

Next-generation all-solid-state battery

Tuan Vo^{a,b,†}, Claas Hüter^b, Stefanie Braun^a, Manuel Torrilhon^a
vo@acom.rwth-aachen.de

^aDepartment of Mathematics, Applied and Computational Mathematics (ACoM), RWTH Aachen University, Schinkelstraße 02, 52062 Aachen, Germany

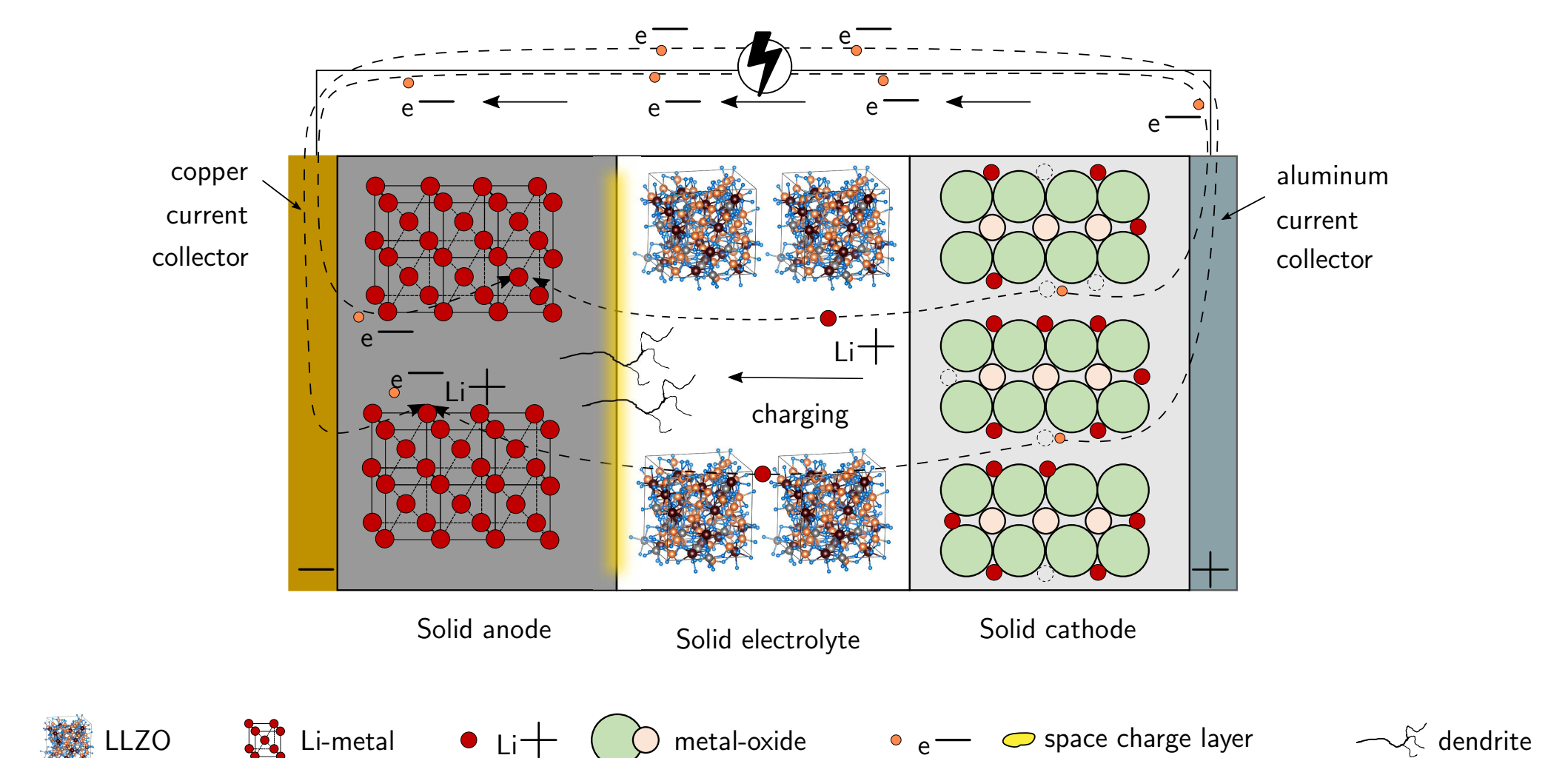
^bInstitute of Energy and Climate Research (IEK-2), Forschungszentrum Jülich, Wilhelm-Johnen-Straße, 52428 Jülich, Germany

Mathematical modelling for the next-generation All-solid-state batteries: Nucleation (SE|SSE)^(*)-interface

Rechargeable Lithium-ion battery (LIB) stays at the heart of electric vehicles, portable electric devices, and energy storage systems [1]. Nowadays, LIBs help human life become more efficient as well as to cope with global environment issues thanks to its zero emission. However, conventional LIB (cLIB) is sensible to temperature and pressure, easily prone to flammable and explosive. This is mainly due to liquid-based electrolyte found in cLIBs. **All-solid-state battery (ASSB)** is, therefore, one of promising candidates to overcome bottlenecks of conventional LIBs. It is because the solid-state electrolyte (SSE) in ASSB, e.g. SSE made of the highly ionic-conductive polycrystalline LLZO, is highly stable towards temperature and pressure. Nevertheless, metallic Lithium dendrite triggered at (SE|SSE)-interface is the main drawback as these dendritic threads extrapolate into grain boundary network of SSE, causing degradation of ionic conductivity and the likelihood of short-circuit.

$$a_{\text{Griffith}} := a^* = \arg \min_{a \in \mathbb{R}} \left(\iint_{\Omega} f(a, \mathbf{u}; \lambda, \mu, \mathbf{d} \otimes \mathbf{d}) d\Omega - \iint_{\Gamma} f(a; \gamma) d\Gamma \right) \Big|_{\mathbf{u}(s)}$$

Next-generation All-solid-state battery (ng-ASSB) should, consequentially, be able to cope with micro-dendritic threads at the (SE|SSE)-interface, and hence, to foresee nucleation points caused by propagations of these dendrites, when possible.

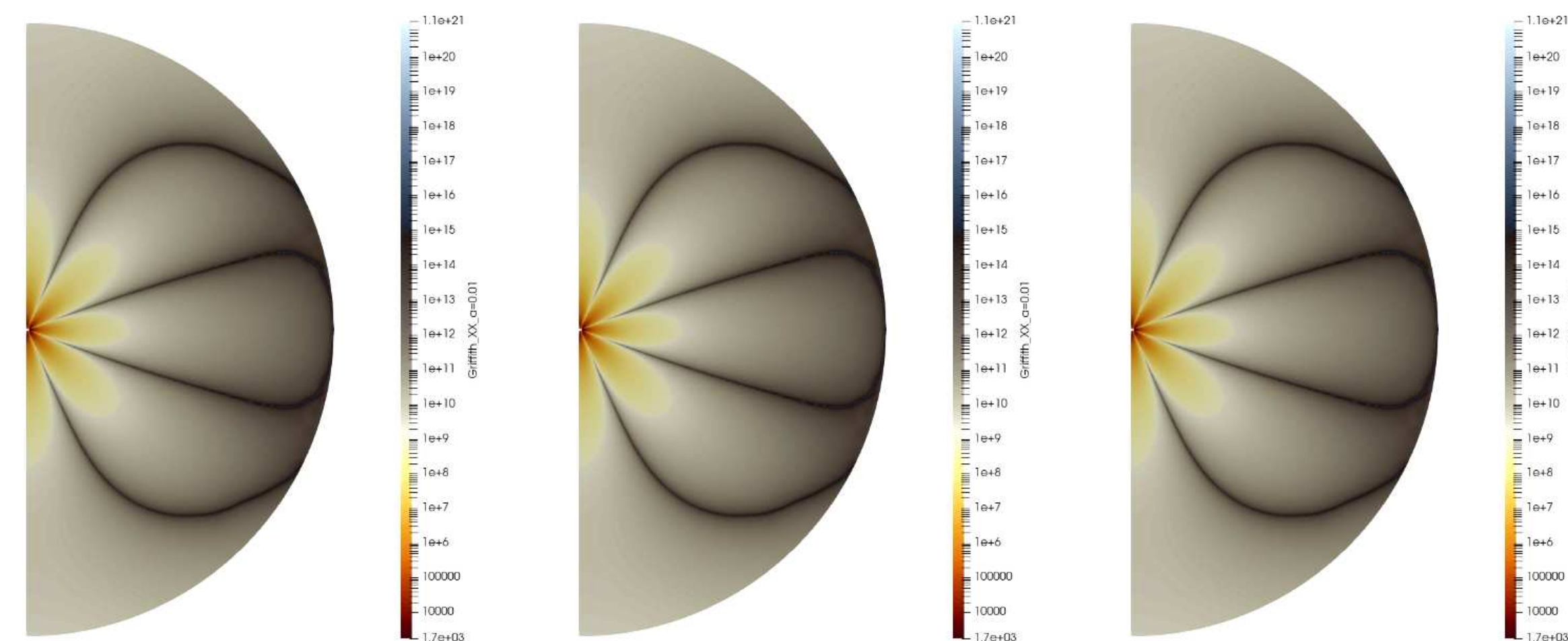
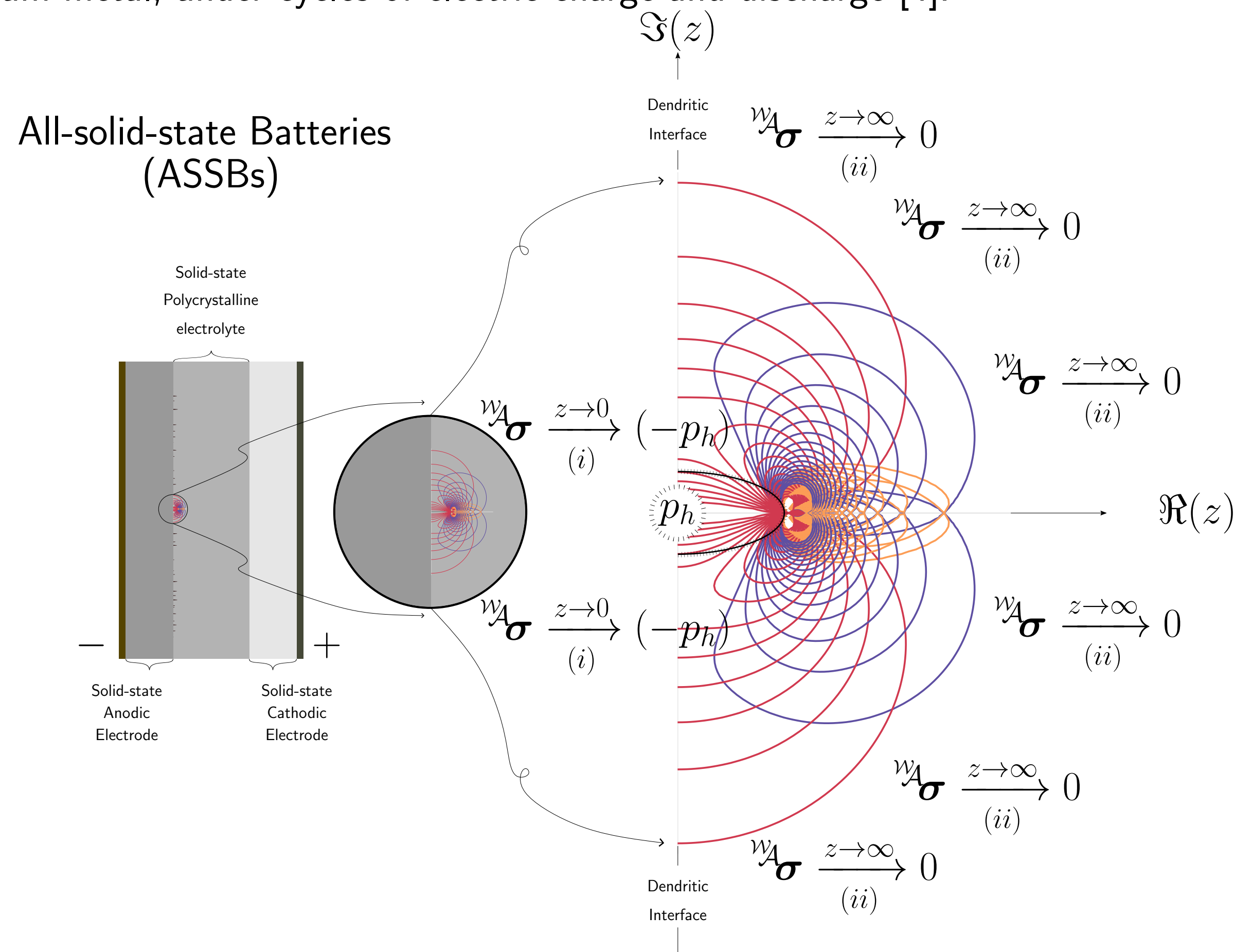


Next-generation All-solid-state battery (ng-ASSB)

Comparison: Analytical vs. Numerical solution

Nucleation interface

Interface between solid electrode and solid-state electrolyte (SE|SSE) taking place at space charge layer (SCL) [2] found in all-solid-state lithium-ion batteries (ASSLiBs) critically exhibits mechanical and electrochemical instability [3]. This evidence points directly to the fact that the soft metallic lithium negative electrode is erroneously prone to triggering dendritic by-products of silvery lithium metal, under cycles of electric charge and discharge [4].



Besides, polycrystalline garnet-typed solid-state electrolyte such as LLZO exhibit grain boundaries and various sizes and shapes of grains under microscopic observation. Therefore, this type of microstructure distinctively leads to nuance destruction of ceramic-like materials. Consequentially, dendritic by-products contribute to degradation of ionic conductivity and trace along grain boundaries in SSE. This phenomenon, notwithstanding, is predicted, quantified, and controlled based on analysing the multi-scale coupled problem subjected to conditions of Griffith criterion.

References

- [1] **T. Vo** *Modeling the swelling phenomena of li-ion battery cells based on a numerical chemo-mechanical coupled approach*. Master thesis, Robert Bosch Batteries Systems GmbH, 2018.
- [2] **S. Braun**, C. Yada and A. Latz. *Thermodynamically consistent model for Space-Charge-Layer formation in a solid electrolyte*. Journal of Physical Chem., 119, 22281-22288, 2015.
- [3] **C. Hüter**, S. Fu, M. Finsterbusch, E. Figgemeier, L. Wells, and R. Spatschek. *Electrode-electrolyte interface stability in solid state electrolyte system: influence of coating thickness under varying residual stresses*. AIMS materials Science, 4(4):867-877, 2017.
- [4] **S. Kim**, J. S. Kim, L. Miara, Y. Wang, S. K. Jung, S. Y. Park, Z. Song, H. King, M. Badding, J. M. Chang, V. Roev, G. Yoon, R. Kim, J. H. Kim, K. Yoon, D. Im, and K. Kang. "High-energy and durable lithium metal batteries using garnet-type solid electrolytes with tailored lithium-metal compatibility," Nature Communications, 13(1):1883, Apr 2022.