Solid State Battery – Challenges, Present and Perspectives

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▸ Energy Materials Team

https://tu-freiberg.de/exphys/energiematerialien

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Die Ressourcenuniversität. Seit 1765.

Samara Center for Theoretical Materials Science

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elfolion Batteriespeicher-Technologie

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Team leader

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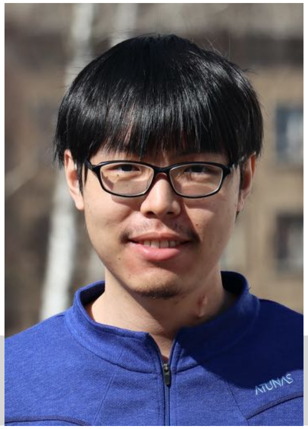
Postdoc



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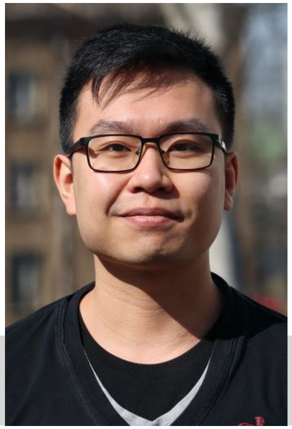

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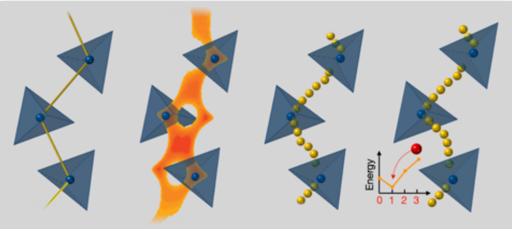
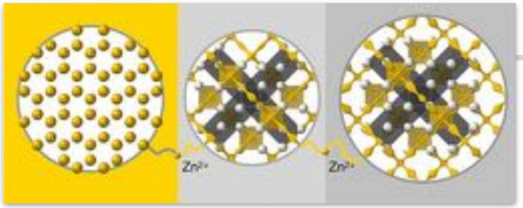
▶ Topics

https://tu-freiberg.de/exphys/energiematerialien



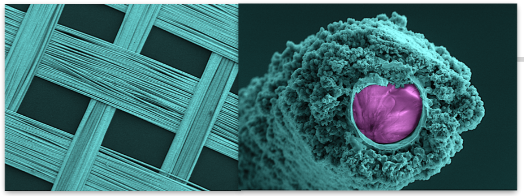
Theoretical methods: GT, BVSE, DFT, ML

Nestler, *et al.*, *Chem. Mater.* 31, 737 (2019).
Meutzner, *et al.*, *Phys, Sci. Rev.* 4, 20180044 (2019).
Eremin, *et al.*, *J. Phys. Chem. C* 123, 29533 (2019).



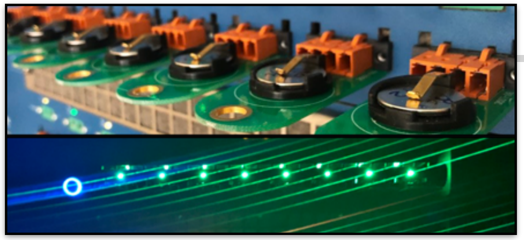
Ionic conductors: Na^{+}/Zn^{2+}/Al^{3+}

Meutzner, *et al.*, *Chem. Eur. J.* 21, 16601 (2015)
Morkhova, *et al.*, *J. Phys. Chem.* 125, 17590 (2021).
Leisegang, *et al.*, *Front. Chem.* 7, 268 (2019).



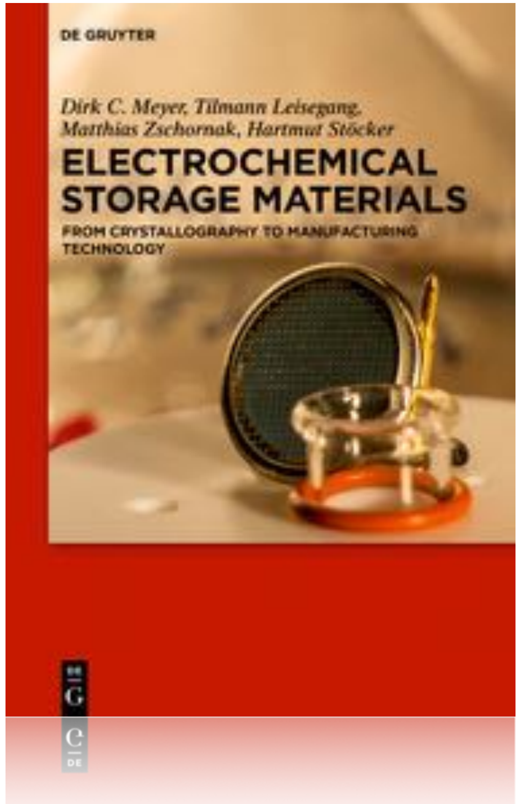
Current collectors: LIB, NIB

ZIM-Project: LiIonSK (ZF4751502JO9).



Batteries: coin/pouch cells, solid state

Stepniak, *et al.*, *RSC Advances* 6, 4007 (2016).
Hanzig, *et al.* *J. Power Sources* 267, 700 (2014).
Nestler, *et al.*, *Crit. Rev. Solid State Mater. Sci.* 44, 298 (2019).
Nestler, *et al.* *AIP Conf. Proc.* 1597, 155 (2014).
Patents: WO2017140581A1, DE102013013785, DE102013013784.



D. C. Meyer, T. Leisegang, *et al.* (Eds.), Berlin, Boston: De Gruyter, 2019.

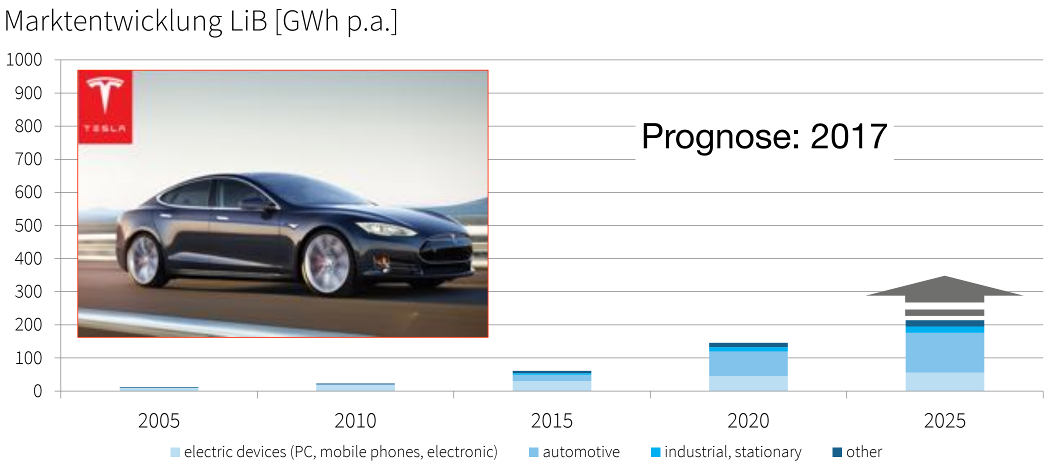
▸ Batteries for Electric Vehicles

~1911

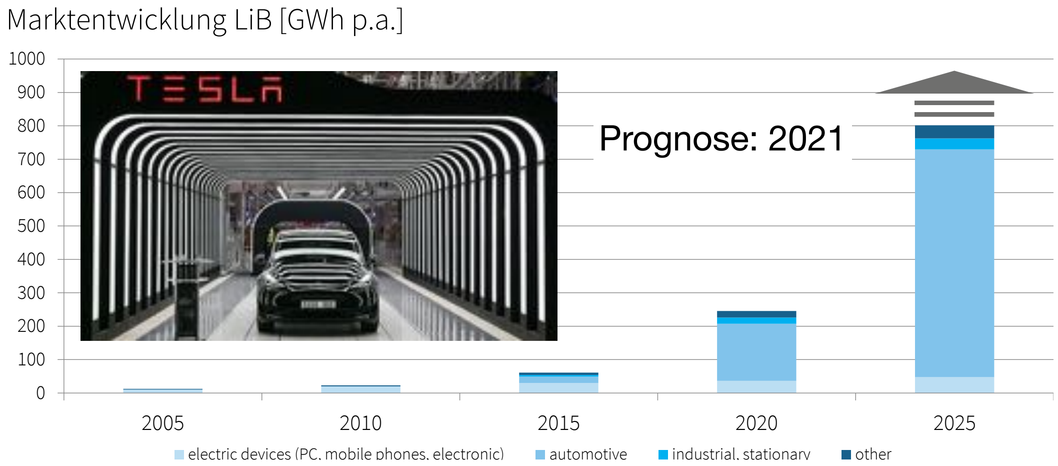
~2013

Leisegang, *et al.*, *Front. Chem.* 7, 268 (2019).

▸ Batteries: Market Development & ASSB Roadmap



Quelle: Avicenne Energy Analysis 2016; Berenberg 2016; SGL Carbon



Quelle: IHS Markit Update 12/2019, Avicenne Reports 2018 & 2019, research reports from major investment banks, SGL Carbon

Lithium all solid sate battery (ASSB) roadmap:

Advanced technologies for industry – Product watch, Solid-state-lithium-ion-batteries for electric vehicles, European Commission, European Union, Brussels, 2021.

▸ Batteries: Market Development & ASSB Roadmap

“The development of all-**solid-state batteries** is one of the most promising and important steps towards **more efficient, sustainable, and safer electric vehicles**.”

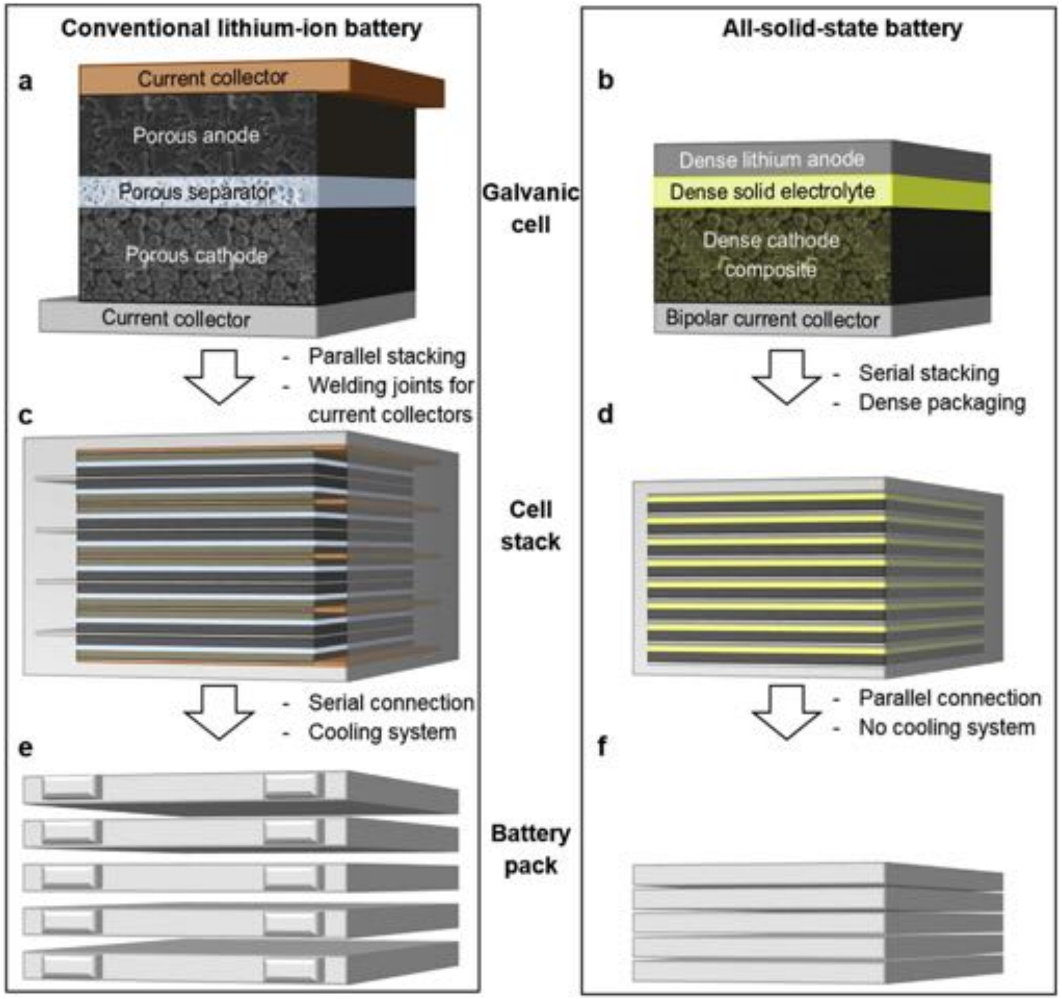
(Frank Weber, BMW board member for development, May 2021)

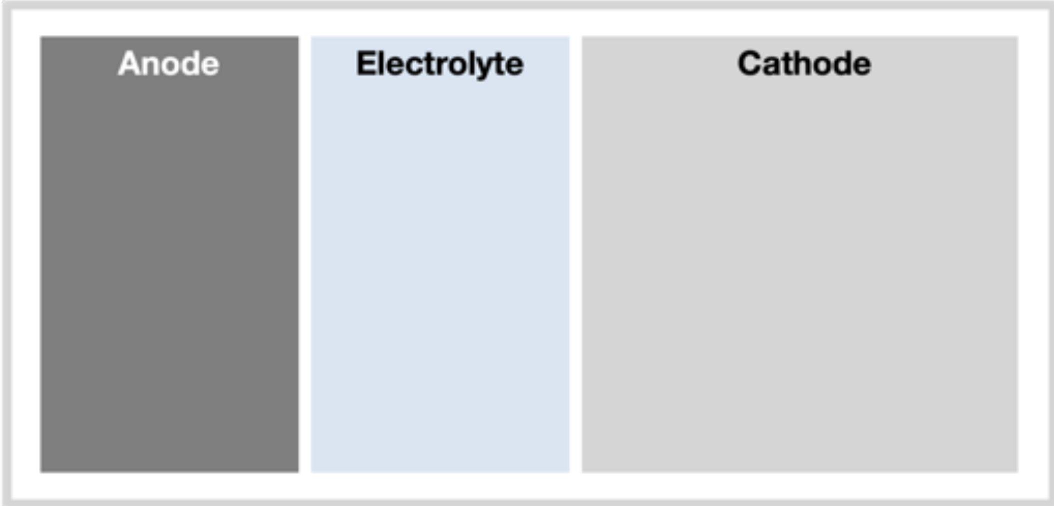
(https://www.electrive.com/2021/05/04/bmw-ford-invest-in-solid-state-battery-specialist-solid-power/)

Lithium all solid sate battery (ASSB) roadmap:

Advanced technologies for industry – Product watch, Solid-state-lithium-ion-batteries for electric vehicles, European Commission, European Union, Brussels, 2021.

▶ Battery





—> increase in **energy density/specific energy**

—> more charge/discharge **cycles**

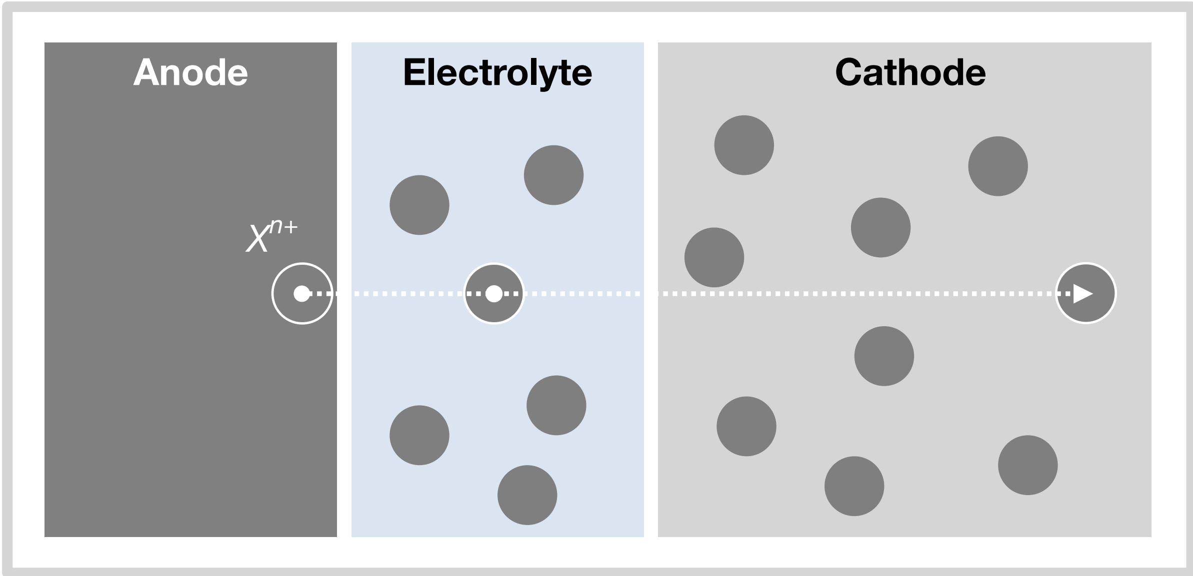
—> higher **safety**

—> wider **temperature** range

—> absence of **leakage** and **corrosion**

Schnell, *et al.*, *J. Power Sources* 382, 160 (2018).

▶ Resources, Economy



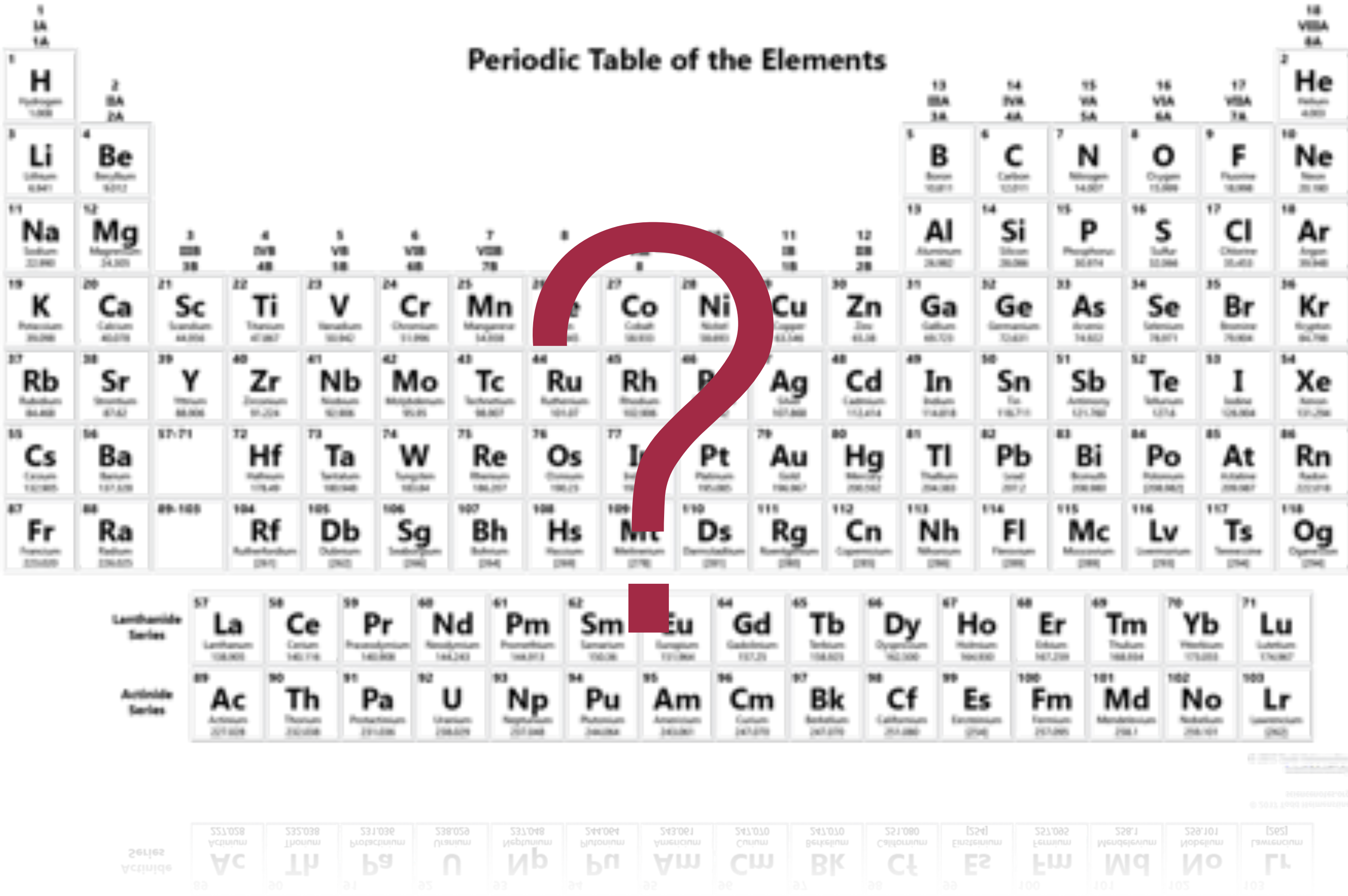
O > 45 at.-%*

X > 30 at.-%*

> 20 at.-%* (rest)

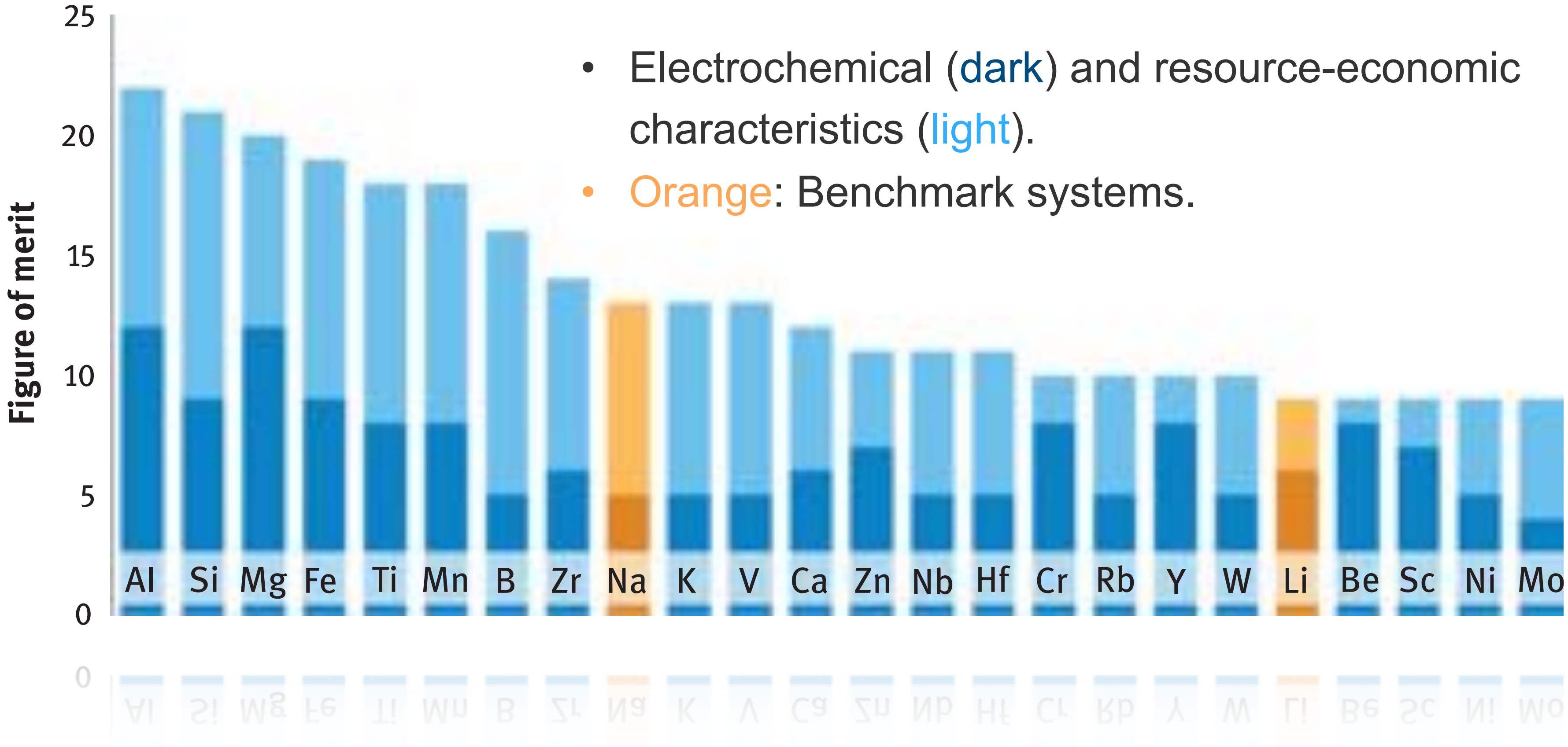
*Prototype: All-Solid-state Li-Ion-battery (Schnell *et al.*, *J. Power Sources* 382, 160 (2018)).
Leisegang, *et al.*, *Front. Chem.* 7, 268 (2019).

▶ Evaluation of Suitable Anode Element



▶ Evaluation of Suitable Anode Element

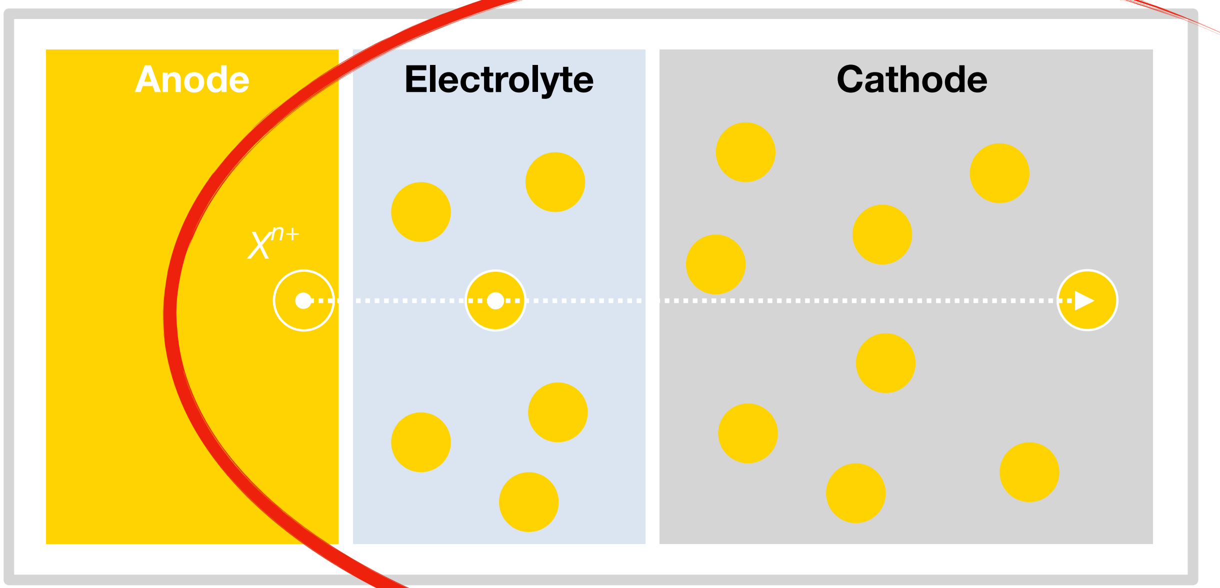
- Strengths and weaknesses analysis of the elements (as anode materials)



- Electrochemical (dark) and resource-economic characteristics (light).
- Orange: Benchmark systems.

Electrochemical Storage Materials: From Crystallography to Manufacturing Technology. D. C. Meyer, T. Leisegang, *et al.* (Eds.), pp. 1–16, Berlin, Boston: De Gruyter, 2019.

▶ Electrolyte and Cathode



O > 45 at.-%*

X > 30 at.-%*

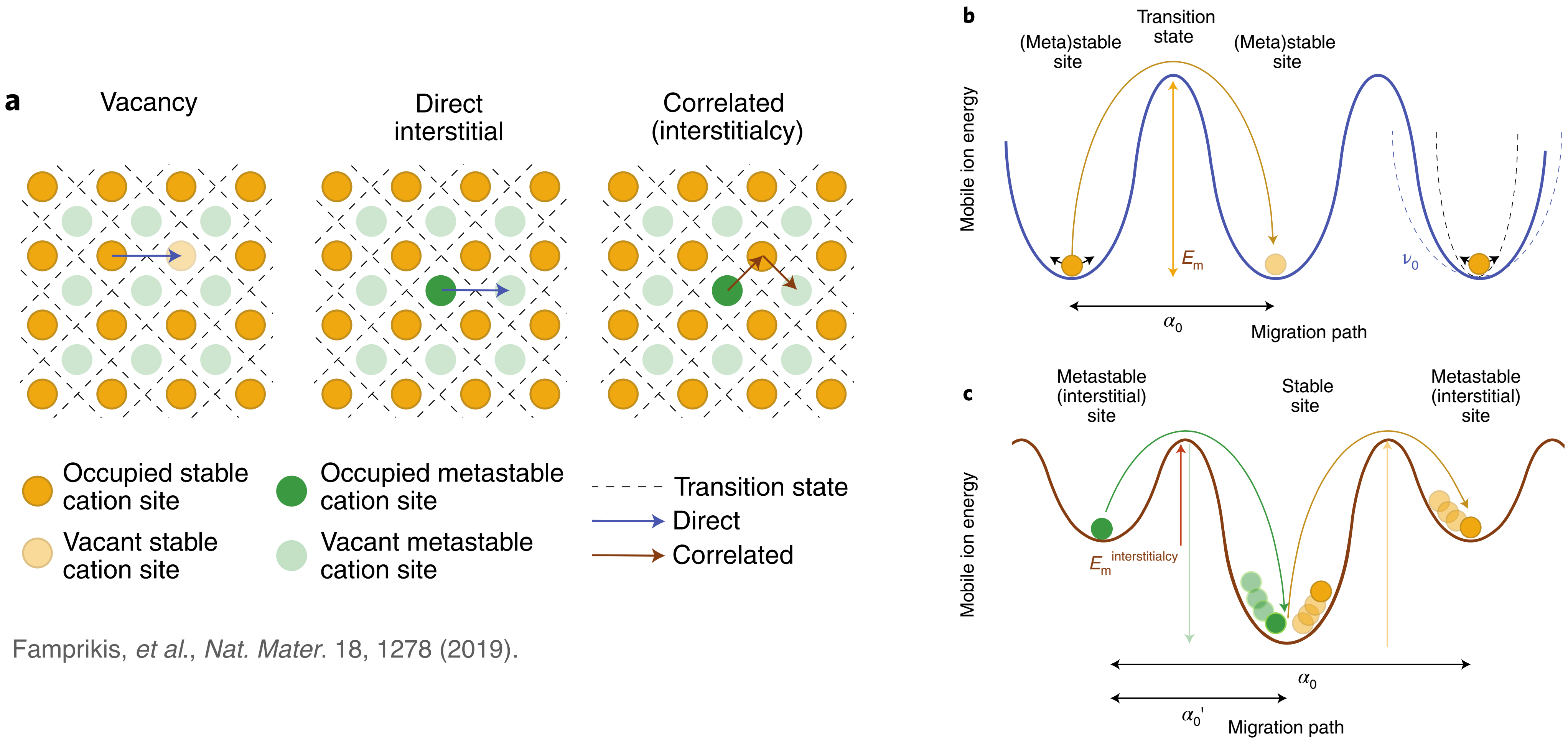
> 20 at.-%* (rest)

- Common property: **ionic conductivity σ**

*Prototype: All-Solid-state Li-Ion-battery (Schnell *et al.*, *J. Power Sources* 382, 160 (2018)).

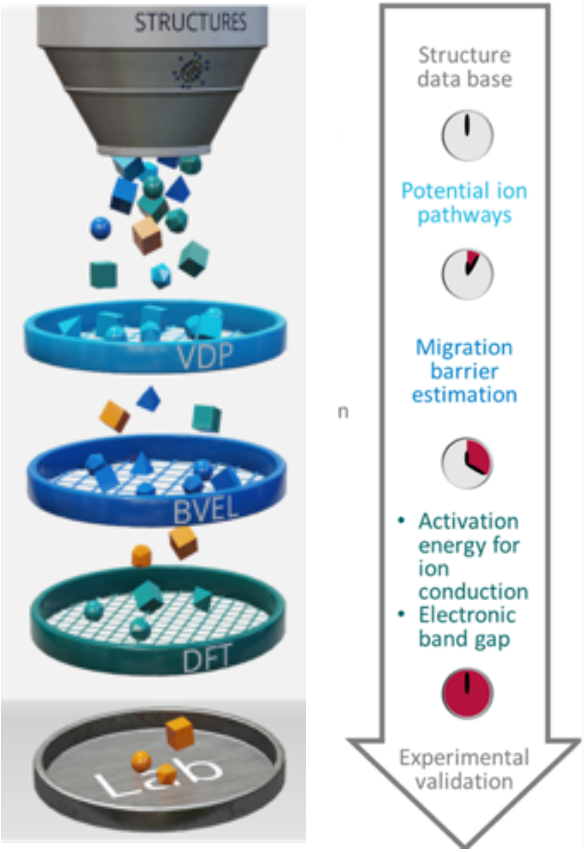
Leisegang, *et al.*, *Front. Chem.* 7, 268 (2019).

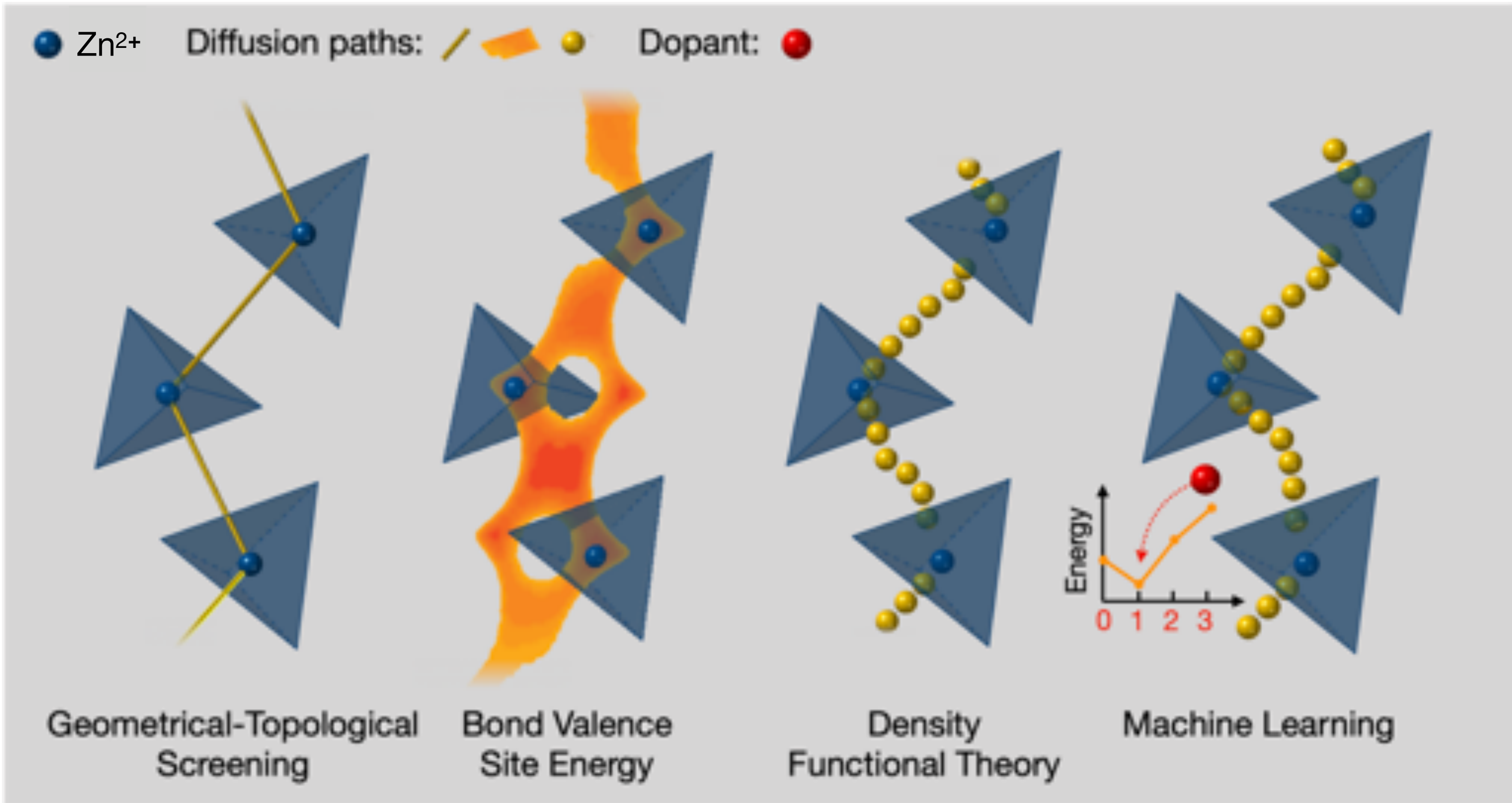
▸ Ionic Conductivity



Famprikis, *et al.*, *Nat. Mater.* 18, 1278 (2019).

▸ Search Algorithm for Ion Conductors





Nestler, *et al.*, *Chem. Mater.* 31, 737 (2019).

Leisegang, *et al.*, *Front. Chem.* 7, 268 (2019).

TOPOSPRO

SoftBV

Eremin, *et al.*, *J. Phys. Chem. C* 123, 29533 (2019).

Blatov, *et al., Cryst. Growth Des.* 14, 7, 3576 (2014).

Chen, *et al.*, *Acta Crystallogr. B,* 75.1, 18 (2019).

▸ Search Algorithm for Ion Conductors

Collection of cathode & solid electrolyte materials: https://batterymaterials.info

Nestler, *et al.*, *Chem. Mater.* 31, 737 (2019).

Leisegang, *et al.*, *Front. Chem.* 7, 268 (2019).

TOPOSPRO

SoftBV

Eremin, *et al.*, *J. Phys. Chem. C* 123, 29533 (2019).

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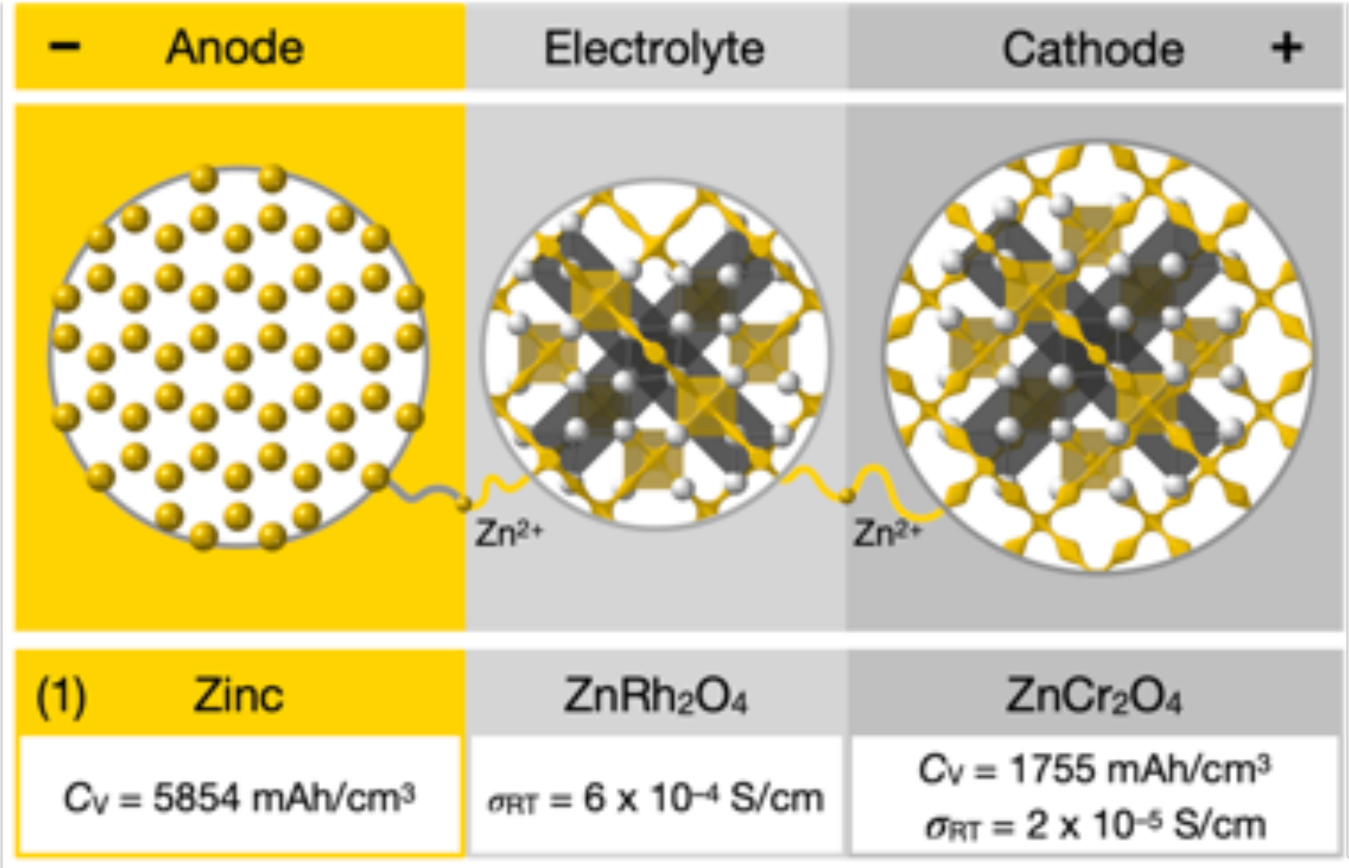
Chen, *et al.*, *Acta Crystallogr. B,* 75.1, 18 (2019).

▶ Solid State Battery: From Materials to Design



Morkhova *et al.*, *J. Phys. Chem*. 125, 17590 (2021).

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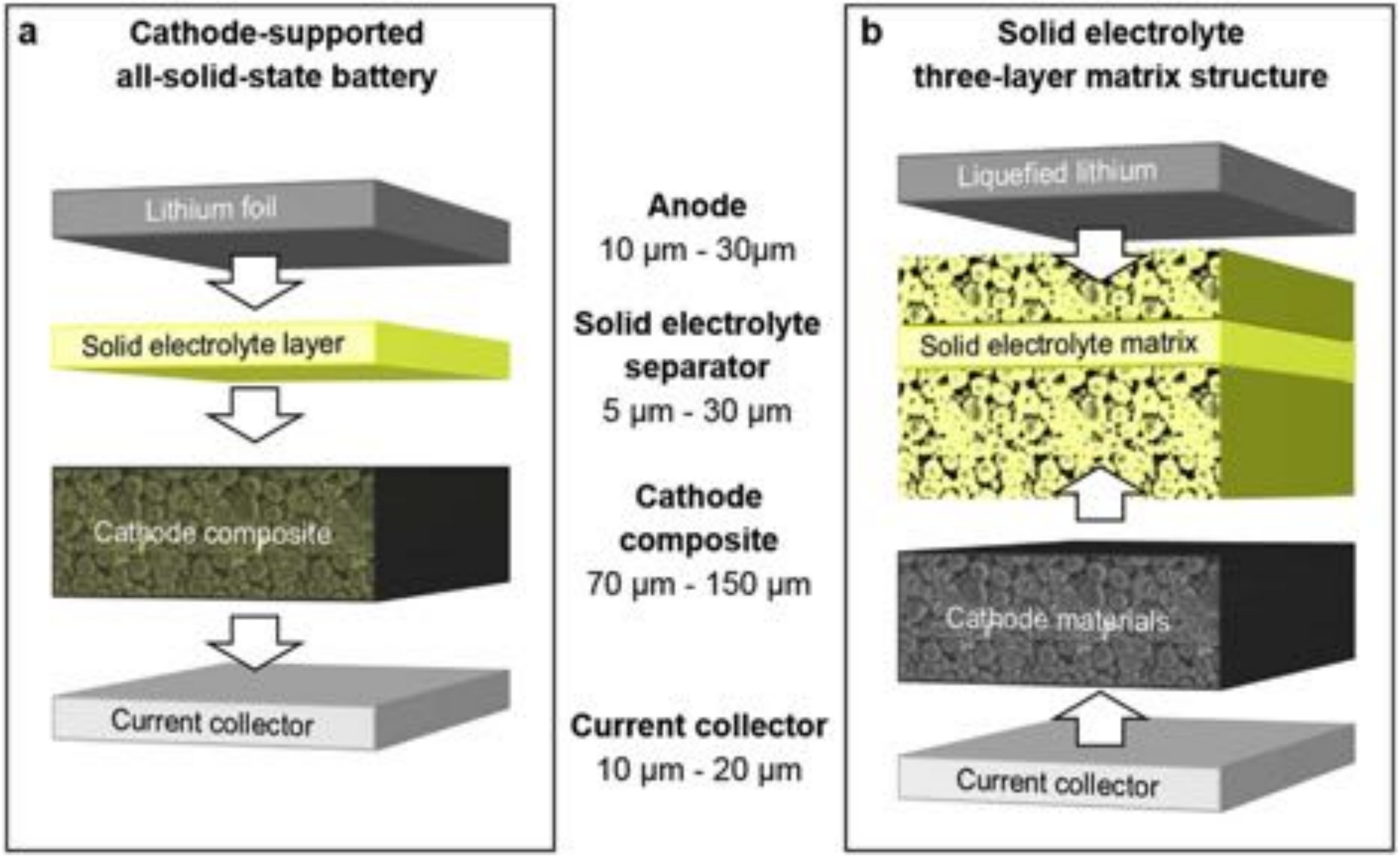
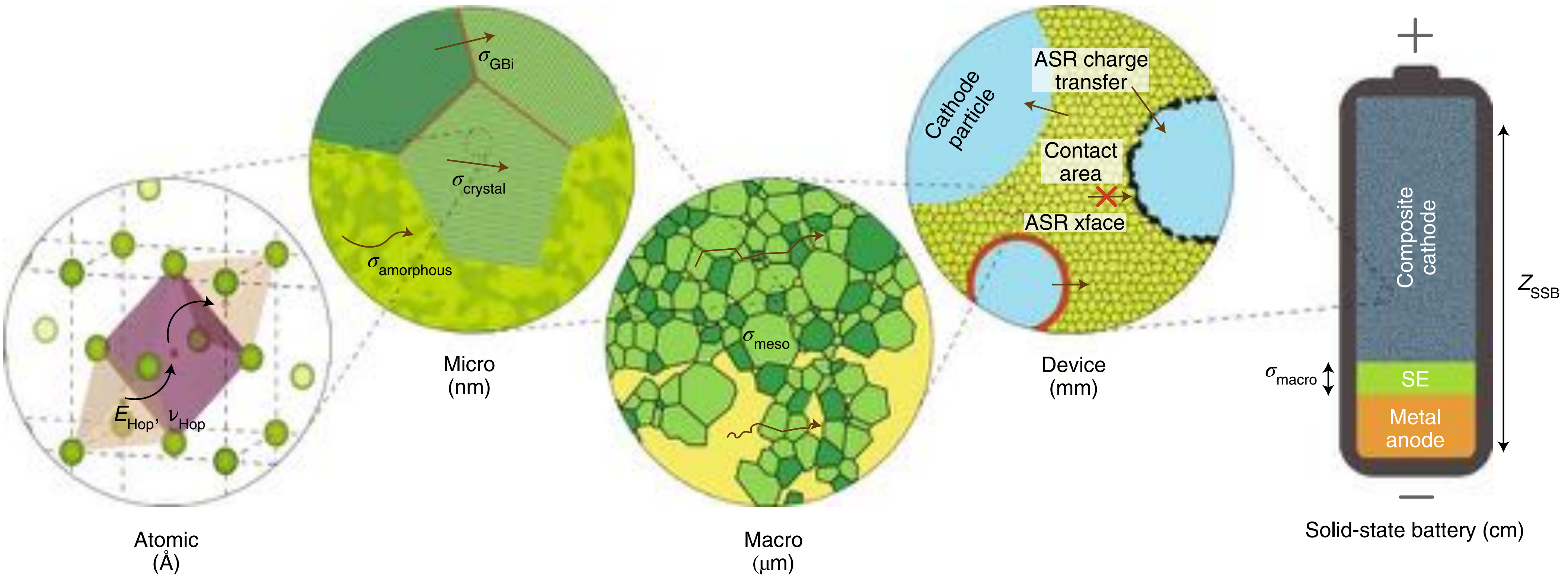


Schnell, *et al.*, *J. Power Sources* 382, 160 (2018).

▸ Solid State Battery: Multiscale Ion Transport & Microstructure

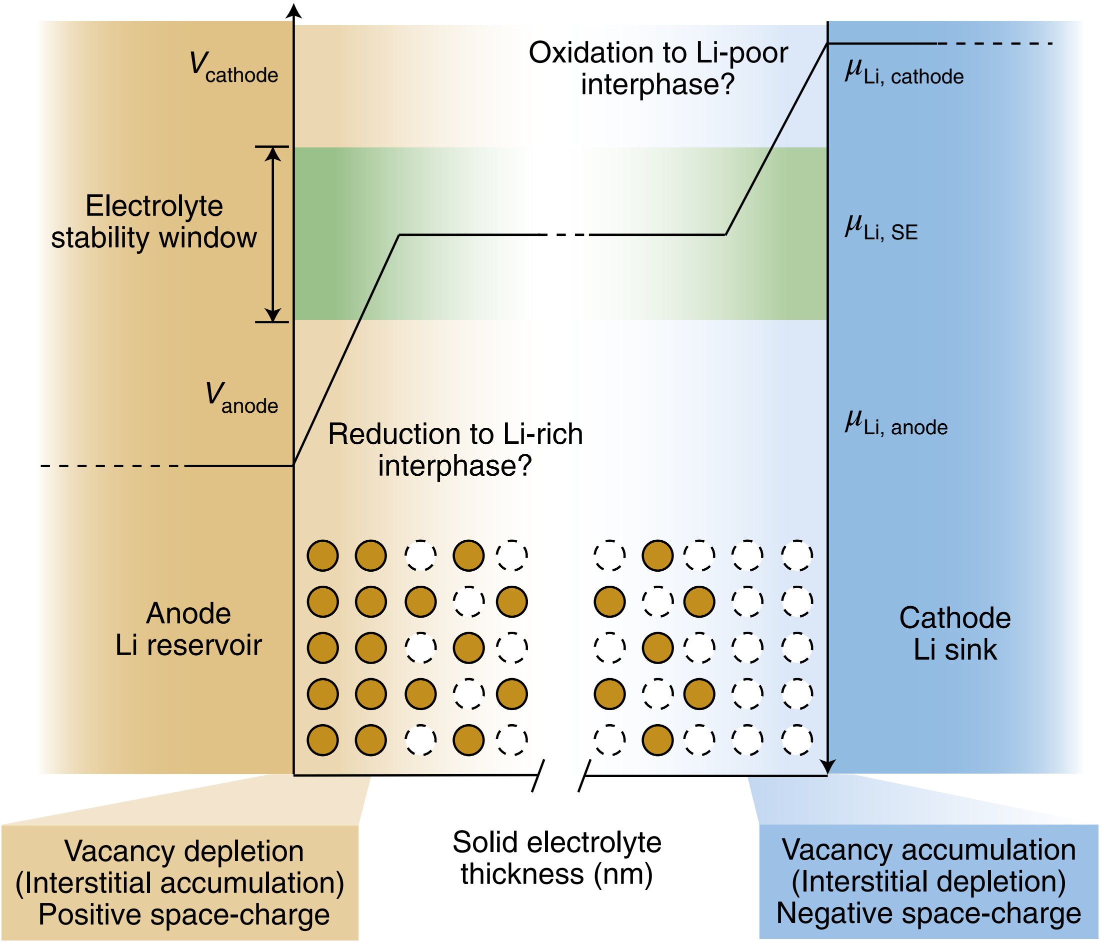


Famprikis, *et al.*, *Nat. Mater.* 18, 1278 (2019).

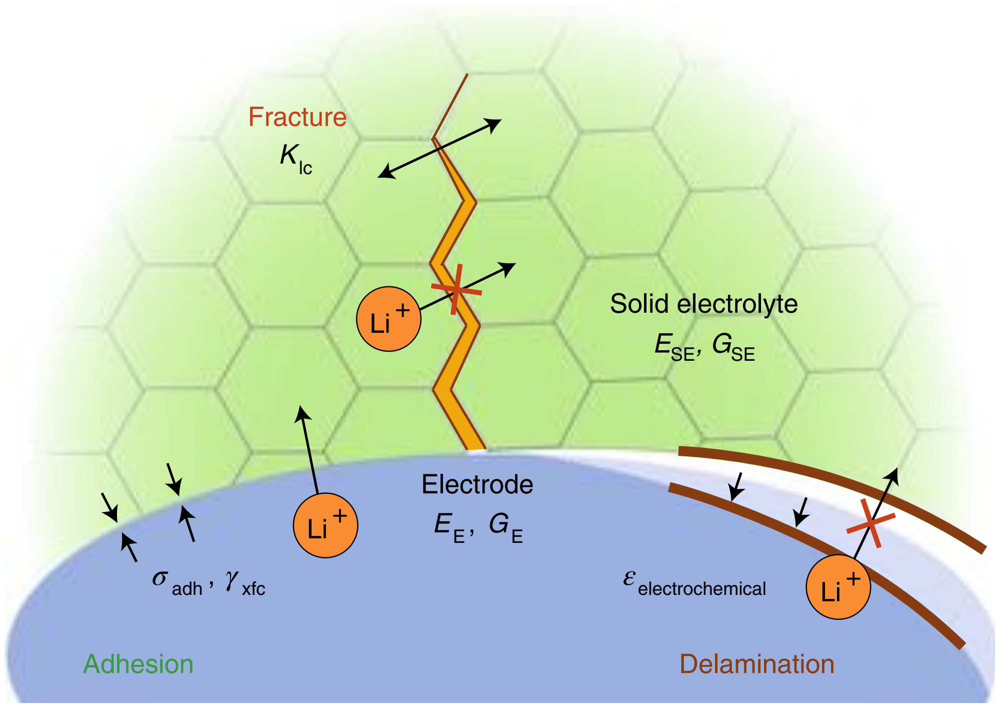
- Various physiochemical and electrochemical transport phenomena occurring at multiple length and time scales.

▸ Solid State Battery: Fundamentals & Challenges

• Evolution of chemical potential:



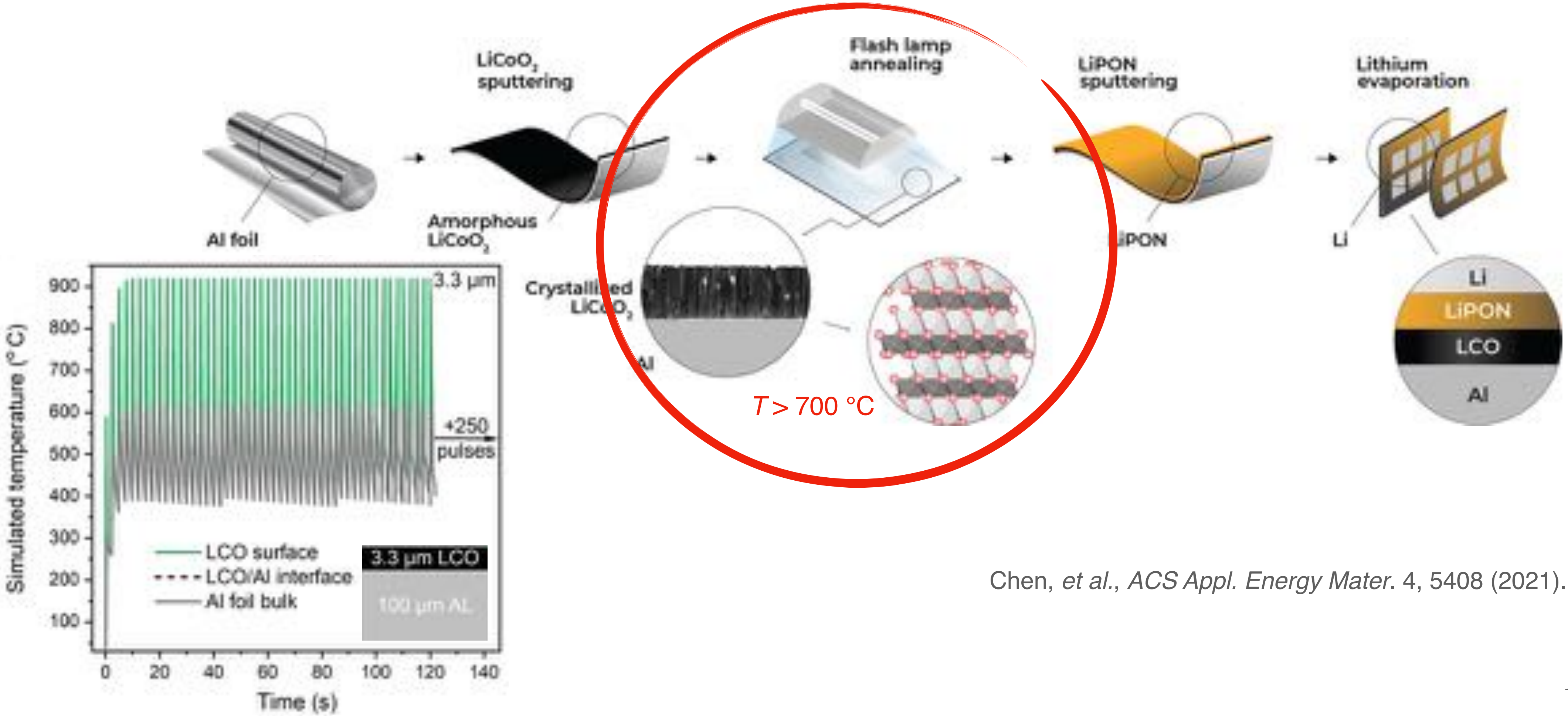
• Mechanical degradation:



Famprikis, *et al.*, *Nat. Mater.* 18, 1278 (2019).

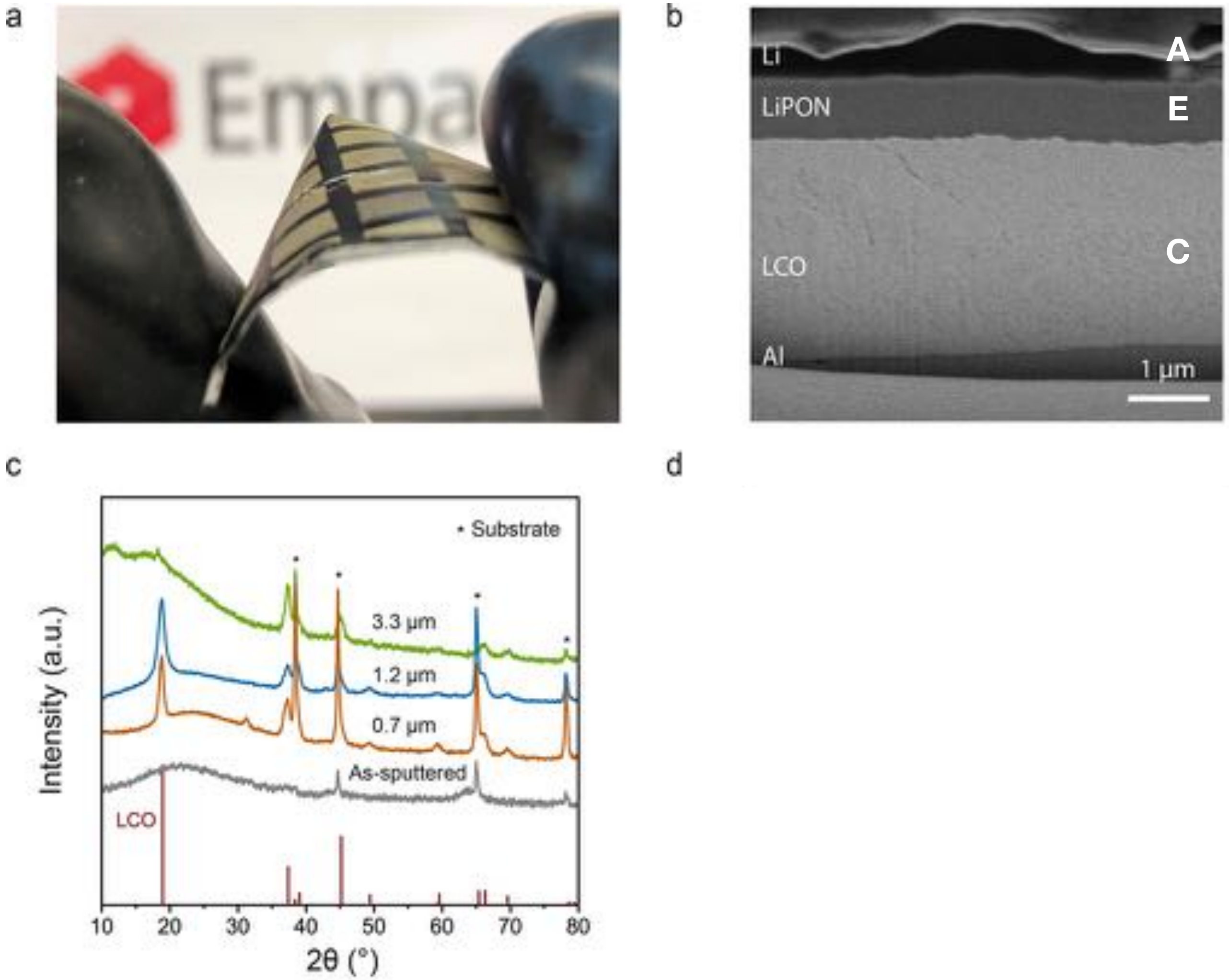
▸ Manufacturing of TF-SSB: SSB Meets FLA

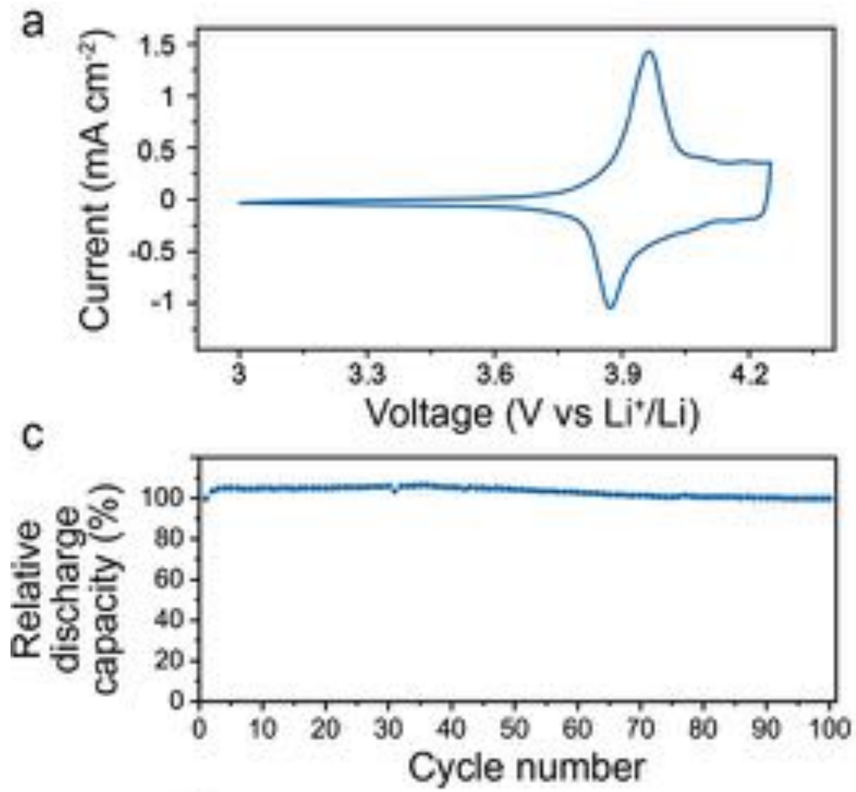
- Thin-film solid-state batteries: low-power devices such as wearable sensors, implantable medical devices, RFID, …



Chen, *et al.*, *ACS Appl. Energy Mater.* 4, 5408 (2021).

▸ Manufacturing of TF-SSB: SSB Meets FLA





Chen, *et al.*, *ACS Appl. Energy Mater*. 4, 5408 (2021).

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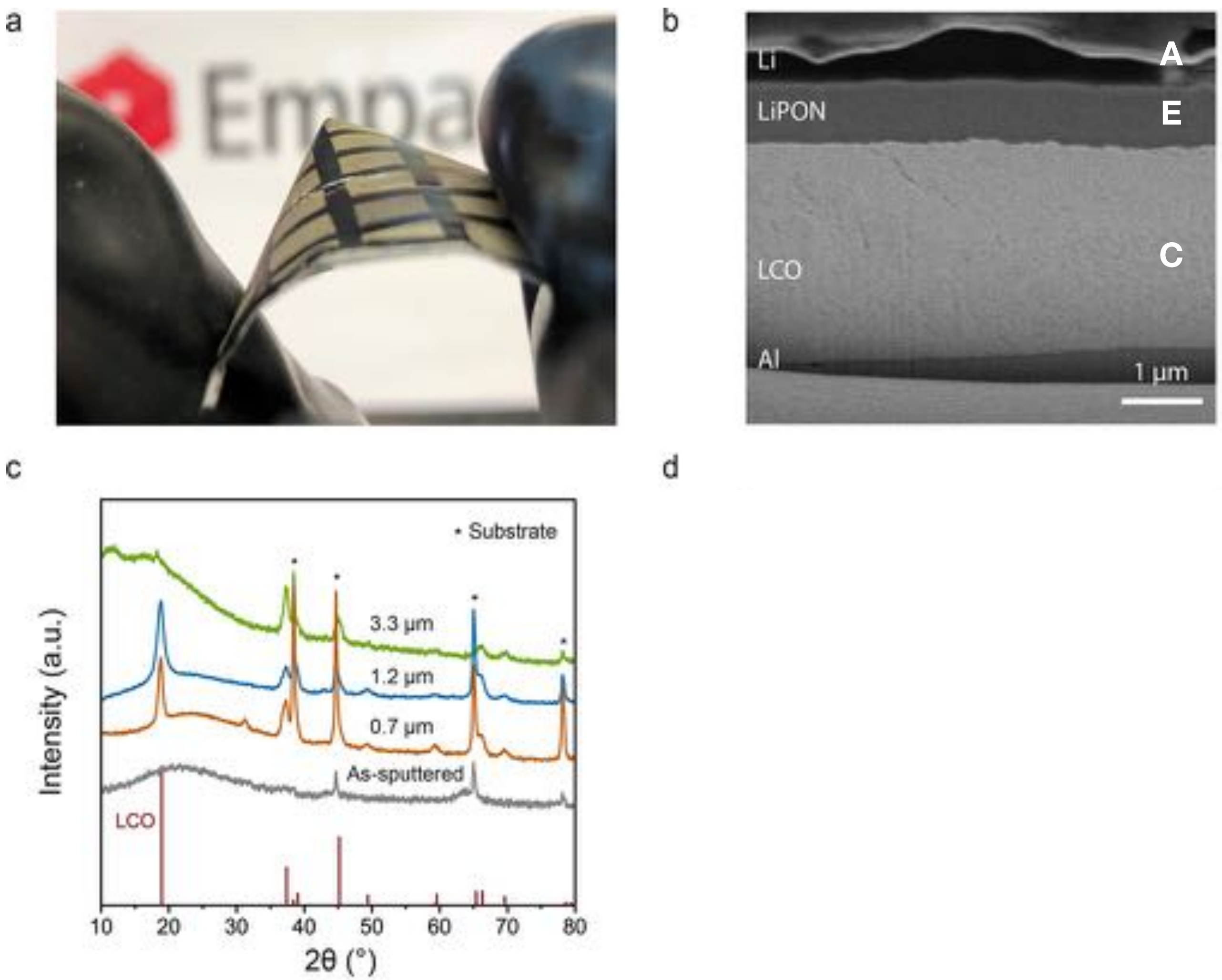
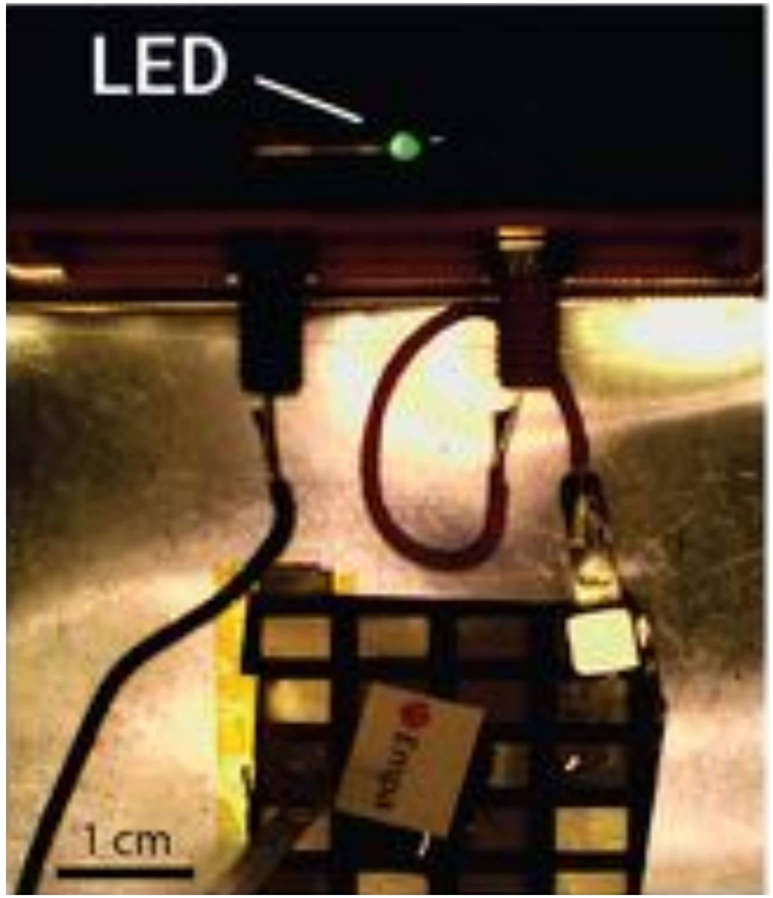
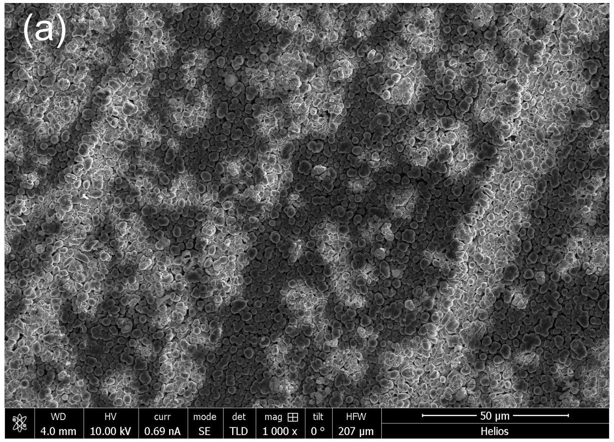
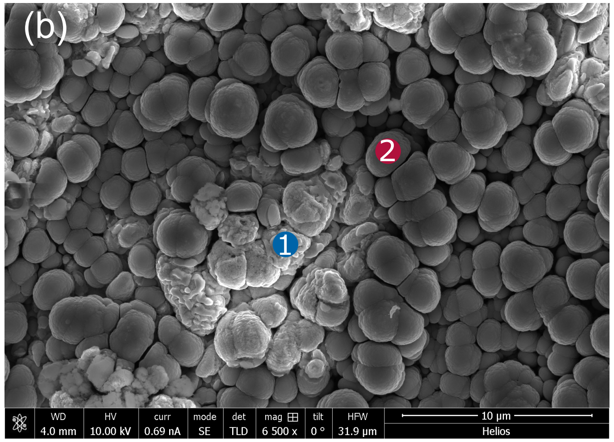


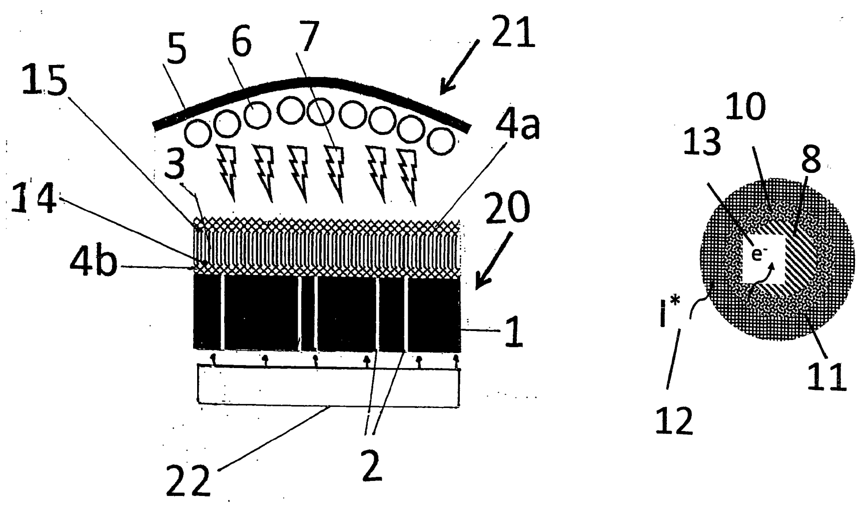


Chen, *et al.*, *ACS Appl. Energy Mater*. 4, 5408 (2021).

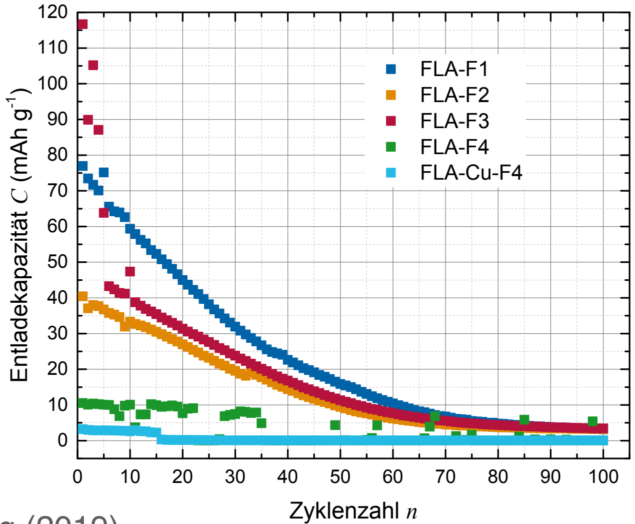
▸ Manufacturing of Electrode: Anode Meets FLA







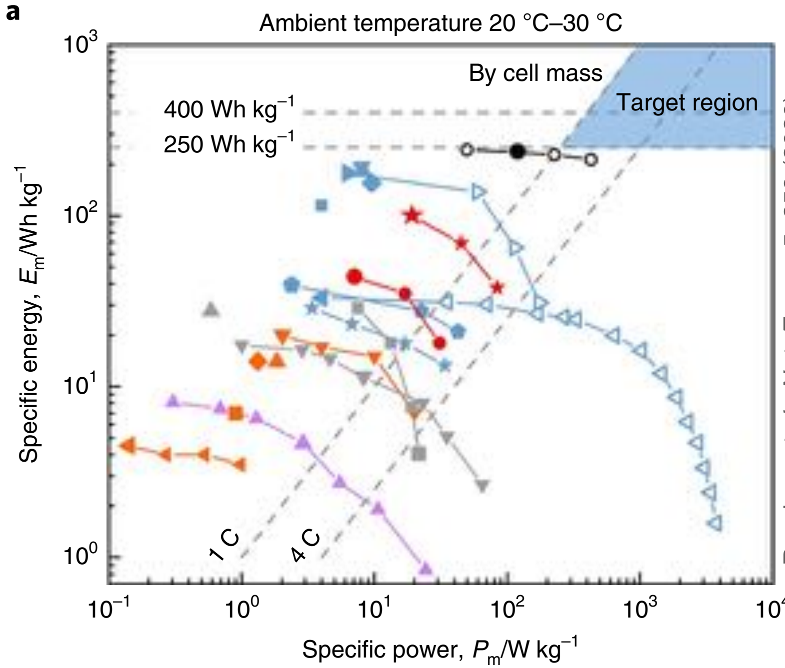
DE102016001949A1/WO2017140581A1.



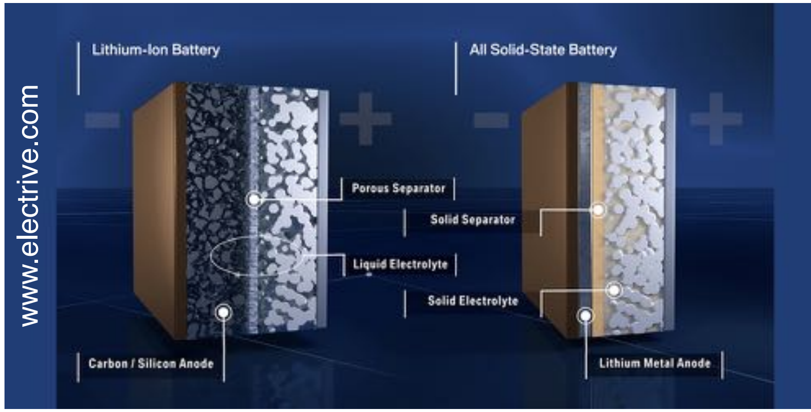
L. Wolf, *Bachelor Thesis*, TU BA Freiberg (2019).

▸ Summary

- **Batteries**: High upcoming materials demand (resources & raw materials)
- **SSBs**:
  - \+ solid-electrolytes more tolerant to changes in temperature, physical damages, to overcharging, deep discharging
  - \+ higher safety, more resource efficient
  - – creating effective solid electrolyte/active material interfaces, overall reduction of the amount of solid electrolyte
  - – interfaces electrochemically (and chemically) stable at both anodic and cathodic limit to avoid formation of unfavorable passivation or reaction layers
  - – mass market processing techniques to achieve the internal resistance and current density requirements for high energy and high power
- **Flash Lamp Annealing**: Formation of crystalline phases and dedicated microstructure, infiltration/mixing of materials, …



Randau, *et al.*, *Nat. Energy* 5, 259 (2020).



www.electrive.com

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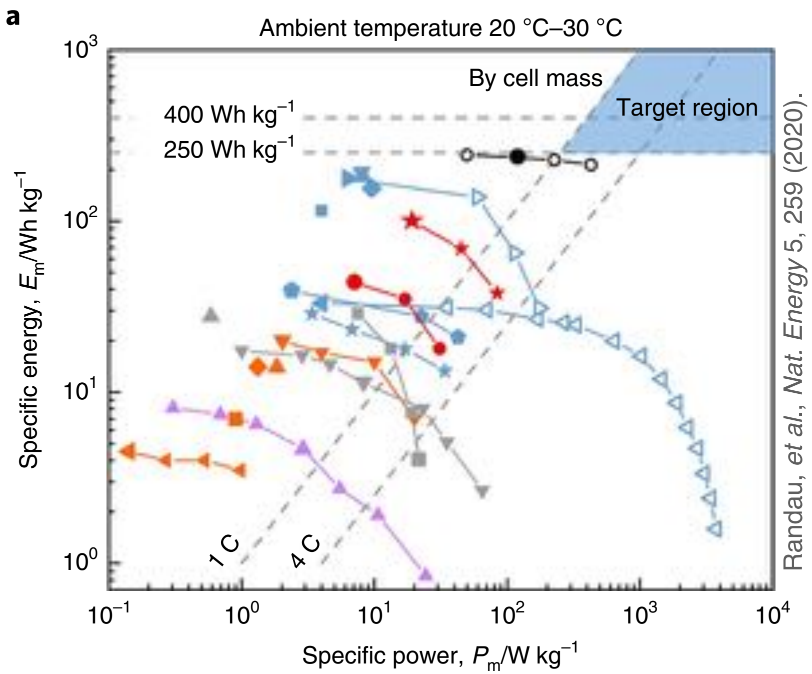

"…excluding cell casing, ASSBs with **specific energy** beyond **400 Whkg^{-1}**, **energy density** beyond **1,000 Whl^{-1}** and more than **90 % energy efficiency** at a **1C rate** are within reach…"

(Randau, *et al.*, *Nat. Energy* 5, 259 (2020))

▶ Acknowledgements

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Empa Materials Science and Technology

elfolion Batteriespeicher-Technologie

Marek Haiduk

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GEFÖRDERT VOM

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Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

ZIM Zentrales Innovationsprogramm Mittelstand