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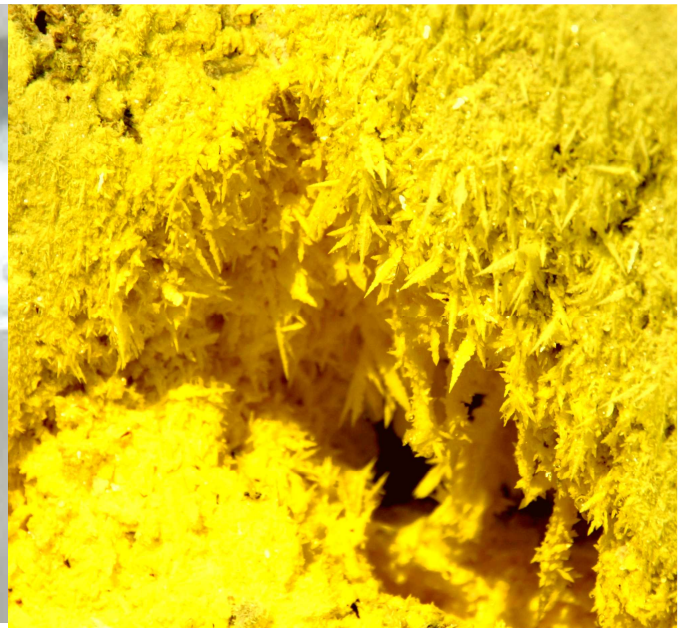

4th Symposium on Energy Storage: Beyond Lithium Ion

Pacific Northwest National Laboratory
June 8, 2011

Electrode Development @ BASF for Lithium/Sulfur Batteries

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BASF SE, 67056 Ludwigshafen, Germany

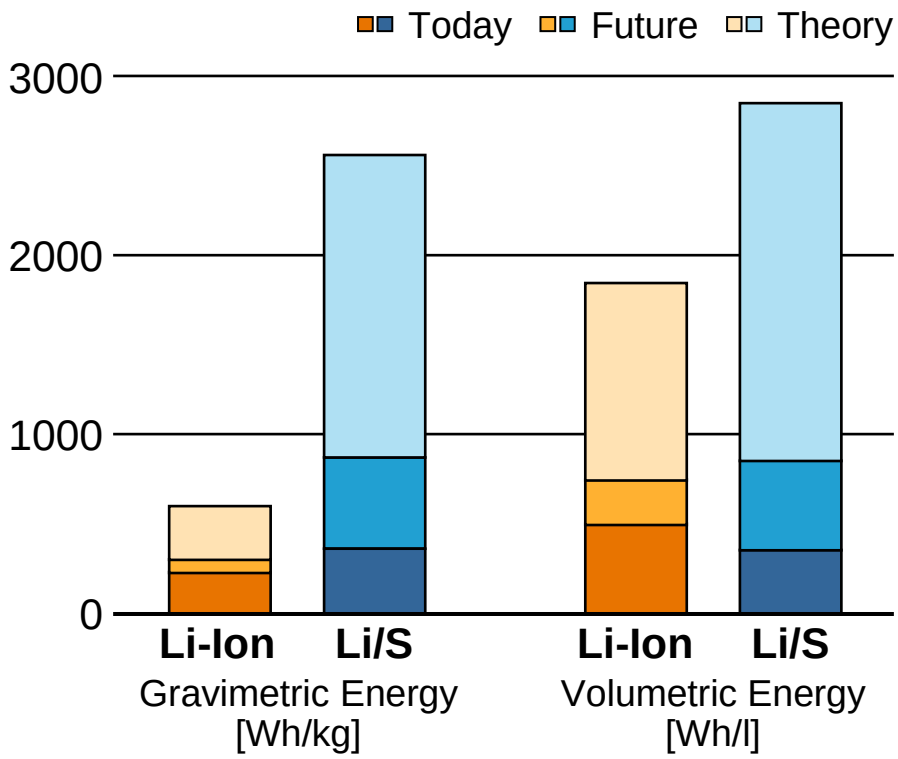
BASF Lithium/Sulfur Research Partner

- Since 2009 joint development agreement with world-leading lithium/sulfur company Sion Power

- Sion Power major developer of Li/S battery systems and protected lithium anode technology

- Acceleration of Li/S research and development with BASF expertise as chemical solution provider

Li/S – The Battery System Beyond Li-ion



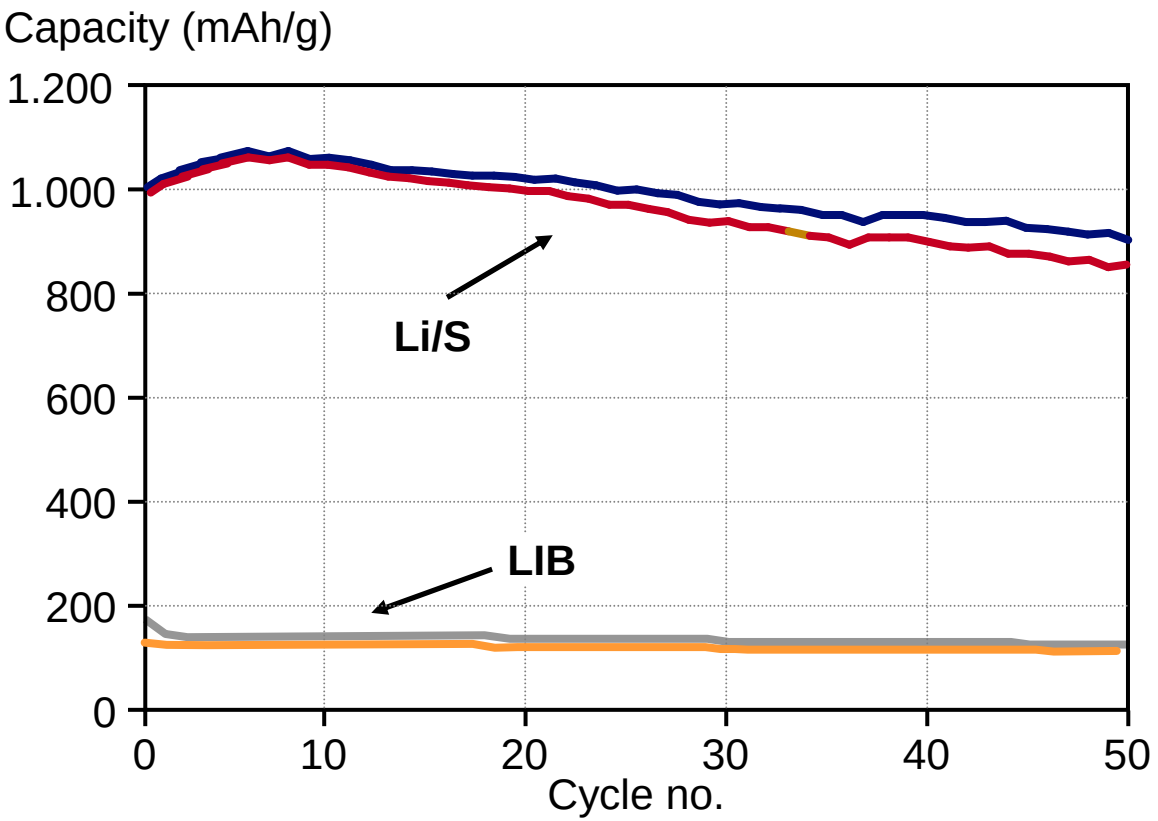
Comparison Li-Ion vs. Li/S batteries

Advantages:

- High **gravimetric** energy density
- **Low cost** and abundant raw materials
- Ideal battery system for **full electric vehicle** application
- Operability at very **low temperatures**
- High potential of **improvement**

Outstanding superiority of Li/S in respect of gravimetric energy density

Potential and Challenges

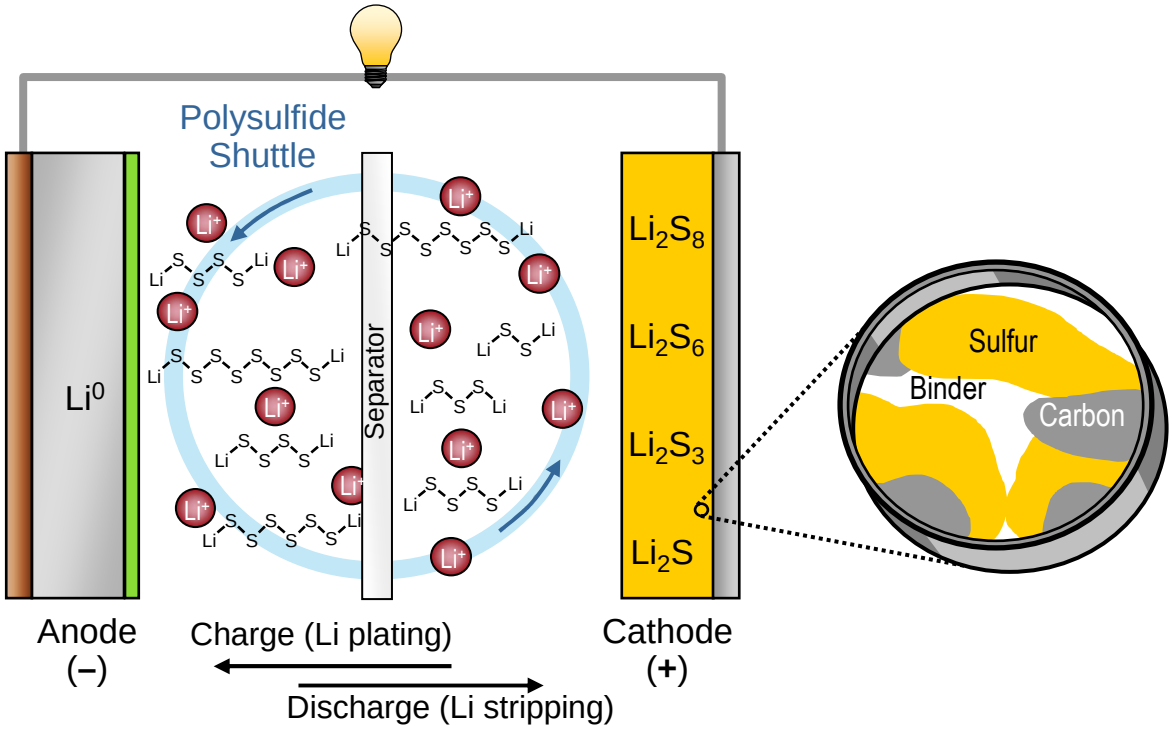


Comparison of cycle data of Li/S cell (red = discharging, blue = charging) and lithium-ion battery (LIB).

- "Life" of Li/S batteries ends currently too early after 50-100 cycles (< 800 mAh)
- Goal: > 500 cycles
- Observed capacity five times higher than lithium-ion batteries

Five times higher capacity than Li-ion technology

Working Principle of Li/S System



Model of Lithium/Sulfur battery

Discharging:

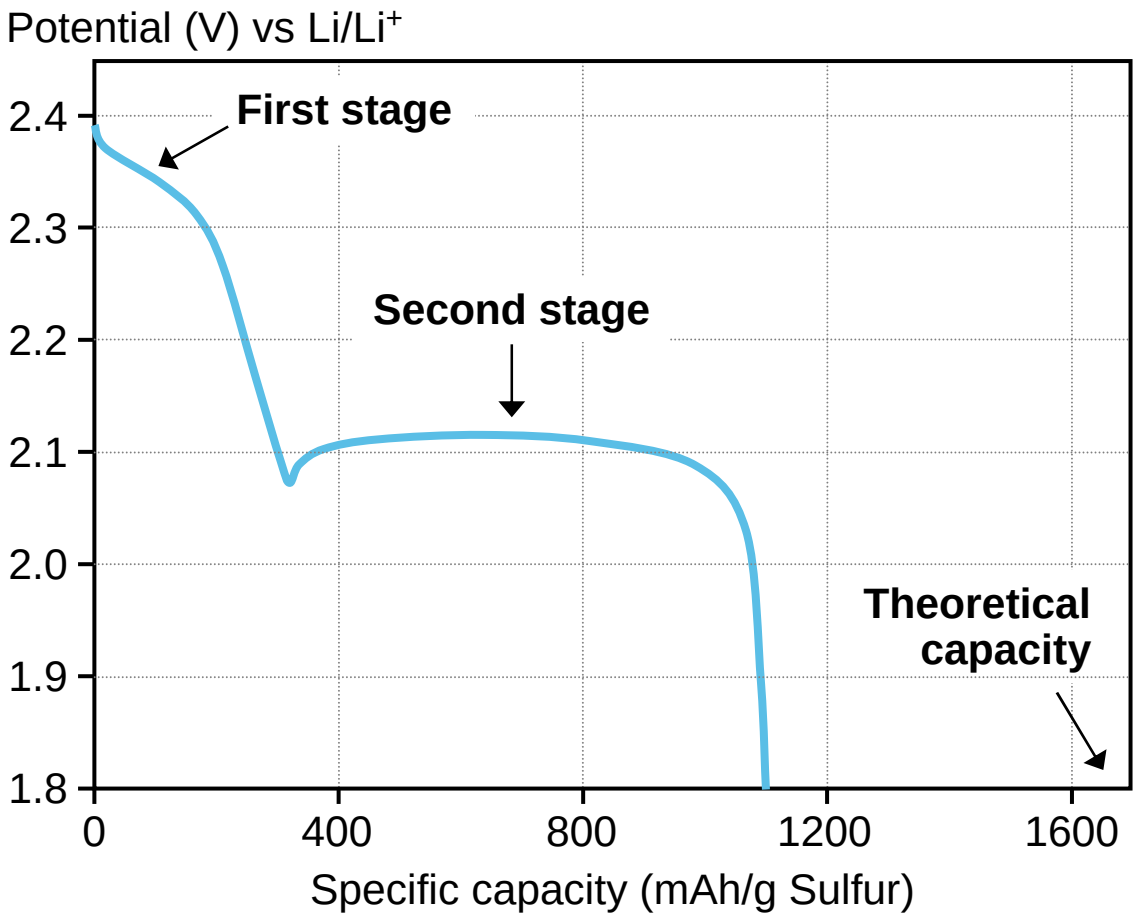
- Li is stripped from anode and lithium sulfides are formed in the cathode

Charging:

- Re-plating of Li and re-formation of elemental sulfur

Speciality of Li/S: (Partly) **dissolving electrodes** during cycling

Discharge Curve



First Stage

- Elemental sulfur is reduced
- Polysulfide up to Li_2S_4 are formed

Second Stage

- Precipitation of Li_2S
- Formation of smaller polysulfides
- 65-75 % of sulfur usage

Speciality of Li/S: (Partly) **dissolving electrodes** during cycling

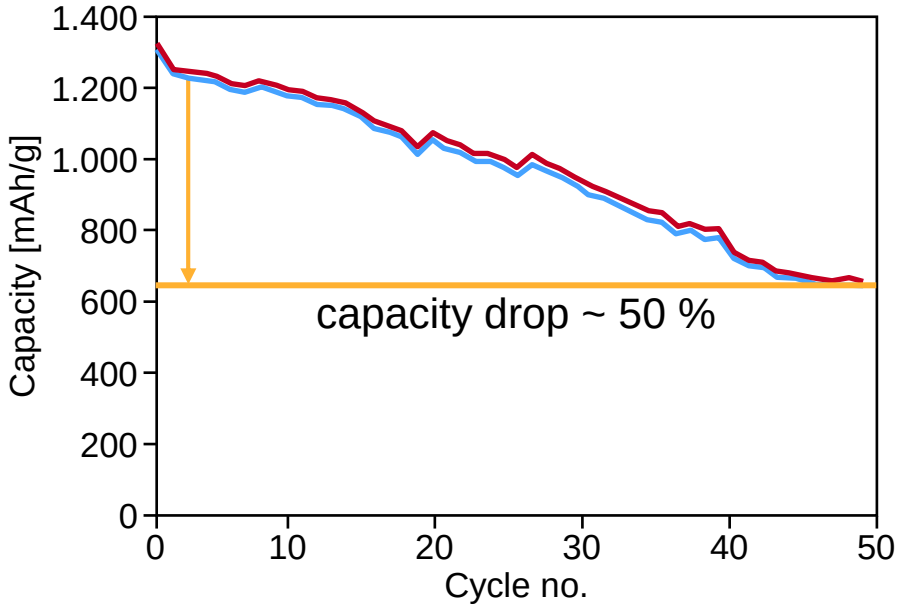
Cathode Development

Special requirements:

- Sulfur cathode sensitive to drying under vacuum
- Partly dissolving cathode
- Carbon particles responsible for structural stability

Approach:

- Utilization of new carbon materials
- Pretreatment of carbon and sulfur material

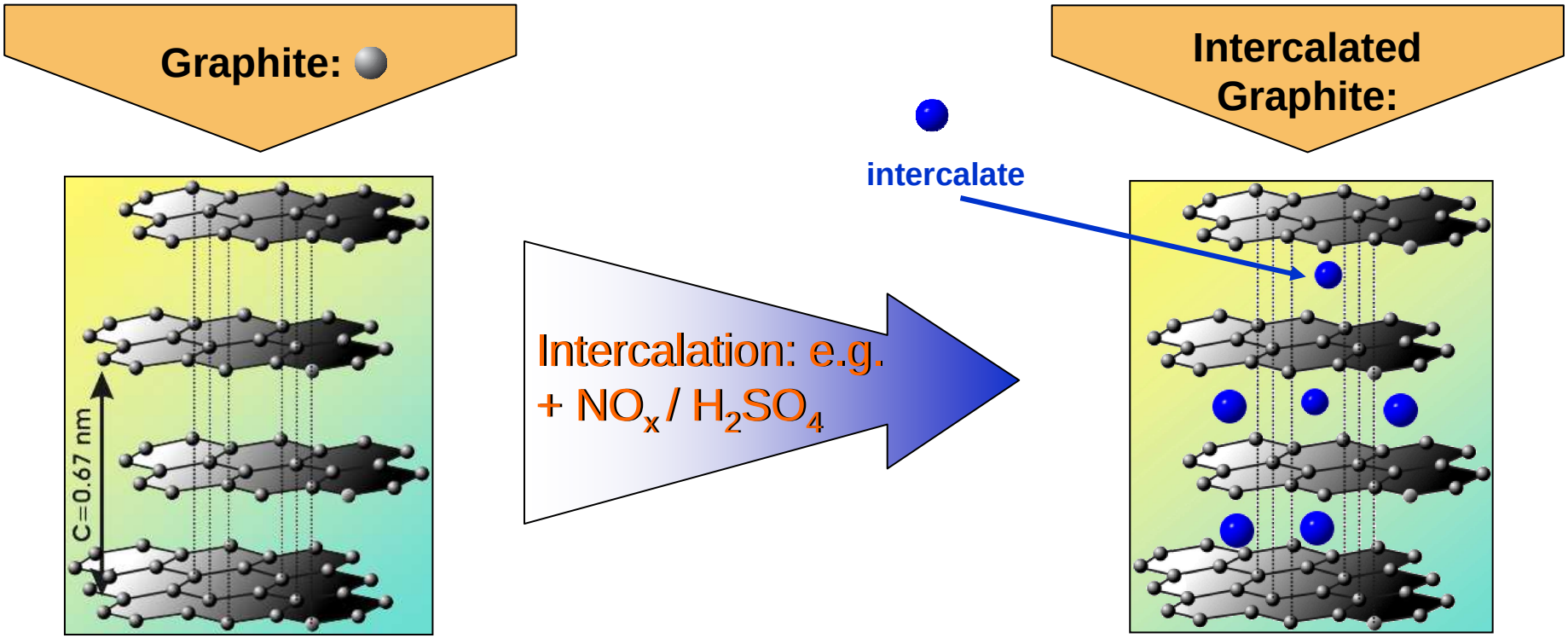


State of the art Li/S battery with **Teflon** binder

Binder and **carbon** development is **key factor** for optimized cathode

Expanded Graphites

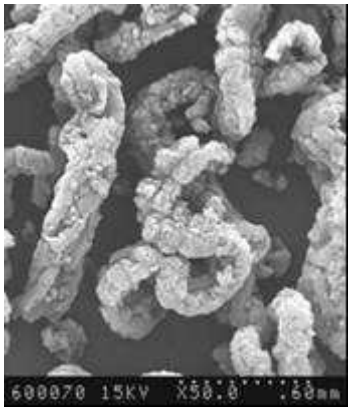
- Intercalated graphites: Intercalation of Lewis acid guest molecules (e.g. SO_3)



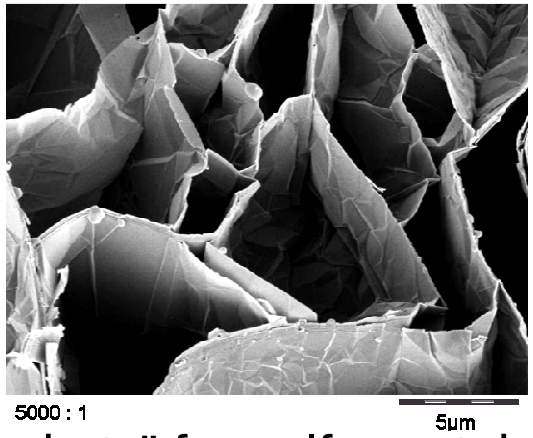
Intercalation is key to **expansion**

Expanded Graphites

Graphite



Expanded Graphite



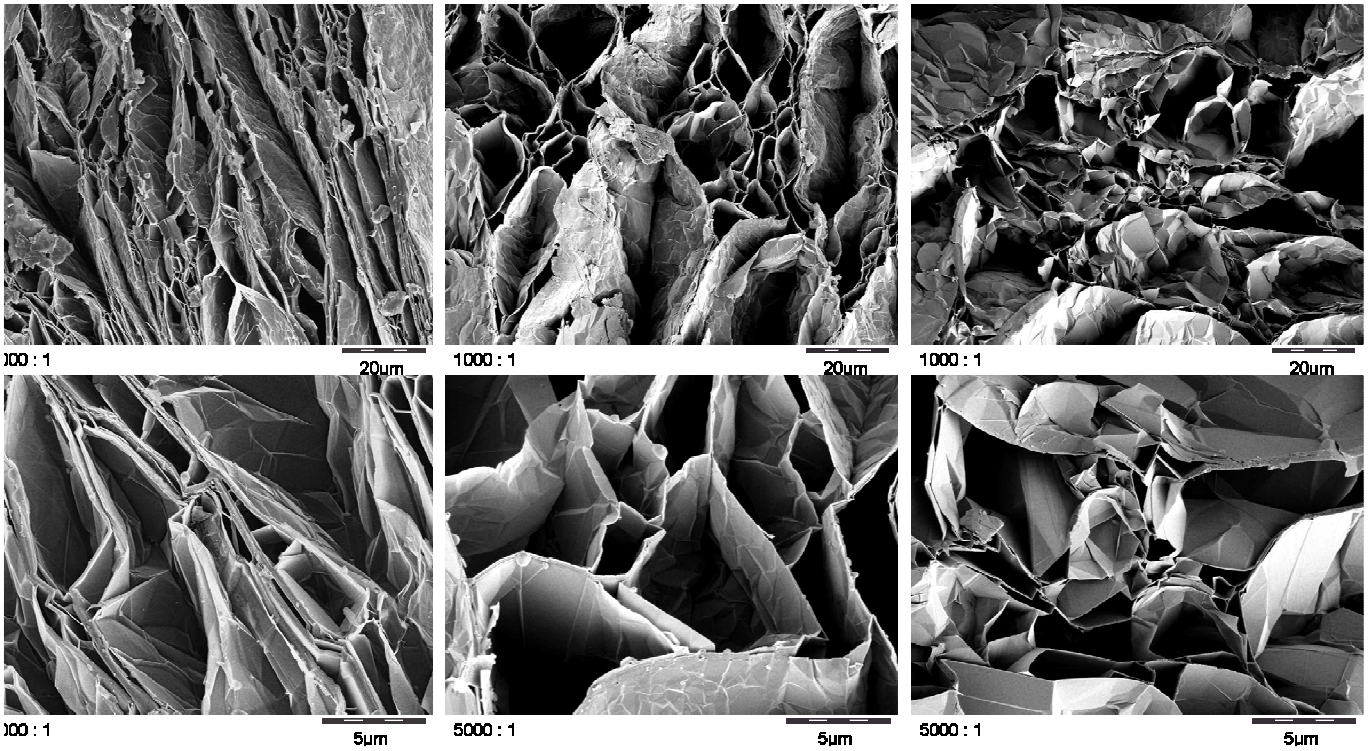
“Pockets” for sulfur uptake

- Expanded graphites can lead to better cell performance
- Highly conductive and light material
- Fixation of sulfur in pockets

Micropockets

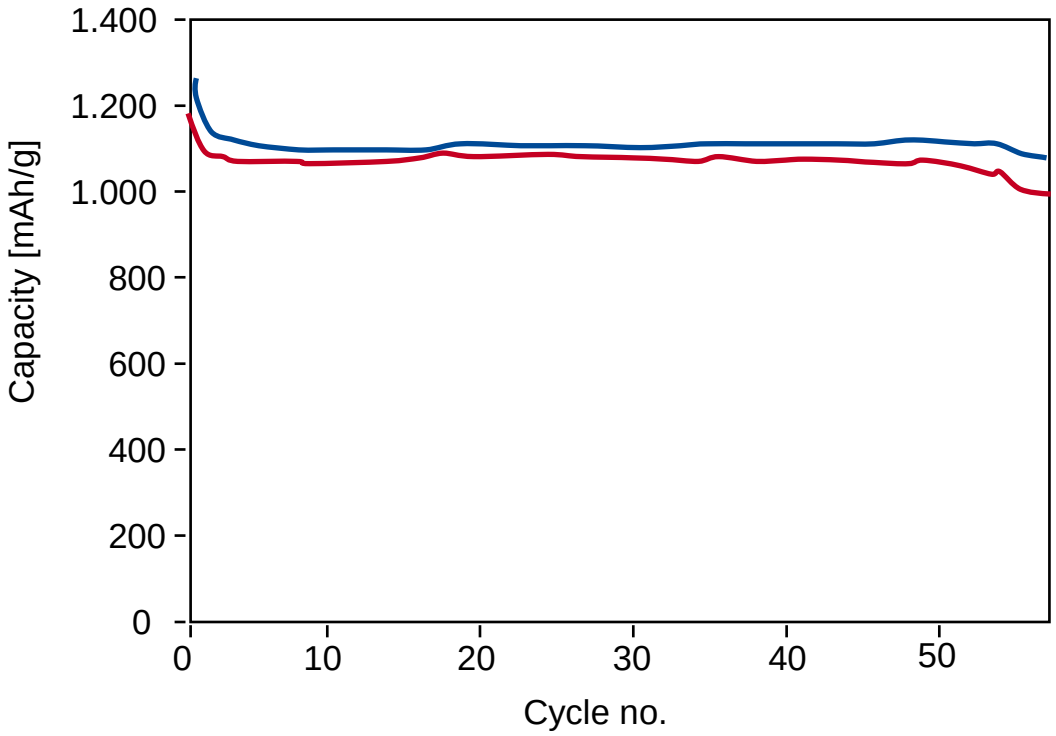
Expanded Graphites

- Temperature / gradient controlled expansion:



Temperature is **key factor** for optimized structure

Expanded Graphites



Charge/discharge capacity of cell with improved cathode

- Over 1100 mAh/g sulfur over 50 cylces
- Consumption of electrolyte responsible for cell failure after 60 cycles
- Testing in 110 mAh cells
- Up to 40% expanded graphites in cathode

Highly **stable performance** for first **50 cycles**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