Next-generation all-solid-state battery

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

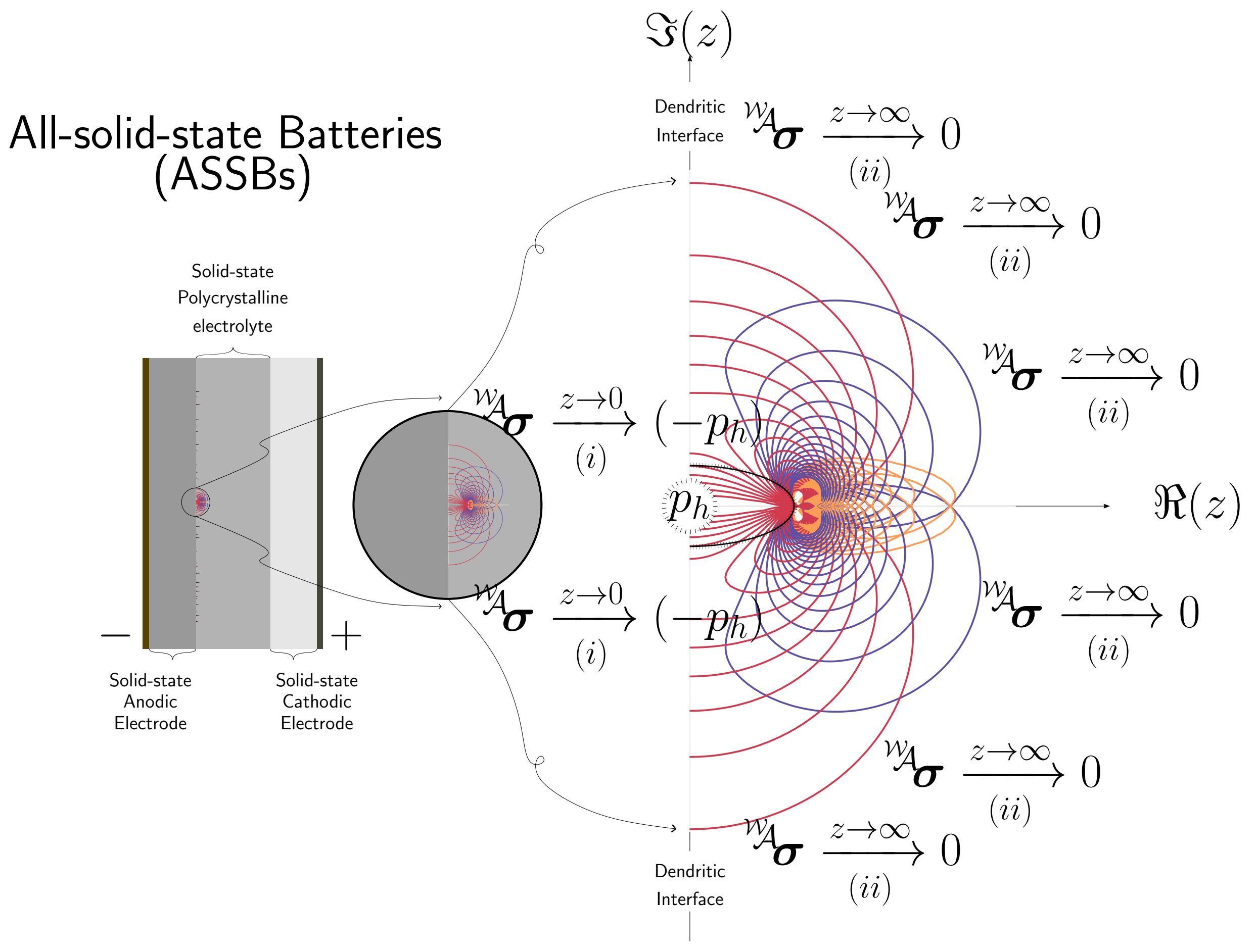
Rechargeable Lithium-ion battery (LIB) is at the heart of every electric vehicle (EV), portable electronic device, and energy storage system [1]. Nowadays, LIBs enable human life more efficient and help to solve global environment issues thanks to EVs' zero emission. However, conventional LIB (c-LIB) is sensible to temperature and pressure, hence, flammable and explosive. This drawback is mainly due to liquid-based electrolyte in c-LIBs.

All-solid-state battery (ASSB) is one of promising candidates to overcome bottlenecks of c-LIBs. Thanks to solid-state electrolyte (SSE), ASSB is highly stable towards temperature and pressure. Nevertheless, metallic Li-dendrite triggered at (SE|SSE)-interface is the main drawback as these dendritic threads extrapolate into grain boundary network of SSE, causing crevice, degradation of ionic conductivity, and the probability of short-circuit.

Next-generation All-solid-state battery (ng-ASSB) with a consideration of nucleation criterion defined by

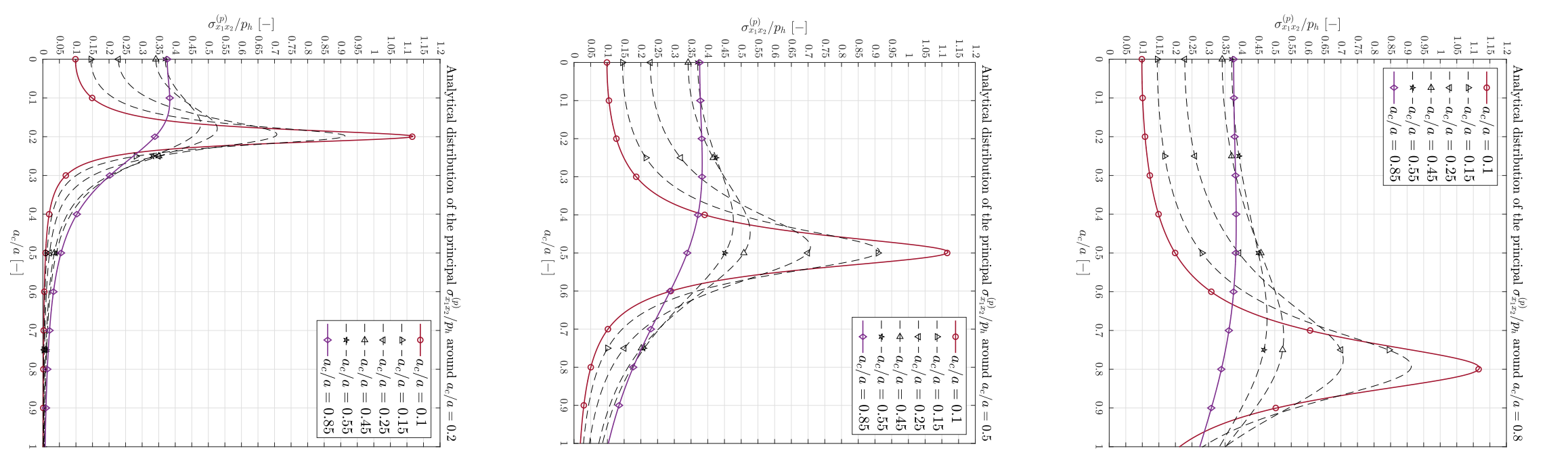
$$a_{\textsf{Griffith}} := a^* = \operatorname*{arg\,min}_{a\in\mathbb{R}} \iiint_\Omega f(a,\boldsymbol{u};\lambda,\mu,\boldsymbol{d}\otimes\boldsymbol{d})\,d\Omega - \left.\iint_\Gamma f(a;\gamma)\,d\Gamma\right|_{\boldsymbol{u}^{(s)}}$$

where, can help to improve ASSB performance.



Interface

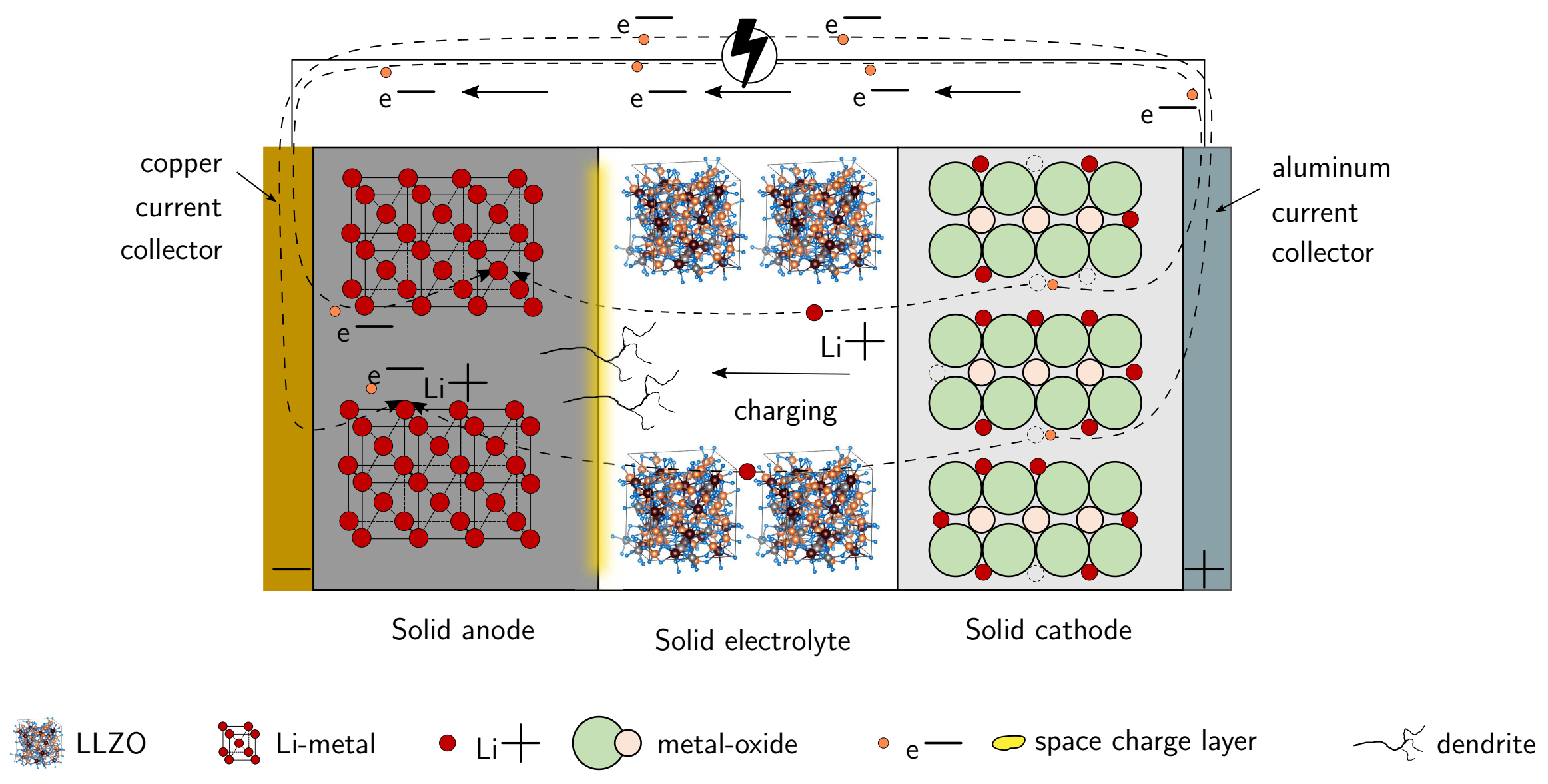
Interface between solid electrode and solid-state electrolyte (SE|SSE) taking place at space charge layer (SCL) [2] found in ASSBs critically exhibits mechanical and electrochemical instability [3]. This evidence points directly to the fact that the soft metallic li anode is erroneously prone to triggering dendrites, under cycles of electric charge & discharge [4].



Distribution: ana. max. shear stress ${}^{\mathcal{W}}\!\!\mathcal{A}\sigma^{\Pi}_{x_1x_2}$ around crack tip a_c.

Next-generation All-solid-state battery

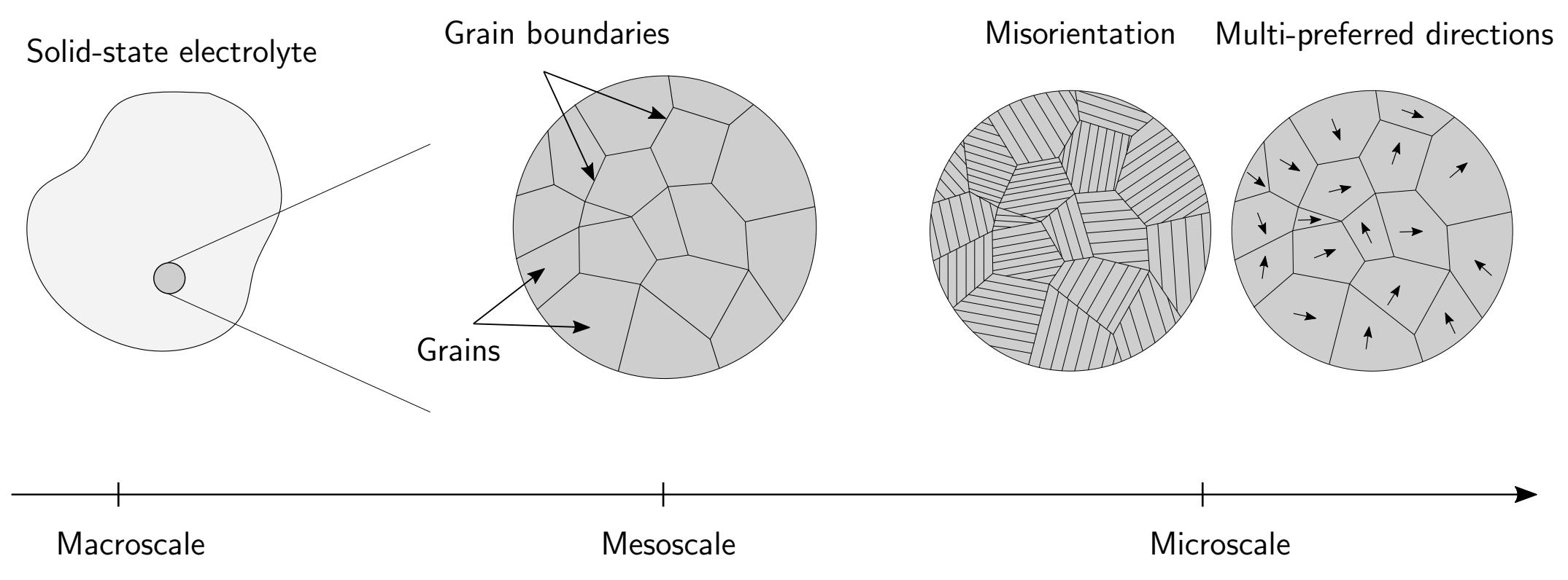
Nucleation taking place at critical dendritic (SE|SSE)-interface



Nucleation taking place at critical dendritic (SE|SSE)-interface
Nucleation taking place at critical dendritic (SE|SSE)-interface

Embedded structural-tensor SSE

Polycrystalline garnet-typed SSE 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, dendrites contribute to degradation of ionic conductivity and trace along grain boundaries in SSE.

Nucleation interface: Taking place at the critical dendritic interface

$$\rho\,\partial_{t^2}^2\boldsymbol{u}^{(s)} + \nabla\cdot\left(\overset{4}{\mathbb{C}}{}^{f^{\mathbb{D}(\Omega)}_{(\lambda,\mu)}} : \nabla\boldsymbol{u}^{(s)}\right) + \rho\nabla V_e = \mathbf{0},$$

$$\text{s.t.}\quad a_{\textsf{Griffith}} := a^* = \operatorname*{arg\,min}_{a\in\mathbb{R}} \iiint_\Omega f(a,\boldsymbol{u};\lambda,\mu,\boldsymbol{d}\otimes\boldsymbol{d})\,d\Omega - \left.\iint_\Gamma f(a;\gamma)\,d\Gamma\right|_{\boldsymbol{u}^{(s)}}$$

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Therefore

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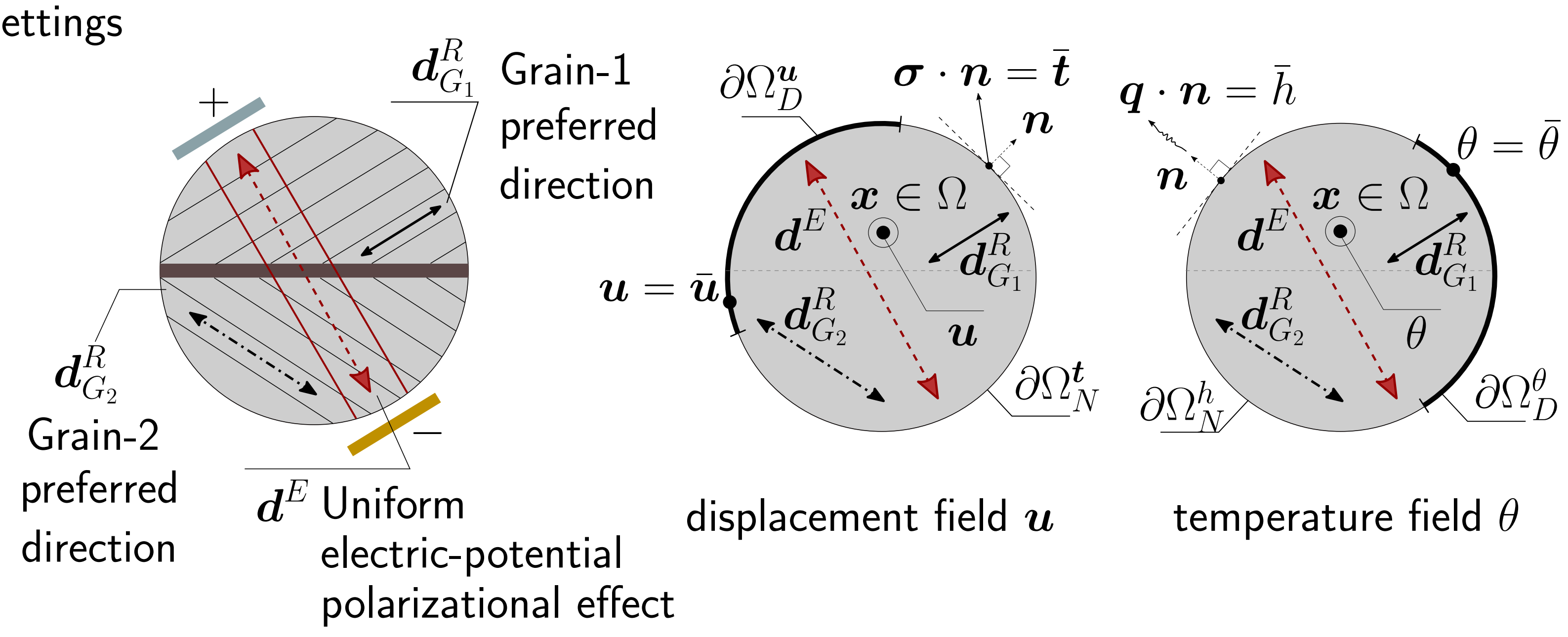
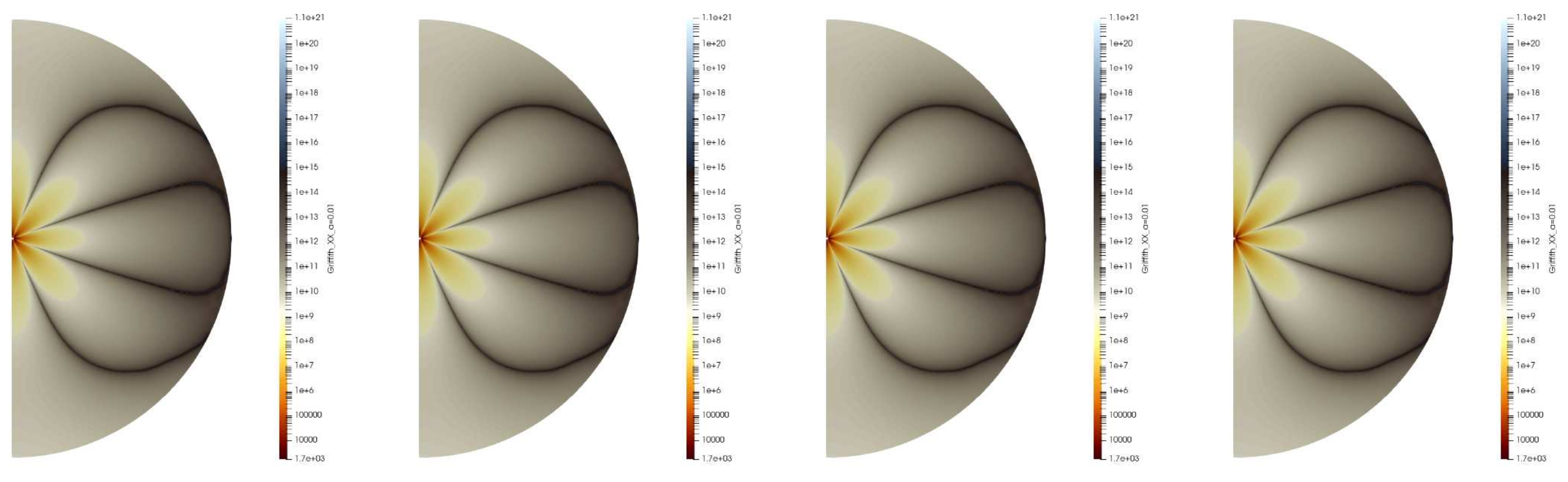
Boundary settings



The set of boundary conditions is likewise the path of the pressure-centric dendritic crack.



Comparison: Analytical vs. Numerical solutions

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