Hybrid Metallic Cation−Anionic Surfactant Additive Regulating Interfacial Chemistry for High−Stability Zn Metal Anodes

Nhat Anh Thieu[1], Peiyuan Gao[2], Wei Li[1], ShanShan Zhang[1], Shaoshuai Chen[1], Xiaolin Li[2,], and Xingbo Liu[1,*]*

[1]Department of Mechanical, Materials and Aerospace Engineering, West Virginia University, Morgantown, WV 26506, USA
[2]Pacific Northwest National Laboratory, Richland, WA 99352, USA

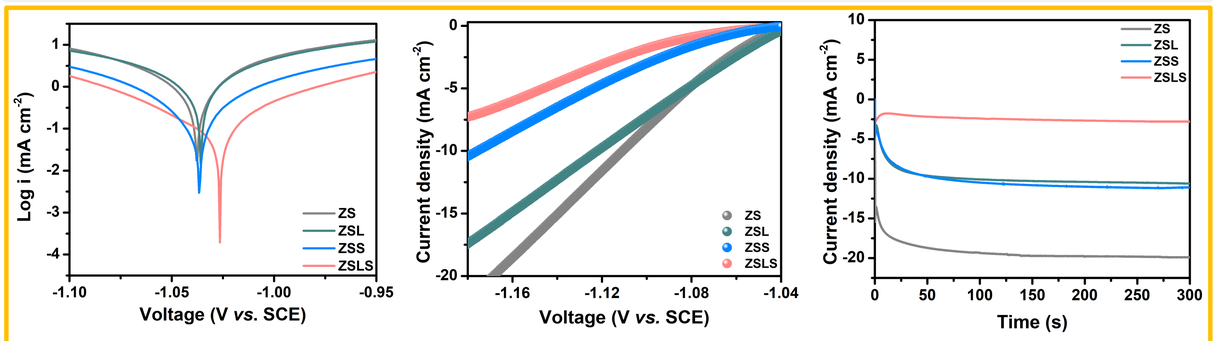
Introduction

Due to their safety, low cost, and environmental friendliness, aqueous zinc-ion batteries (AZIBs) have become an increasingly attractive solution for grid-scale energy storage. However, the anode-electrolyte interface is susceptible to instability due to irreversible processes, including dendrite growth, water-induced side reactions, and hydrogen evolution reactions (HER), which prevent the practical application of AZIBs. This year, our research efforts focused on developing stable AZIBs through the synergistic effect of hybrid metallic cation-anionic surfactant additive in 1 M ZnSO4 to regulate the anode-electrolyte interface.

Approach and Objective

- Providing a novel method for stabilizing Zn anodes by combining the La^{3+} cations and anionic surfactant, sodium dodecyl sulfate (SDS), as a hybrid additive.
- Investigating the protective mechanisms of the hybrid additive in regulating the anode-electrolyte interface chemistry.

Synergistic effects of La^{3+}-SDS additive



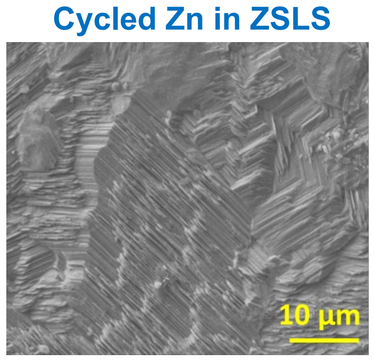
Denote: 1 M $ZnSO_4$ = ZSL, 1 M $ZnSO_4$ + 150 ppm $La(NO_3)_3$ = ZSL, 1 M $ZnSO_4$ + 200 ppm SDS = ZSS, 1 M $ZnSO_4$ + 150 ppm $La(NO_3)_3$ + 200 ppm SDS = ZSLS

$ZnSO_4$-containing hybrid La^{3+}-SDS additive significantly inhibits corrosion, HER, and regulates Zn deposition compared to blank $ZnSO_4$ and $ZnSO_4$-containing single additive.

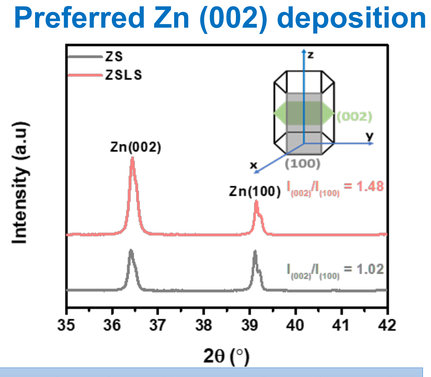
Regulating Zn (002) deposition

Cycled Zn in ZS

Cycled Zn in ZSLS

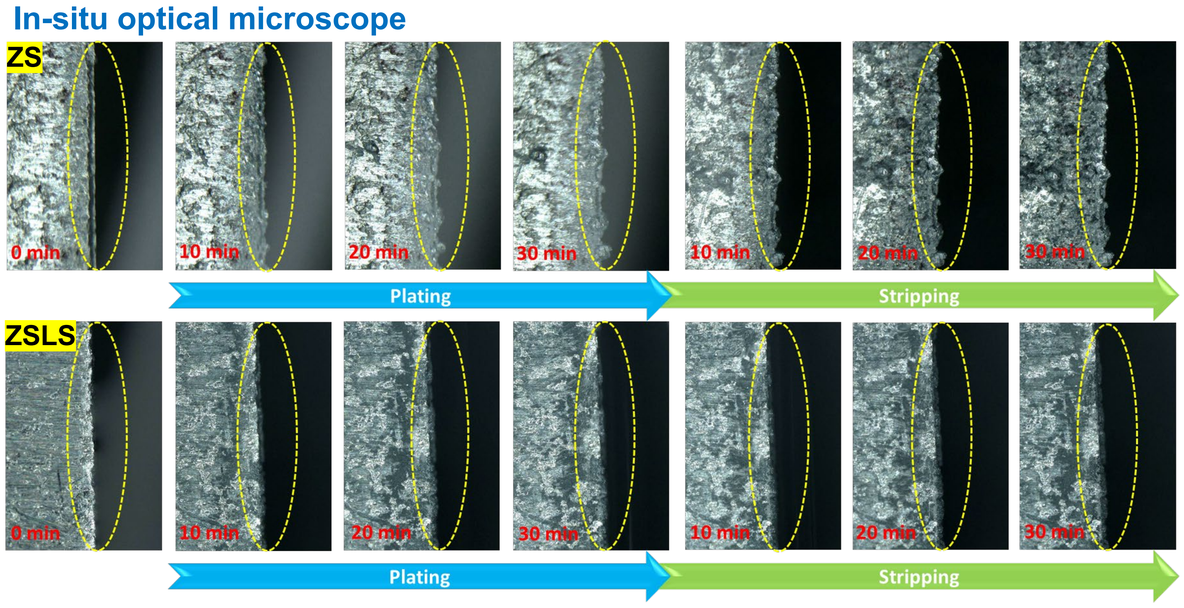


Preferred Zn (002) deposition



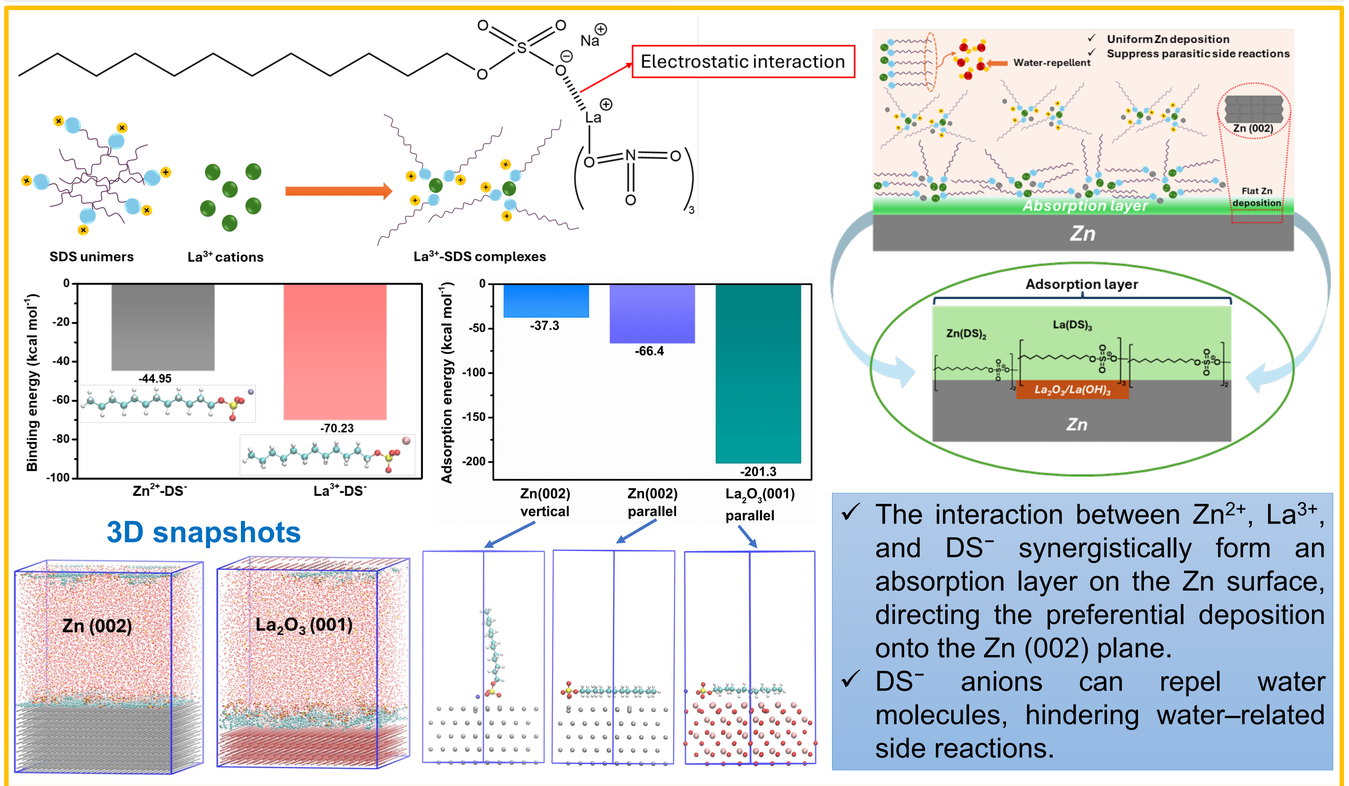
Hybrid La^{3+}-SDS additive enables a homogeneous anode-electrolyte interface and preferential Zn deposition along the (002) basal plane, leading to the dendrite-free Zn anode.

In-situ optical microscope



Hybrid La^{3+}-SDS additive allows Zn^{2+} forms evenly small nuclei on the Zn surface with a compact layer, leading to a flat and uniform Zn anode.

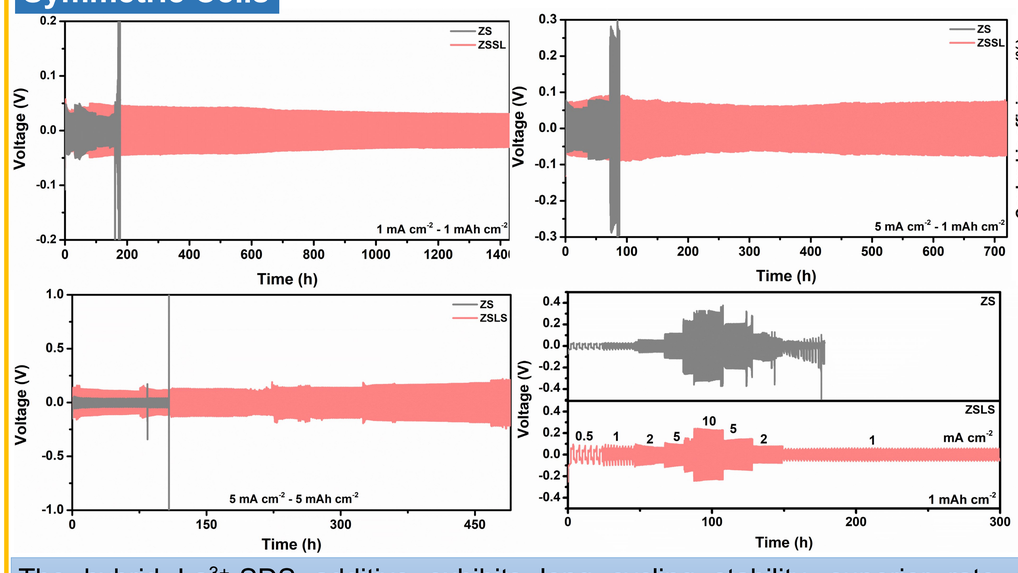
Protective mechanism



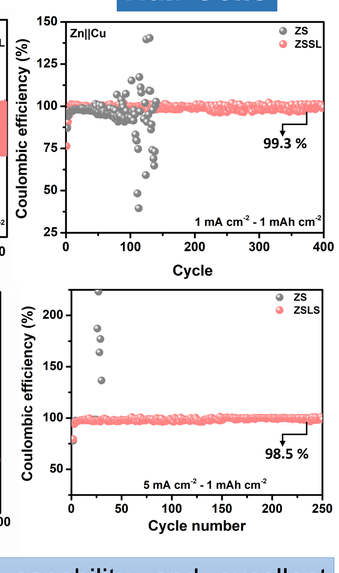
- ✓ The interaction between Zn^{2+}, La^{3+}, and DS^- synergistically form an absorption layer on the Zn surface, directing the preferential deposition onto the Zn (002) plane.
- ✓ DS^- anions can repel water molecules, hindering water–related side reactions.

Electrochemical performance

Symmetric Cells

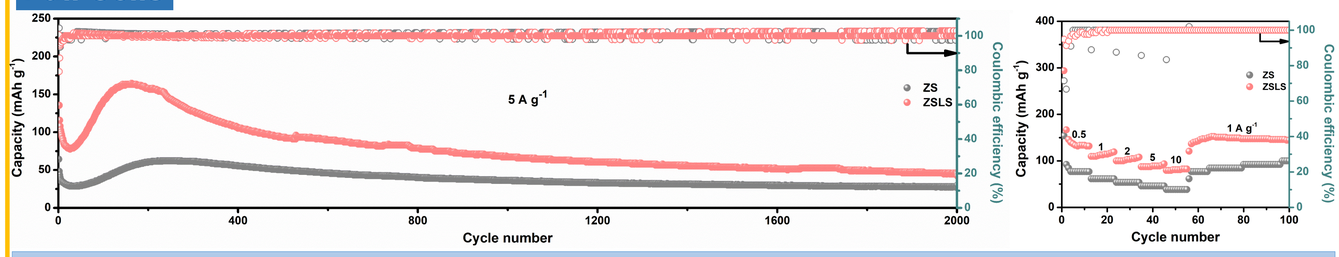


Half Cells



The hybrid La^{3+}-SDS additive exhibits long cycling stability, superior rate capability, and excellent Coulombic efficiency, indicating its great protective effect on Zn anodes.

Full Cells



The Zn||V_2O_5 full cell, incorporating the ZSLS, exhibits a high capacity of 163.2 mAh g^{-1} and preserves 53.9 mAh g^{-1} after 2000 cycles at 5 A g^{-1}, demonstrating a better performance over the ZS-based cell.

Conclusions

- Hybrid La^{3+}-SDS additive enables dendrite-free, long-life AZIBs by effectively regulating interfacial reactions and inducing homogeneous Zn deposition with preferential crystallographic orientation along the Zn (002) plane.
- Hybrid La^{3+}-SDS additive also effectively suppress HER and water-induced side reactions.

Future work

- Investigating the feasibility of amphiphilic copolymers as additives for Zn anode stabilization.
- Developing Zn-ion batteries in scale-up pouch cell configuration.

Acknowledgments

This This material is based upon work supported by the U.S. Department of Energy, Office of Electricity (OE), Energy Storage Division. We acknowledge the use of the WVU Shared Research Facilities for material characterizations.

Reference:
N. A. Thieu, P. Gao, W. Li, S. Zhang, S. Chen, X. Li, **X. Liu.** Hybrid Metallic Cation−Anionic Surfactant Additive Regulating Interfacial Chemistry for High−Stability Zn Metal Anodes. Submitted (2025)

Contact: **Xingbo Liu**
West Virginia University
Tel.: 304-293-0120
Email: xingbo.liu@mail.wvu.edu