Multiscale Structured Hybrid Electrolyte Design for Water Activity Regulation in Aqueous Zn Batteries

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PROJECT PROFILE
Topic: Zinc & Lead Batteries
Vertical: Materials and Systems Innovation
Strategy Pathway: Grow
Project start and finish: FY19-present

Background and Significance

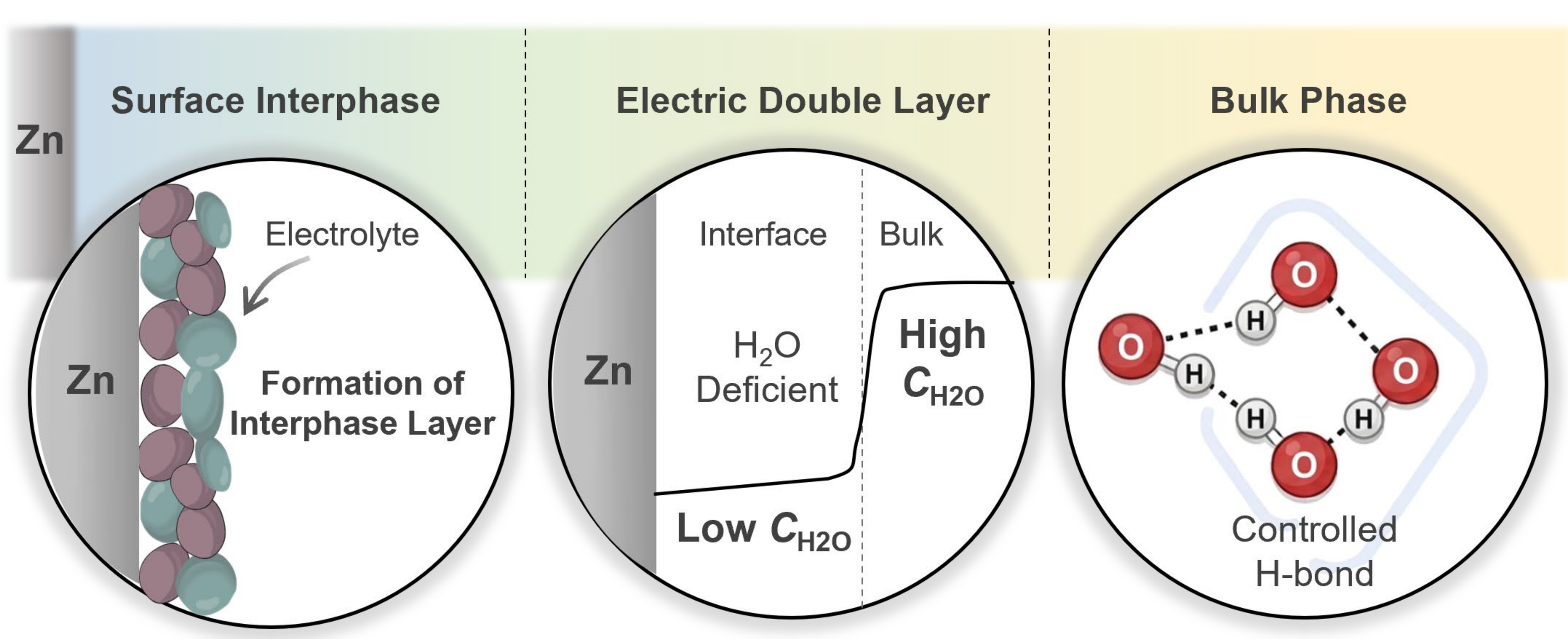
❑ Problem and challenge

- Aqueous Zn batteries are promising for grid storage due to nonflammable electrolytes and abundant Zn resources, but high water activity in the electrolyte promotes H_2 gas evolution and unstable Zn deposition, limiting battery durability.

❑ Current practice and limitations

- Electrolyte additives, highly concentrated salts, artificial coatings, and surface protection layers can improve Zn stability, but often add cost, complexity, or durability concerns.
- Most approaches target either bulk electrolyte chemistry or surface protection, while integrated control across the bulk electrolyte, interface, and interphase remains limited.

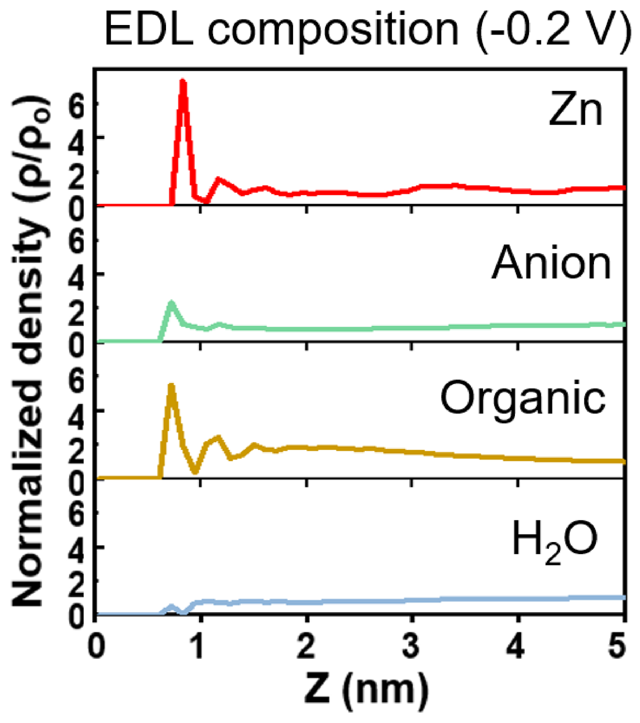
Approach



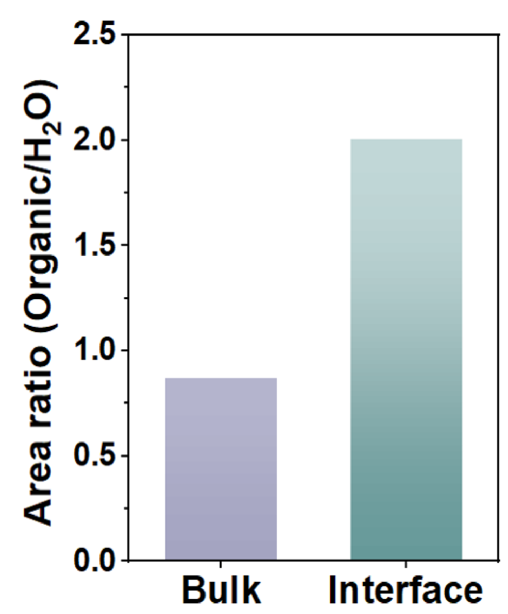
- Develop structured hybrid electrolytes that regulate water activity across the bulk electrolyte, Zn interface, and interphase to suppress parasitic reactions, stabilize Zn plating and stripping, and improve cell durability.
- Our approach is to control the electrolyte structure by hybridizing nonaqueous and aqueous solvents.

Results

EDL composition (-0.2 V)

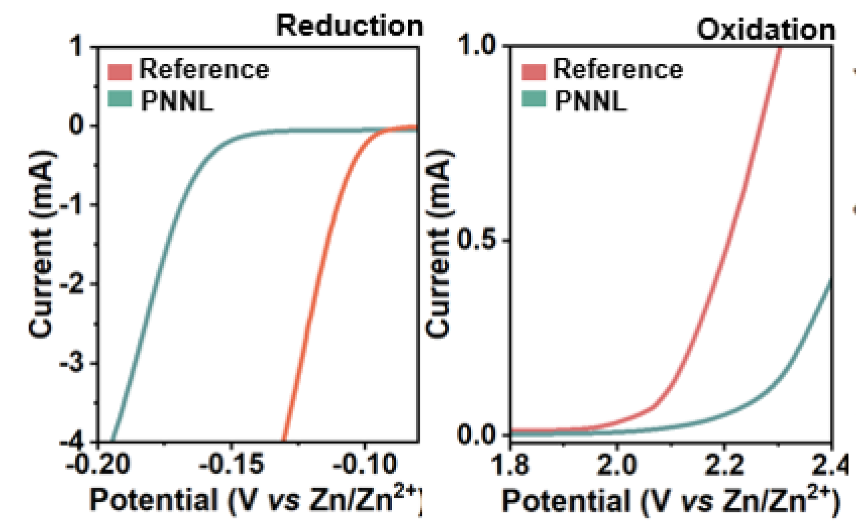


Surface-Enhanced Raman

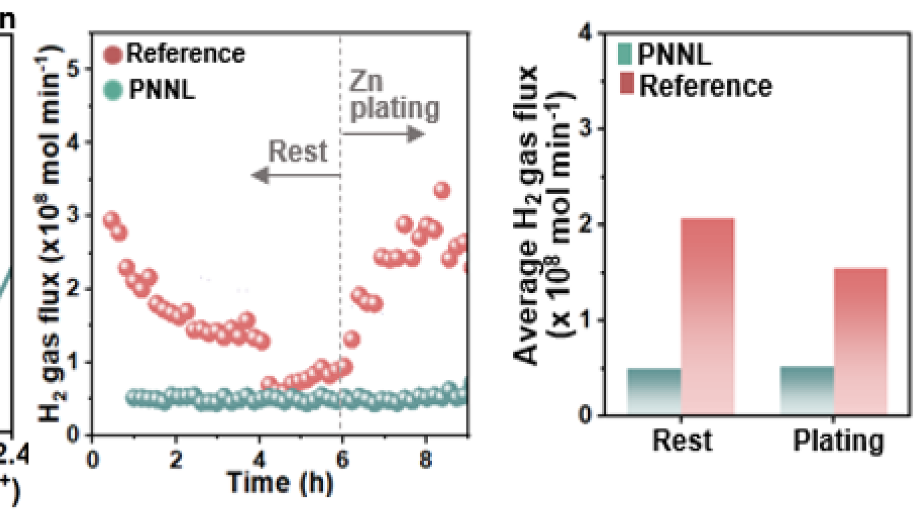


Organic enriched electric double layer (EDL) with reduced interfacial H_2O

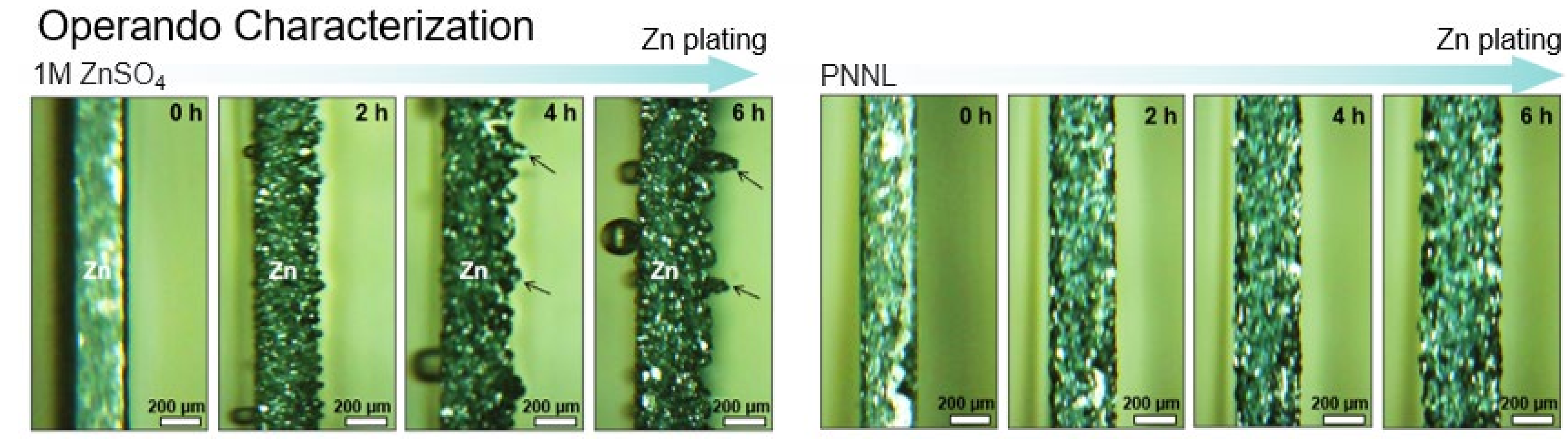
LSV curves



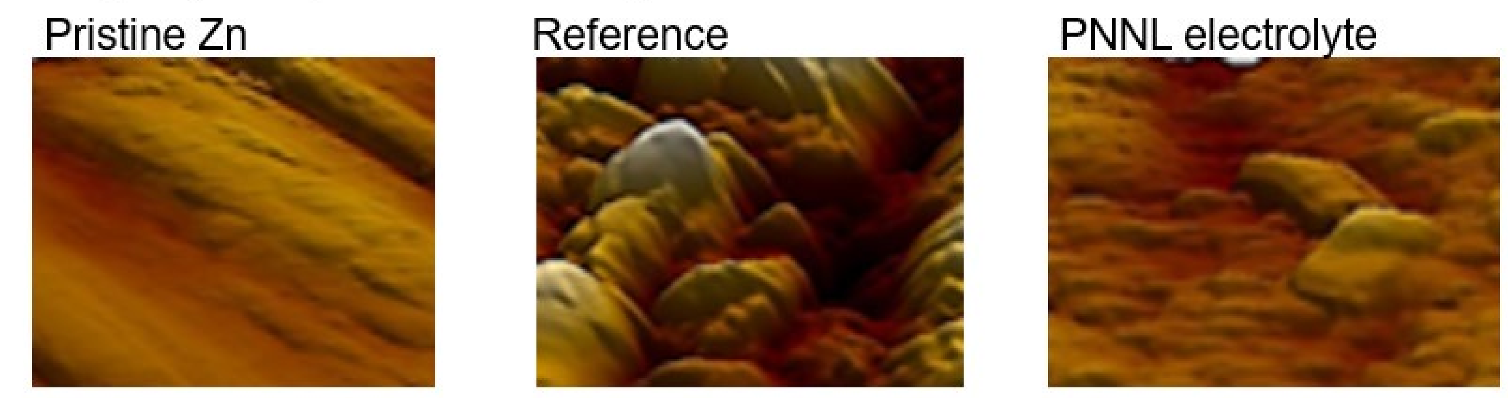
Gas evolution (DEMS analysis)



Operando Characterization

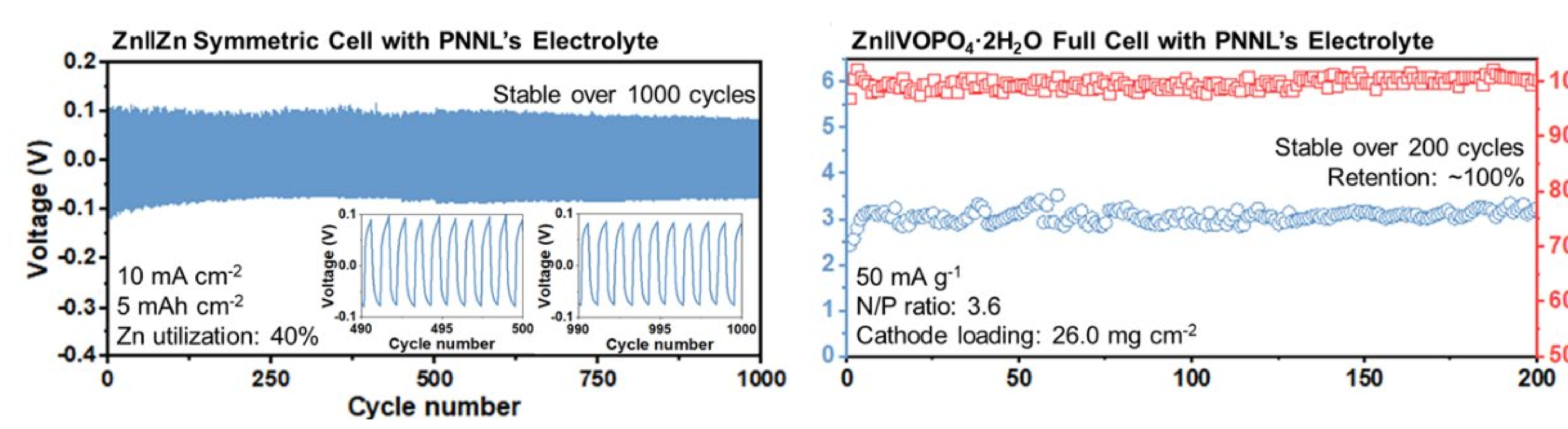


AFM images (Zn deposition behavior)



- The PNNL electrolyte with well-regulated H_2O reactivity suppresses H_2 gas evolution and enables uniform Zn deposition.

❑ Electrochemical Performance



FY 26 milestone	Demonstrated Achievement
High utilization Zn cycling	Zn/Zn cell operated for >1000 cycles at DOD > 20% ☺
High \capacity full cell cycling	> 80% capacity retention over 200 cycles at >3 mAh cm^{-2} ☺

Conclusions, Impact, and Future Directions

- This work establishes a near term design foundation to support electrolyte optimization, cell level validation, and industry relevant development by addressing key Zn failure modes such as gas evolution, corrosion, and unstable cycling..
- Future work will focus on establishing governing principles for generalized electrolyte formulation, using these principles to develop next generation structured electrolytes, and validating the optimized electrolytes in scaled aqueous Zn battery formats.

Acknowledgement

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