22. GMA/ITG-Fachtagung Sensoren und Messsysteme 2024 | 11.06.2024 | Nürnberg

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Kontinuierliche Überwachung der Ausdehnung von Lithium-Ionen Zellen mittels dielektrischer Elastomer Sensoren DES

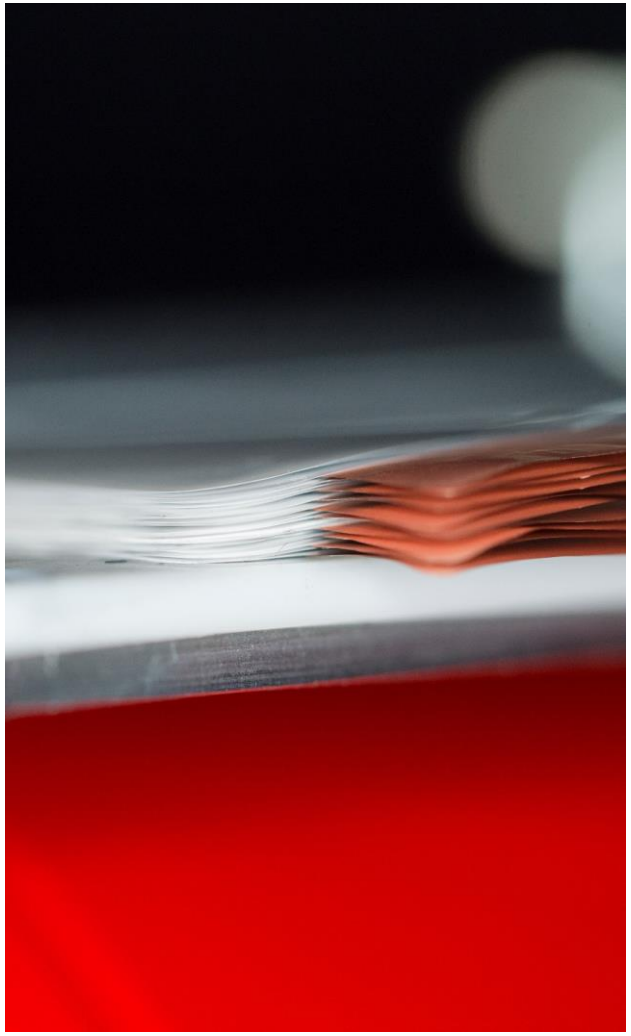
Continuous monitoring the expansion of lithium-ion cells using dielectric elastomer sensors DES

Fraunhofer Institute for Silicate Research ISC

Outline

Continuous monitoring the expansion of lithium-ion cells using DES

1. **Motivation**
2. **Dielectric elastomer sensors DES**
   - **Working principle**
   - **Sensor development & characterization**
   - **Sensor array manufacturing**
3. **Monitoring compression load of battery cells**
   - **Experimental setup and results**
4. **Conclusion and acknowledgement**



Dielectric elastomer sensors DES

Motivation

Motivation:

- **Lithium-Ion** pouch cells undergo a **reversible volume change (thickness change)** during life cycle: **Intercalation of Li-ions** dependent on **charging state (SoC)**

- **Permanent thickness change** of cell after **cell ageing** or in the **event of damage**

- Information about **cell expansion interesting for**:
  - **Early detecting** event of damage (**thermal runaway**)
  - Additional parameter for **smart battery management system** (BMS): Increase **fast charging capability** & **enhanced life cycle**

https://de.wikipedia.org/wiki/Pouch-Zelle

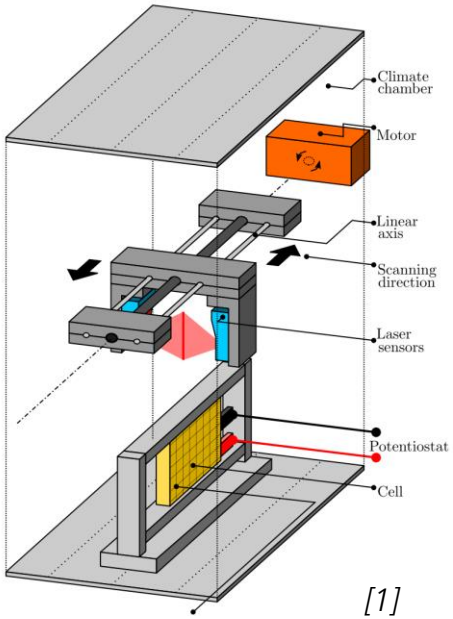
Dielectric elastomer sensors DES

Motivation

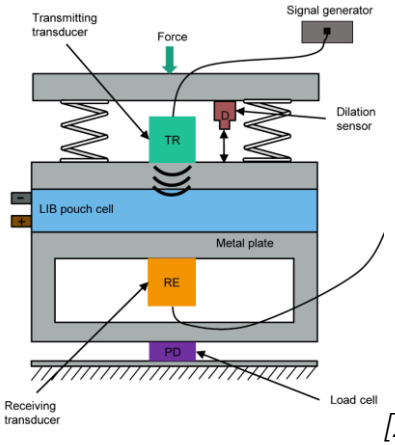
Motivation:

- On **lab level**: **complex** and **bulky sensor systems** for dilation monitoring (laser triangulation)
- On **battery module level**: very limited **assembly space**, **weight**, **costs**

→ **Not suitable** for **mobile application**



[1]



[2]

[1] F. B. Spingler, W. Wittmann, J. Sturm, B. Rieger, A. Jossen, Journal of Power Sources, 393 152 (2018). Doi: 10.1016/j.jpowsour.2018.04.095

[2] S. Feiler, P. Daubinger, L. Gold, S. Hartmann, G. A. Giffin, Batteries & Supercaps 2023, 6. Doi: 10.1002/batt.202200518

→ **Development of sensor system for continuously monitoring cell expansion inside a battery module**

→ **Use of soft dielectric elastomer sensors as a separating layer between individual cells**

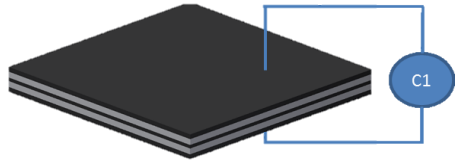
Dielectric elastomer sensors DES

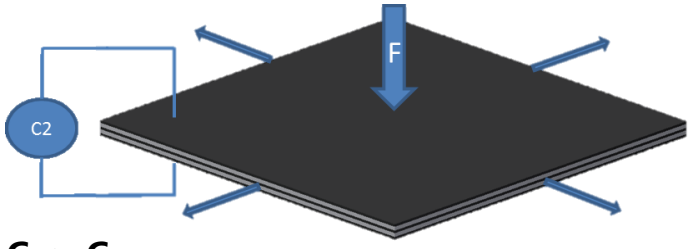
Working principle

Capacitive compression sensors based on **DES**

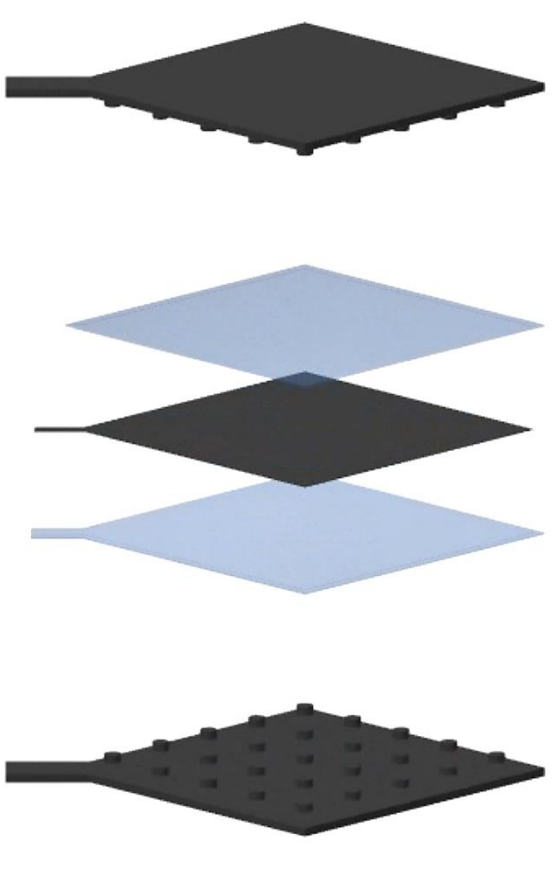
- **Stretchable capacitor** based on conductive and insulating silicone rubber material
- **Adaptable** sensor **sensitivity:** multilayered rubber film and elastomeric structures
  - Both influences mechanical stiffness under compression load
  - **Compression load**
    → change of geometry
    → **change of electrical capacitance**

$$C = \varepsilon_0 * \varepsilon_r * \frac{A}{d}$$





$C_2 > C_1$



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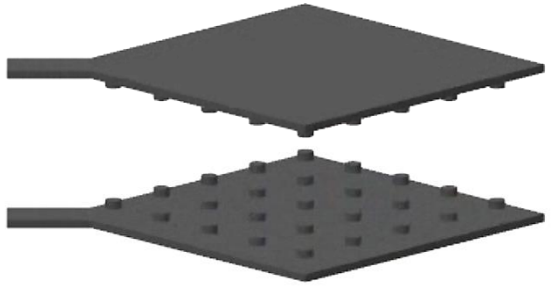
Dielectric elastomer sensors DES

Sensor development & characterization

Screening of **different elastomeric structures:**



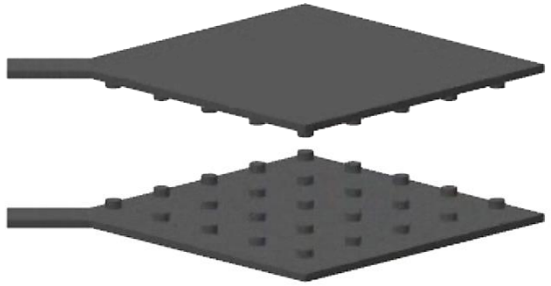
- Cylindrical, hemispherical, sinusoidal structures
- Different aspect ratios / sizes evaluated
- Variation of material hardness → sensor stiffness

https://doi.org/10.1117/12.2658246

Dielectric elastomer sensors DES

Sensor development & characterization

Screening of **different elastomeric structures:**



- Cylindrical, hemispherical, sinusoidal structures
- Different aspect ratios / sizes evaluated
- Variation of material hardness → sensor stiffness

Structure	Intermediate layer
Series 0100: reference Aspect ratio*: 0.5:1, distance 4 mm	Young's modulus: 790 kPa
Series 0200 Aspect ratio*: 1:1, distance 3 mm	Young's modulus: 790 kPa
Series 0300 Aspect ratio*: 1:1, distance 3 mm	Young's modulus: 1700 kPa
Series 0400 Aspect ratio*: 1:1, distance 3 mm	Young's modulus: 1700 kPa Thickness increase of + 200 µm

Structure	
Cylindrical 1, 0.5 mm Aspect ratio*: 0.5:1, distance 4 mm	
Cylindrical 2, 1 mm Aspect ratio*: 1:2, distance 6 mm	
Hemisphere Aspect ratio*: 1:2, distance 4 mm	
Sine fine Amplitude / wave length = 1:3	
Sine coarse Amplitude / wave length = 2:5	

aspect ratio = height / width

Dielectric elastomer sensors DES

Sensor development & characterization

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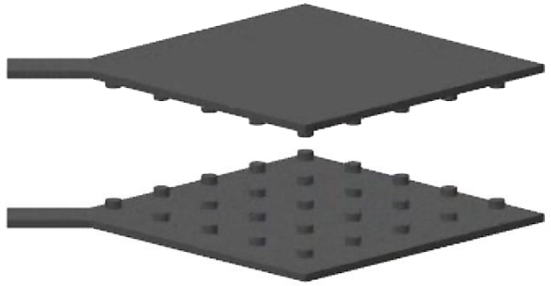
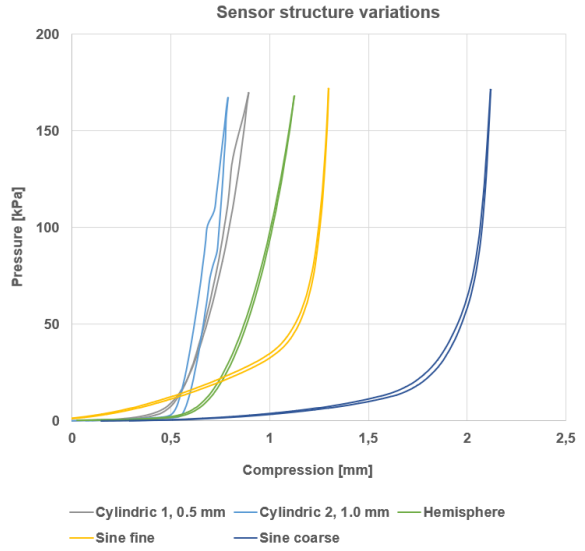
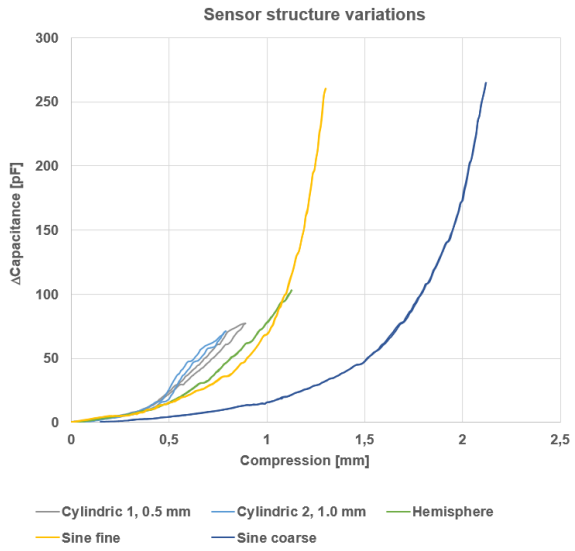
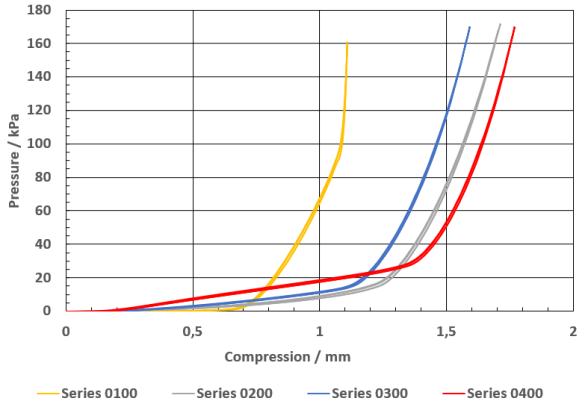


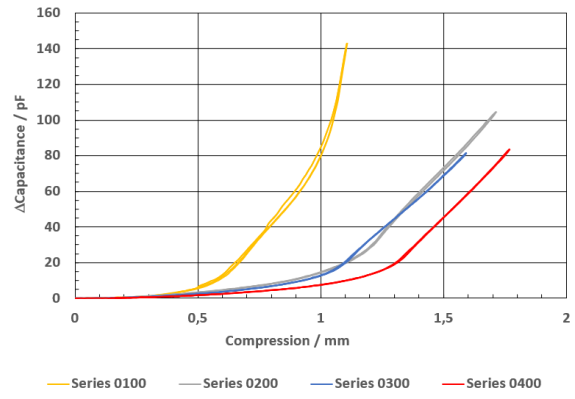
- Cylindrical, hemispherical, sinusoidal structures
- Different aspect ratios / sizes evaluated
- Variation of material hardness → sensor stiffness

→ **Electromechanical evaluation** of sensor configurations





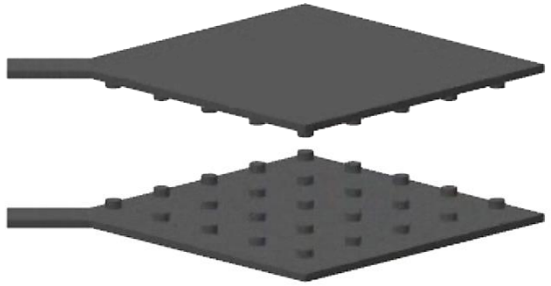




Dielectric elastomer sensors DES

Sensor development & characterization

Screening of **different elastomeric structures:**



- Cylindrical, hemispherical, sinusoidal structures
- Different aspect ratios / sizes evaluated
- Variation of material hardness
  → sensor stiffness

Type of sensor	Δpressure [kPa] Start: approx. 25 kPa	Δcompression [mm] Target ca. 200 µm	Capacitance [pF]	ΔCapacitance [pF]
Cylindrical 1: 0.5 mm	25,6 -> 105,8	0,419 -> 0,625	40,7 -> 85,7	**45,0**
Cylindrical 2: 1.0 mm	22,8 -> 152,3	0,571 -> 0,772	41,8 -> 68,4	**26,6**
Hemisphere	23,8 -> 81,7	0,76 -> 0,963	41,8 -> 72,3	**30,5**
Sine: fine	24,9 -> 36,3 25,0 -> 35,2	0,814 -> 1,018 1,235 -> 1,429	37,0 -> 73,8 26,2 -> 39,5	**36,8** **13,3**
Sine: coarse	25,2 -> 47,2 24,9 -> 63,2	1,393 -> 1,594 1,791 -> 1,998	81,0 -> 116,8 101,0 -> 172,6	**35,8** **71,6**

Type of sensor	Δpressure [kPa] Start: approx. 25 kPa	Δcompression [mm] Target approx. 200 µm	Capacitance [pF]	ΔCapacitance [pF]
Series 0100	25,4 -> 84,4	0,840 -> 1,048	47,5 -> 98,1	**50,6**
Series 0200	25,6 -> 80,1	1,302 -> 1,511	44,1 -> 73,3	**29,2**
Series 0300	24,8 -> 76,5	1,202 -> 1,399	33,2 -> 55,6	**22,4**
Series 0400	25,0 -> 44,4	1,253 -> 1,459	15,9 -> 40,0	**24,1**

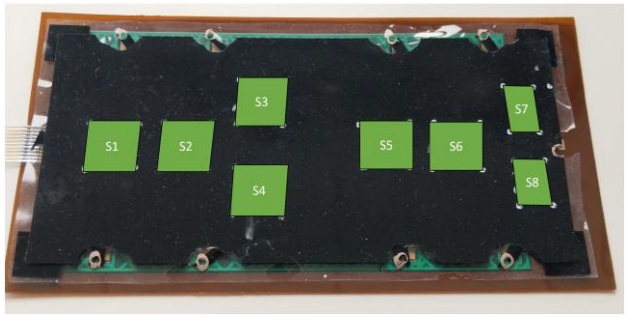
→ **Sensor assessment** according to **mechanical specifications**

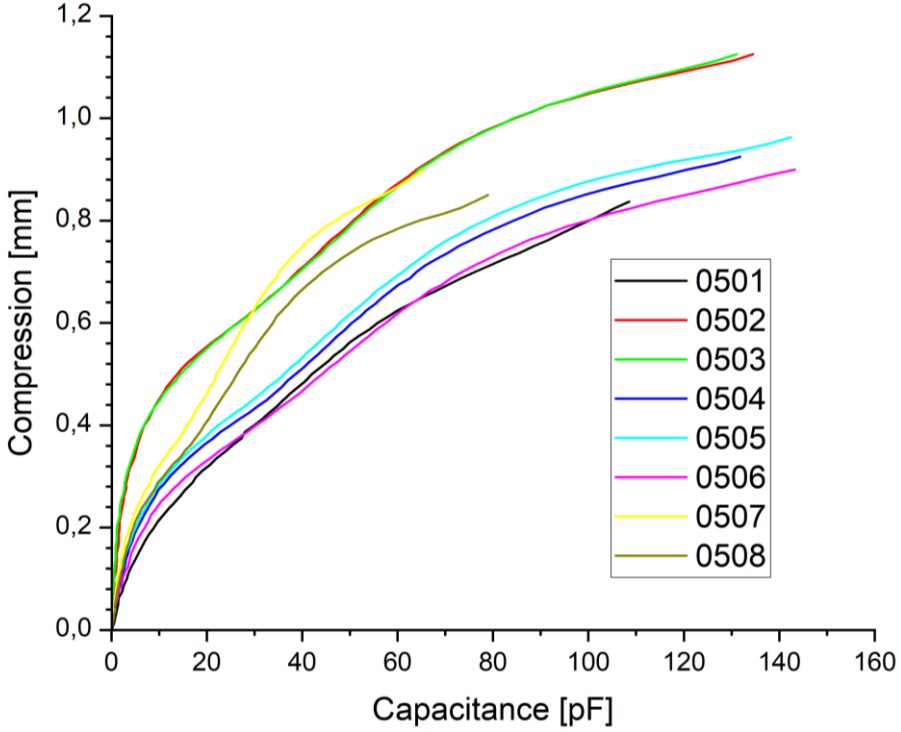
Dielectric elastomer sensors DES

Sensor array manufacturing

Sensor array manufacturing:

- **Sensor film size** adapted to **cell geometry** (Kokam 12 Ah)
- Sensor film **thickness: ~ 3 mm**
- **Implementation of sensor points** within intermediate silicone film: **local resolution** of **8 sensor points**
- **Electromechanical characterization** of sensor points: **compression vs. sensor capacity**
- **Sensor reading** by **microcontroller**: implemented **compression calculation** on firmware (polynominal fit)





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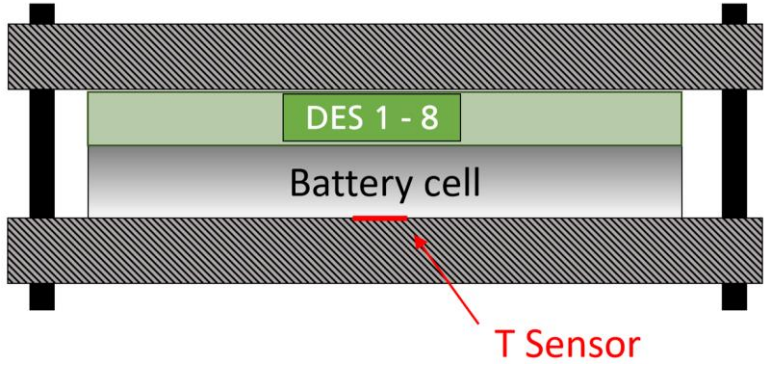
Dielectric elastomer sensors DES

Experimental setup and results

Experimental setup:

- Mechanically braced setup
- Additional T-sensor (PT100)
- Tested at 25 °C

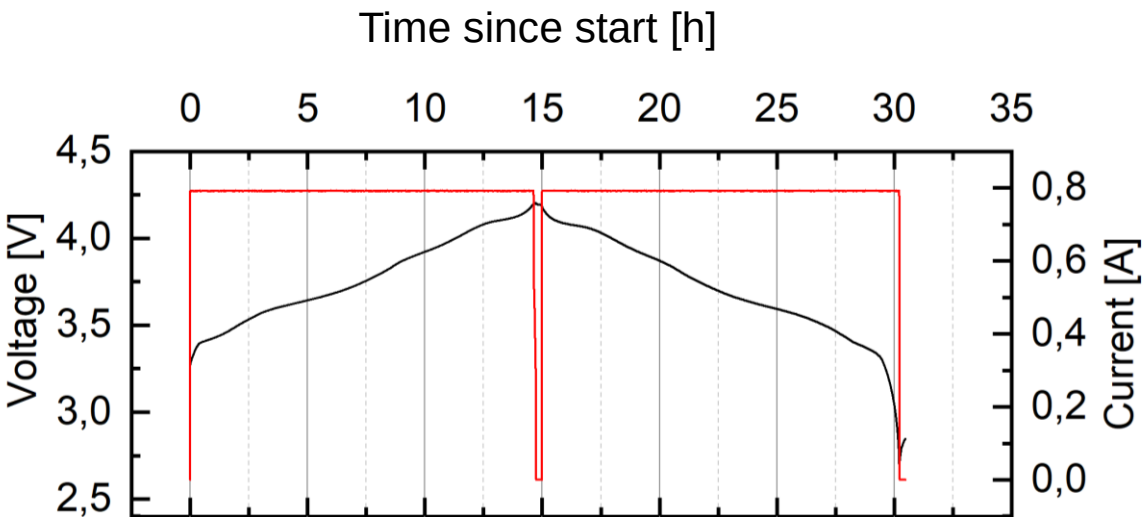


Dielectric elastomer sensors DES

Experimental setup and results

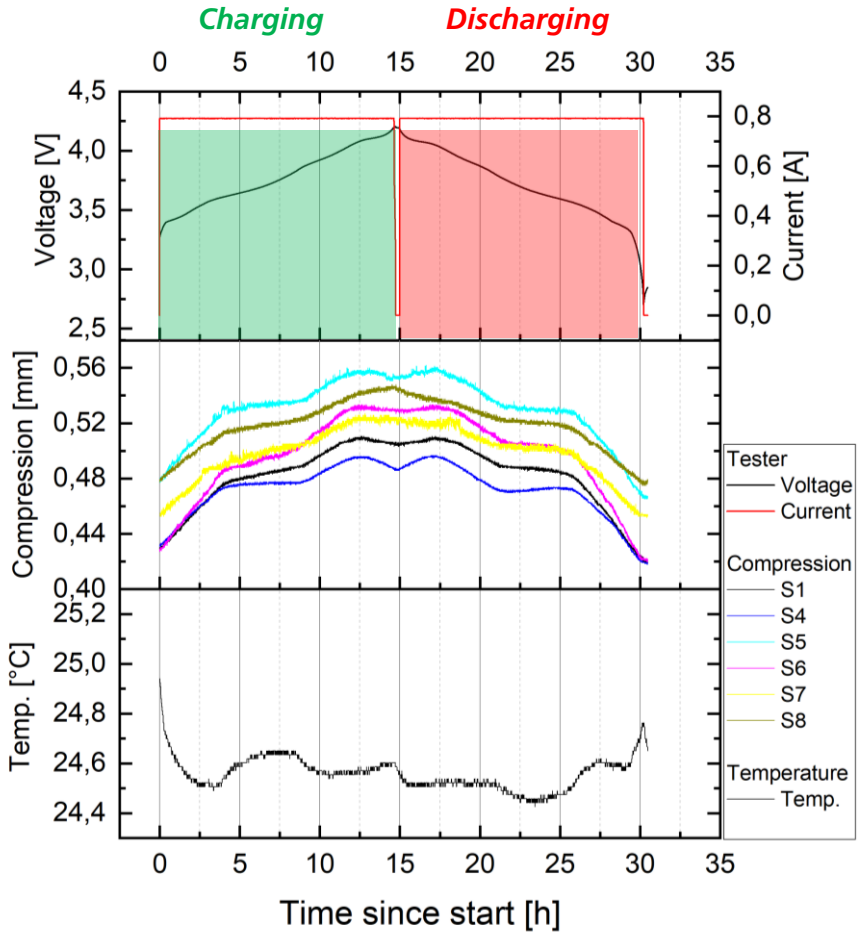
Results:

- Cycling cell voltage between **fully charged** (4.2 V) and **fully discharged** (2.7 V)
- Cycling profile: **charging and discharging** at **C/15** (0.8 A)
- **Preload** balanced between **15 and 42 kPa**
- Continuous **compression** and **temperature monitoring**



Dielectric elastomer sensors DES

Experimental setup and results

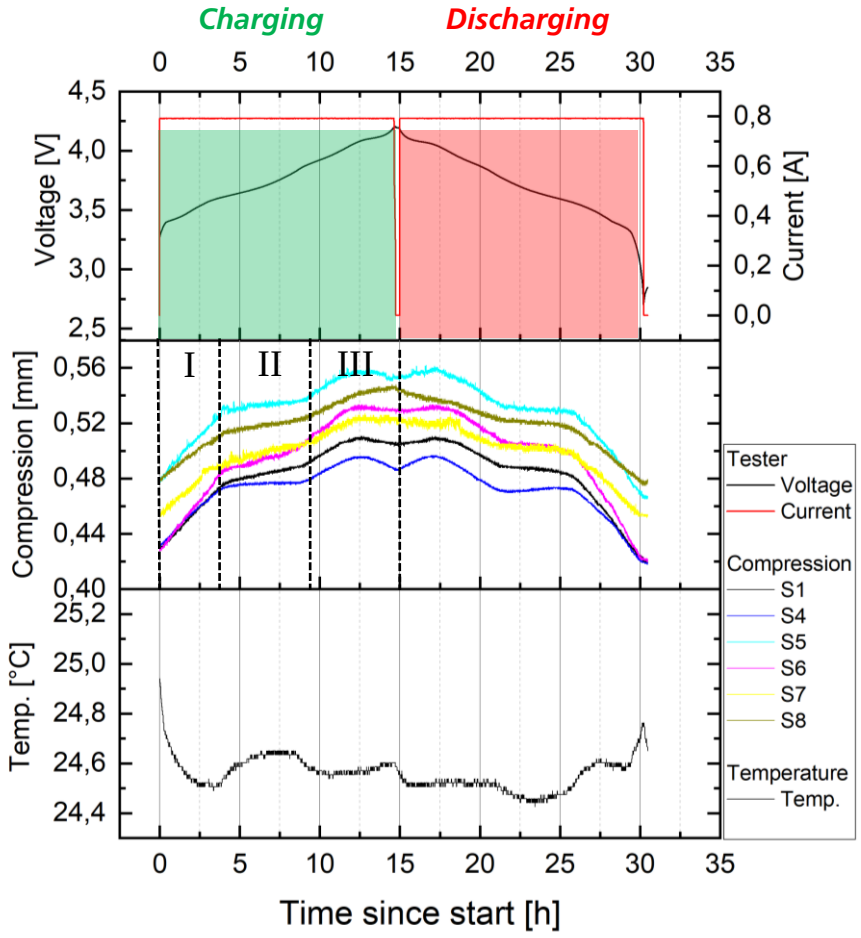


Results:

- **Charging**: intercalation of Li-ions into anode material (graphite) → **volume expansion**
- **Discharging**: de-intercalation → **volume contraction**
- **Cell expansion** is transformed into **sensor compression**:
  → sensor **capacity increases** during **charging** and **decreases during discharging**
- **Temperature** almost constant: no temperature related sensor effects

Dielectric elastomer sensors DES

Experimental setup and results



Results:

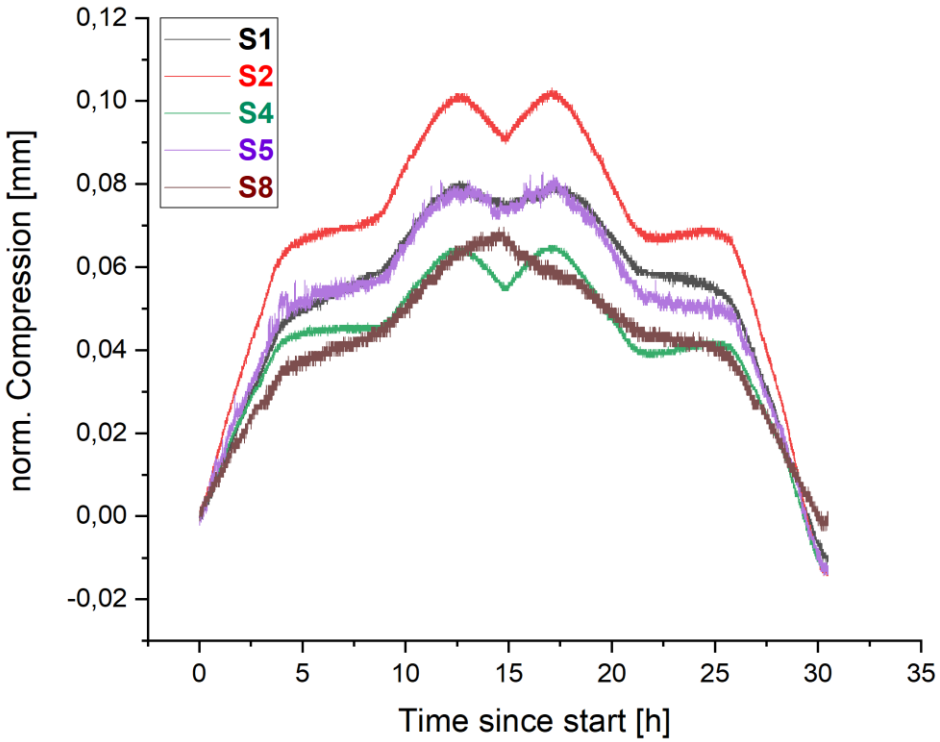
- **Intercalation** takes place in **multiple stages**[3] with different **speed of expansion**
  - I: High expansion rate
  - II: Reduced expansion rate
  - III: High expansion rate, but overlapped with contrary contraction of cathode material
  - → **relative minimum** in expansion in **fully charged state**

[3] Daubinger P., Ebert F., Hartmann S., Giffin G. A. (2021). Impact of electrochemical and mechanical interactions on lithium-ion battery performance investigated by operando dilatometry. Journal of Power Sources, Volume 488
https://doi.org/10.1016/j.jpowsour.2021.229457

Dielectric elastomer sensors DES

Experimental setup and results

Exemplary sensor positions



Normalized compression - results:

- **Maximum change** in cell expansion can **not be clearly** assigned to **central positions**
- **Shoulder-shaped curve profile** (Lithium intercalations stages) **more dominant** in **central positions**
- **Cathode contraction** in fully charged state (relative minimum) **less dominant near the cell tabs** (S7 & S8)

→ Cell expansion and contraction can be monitored very well, even locally distributed!

→ Sensor sensitivity high enough for measuring electrochemical processes inside the battery!

Conclusion

- **Soft compression load sensors** based on **dielectric elastomer** can be integrated as cell separating layer in battery modules
- **Layer stiffness** and **sensor sensitivity** can be **adapted** towards **different cell designs** (pouch, prismatic, cylindrical) and **cell chemistries** (solid-state)
- **Locally resolved sensing** can be implemented **without creating mechanical pressure peaks** (homogenous stiffness)
- **Thin** and **lightweight** sensor system: applicable **for mobile applications**
- **One sensor layer** measuring **accumulated cell expansion** within a battery module

→ Multifunctional cell separating layer with multiple functionalities:

- **Homogenous mechanical preload**
- **Simultaneously monitoring cell expansion with a local resolution**
- **Insights into State of Charge and electrochemical processes**

Acknowledgement

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Visit us in the exhibition: hall 1, booth 430

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https://www.spartacus-battery.eu/

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https://phoenix-smartbatteries.eu/

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