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Dielectric elastomer sensors adapted for monitoring expansion of clamped battery cells

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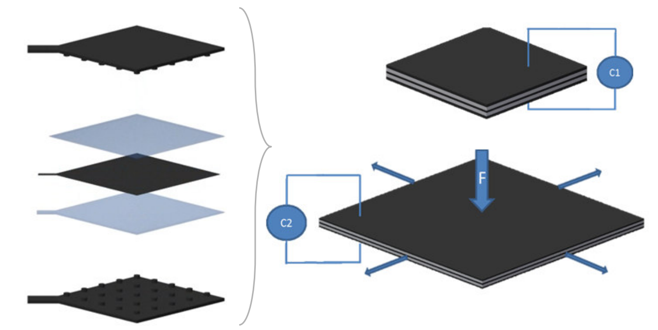
Abstract

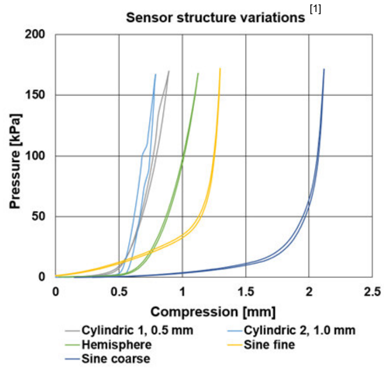
Condition monitoring of Li-ion cells in battery packs for electric vehicles is becoming increasingly important, not only in terms of safety, but also with respect to predictive maintenance and recycling applications. In addition to measuring pack temperature and electrical properties of the cell, monitoring cell expansion in a stacked battery pack provides critically valuable information about the health condition of the cell. Indeed, the cell volume effectively changes during charging and discharging, but also gradually does so irreversibly due to the cell aging. This work presents the development of a dielectric elastomer sensor (DES) system specifically adapted for monitoring the expansion of clamped Li-ion cells. By attaching special elastomer-based structures on both sides of an elastomer film, a thin and soft deformation sensor is realized. Different sensors composed of different elastomer structures were investigated and compared in order to guide the development of the optimal configuration leading to the requested deformation range of the battery cell. The sensor characterization was performed by applying a controlled deformation and by simultaneously recording the sensor signal. Cycling experiments using a sensor array in a clamped setup with the battery cell showed that its expansion could be monitored with high precision during charging and discharging, thereby exposing the great potential of such approach in the field of condition monitoring of Li-ion battery cells.

Dielectric sensor configuration



Sensor structure variations [1]	
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



Evaluation with respect to battery requirements [1]

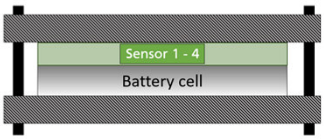
- Initial preload: **25 kPa**
- Additional compression of **200 µm**

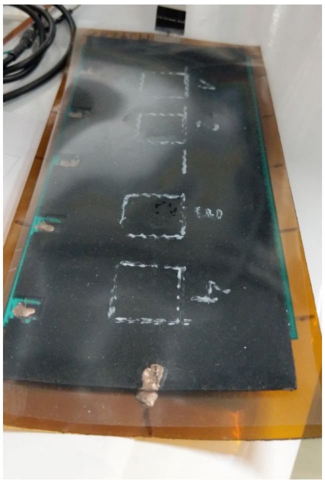
Type of sensor	Δpressure [kPa] Start: approx. 25 kPa	Δcompression [mm] Target ca. 200 µm	ΔCapacitance [pF]
Cylindrical 1: 0.5 mm	25,6 -> 105,8	0,419 -> 0,625	**45,0**
Cylindrical 2: 1.0 mm	22,8 -> 152,3	0,571 -> 0,772	**26,6**
Hemisphere	23,8 -> 81,7	0,76 -> 0,963	**30,5**
Sine: fine	24,9 -> 36,3 25,0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

Sensor array preparation and test setup [1]

→ Highest change of sensor capacity = **Cylindrical 1**

- 4 individual sensor points: located to the middle axis of the array
- Attached towards a flexible PI film for easier handling
- Setup screwed together between two aluminum plates





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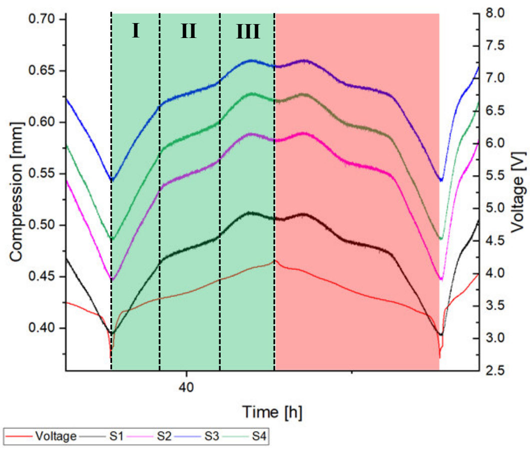
Test results and interpretation

- **Charging**: intercalation of Li-ions into anode material (graphite)
  → **volume expansion**
  → **Compression of sensor**
- **Discharging**: de-intercalation
  → **volume contraction**
  → **Relaxation of sensor**



Preload: S1 = 22 kPa S2 = 22 kPa S3 = 44 kPa S4 = 19 kPa

- **Calculated compression** by using a polynomial fit
- Intercalation takes place in **multiple stages**[2] 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
- Vice versa behavior **during discharge**

Conclusion

- **Precise monitoring** of cell **expansion & contraction** and discrimination of **different expansion rates**
- Development of an **intermediate cell separating layer** with **multiple functions:**
  - Intermediate layer creating a **homogenous mechanical load** to battery cell pack
  - **Cell breathing possible** by soft intermediate layer
  - **Detection** of **cell expansion and contraction** with local resolution

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SPARTACUS

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[2] 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