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Johannes Ziegler, Johannes Ehrlich

Überwachung des Modulinnendrucks von Batteriemodulen mittels dielektrischer Elastomer Sensoren DES

Monitoring the internal pressure of battery modules using dielectric elastomer sensors DES

Fraunhofer Institute for Silicate Research ISC

Outline

Monitoring the internal pressure of battery modules using dielectric elastomer sensors DES

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   - **Sensor development & characterization**
   - **Sensor array manufacturing**
3. **Monitoring compression load of battery cells**
   - **Experimental setup and results**
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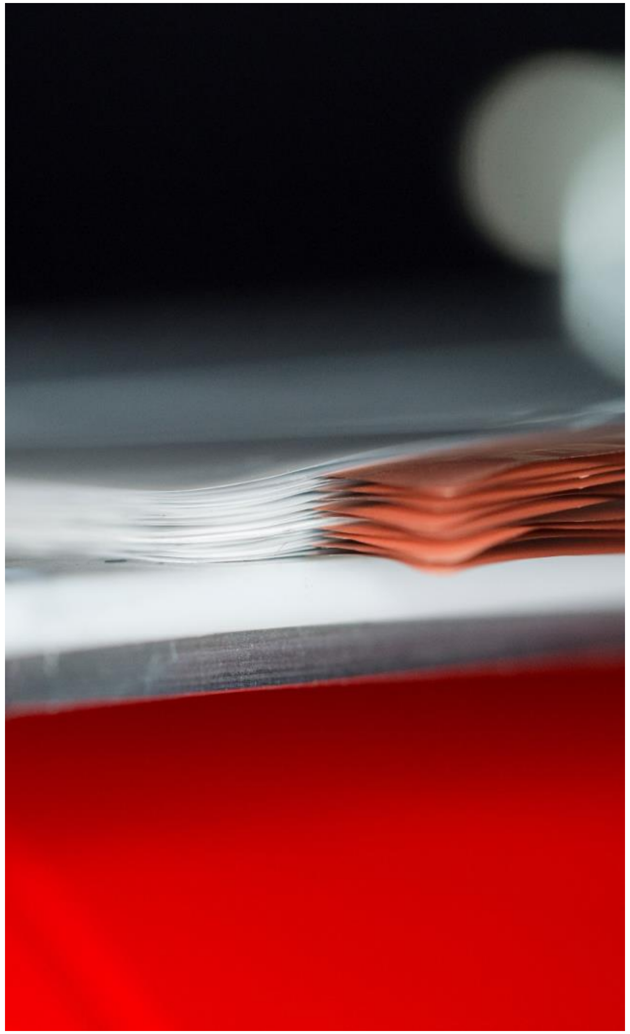


Dielectric elastomer sensors DES

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)**

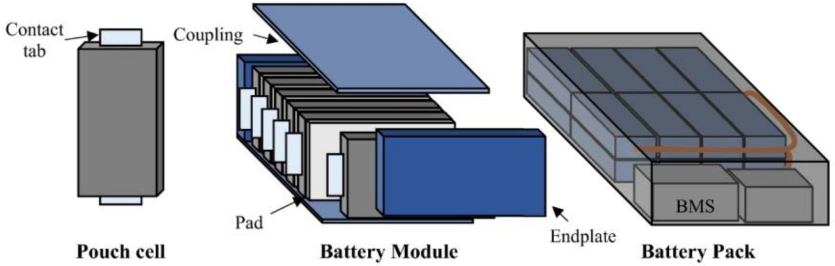
- **Permanent thickness change** of cell after **cell ageing** or in the **event of damage**

- 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

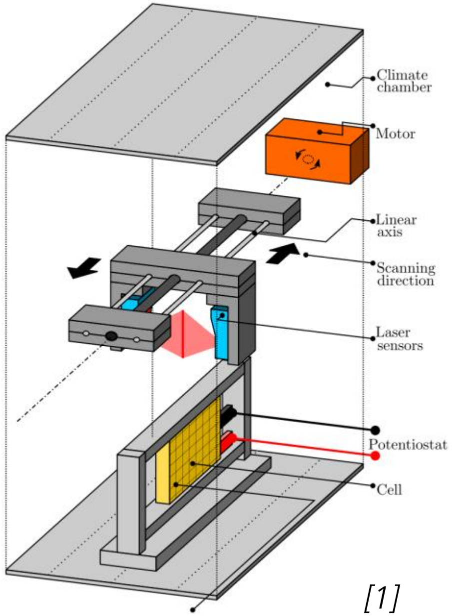


[3]

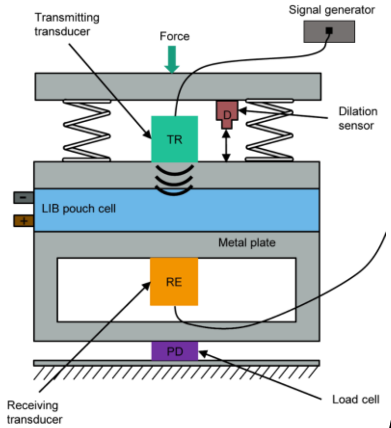
Motivation:

- 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]

→ **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**

[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

[3] Choi, H., Son, H., Choi, Y.H. et al. Reliability-based design optimization of a pouch battery module using Gaussian process modeling in the presence of cell swelling. Struct Multidisc Optim 66, 227 (2023). https://doi.org/10.1007/s00158-023-03662-1

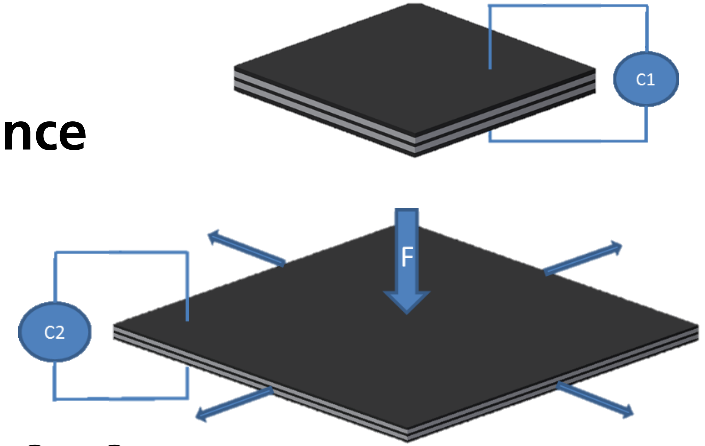
Dielectric elastomer sensors DES

Working principle

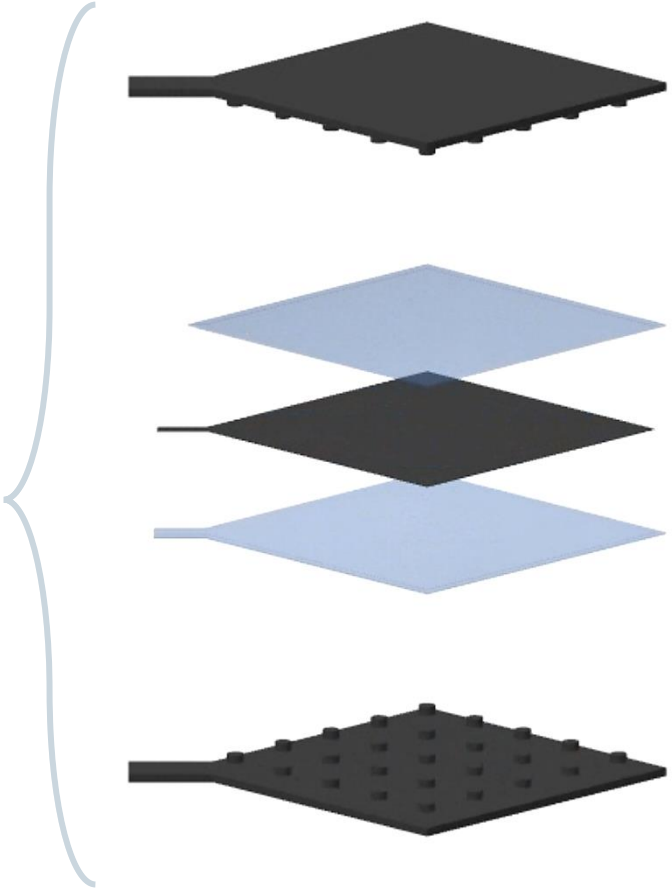
Capacitive compression sensors based on **DES**

- **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**

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



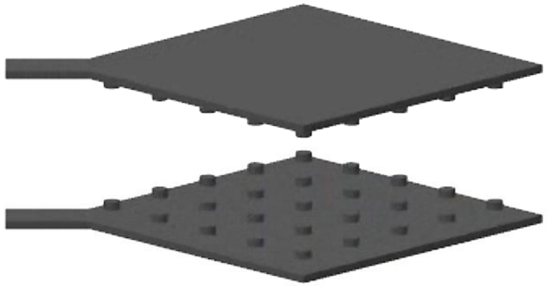
$C_2 > C_1$



Dielectric elastomer sensors DES

Sensor development & characterization

Screening of **different elastomeric structures:**



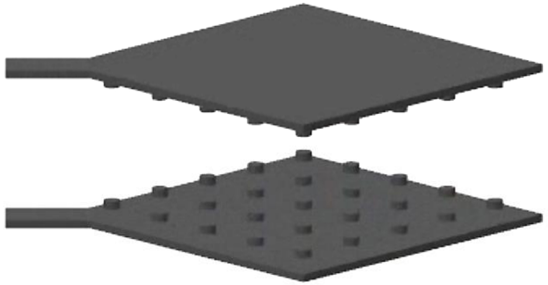
- Cylindrical, hemispherical, sinusoidal structures
- Different aspect ratios / sizes evaluated
- Variation of material hardness → sensor stiffness

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*

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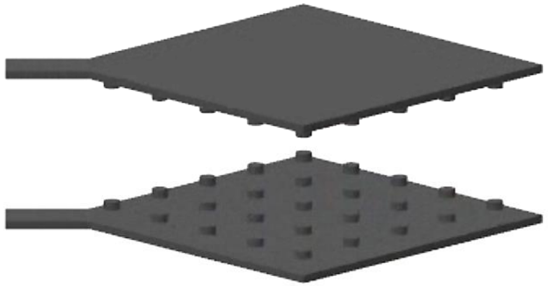

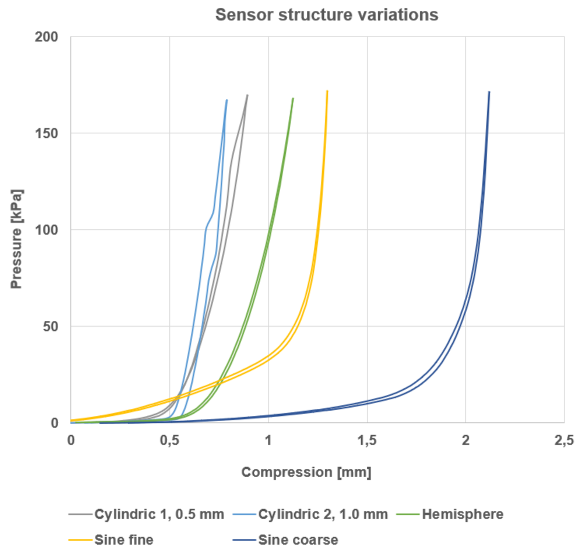

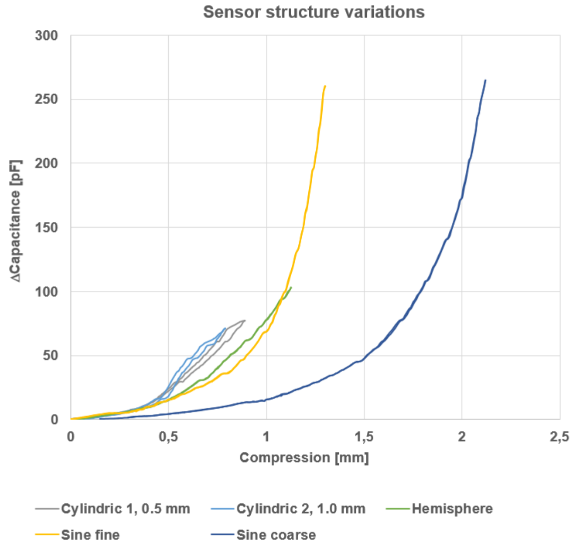

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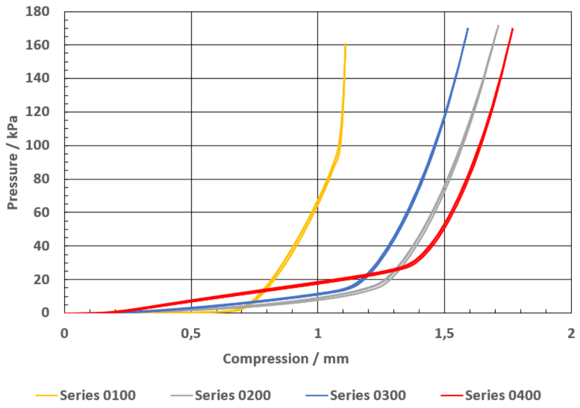
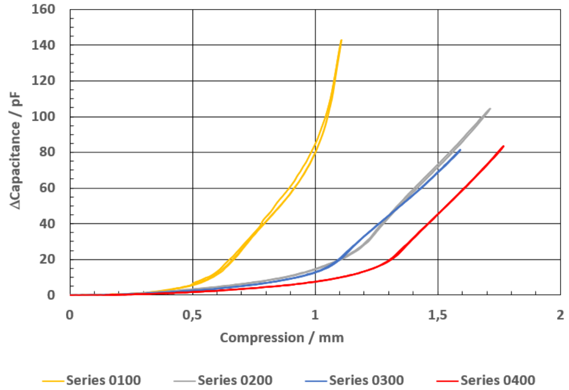


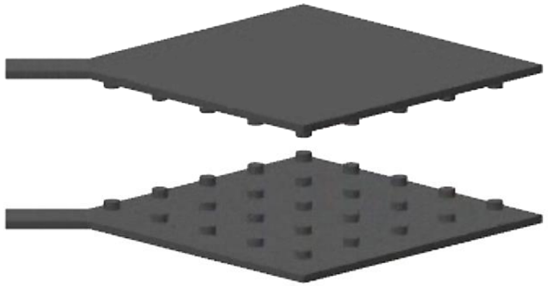


→ Adjustable **electromechanical sensor behavior**

Dielectric elastomer sensors DES

Sensor development & characterization

Screening of **different elastomeric structures:**



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**

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

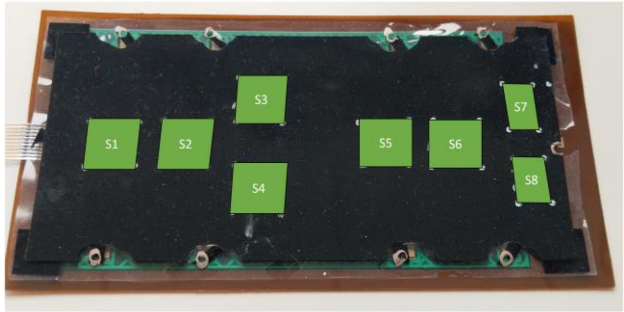
→ **Sensor assessment** according to **mechanical specifications**

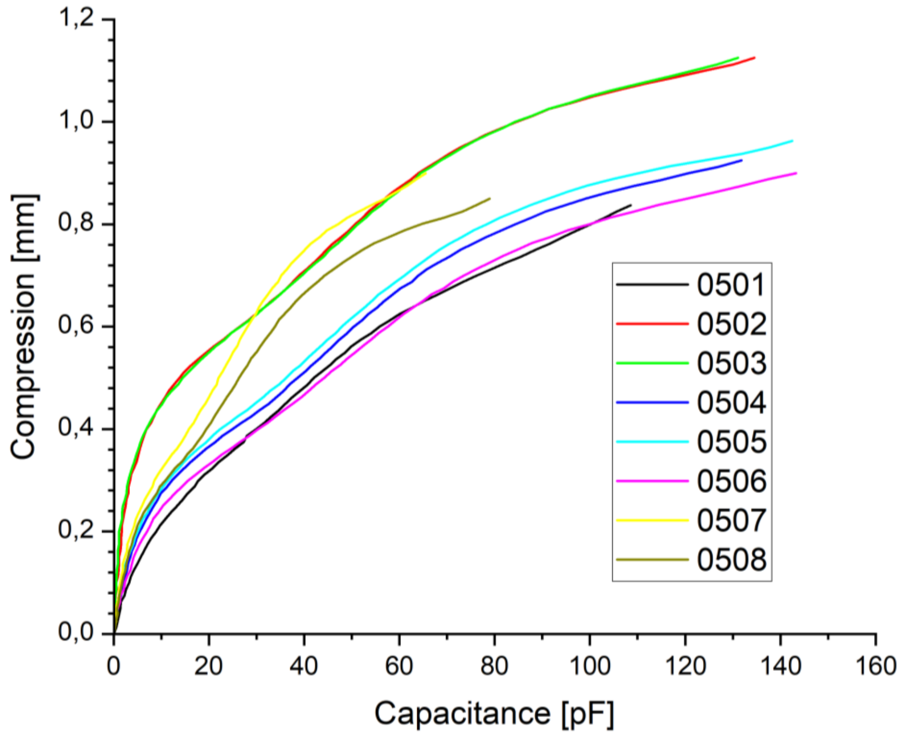
Dielectric elastomer sensors DES

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)



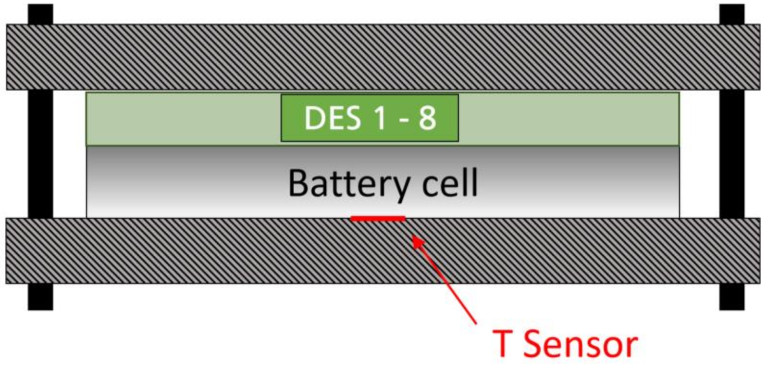


Dielectric elastomer sensors DES

Experimental setup and results

Experimental setup:

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

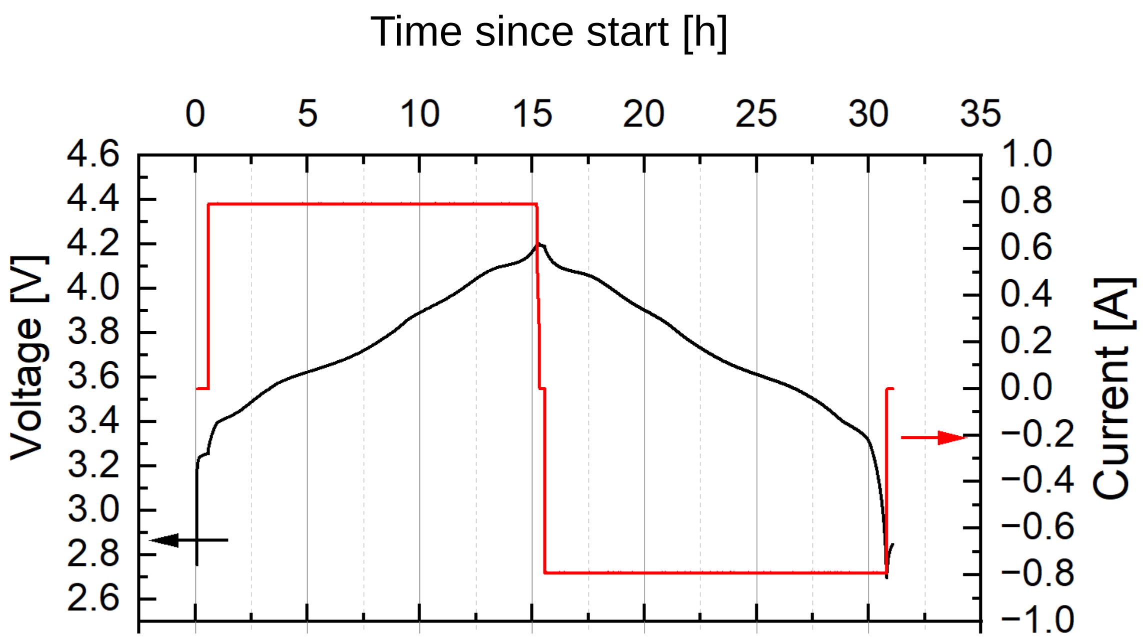


Dielectric elastomer sensors DES

Experimental setup and results

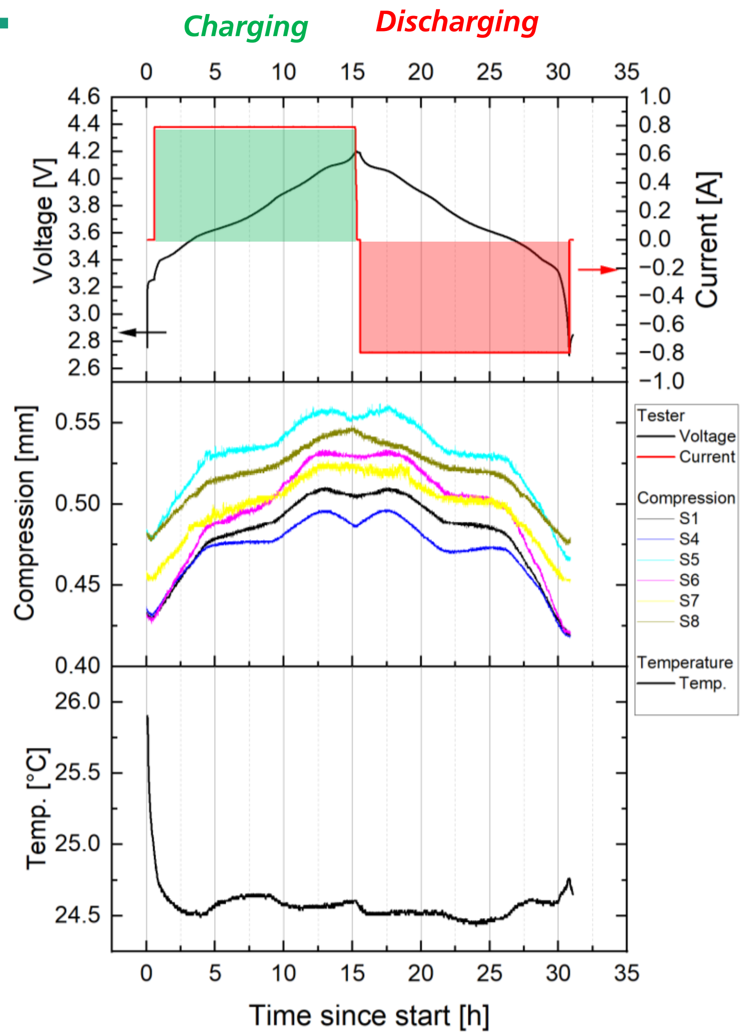
Results:

- 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



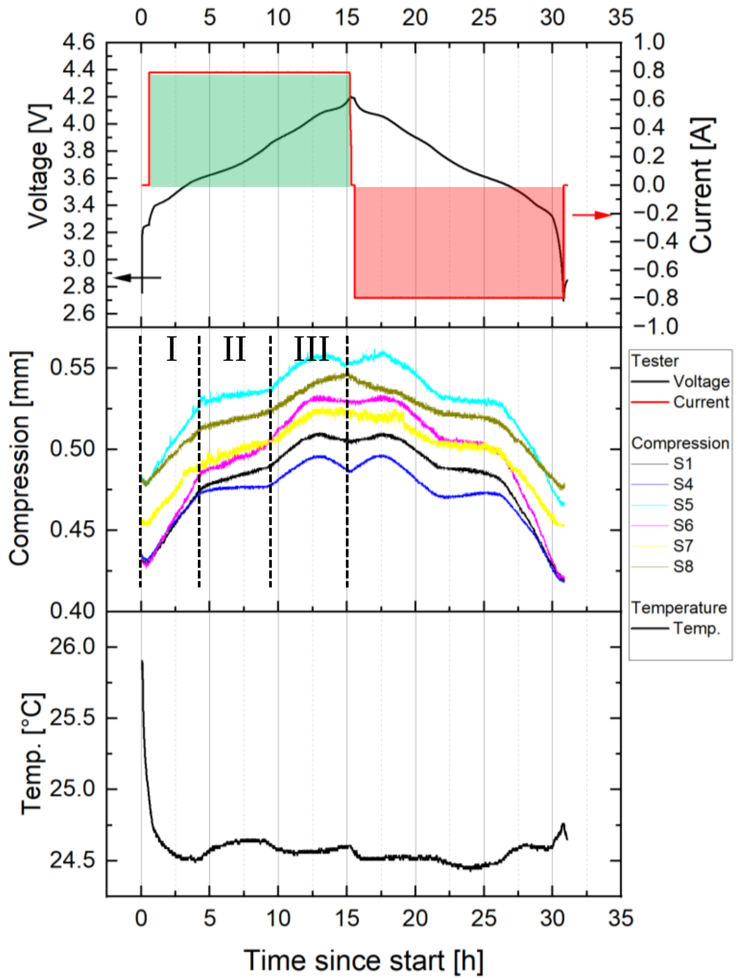
Results:

- **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

[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*



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**

→ 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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https://www.spartacus-battery.eu/

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https://phoenix-smartbatteries.eu/

Contact

Johannes Ehrlich
Center Smart Materials and Adaptive Systems
Fraunhofer ISC
Tel. +49 931 4100-235
johannes.ehrlich@isc.fraunhofer.de
www.isc.fraunhofer.de / www.cesma.de