Solid-State Lithium–Sulfur Batteries for Reliable Energy Storage in Harsh Environments

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The increasing demand for high-performance energy storage systems has driven extensive research into next-generation batteries that offer higher energy density, enhanced power output, and durability in extreme environments. As the world shifts toward electrification and advanced mobility, energy storage technologies must evolve to meet the stringent requirements of applications such as defense, deep-sea exploration, aerospace, and industrial surveying. Conventional lithium-ion batteries (LIBs) have dominated the market due to their high efficiency and reliability. Still, their limited thermal stability (−20 °C to 60 °C), safety concerns, and low energy density necessitate the development of alternative solutions. Besides, their performance also degrades over time, with reduced capacity and efficiency after repeated charge-discharge cycles [1]. Among advanced battery concepts, rechargeable lithium-sulfur (Li-S) batteries stand out due to their high theoretical gravimetric energy density, cost-effectiveness, environmental sustainability, efficiency, and reliability. However, despite their advantages, achieving long cycle stability, high power density, and survivability in extreme conditions remains a significant challenge. Harsh operational environments (e.g., radiation Exposure, mechanical Stress…), extreme temperatures, and vacuum conditions impose severe limitations on conventional Li-S batteries, requiring innovative design strategies to enhance their electrochemical stability and performance [2].

This study presents the practical development of solid-state Li–S cells in both coin and pouch cell formats. The design features a sulfur-based cathode fabricated by vertically aligning tens of trillions of carbon nanotubes (S@VACNTs) per cm^2 on standard aluminium foil, serving as a current collector. The resulting batteries exhibit exceptional survivability under extreme conditions, including stable operation at temperatures up to 150 °C and in vacuum levels down to 10^{-3} mbar, with no signs of degradation, degassing, or explosion. This work demonstrates a rare combination of high thermal stability and rechargeability, achieving consistent performance at 150 °C over 50 cycles, a level seldom attained by existing battery technologies. The synergy between thermal robustness and electrochemical durability positions the proposed system as a viable solution for high-reliability energy storage under extreme conditions.

References

[1] S. Ma et al., Progress in Natural Science: Materials International, 28 (2018) 653-666
[2] W. Qu et al., Energy & Environmental Materials, 6 (2023) e12444