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# TOWARDS SAFER BATTERIES SOLID-STATE ELECTROLYTES AND INTERFACE STABILIZATION MECHANISMS

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## Abstract

*Background: Solid-state batteries are being explored as safer options than traditional lithium-ion batteries due to the increased safety from the solid-state electrolytes which reduce risks associated with thermal runaway, leakage and flammability. But they are limited in practical performance by the instability of the electrode/electrolyte interfaces, the resistance at the interfaces, the formation of dendrites and chemo-mechanical degradation during cycling.*

*Objective: This work was motivated by the desire to consider the role of solid-state electrolytes and interface stabilization mechanisms for safer and longer lasting battery systems.*

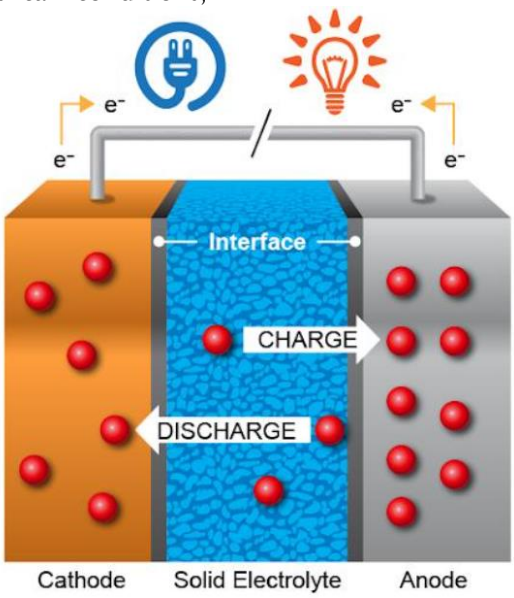
*Method: The method used is literature based, which involves searching for studies in recent years and selecting those published in 2021-2026 that are peer-reviewed. The review was mainly concerned with oxide, sulfide, polymer, composite and quasi-solid electrolytes, highlighting the following areas: ionic conductivity, electrochemical stability, area-specific resistance, lithium dendrite suppression, artificial interphases, and cathode/electrolyte compatibility.*

*Result: The results indicated that oxide electrolytes results in thermal/mechanical stability, sulfide electrolytes results in high ionic conductivity, polymer electrolytes results in flexibility and composite systems results in a balance of conductivity and interfacial contact. However, the quality of the interface rather than the type of electrolyte was the major factor for safety and performance. Electron-blocking interlayers, lithiophilic coatings, cathode protective layers, molecular anchoring, entropy-stabilized interfaces and dynamically adaptive interphases decreased interfacial degradation, ensured uniform Li+ flux and inhibited dendrite growth and enhanced cycling stability.*

*Conclusion: Solid-state electrolytes are a potential pathway to safe, high-energy batteries, but scalable, stable and mechanically adaptable interfaces are needed for commercialization. Good engineering of the interfaces will be key to minimizing short-circuit, durability, and to implement lithium metal solid-state battery applications.*

## INTRODUCTION

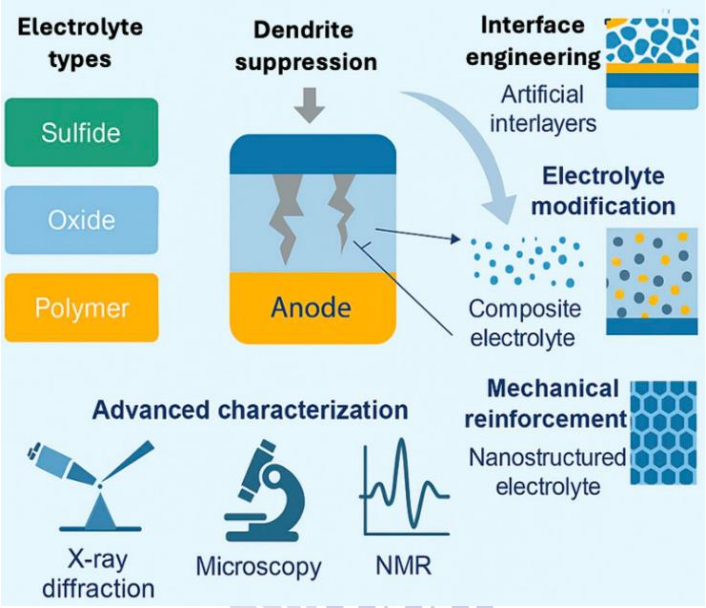
The solid-state battery has been identified as a significant scientific pathway to safer and higher energy electrochemical storage technologies, which rely on solid-state electrolytes (SSEs) instead of the flammable organic liquid electrolyte used in conventional batteries, which reduces the risk of leakage, volatility and thermal runaway, and makes it possible to use high-energy-density lithium-metal anodes. Typical Lithium-ion battery (li-ions) safety failures typically start when the electrolyte decomposes, the separator shrinks under abusive thermal, mechanical or electrical conditions, and/or the internal short circuits. SSEs, however, offer the benefits of nonflammability, broad thermal range, and enhanced mechanical strength, but their usefulness will not only rely on bulk ionic conductivity but also on the ability to effectively transport ions between solid–solid interfaces. This transition towards safer batteries is not just a material switch from liquid to solid electrolyte, but a concerted redesign of both electrolyte chemistry and electrode architecture, along with the mechanisms of the interface (Chen et al., 2021; Paul et al., 2022; Liu et al., 2026).




An essential role played by an SSE is to transport Li+ or Na+ ions while suppressing the electronic conduction, which can be summarized as: high ionic conductivity, low electronic conductivity and electrochemical stability. σion≫σe. For experimental studies, the ionic conductivity is usually determined as: = LRbA, is the resistance of the electrolyte., L is the thickness of the electrolyte, A is the contact area, and R is the resistance of the electrolyte b is bulk resistance. The relationship of the transport with the temperature is typically an Arrhenius-type relation, σT=σ0 exp (-EakBT). Where, E is activation energy. The oxide/garnet SSEs show high chemic stability and mechanical rigidity, sulfide SSEs exhibit high conductivity at room temperature and soft contact at interfaces, polymer electrolytes are flexible and easy to process, and composite electrolytes are composed of ceramics and polymers, which can be obtained by balancing conductivity, toughness, and electrode compatibility (Qin et al., 2021; Liang et al., 2022; Liang et al., 2023; Yang et al., 2023).

The interface remains the main problem, however, due to the fact that it is a solid–solid contact as opposed to a liquid wetting. The electrolyte in liquid batteries can leak into the pores and continually re-wet the surfaces of the electrodes; in all-solid-state batteries, the poor physical contact will create voids and high local current density, as well as high interfacial area specific resistanceASR=Rint A, where, Rint may contain contact resistance, space-charge resistance and charge-transfer resistance. A Nernst–Planck form of ion flux at the interface may be used to describe

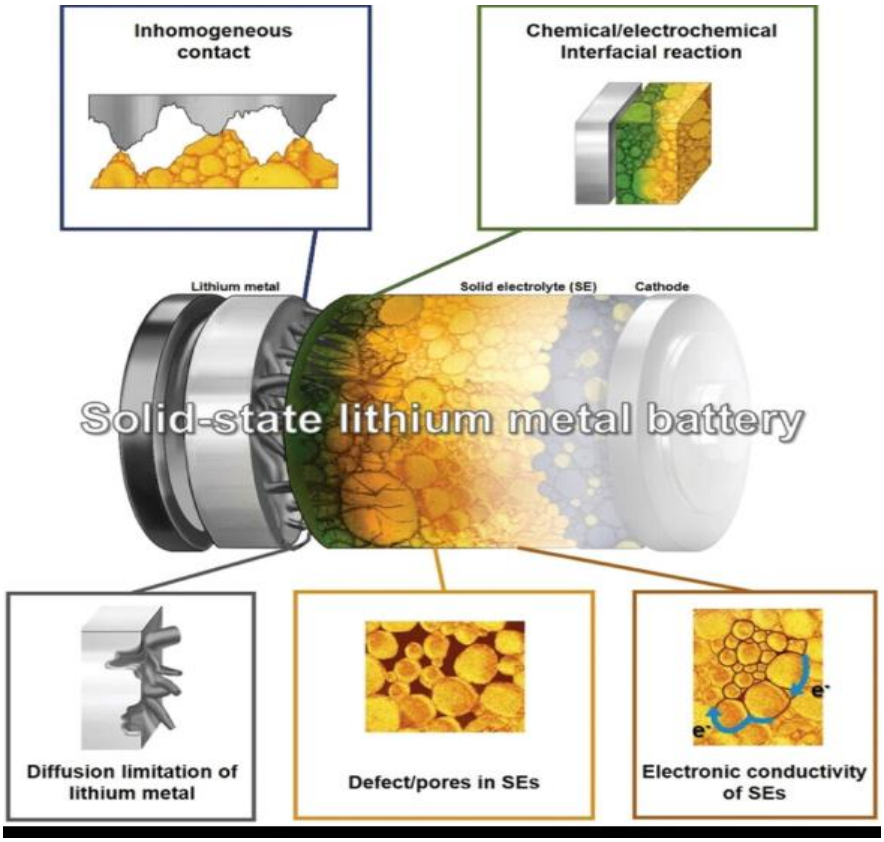
the ion flux. JLi+=-D∇c-RTDzFc∇ϕ. It is shown that the interfacial polarization is governed by the combination of the concentration and electric-field gradients and transport pathways, i.e., $_{c}\nabla\phi$. Therefore, in order to make the solid-state batteries safer, higher σ is not the only requirement. The ASR's that are low are also homogeneousJLi+. The stable interphase chemistry during repeated plating, stripping, lithiation and delithiation (Paul et al., 2022; Liang et al., 2023; Liu et al., 2026).



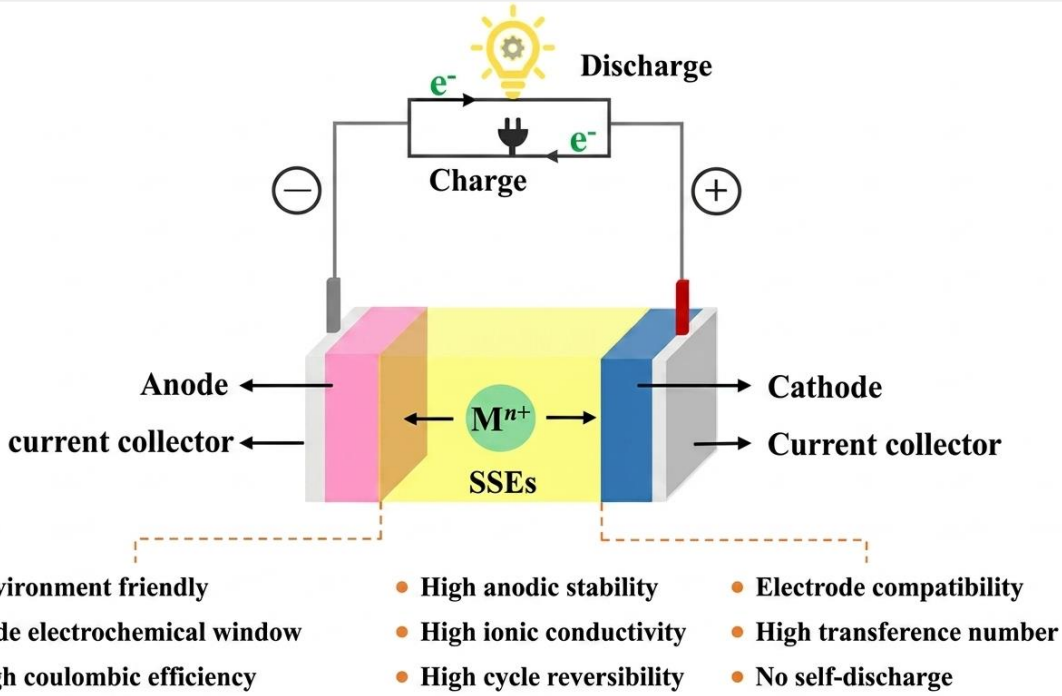

Chemical compatibility, electrochemical oxidation, transition-metal migration, oxygen release and interphase thickening under high voltage are known to occur at the cathode/SSE interface, which is the origin of degradation. Chemical incompatibility, electrochemical oxidation, transition-metal migration, oxygen release, and interphase thickening under high voltage have all been confirmed as origin of degradation at the cathode/SSE interface. Zuo et al. (2021) demonstrated that the degradation at the LGPS|NCM interface could be described as a Wagner type diffusion controlled process, with the interphase growth having a dependence of the form x∝t,, meaning that the reaction layers slowly grow thicker over time or when cycling. This can be especially severe for high nickel layered cathodes or high-voltage cathodes when coupled with sulfide or polymer SSEs, as the cathode potential can fall outside the range of oxidative stability for the SSE. Recently, artificial cathode-electrolyte interphases, oxide/fluoride coatings, entropy-stabilized cathodes and fast sintering routes that can satisfy both the thermodynamic compatibility and physical contact have been the subject of focus (Zuo et al., 2021; Li et al., 2022; Kong et al., 2024; Zhou et al., 2025).

Another significant safety concern at the anode/SSE interface is the instability of lithium metal, which can lead to the growth of filamentary lithium, voids or pathways of electronic conductivity that create a short circuit. The optimum SSE should be less than or equal to σe →0. A high number of defects, pores, grain boundaries, and poor lithiophilicity can increase the electric field concentration, and thus promote dendrite penetration; however, ideal structure (→0, good transport, uniform distribution of interfacial current) can decrease the electric field concentration and subsequent dendrite penetration. Electronic leakage reduction by interlayer and wetting of Li and reducing nucleation barriers is thus important, making these electron-blocking and lithiophilic interlayer

important stabilization tools. The following are examples of the various strategies that have been developed to enhance cycling stability and reduce dendritic failure pathways: flexible electron-blocking shields, lithiophilic/electron-blocking interlayers, tailored Li-metal compatibility on garnet electrolytes, and thin-lithium interface engineering (Huo et al., 2021; Lee et al., 2022; Kim et al., 2022; Ji et al., 2024; Zhang et al., 2024).




There are four types of interface stabilization methods: physical, chemical, electrochemical and mechanical, but in real solid-state batteries all these methods are implemented simultaneously. The pressure, soft interlayers, polymer infiltration or sintering techniques can be employed to physically stabilize intimate contact, parasitic reactions can be suppressed by coatings like $LiNbO_3$, $Li_2ZrF_6$, LiF-rich layers, or artificial SEI/CEI films can be used to chemically stabilize intimate contact, the redox environment and the solvation of ions are regulated by electrochemical stabilization, and mechanical stabilization allows volume changes during cycling. The quasi-solid electrolytes with molecular anchoring can be used to reconstruct $Li^+$ solvation and generate dense interphases, and surface-engineered inorganic electrolytes and regenerative solid interfaces can enhance the long-cycle performance by ensuring contact and repairing or stabilizing damaged interfacial regions (Qiu et al., 2023; Kim et al., 2023; Yu et al., 2024; Zhou et al., 2025).




The key scientific shift from passive safety to active interface control from a safety point of view is the most important scientific transition. Passive safety relies on replacing the flammable liquid electrolyte with a thermally stable solid, while active interface control relies on designing ion-selective, electron-insulating, chemically compatible, mechanically compliant and self-adaptive interfaces. The change in free energy at the interface, ΔG.rnx electrochemical stability windowEwindow, interfacial resistance Rint. J is the current density is the current density. They are thus not individual safety measures, but rather interdependent. The low-pressure or pressure-free operation of practical pouch-cell and EV-scale systems requires the development of adaptive interphases that allow for continuous conduction of $Li^+$ without void formation and dendrite growth, which is especially promising (Cen et al., 2025; Kong et al., 2024; Liu et al., 2026).

Realization of safer batteries based on SSEs thus requires solving a coupled materials-interface problem: the electrolyte needs to possess high ion conductivity, to be chemically stable with respect to both electrodes, to be electronically leak-proof, to be able to withstand mechanical stress, and to ensure close contact over thousands of cycles. The challenge is that solid-state batteries offer safety and energy density benefits, but there are many issues preventing their practical use including unstable electrode/SSE interfaces, high interfacial resistance, dendrite formation, and progressive chemo-mechanical degradation. This study is important because insights and stabilization of these interfaces will decrease the likelihood of thermal runaway, increase cycle life, allow for lithium-metal and high voltage cathode chemistries, and speed up safe battery commercialization. This study aims to critically elucidate the role of solid-state electrolytes and interface stabilization mechanisms in making batteries safer, based on ion-transport physics, interfacial degradation reactions, dendrite suppression, and novel artificial interphase approaches.

## Method

The methodology will be of systematic literature based and mechanistic review type, which will assess the role of solid state electrolytes and interface stabilization mechanisms in developing safer battery systems. The 2021–2026 peer-reviewed studies will be selected through databases like Scopus, Web of Science, ScienceDirect, ACS, Wiley, Springer Nature, and Nature Portfolio, which will be searched using keywords such as

"solid-state electrolyte," "all-solid-state lithium battery" "interface stabilization", "lithium dendrite suppression", "electron-blocking interlayer", "garnet electrolyte", "sulfide electrolyte", and "solid electrolyte interphase". Studies that directly address the chemistry of SSEs, degradation of the electrode/electrolyte interface, dendrite growth, ionic transport, artificial interphases, electrochemical stability and safety performance will be included. Recent studies of the mechanisms, given that interface instability is now regarded as one of the primary challenges between a laboratory scale solid-state battery and actual deployment, particularly in lithium metal batteries (Paul et al. 2022), will be emphasized in the review. The method used by Zuo et al. (2021) will be used as a primary methodological model as this paper integrated electrochemical and spectrometric analysis to monitor the degradation of $Li_{10}GeP_2S_{12}$|NCM interface and explained the degradation process with a Wagner-type diffusion controlled model.

Selected studies analyzed based on three interrelated parameters: bulk electrolyte performance, interfacial stability and electrochemical behavior of relevance to safety. The ionic conductivity (σ), activation energy (E) was compared for bulk electrolytes (Ea). Electrochemical stability window, mechanical modulus, electronic conductivity (σe) are the most significant. The most important are electrochemical stability window, mechanical modulus and electronic conductivity σ=RbAL. In some cases (e.g., ), ionic conductivity can be written as Rb. The effective radius R is the reciprocal of the thickness of the electrolyte L. The bulk resistance, and the area of the A electrode. Interfacial stability will be measured by area specific resistance (ASR=RintA). and critical temperature (JCCD), The interphase composition, $Li^+$ flux uniformity, and the chemical compatibility between electrode and SSE. The electron-blocking interface studies, such as Zhang et al. (2024), will help evaluate the ability of interlayers to block electron leakage and penetration of lithium dendrites into garnet-based quasi-solid-state batteries, and the cathode/electrolyte compatibility analysis by Kong et al. (2024) will help assess how the interface engineering approach reduced the resistance at the interface to 31.6 Ω·cm. at 25 °C.

The last methodological step will combine the stabilization mechanisms in a comparative framework that includes physical contact engineering, artificial SEI/CEI formation, lithiophilic interlayers, electron-blocking coatings, molecular anchoring, adaptive interphases, and alloy-forming interlayers. Each mechanism will be evaluated based on its effectiveness to reduce Rint, homogenize JLi. These include dendrite suppression, capacity retention and safe operating at low or no external pressure. As examples, Qiu et al. (2023) will be evaluated to assess the molecular anchoring; and Cen et al. (2025) will be examined to determine adaptive interphases, because their pressure-free all-solid-state lithium-metal batteries retained 90.7% capacity after 2,400 cycles at 1.25 mA cm-2. Recent 2026 interface-stabilization studies with in situ lithiated Sn interlayers will also be added that will enable bridging between lab-based pellet cell results and the scalability and safety of pouch cells.

**Results**

**Table 1:** ***Comparative Results of Major Solid-State Electrolyte Systems***

| Solid-state electrolyte type | Representative materials | Main result observed | Safety contribution | Remaining limitation |
|---|---|---|---|---|
| Oxide/garnet SSEs | LLZO, LLZTO | High chemical and thermal stability with strong mechanical rigidity | Helps suppress leakage, flammability, and mechanical penetration | Poor solid–solid contact and high interfacial resistance |

| Solid-state electrolyte type | Representative materials | Main result observed | Safety contribution | Remaining limitation |
|---|---|---|---|---|
| Sulfide SSEs | LGPS, argyrodite, $Li_3PS_4$-based systems | High ionic conductivity and soft electrode contact | Enables fast $Li^+$ transport at room temperature | Sensitive to moisture and interfacial decomposition |
| Polymer SSEs | PEO-based, PVDF-based systems | Flexible and processable electrolyte structure | Improves mechanical accommodation during cycling | Lower ionic conductivity at room temperature |
| Composite SSEs | Polymer–ceramic hybrid electrolytes | Balanced flexibility, conductivity, and interface compatibility | Reduces brittleness and improves electrode contact | Complex processing and phase-distribution control |
| Quasi-solid-state systems | LLZTO with ionic-liquid interface | Improved wetting at cathode/SSE interface | Better cycle life under low or no external pressure | Partial liquid component may reduce pure solid-state safety advantage |

Table 1 reveals that there is no single solid-state electrolyte system which meets all of the safety, conductivity and interface-stability requirements. The oxide and sulfide electrolyte systems exhibit higher safety and mechanical stability, while composite systems exhibit high interfacial contact but high chemical stabilization methods (Paul et al., 2022; Kim et al., 2023).

**Table 2:** ***Observed Interfacial Degradation Results in Solid-State Batteries***

| Interface region | Degradation mechanism | Result on battery performance | Safety concern | Supporting evidence |
|---|---|---|---|---|
| Cathode/SSE interface | Oxidative decomposition of SSE | Increased interfacial resistance and polarization | Heat generation and capacity fading | LGPS/NCM degradation follows diffusion-controlled CEI growth |
| Li-metal/SSE interface | Nonuniform Li plating/stripping | Void formation, dendrite growth, and short circuit risk | Internal short circuit and thermal instability | Li dendrite penetration remains a major commercialization barrier |
| Grain boundaries in SSE | Local electronic leakage and field concentration | Accelerated lithium filament growth | Sudden failure under high current density | Electron leakage can promote dendrite penetration |
| Poor solid–solid contact | Loss of physical contact during cycling | Increased bulk/interfacial resistance | Poor cycling reliability | Reference $Li_3PS_4$ systems showed resistance rise and contact loss |
| High-voltage cathode interface | Transition-metal migration and side reactions | Cathode instability and reduced capacity retention | Reduced long-term safety under high voltage | Stabilized interfaces reduce migration and resistance |

As shown in Table 2, the failure mechanism of solid-state batteries is not just electrolyte failure but a combination of degradation at the interface, rather than failure of the electrolyte itself. Cathode side reaction layer growth and anode side lithium dendrite generation, both of which increase the resistance, polarization and risk of safety, are the two critical problems (Zuo et al., 2021; Zhang et al., 2024).

**Table 3** ***Results of Interface Stabilization Strategies***

| Stabilization strategy | Mechanism | Reported result | Safety relevance |
|---|---|---|---|
| Electron-blocking interlayer | Blocks electron leakage into SSE | KF/LiF interlayer on LLZTO inhibited lithium dendrite growth and enabled long Li symmetric-cell cycling | Reduces internal short-circuit risk |
| Lithiophilic interlayer | Improves Li wetting and uniform nucleation | Ag/Ag-C interlayer regulated Li stripping/plating and prevented dendrite penetration | Promotes uniform Li deposition |
| Cathode protective coating | Suppresses direct cathode/SSE reaction | Reduces CEI growth and interfacial resistance | Improves high-voltage safety |
| Entropy-stabilized cathode interface | Improves thermodynamic compatibility and contact | HE-DRX/LLZTO interface reduced resistance to 31.6 Ω·cm² | Reduces polarization and heat generation |
| Dynamically adaptive interphase | Maintains contact during Li volume change | LiI-derived adaptive interphase enabled long cycling under low/zero pressure | Supports safer pressure-free battery operation |



As indicated in Table 3, effective stabilization is only possible if the combination of chemical protection, electronic insulation and mechanical contact preservation is used. It is important to note that electron-blocking and adaptive interphases directly inhibit dendrite short circuits and enable $Li^+$ transport ( Zhang et al., 2024; Cen et al., 2025).

**Table 4:** ***Electrochemical Performance Results from Selected Interface-Engineered Solid-State Batteries***

| Study/system | Interface design | Key performance result | Main conclusion |
|---|---|---|---|
| KF-modified LLZTO system | KF converted partly into KF/LiF interlayer | Li symmetric cells cycled ~3000 h at 0.2 mA $cm^{-2}$ and >350 h at 0.5 mA $cm^{-2}$ | Electron-blocking interface suppresses dendrite penetration |
| Ag-C/Ag/LLZTO/NCM333 pouch cell | Ag-coated LLZTO with Ag-C interlayer | 800 cycles at 1.6 mA $cm^{-2}$ and 25 °C without external pressure; ~85% capacity retention | Lithiophilic interlayer improves pressure-free cycling |
| HE-DRX/LLZTO cathode interface | Ultrafast high-temperature sintering | Interface resistance reduced to 31.6 Ω·cm², about 700 times lower than $LiCoO_2$/LLZTO | Strong cathode/SSE contact improves interface kinetics |
| HE-DRX ASSLB at high temperature | Entropy-stabilized cathode/electrolyte interface | 239.7 ± 2 mAh $g^{-1}$ at 25 mA $g^{-1}$ and 95% retention after 100 cycles at 150 °C | Stable interface enables high- |

| Study/system | Interface design | Key performance result | Main conclusion |
|---|---|---|---|
| | | | temperature operation |
| Li–B/$Li_{3.2}PS_4I_{0.2}$/LTO system | Dynamically adaptive LiI-rich interphase | 113.8 mAh $g^{-1}$ at 2400th cycle with 90.7% capacity retention | Adaptive interphase improves long-term cycling stability |
| Pressure-free pouch cell | DAI-assisted pouch configuration | 74.4% capacity retention after 300 cycles without external pressure | Interface adaptation supports practical pouch-cell design |

As shown in Tab.4, the cycle life, capacity retention and resistance control of solid-state batteries is significantly improved through interface engineering. Ideally, the interlayer will simultaneously block electrons, conduct $Li^+$, have good wetting, and maintain mechanical contact during repeated cycling (Kim et al., 2023; Kong et al., 2024; Cen et al., 2025).

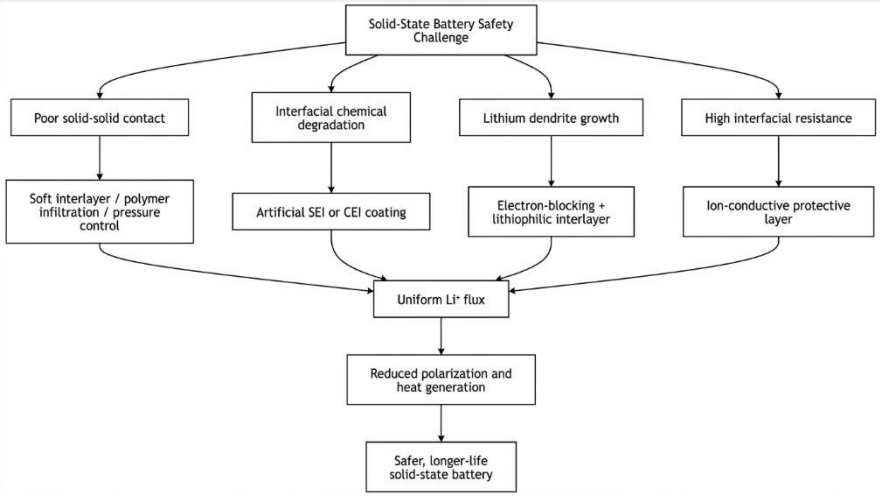
**Table 5:** ***Overall Safety-Related Results and Practical Implications***

| Safety parameter | Result from literature synthesis | Practical implication |
|---|---|---|
| Flammability risk | SSEs reduce dependence on volatile organic liquid electrolytes | Lower probability of electrolyte leakage and fire |
| Dendrite suppression | Electron-blocking and lithiophilic interlayers reduce Li filament growth | Lower short-circuit risk |
| Thermal stability | Oxide and ceramic SSEs show stronger high-temperature tolerance | Better safety under thermal abuse |
| Interfacial resistance | Stabilized cathode/SSE interfaces reduce polarization | Less heat generation during cycling |
| Mechanical reliability | Adaptive interphases maintain contact during volume change | Improved cycling under low or zero pressure |
| Commercial readiness | Pouch-cell demonstrations show progress toward scalable systems | Interface design is essential for EV-level application |

Table 5 shows that the safety benefit of solid-state batteries will be very significant if the interface is stabilized, as well as the change of liquid electrolytes to solid. Commercialisation could be achieved by further developing pressure-free or low-pressure solid state cells that exhibit stable Li-metal/SSE and cathode/SSE interfaces (Paul et al., 2022; Cen et al., 2025).

**Discussion**

The results indicate that solid-state electrolytes are more superior in terms of enhancing battery safety primarily by using nonflammable or less flammable solid ion conductors in place of flammable organic liquid electrolytes. This discovery aligns with Paul et al. 2022 who noted that the performance of solid-state batteries is still heavily limited by poor ionic conductivity, loss of contact between the solid electrolyte and electrode, dendrite growth, and electrode–electrolyte interfacial impedance. So, the safety benefit of solid-state batteries should not be seen as guaranteed as it depends on the ability of the solid electrolyte to remain chemically, electrochemically, and mechanically intact with the two electrodes over the long-term in cycling.




The comparison of different solid electrolyte families (oxide, sulfide, polymer and composite) shows that each electrolyte family has its own sets of safety and performance advantages. While LLZO and LLZTO are good mechanically and chemically, they often do not have good solid–solid contact with lithium metal, and sulfide electrolytes are good for ionic conductivity and are easier to contact with lithium metal, but are more prone to chemical and moisture degradation. In line with this, Jia et al. (2024) also highlighted the different merits and limitations of the sulfide electrolyte, oxide electrolyte, polymer electrolyte and halide electrolyte, and further suggested that the practical solid electrolyte should not only have high ionic conductivity but also strong electrochemical stability, mechanical strength, low cost and process ability.

The results also reveal that cathode/SSE interfacial degradation is a significant factor in the degradation of capacity and resistance of all-solid-state batteries. Zuo et al. (2021) demonstrated the thermodynamic instability of the $Li_{10}GeP_2S_{12}|LiNi_{1-x-y}Co_xMn_yO_2$ interface and the degradation process, which was found to be diffusion-controlled, following a Wagner-type model whereby reaction-layer growth is closely correlated to electronic transport across the interphase. This is consistent with the conclusion that the potential of the cathode-side stabilization needs to reduce the oxidative decomposition, oxygen release, migration of a transition metal, and high voltage side reaction, particularly in the case of high nickel or high voltage cathodes with sulfide electrolyte.

Results show that the major safety issues at the lithium-metal/SSE interface are dendrite growth, void formation and non-uniform Li plating. Kim et al. (2022) presented that the compatibility of lithium metal with tailored garnet-type LLZO electrolytes is improved, and Kim et al. (2023) reported that the penetration of the lithium dendrites by Ag-coated LLZTO and silver–carbon interlayer prevents the lithium stripping/plating. The results validate that the engineering of the interfaces should not only enhance ionic transport, but also influence lithium nucleation, electronic leakage, and maintain close physical contact during cycles of volume change.

The outcome from the interface-engineering exercises indicates that multifunctional rather than single purpose stabilization strategies prove to be the most effective. Qiu et al. (2023) demonstrated that the molecular anchoring in a quasi-solid polymer electrolyte (QSPE) can reconstruct the $Li^+$ solvation in the electrolyte and create a stable cathode–electrolyte interphase (CEI), enabling Li|Li symmetric cycling for more than 9000 h and achieving 91.55% capacity retention after 300 cycles at 4.7 V. Zhang et al. (2024) showed that while electron-blocking interfaces can extend the lifespan of garnet-based quasi-solid-state lithium-metal batteries, electronic insulation is as crucial as ionic conduction for dendrite suppression and battery safety.

Overall, the discussion shows the need for the development of robust, adaptable, and scalable interfaces with solid-state electrolytes for future safer batteries. The electrochemical resistance between the cathode/electrolyte interface has been reduced to 31.6 $\Omega \cdot cm^2$ by entropy stabilization and fast kinetics (Kong et al., 2024); a $Li_2ZrF_6$ protective layer can prevent harmful reactions between high voltage $LiCoO_2$ and sulfide SSEs (Zhou et al., 2025). Cen et al. (2025) took a major step forward by developing dynamically adaptive interphases that keep their contact in low and zero-pressure conditions, which retained 90.7% of the capacity after 2400 cycles and preserved 74.4% capacity in zero-pressure pouch cells after 300 cycles. The overall result highlights the need for safe materials of electrolyte, as well as engineered interfaces that will not undergo chemical decomposition or lose mechanical contact or be shorted by dendrites for use in practical solid-state batteries.

**Future Direction**

Future work should be aimed at creating a scalable, low-pressure and self-adaptive interface design that can be used with realistic pouch-cell designs, rather than just small laboratory pellet-cell designs. Operative characterization, careful design of electrolyte/interlayer using AI, thin solid-electrolyte processing, high loading cathodes, limited- or no-lithium configuration, and practical current density, loading, temperature and pressure testing over long periods of time require greater attention. Standardized safety metrics such as critical current density, thermal runaway resistance, interfacial resistance growth rate, gas evolution, and mechanical failure threshold should also be determined for future comparisons of solid-state battery safety, as done here.

**Limitations**

The limitations of this study are that it is a literature-synthesis approach rather than an original experimental approach. The reported performance values vary based on cell formats, electrolyte thickness, stack pressure, cathode loading, testing temperature and current density, making it difficult to compare the performance of different cells directly. Besides this, there are numerous high performance solid-state battery results acquired in laboratory conditions but pouch cells in commercial applications need to be validated in high areal capacity, fast charging, long cycling and abuse conditions.

**Conclusion**

To conclude, solid-state electrolytes offer a promising way towards safer batteries, as they improve thermal stability, enable lithium-metal anodes, and decrease the flammability; however, mainly interface stabilization is necessary for their practical success. The major issues identified for the commercialization are cathode/SSE degradation, dendrite growth of lithium, formation of voids and interfacial resistance. The use of protective coatings, electron-blocking layers, lithiophilic interlayers, molecular anchoring, entropy-stabilized interfaces and dynamically adaptive interphases offers a great potential to enhance safety and cycling stability. Thus, a series of advancements in electrolyte chemistry, electrode compatibility, interfacial mechanics, and cell engineering on a scalable level will be needed for safer next-generation batteries.

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