Toward Longer Life, High Energy Li-S Batteries

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Beyond Lithium-Ion, Nice
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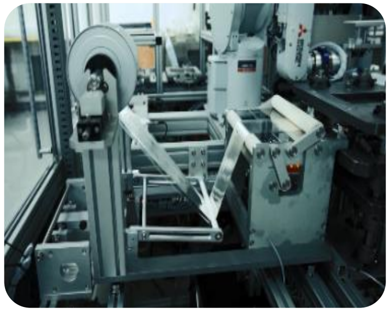
OXIS ENERGY
Next Generation Battery Technology

Introduction

OXIS Energy Introduction

- More than 10 years of research and a total investment of **US$78 million** in **Li-S technology**.
- Based at the Culham Science Centre near Oxford with one of the largest high specification dry room facilities in Europe.
- Currently has over 70 employees (21 R&D scientists, 17 PhDs)
- OXIS has succeeded in establishing partnerships with leading multinational companies and academic institutions, including:
  - **Sasol** (Petrochemicals giant, South Africa), **Umicore** (Large cathode materials producer, Belgium), **Samsung** (Electronics and consumer goods, South Korea), **Confrapar** (Aerotec Fund, Brazil)
- Strong Patent portfolio: 141 granted, 107 pending, 39 families

Electrode Structure – Electrolyte composition – Anode protection
Cycling conditions – Li/S battery – Battery pack architecture



OXIS Li-S Cell Technology

- Average voltage: **2.15 V**
- Discharge capacity: **1200 mAh $g^{-1}_{(S)}$**
- Practical gravimetric energy: **400-600 Wh kg^{-1}**
  (*vs.* 200-300 Wh $kg^{-1}_{(Li\text{-}ion)}$)

High Gravimetric Energy

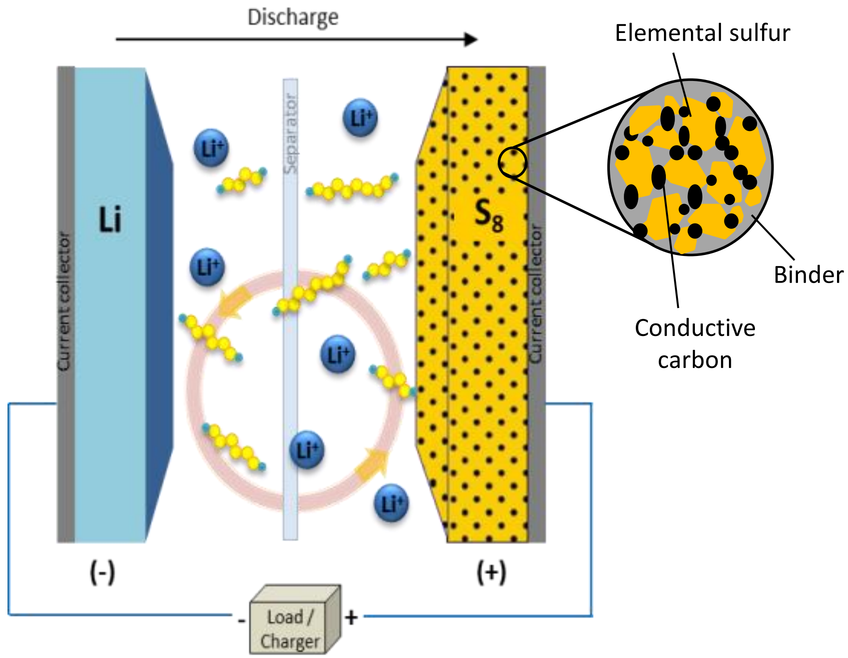
- **425Wh/kg** demonstrated on Li-S pouch cells
- Nearly double compared with best in class Li-ion cells

Low Predicted Costs

- Sulfur costs <$200/Tonne compared with Cobalt at around $60,000/Tonne
- Cell cost at equivalent production volumes will be less for Li-S compared to Li-ion

Environmentally Friendly

- No heavy metals in composition
- No HF formation from Electrolyte
- Aqueous based cathode production

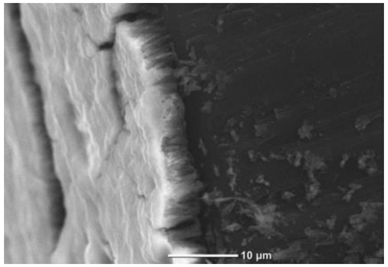


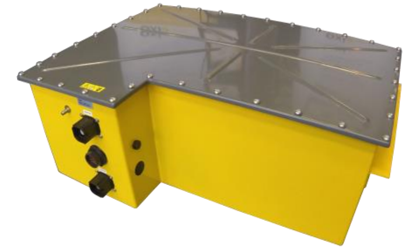
$$(-)\ :\ 16\ Li^{\circ} \rightarrow 16\ Li^{+} + 16\ e^{-}$$
$$(+)\ :\ S_8 + 16\ e^{-} \rightarrow 8\ S^{2-}$$
$$\mathbf{16\ Li^{\circ} + S_8 \rightarrow 8\ Li_2S}$$

16 electron process
≡ **2 e^- per S atom**

S = 32 g mol^{-1}

Li-S Technology Development – Our holistic approach





Research & Development
(21 Employees, growing)

Li-S Production
(18 Employees)

Battery Systems
(6 Employees)

- New Materials Development
- Cell Design + Optimisation
- Electrochemical Testing

- Component Manufacture: Cathode, Anode, Electrolyte
- Li-S Pouch Cell Production

- Prototype Battery Pack Design and Build
- Battery Management System Development (Control Electronics)

All areas are key to developing effective Li-S batteries

Cell chemistry can be tailored to meet the needs of different industrial segments:

Marine, Defense, Aviation, **Automotive** and Stationary Energy Storage.

Li-S for Automotive Applications

Improved Power

Extended cycle life

Improved Vol. Energy

Advances in negative electrode chemistry for longer cycle life

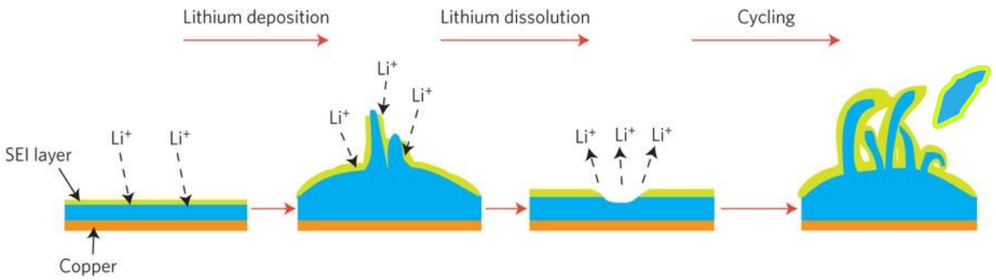
Negative electrode protection to pilot scale

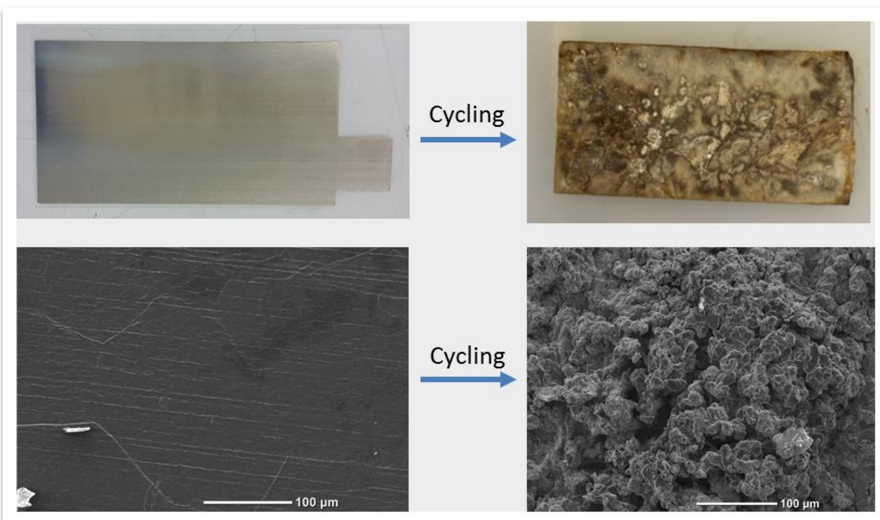
Next-generation 400 Wh kg^{-1} cell for large electric vehicles

Negative electrodes for Li-S batteries

Why is Lithium protection important?

- Automotive applications require >500 cycles
- Cycle-Life of >400 Wh Kg^{-1} Li-S cells is currently 60-100 cycles
- The negative electrode plays a crucial role in defining cycle life





- Dendritic/mossy lithium
- Dead lithium
- Large volume change
- Electrolyte decomposition
- Irreversible Li corrosion

Negative Electrode Requirements:

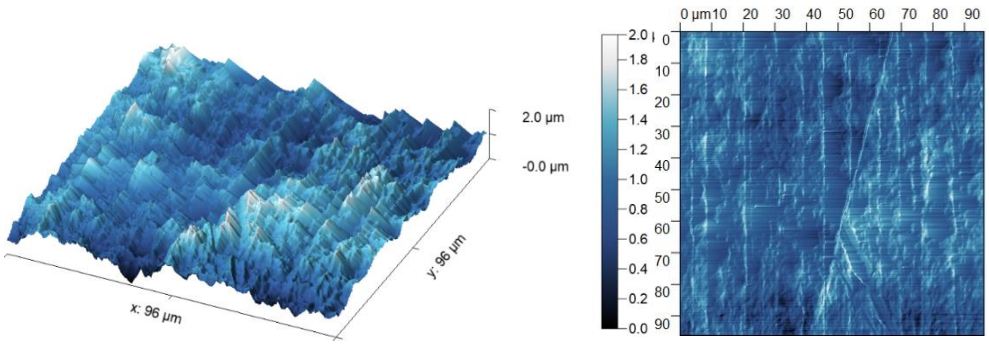
- High lithium content
- Electron transport
- Stability towards the electrolyte
- Mechanically robust

The traditional approach of a lithium metal electrode only satisfies the top two requirements

G. Zheng et al. Interconnected hollow carbon nanospheres for stable lithium metal anodes. *Nature Nanotechnology*, 2014

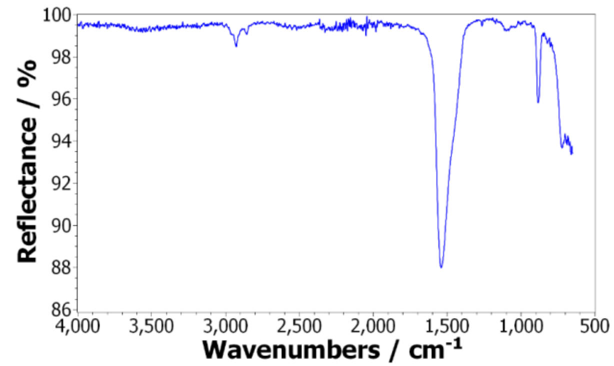
Lithium metal baseline characterization – In-house capabilities

AFM

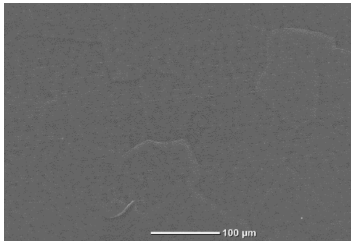


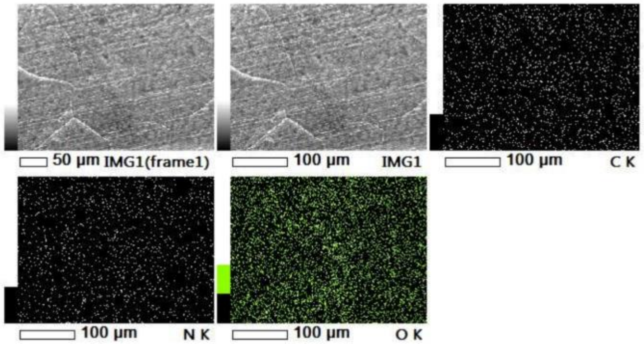
Average: 0.808 µm
RMS roughness (S_q): 194.4 nm
Mean roughness (S_a): 154.4 nm

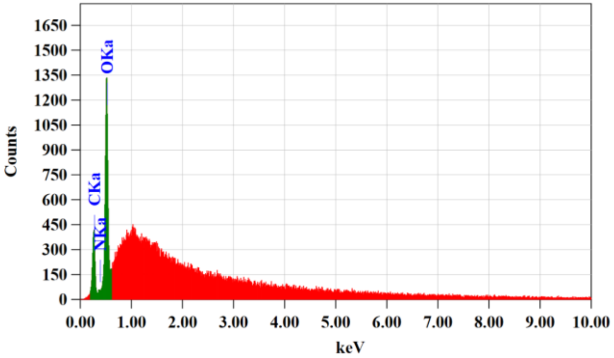
FTIR



SEM/EDX







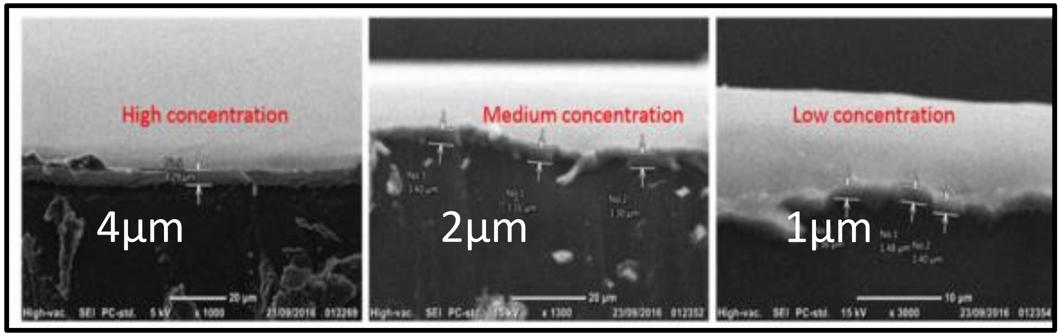
Polymeric protective layers via printing

Lithium protection layer requirements:

- Li^+ conductive and relatively thin
- Electrically insulating
- Stable against lithium metal and electrolyte
- Mechanically robust / relatively flexible
- Uniform

Polymeric layer printing robot:

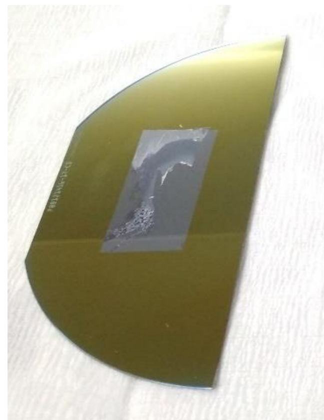
- Tailorable mechanical and chemical properties, wide array of polymer protection layers available
- Easy scaling-up



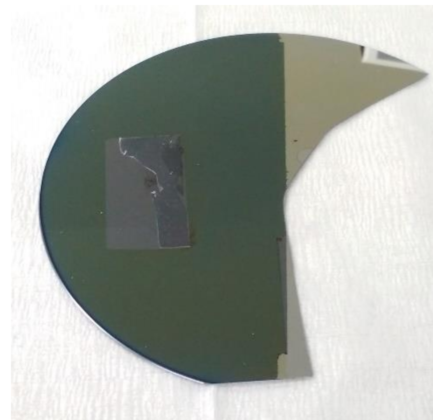
Ceramic protective layers via physical vapor deposition

OXIS Lab-scale sputtering System

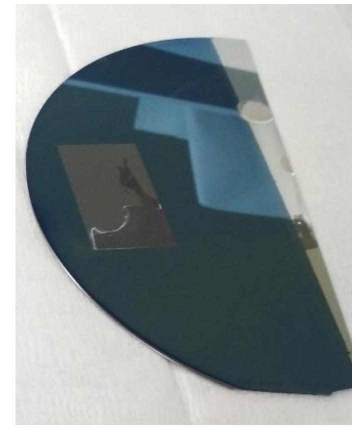
Lower film thk



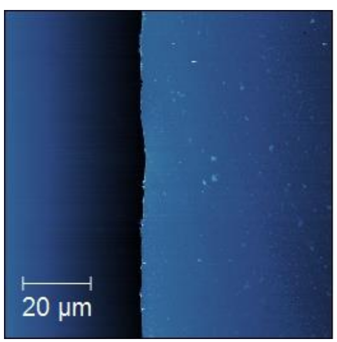
Intermediate film thk

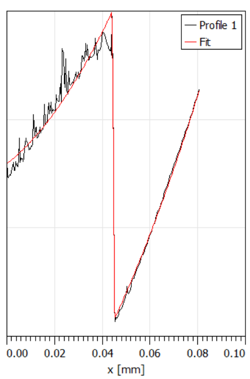


Higher film thk

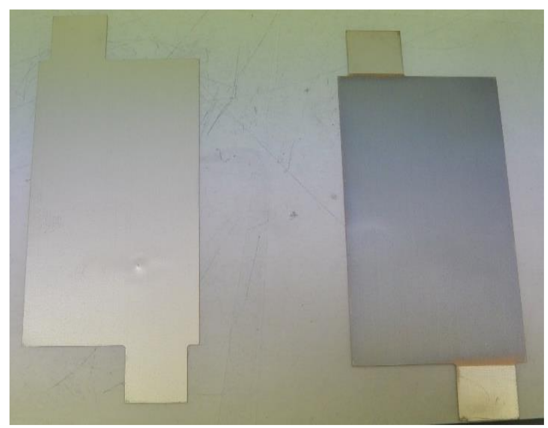


Parameters control





Fresh Lithium **Protected Lithium**

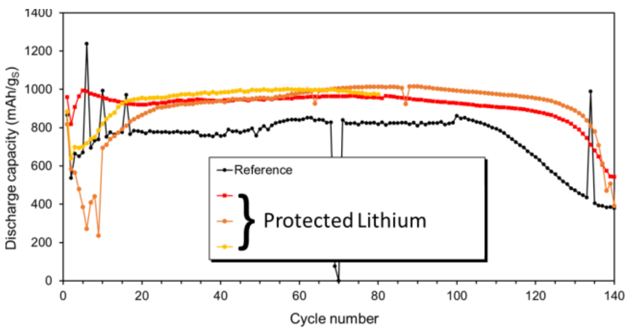


- Excellent control of the film thickness
- Wide variety of materials available for deposition

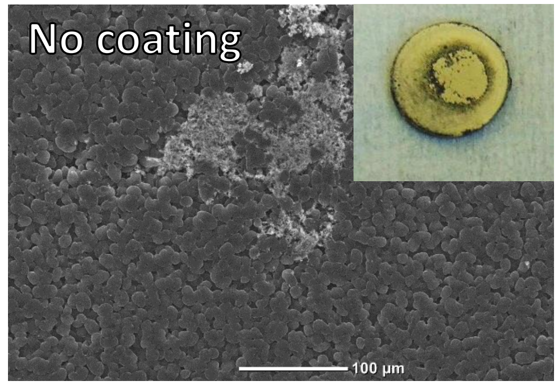
OXIS Li-S cells – Latest developments

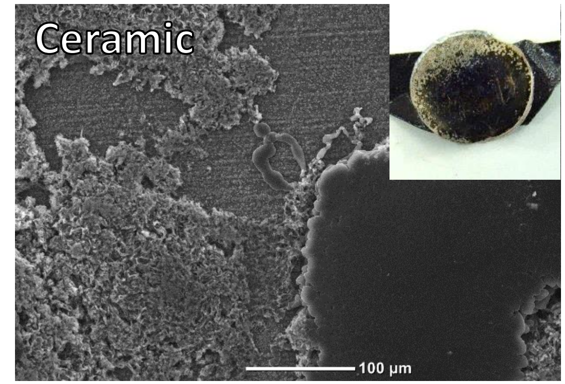
Electrochemical results

Ceramic layer

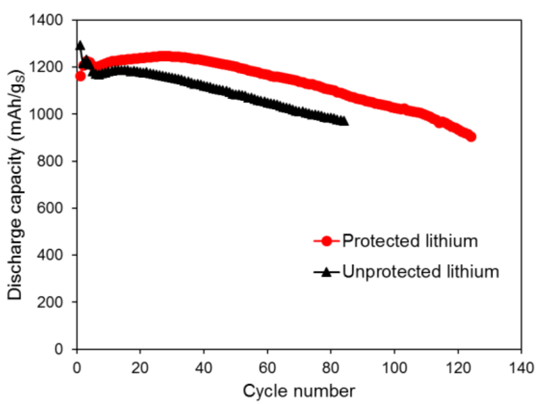


After 50 Cycles

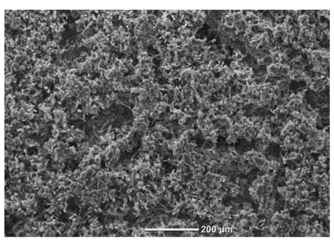




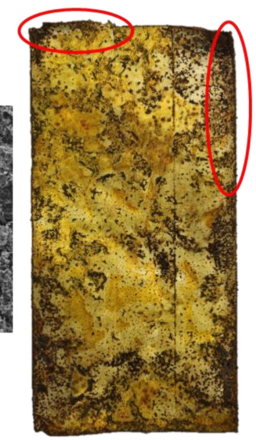
Polymeric layer



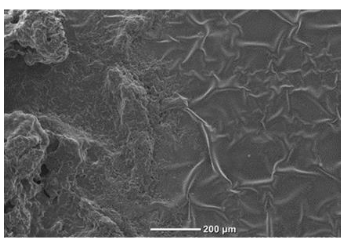
Unprotected lithium
50 cycles



High surface area
→ Electrolyte depletion



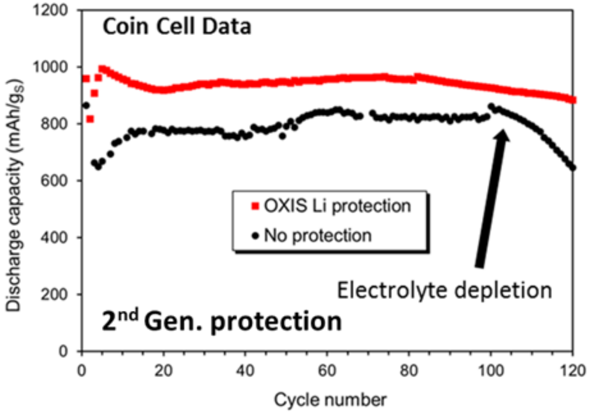
Protected lithium
50 cycles



Less mossy growth
→ Longer cycle life

- Improved cycle life by both ceramic and polymeric layers
- Scaling-up is in development

Hybrid/composite layers and high energy cells



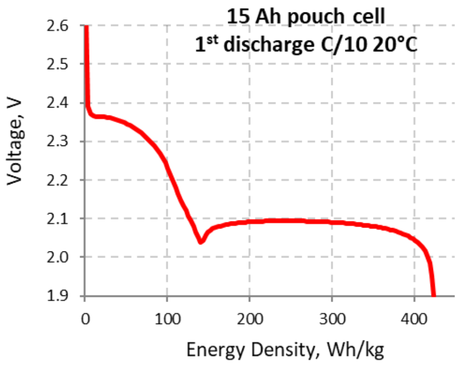
- Recent developments have been evaluated in coin cells
- scaling up coating processes, evaluation in pouch cells

Protected lithium
(scale up)

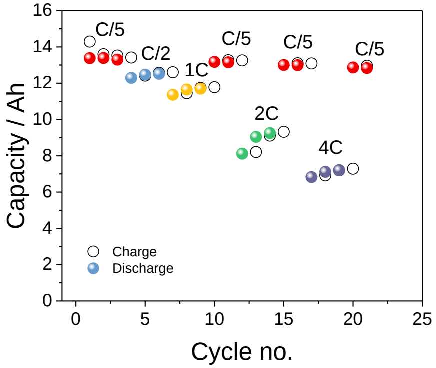
Latest developments: high energy cells

> 425 Wh Kg^{-1} at lower C-rates (C/10)

> 360 Wh Kg^{-1} at higher rates C-rates (C/5)



14 Ah pouch cell, C-rate test



Only 40% capacity loss when current is increased to 4C

Concluding Remarks

OXIS today: **>400 Wh kg^{-1} Li-S cell**

Commercializing Lithium Sulfur Batteries: Are We Doing the Right Research?
DOI: 10.1149/2.0071801jes

Materials/cell development and optimisation:

- Easily **scalable** and **practical** solutions
- **Application** defines the cell chemistry
- Emphasis has to be put on **enhancing cycle life**

Thank you!

OXIS R&D team

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