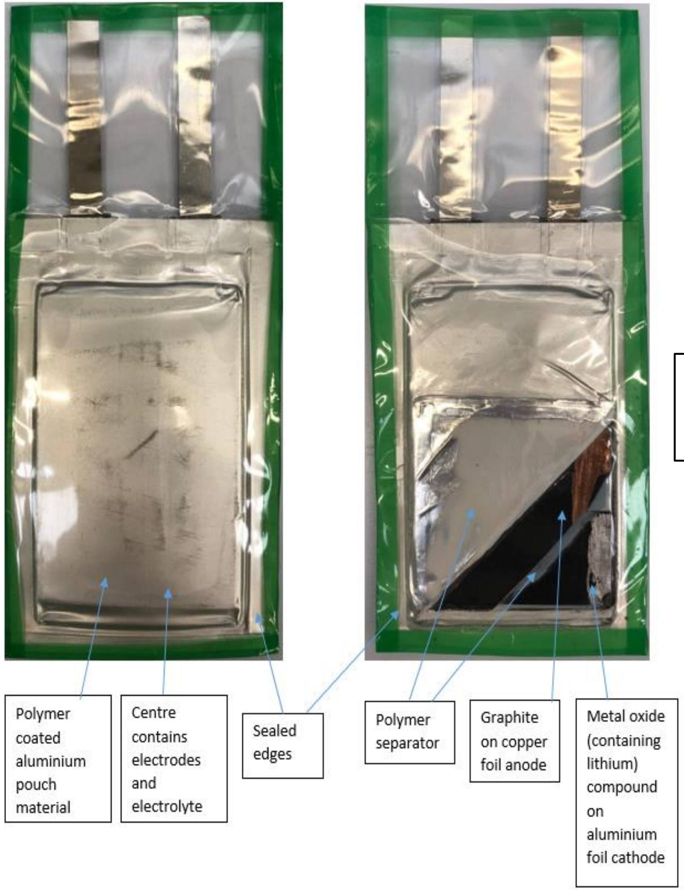
Internal cell phenomena

- SEI layer formation
- Parasitic reactions
- Phase changes
- Lithium concentration



Reference: H. Lee, M. Yanilmaz, O. Toprakci, K. Fu, X. Zhang, A review of recent developments in membrane separators for rechargeable lithium-ion batteries

Cell design- pouch cell



1.4Ah li-ion pouch cell

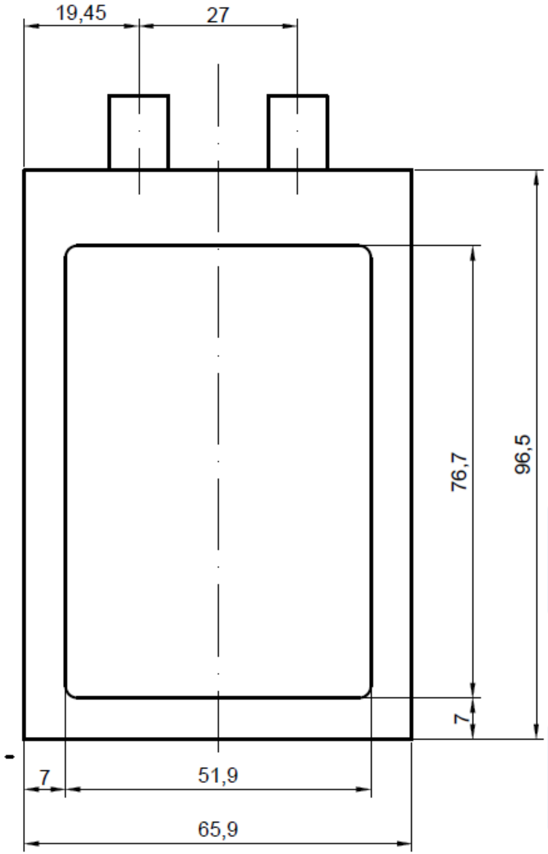
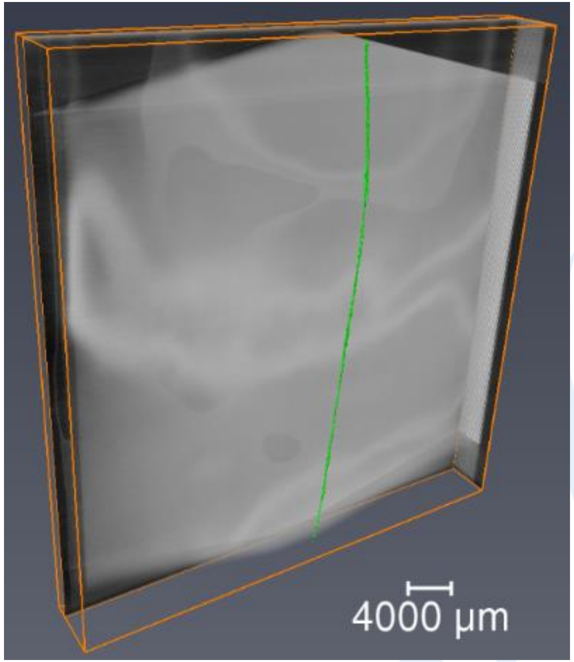
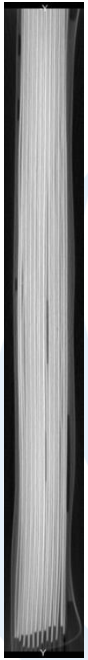


Image credits: Coventry University

Cell design- sensor placement





X-Ray of fibre sensor in cell- side profile 5mm width

Sensor placed adjacent to an anode in cell.

Image credits: Coventry University

Cell and Optics Unit (OU) system schematic

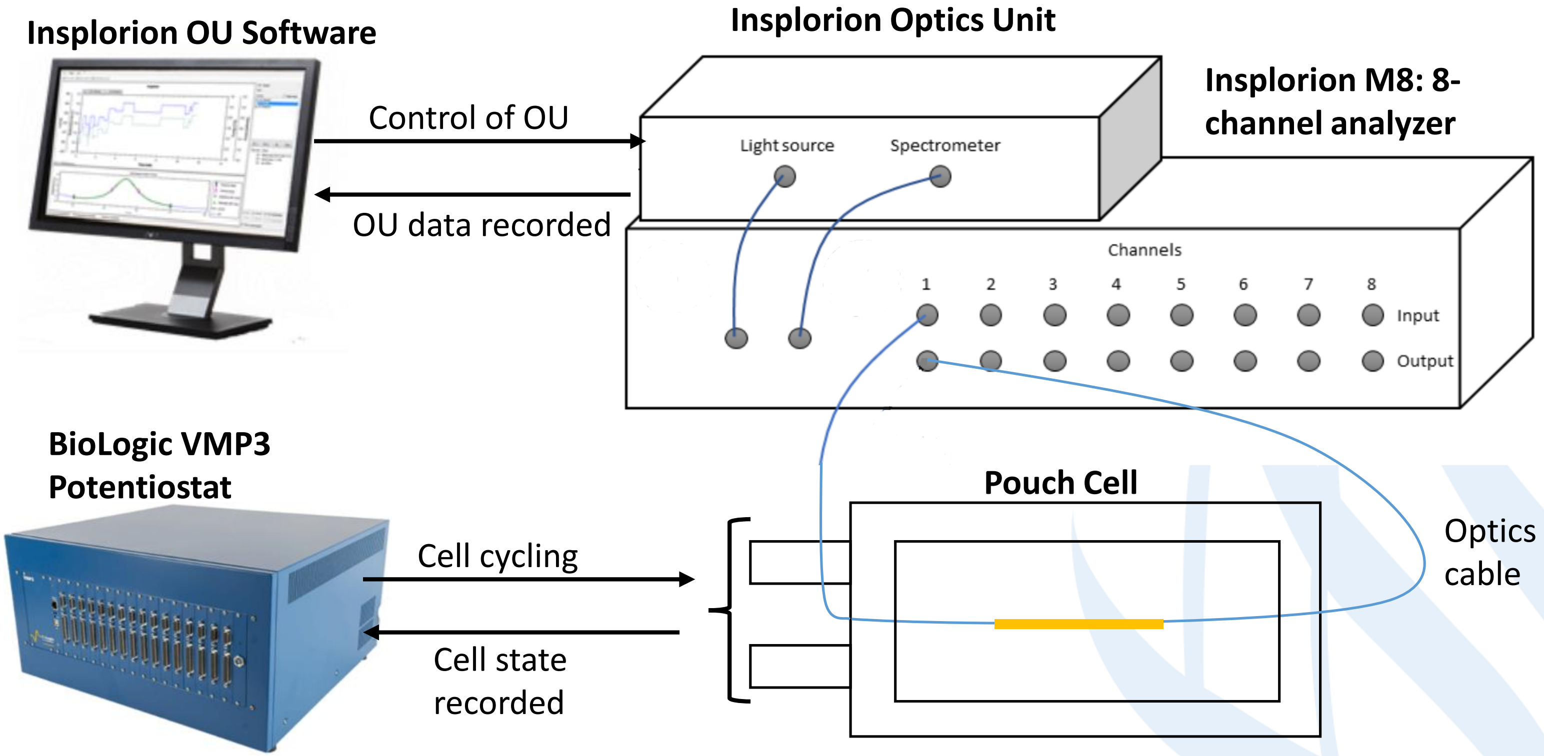
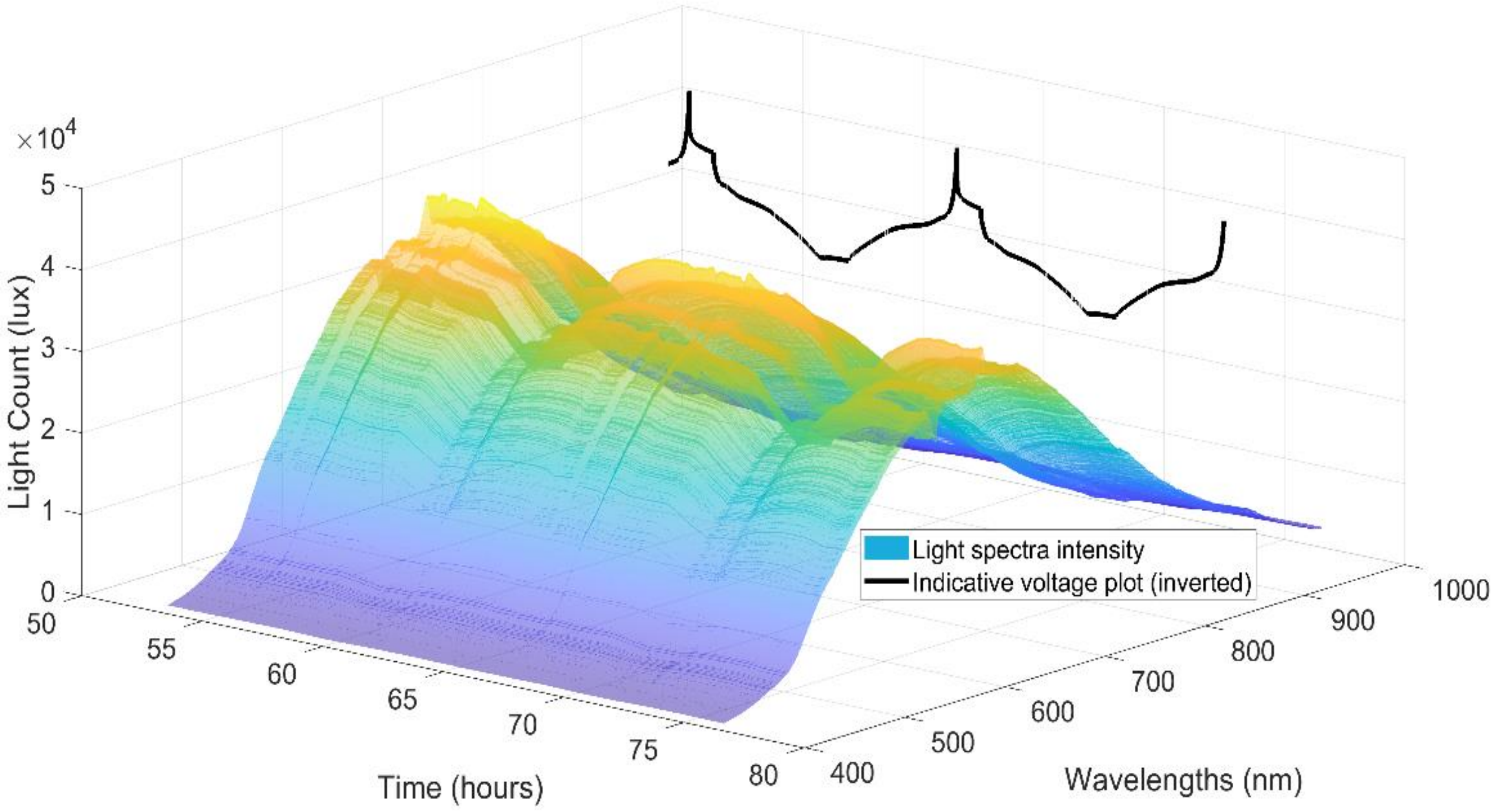


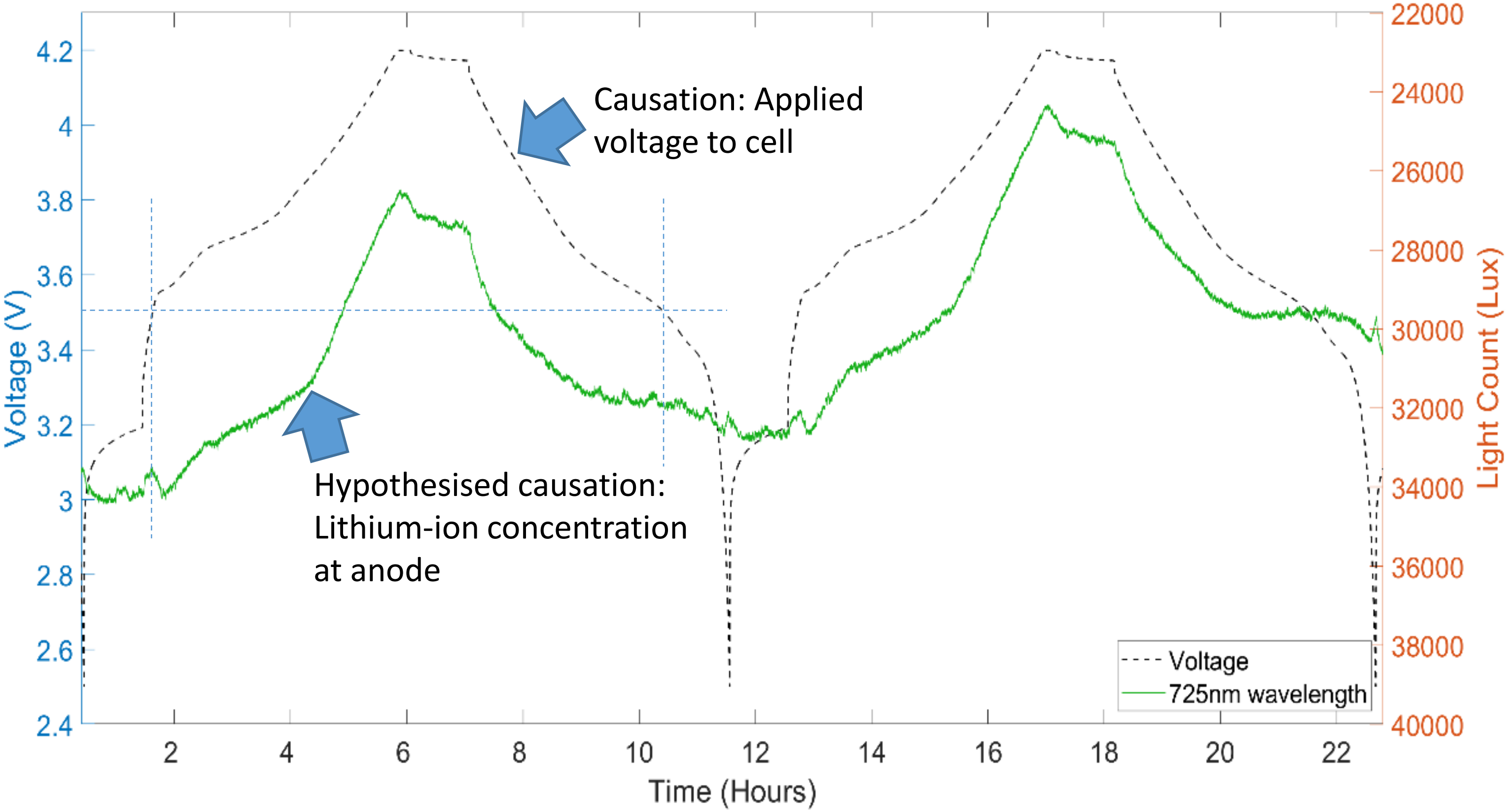
Image credits: C. Sundvall, E. Langhammer, I. Löfgren, A. Holmer, D. Westerlund, Operando Nanoplasmonic sensing – a means of improving battery control – WP2 Report- ACES Project, 2021

Optical signal response to cell state



C. Gardner, E. Langhammer, W. Du, D.J.L. Brett, P.R. Shearing, A.J. Roberts, T. Amietszajew, In-Situ Li-Ion Pouch Cell Diagnostics Utilising Plasmonic Based Optical Fibre Sensors, Sensors. 22 (2022)

OU signal and cell state correlation- C/5



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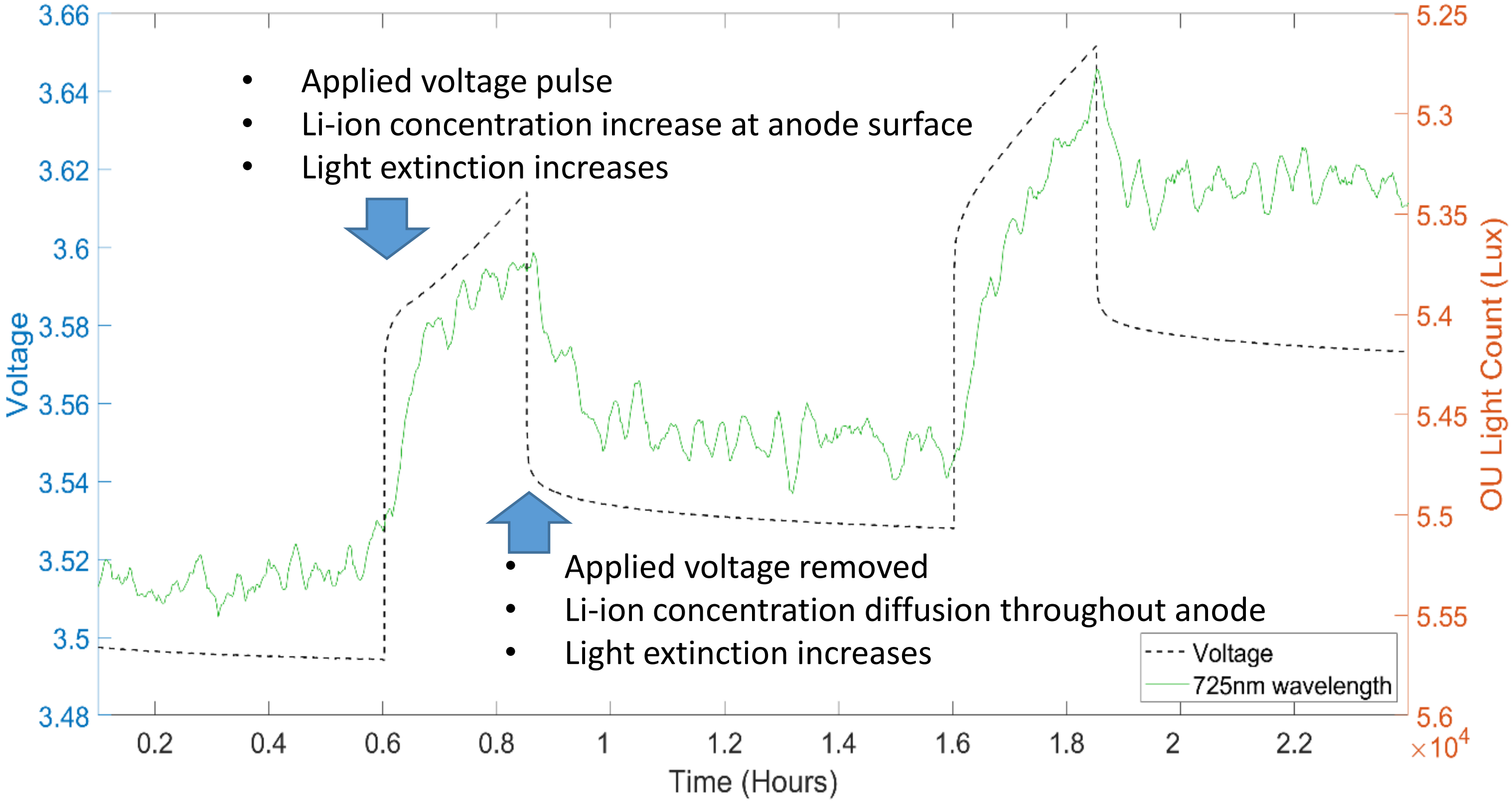
GITT test



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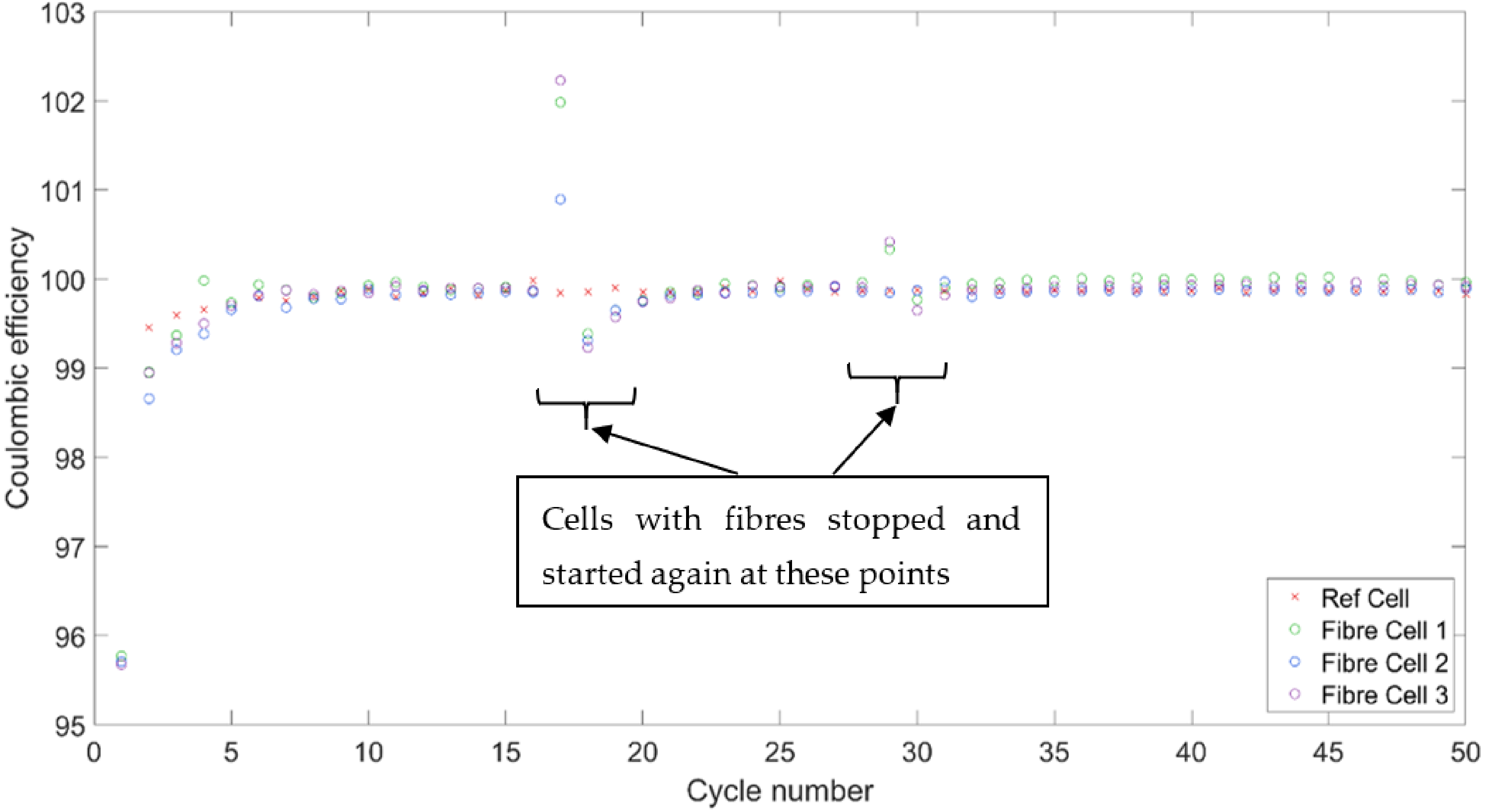
Negligible impact on cell performance- C/5



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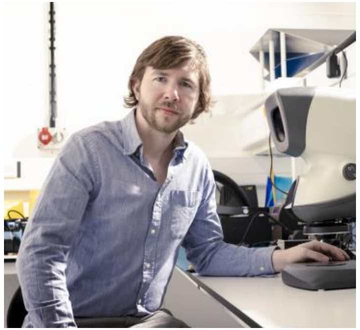
Potential benefits

- Measuring chemical changes and/ or lithium-ion concentration offers a variety of possibilities.
- Enabling an unprecedented view into internal cell phenomena.
- Superior in-situ diagnostics could enable better optimisation of battery use and size.
- Could be used to recalibrate ‘open loop’ sensing methods.
- Detect failure modes like lithium plating or overheating in real time
- Providing battery state of health information- could be useful when re-purposing EV batteries for energy storage, or help to enable ‘battery swapping’.

Thank you for listening; any questions?

Contact details:



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Article

In-Situ Li-Ion Pouch Cell Diagnostics Utilising Plasmonic Based Optical Fibre Sensors

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Abstract: As the drive to improve the cost, performance characteristics and safety of lithium-ion batteries increases with adoption, one area where significant value could be added is that of battery diagnostics. This paper documents an investigation into the use of plasmonic-based optical fibre sensors, inserted internally into 1.4 Ah lithium-ion pouch cells, as a real time and in-situ diagnostic technique. The successful implementation of the fibres inside pouch cells is detailed and promising correlation with battery state is reported, while having negligible impact on cell performance in terms of capacity and columbic efficiency. The testing carried out includes standard cycling and galvanostatic intermittent titration technique (GITT) tests, and the use of a reference electrode to correlate with the anode and cathode readings separately. Further observations are made around the sensor and analyte interaction mechanisms, robustness of sensors and suggested further developments. These finding show that a plasmonic-based optical fibre sensor may have potential as an opto-electrochemical diagnostic technique for lithium-ion batteries, offering an unprecedented view into internal cell phenomena.

check for updates

Citation: Gardner, C.; Langhammer, E.; Du, W.; Brett, D.J.L.; Shearing, P.R.; Roberts, A.J.; Amietszajew, T. In-Situ Li-Ion Pouch Cell Diagnostics